Metropolitan Sewage District, that are doing stormwater master planning to reduce flooding, bank erosion, and water quality problems on a watershed scale.

Designing stormwater management on a watershed scale creates the opportunity to evaluate a system of SCMs and maximize overall effectiveness based on multiple criteria, such as the incremental costs to development beyond traditional stormwater infrastructure, the limitations imposed on land area required for site planning, the effectiveness at improving water quality or attenuating discharges, and aesthetics. Because the benefits that accrue with improved water quality are generally not realized by those entities required to implement SCMs, greater value must be created beyond the functional aspects of the facility if there is to be wide acceptance of SCMs as part of the urban landscape. Stormwater systems designed on a watershed basis are more likely to be seen as a multi-functional resource that can contribute to the overall quality of the urban environment. Potential even exists to make the stormwater system a primary component of the civic framework of the community—elements of the public realm that serve to enhance a community's quality of life like public spaces and parks. For example, in central Minneapolis, redevelopment of a 100-acre area called Heritage Park as a mixed-density residential neighborhood was organized around two parks linked by a parkway that served dual functions of recreation and stormwater management.

Key elements of the watershed approach to designing systems of SCMs are discussed in detail below. They include the following:

1. Forecasting the current and future development types.
2. Forecasting the scale of current and future development.
3. Choosing among on-site, distributed SCMs and larger, consolidated SCMs.
4. Defining stressors of concern.
5. Determining goals for the receiving water.
6. Noting the physical constraints.
7. Developing SCM guidance and performance criteria for the local watershed.
8. Establishing a trading system.
9. Ensuring the safe performance of the drainage network, streams, and floodplains.
10. Establishing community objectives for the publically owned elements of stormwater infrastructure.
11. Establishing a maintenance plan.

Forecasting the Current and Future Development Types

Forecasting the type of current and future development within the local watershed will guide or shape how individual practices and SCMs are generally assembled at each individual site. The development types that are generally thought of include Greenfield development (small and large scales), redevelopment within established communities and on Brownfield sites, and retrofitting of existing urban areas. These development types range roughly from lower density to higher density impervious cover. Box 5-10 explains how the type of development can dictate stormwater management, discussing two main categories—*Greenfield* development and *redevelopment* of existing areas. The former refers to development that changes pristine or agricultural land to urban or suburban land uses, frequently low-density residential housing. Redevelopment refers to changing from an existing urban land use to another, usually of higher

BOX 5-10
Development Types and their Relationship to the Stormwater System

Development falls into two basic types. Greenfield development requires new infrastructure designed according to contemporary design standards for roads, utilities, and related infrastructure. Redevelopment refers to developed areas undergoing land-use change. In contrast to Greenfields, infrastructure in previously developed areas is often in poor condition, was not built to current design standards, and is inadequate for the new land uses proposed. The stormwater management scenarios common to these types of development are described below.

Greenfield Development

At the largest scale, Greenfield development refers to planned communities at the developing edge of metropolitan areas. Communities of this type often vary from several hundred acres to very large projects that encompassed tens of thousands of acres requiring buildout over decades. They often include the trunk or primary stormwater system as well as open stream and river corridors. The most progressive communities of this type incorporate a significant portion of the area to stormwater systems that exist as surface elements. Such stormwater system elements are typically at the subwatershed scale and provide for consolidated conveyance, detention, and water quality treatment. These elements of the infrastructure can be multi-functional in nature, providing for wildlife habitat, trail corridors, and open-space amenities.

Greenfield development can also occur on a small scale—neighborhoods or individual sites within newly developing areas that are served by the secondary public and tertiary stormwater systems. This smaller-scale, incremental expansion of existing urban patterns is a more typical way for cities to grow. A more limited range of SCMs and innovative stormwater management practices are available on smaller projects of this type, including LID practices.

Redevelopment of Existing Areas

Redevelopment within established communities is typically at the scale of individual sites and occasionally the scale of a small district. The area is usually served by private, on-site systems that convey larger storm events into preexisting stormwater systems that were developed decades ago, either in historic city centers or in "first ring," post-World War II suburbs adjacent to historic city centers. Redevelopment in these areas is typically much denser than the original use. The resulting increase in impervious area, and typically the inadequacy of existing stormwater infrastructure serving the site often results in significant development costs for on-site detention and water quality treatment. Elaborate vaults or related structures, or land area that could be utilized for development, must often be committed to on-site stormwater management to comply with current stormwater regulations.

Brownfields are redevelopments of industrial and often contaminated property at the scale of an individual site, neighborhood, or district. Secondary public systems and private stormwater systems on individual sites typically serve these areas. In many cases, especially in outdated industrial areas, little or no stormwater infrastructure exists, or it is so inadequate as to require replacement. Water quality treatment on contaminated sites may also be necessary. For these reasons, stormwater management in such developments presents special challenges. As an example, the most common methods of remediation of contaminated sites involve capping of contaminated soils or treatment of contaminants in situ, especially where removal of contaminated soils from a site is cost prohibitive. Given that contaminants are still often in place on redeveloped Brownfield sites and must not be disturbed, certain SCMs such as infiltration of stormwater into site soils, or excavation for stormwater piping and other utilities, present special challenges.

density, such as from single-family housing to multi-family housing. Finally, *retrofitting* as used in this report is not a development type but rather the upgrading of stormwater management within an existing land use to meet higher standards.

Table 5-7 shows which SCMs are best suited for Greenfield development (particularly low-density residential), redevelopment of urban areas, and intense industrial redevelopment. The last category is broken out because the suite of SCMs needed is substantially different than for urban redevelopment. Each type of development has a different footprint, impervious cover, open space, land cost, and existing stormwater infrastructure. Consequently, SCMs that are ideally suited for one type of development may be impractical or infeasible for another. One of the main points to be made is that there are more options during Greenfield development than during redevelopment because of existing infrastructure, limited land area, and higher costs in the latter case.

TABLE 5-7 Applicability of Stormwater Control Measures by Type of Development

Stormwater Control Measure	**Low-Density Greenfield Residential**	**Urban Redevelopment**	**Intense Industrial Redevelopment**
Product Substitution	○	●	●
Watershed and Land-Use Planning	■	■	○
Conservation of Natural Areas	■	◆	○
Impervious Cover Minimization	■	◆	◆
Earthwork Minimization	■	◆	◆
Erosion and Sediment Control	■	■	■
Reforestation and Soil Conservation	■	●	●
Pollution Prevention SCMs	◆	●	■
Runoff Volume Reduction—Rainwater Harvesting	■	■	●
Runoff Reduction—Vegetated	■	○	●
Runoff Reduction—Subsurface	■	○	◆
Peak Reduction and Runoff Treatment	■	◆	○
Runoff Treatment	●	●	■
Aquatic Buffers and Managed Floodplains	●	◆	○
Stream Rehabilitation	○	◆	◆
Municipal Housekeeping	○	○	NA
IDDE	○	○	○
Stormwater Education	●	●	●
Residential Stewardship	■	●	NA

NOTE: ■, always; ●, often; ○, sometimes; ◆, rarely; NA, not applicable.

Forecasting the Scale of Current and Future Development

The choice of what SCMs to use depends on the area that needs to be serviced. It turns out that some SCMs work best over a few acres, whereas others require several dozen acres or more; some are highly effective only for the smallest sites, while others work best at the stream corridor or subwatershed level. Table 5-1 includes a column that is related the scale at which individual SCMs can be applied ("where" column). The SCMs mainly applied at the site scale include runoff volume reduction—rainwater harvesting, runoff treatment like filtering, and pollution prevention SCMs for hotspots. As one goes up in scale, SCMs like runoff volume reduction—vegetated and subsurface, earthwork minimization, and erosion and sediment control take on more of a role. At the largest scales, watershed and land-use planning, conservation of natural areas, reforestation and soil conservation, peak flow reduction, buffers and managed floodplains, stream rehabilitation, municipal housekeeping, IDDE, stormwater education, and residential stewardship play a more important role. Some SCMs are useful at all scales, such as product substitution and impervious cover minimization.

Choosing Among On-Site, Distributed SCMs and Larger, Consolidated SCMs

There are distinct advantages and disadvantages to consider when choosing to use a system of larger, consolidated SCMs versus smaller-scale, on-site SCMs that go beyond their ability to achieve water quality or urban stream health. Smaller, on-site facilities that serve to meet the requirements for residential, commercial, and office developments tend to be privately owned. Typically, flows are directed to porous landscape detention areas or similar SCMs, such that volume and pollutants in stormwater are removed at or near their source. Quite often, these SCMs are relegated to the perimeter project, incorporated into detention ponds, or, at best, developed as landscape infiltration and parking islands and buffers. On-site infiltration of frequent storm events can also reduce the erosive impacts of stormwater volumes on downstream receiving waters. Maintenance is performed by the individual landowner, which is both an advantage because the responsibility and costs for cleanup of pollutants generated by individual properties are equitably distributed, and a disadvantage because ongoing maintenance incurs a significant expense on the part of individual property owners and enforcement of properties not in compliance with required maintenance is difficult. On the negative side, individual SCMs often require additional land, which increases development costs and can encourage sprawl. Monitoring of thousands of SCMs in perpetuity in a typical city creates a significant ongoing public expense, and special training and staffing may be required to maintain SCM effectiveness (especially for subgrade or in-building vaults used in ultra-urban environments). Finally, given that as much as 30 percent of the urban landscape is comprised of public streets and rights-of-way, there are limited opportunities to treat runoff from streets through individual on-site private SCMs. (Notable exceptions are subsurface runoff-volume-reduction SCMs like permeable pavement that require no additional land and promote full development density within a given land parcel because they use the soil areas below roads and the development site for infiltration.)

In contrast, publicly owned, consolidated SCMs are usually constructed as part of larger Greenfield and infill development projects in areas where there is little or no existing infrastructure. This type of facility—usually an infiltration basin, detention basin, wet/dry pond, or stormwater wetland—tends to be significantly larger, serving multiple individual properties.

Ownership is usually by the municipality, but may be a privately managed, quasi-public special district. There must be adequate land available to accommodate the facility and a means of up-front financing to construct the facility. An equitable means of allocating costs for ongoing maintenance must also be identified. However, the advantage of these facilities is that consolidation requires less overall land area, and treatment of public streets and rights-of-way can be addressed. Monitoring and maintenance are typically the responsibility of one organization, allowing for effective ongoing operations to maintain the original function of the facility. If that entity is public, this ensures that the facility will be maintained in perpetuity, allowing for the potential to permanently reduce stormwater volumes and for reduction in the size of downstream stormwater infrastructure. Because consolidated facilities are typically larger than on-site SCMs, mechanized maintenance equipment allows for greater efficiency and lower costs. Finally, consolidated SCMs have great potential for multifunctional uses because wildlife habitat, recreational, and open-space amenities can be integrated to their design. Box 5-11 describes sites of various scales where either consolidated or distributed SCMs were chosen.

Defining Stressors of Concern

The primary pollutants or stressors of concern (and the primary source areas or stormwater hotspots within the watershed likely to produce them) should be carefully defined for the watershed. Although this community decision is made only infrequently, it is critical to ensuring that SCMs are designed to prevent or reduce the maximum load of the pollutants of greatest concern. This choice may be guided by regional water quality priorities (such as nutrient reduction in the Chesapeake Bay or Neuse River watersheds) or may be an outgrowth of the total maximum daily load process where there is known water quality impairment or a listed pollutant. The choice of a pollutant of concern is paramount, since individual SCMs have been shown to have highly variable capabilities to prevent or reduce specific pollutants (see WERF, 2006; ASCE, 2007; CWP, 2007b). In some cases, the capability of SCMs to reduce a specific pollutant may be uncertain or unknown.

Determining Goals for the Receiving Waters

It is important to set biological and public health goals for the receiving water that are achievable given the ultimate impervious cover intended for the local watershed (see the Impervious Cover Model in Box 3-10). If the receiving water is too sensitive to meet these goals, one should consider adjustments to zoning and development codes to reduce the amount of impervious cover. The biological goals may involve a keystone species, such as salmon or trout, a desired state of biological integrity in a stream, or a maximum level of eutrophication in a lake. In other communities, stormwater goals may be driven by the need to protect a sole-source drinking water supply (e.g., New York watersheds) or to maintain water contact recreation at a beach, lake, or river. Once again, the watershed goals that are selected have a strong influence on the assembly of SCMs needed to meet them, since individual SCMs vary greatly in their ability to achieve different biological or public health outcomes.

BOX 5-11
Examples of Communities Using Consolidated versus Distributed SCMs

Stapleton Airport New Community

This is a mixed-use, mixed-density New Urbanist community that has been under development for the past 15 years on the 4,500-acre former Stapleton Airport site in central Denver. As shown in Figures 5-55 and 5-56, the stormwater system emphasizes surface conveyance and treatment on individual sites, as well as in consolidated regional facilities.

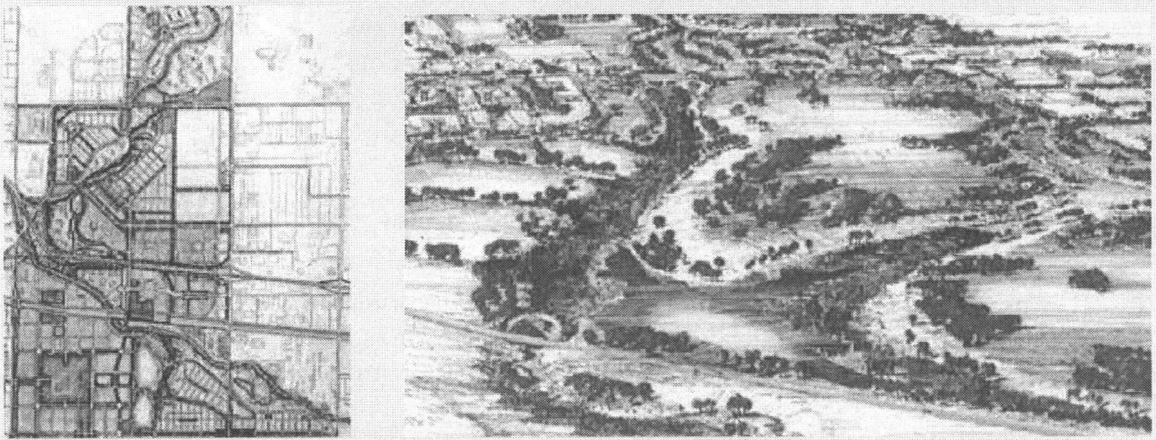

FIGURE 5-55 The community plan, shown on the left, is organized around two day lighted creeks, formerly buried under airport runways, and a series of secondary conveyances which provide recreational open space within neighborhoods. The image on the right illustrates one of the multi-functional creek corridors. Consolidated stormwater treatment areas and surface conveyances define more traditional park recreation and play areas. Courtesy of Stapleton Redevelopment Foundation.

FIGURE 5-56 A consolidated treatment area adjacent to one of several neighborhoods that have been constructed as part of the project's build-out.

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Heritage Park Neighborhood Redevelopment

A failed public housing project adjacent to downtown Minneapolis, Minnesota, has been replaced by a mixed-density residential neighborhood. Over 1,200 rental, affordable, and market-rate single- and multi-family housing units have been provided in the 100-acre project area. The neighborhood is organized around two neighborhood parks and a parkway that serve dual functions as neighborhood recreation space and as surface stormwater conveyance and a consolidated treatment system (see Figure 5-57). Water quality treatment is being provided for a combined area of over 660 acres that includes the 100-acre project area and over 500 acres of adjacent neighborhoods. Existing stormwater pipes have been routed through treatment areas with treatment levels ranging from 50 to 85 percent TSS removal, depending on the available land area.

FIGURE 5-57 View of a sediment trap and porous landscape detention area in the central parkway spine of Heritage Park. The sediment trap in the center left of the photo was designed for ease of maintenance access by city crews with standard city maintenance equipment. Courtesy of SRF Consulting Group, Inc.

The High Point Neighborhood

This Seattle project is the largest example of the city's Natural Drainage Systems Project and it illustrates the incorporation of individual SCMs into street rights-of-way as well as a consolidated facility. The on-site, distributed SCMs in this 600-acre neighborhood are swales, permeable pavement, and disconnected downspouts. A large detention pond services the entire region that is much smaller than it would have been had the other SCMs not been built. Both types of SCMs are shown in Figure 5-58.

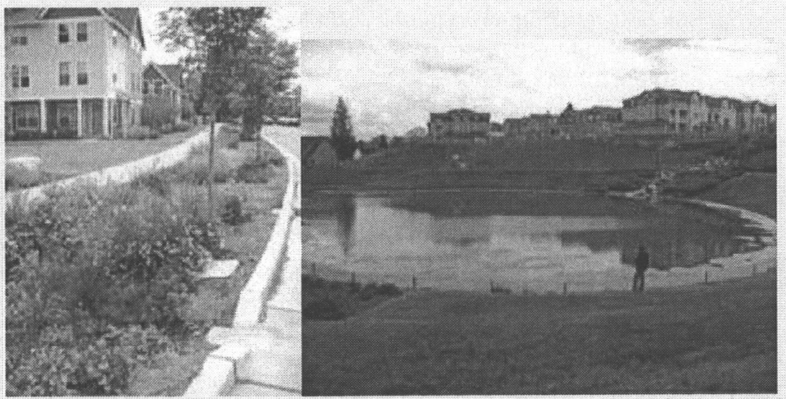

FIGURE 5-58 Natural drainage system methods have been applied to a 34-block, 1,600-unit mixed-income housing redevelopment project called High Point. Vegetated swales, porous concrete sidewalks, and frontyard rain gardens convey and treat stormwater on-site. On the right is the detention pond for the development.

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BOX 5-11 Continued

Pottsdammer Platz

This project, in the heart of Berlin, Germany, illustrates the potential for stormwater treatment in the densest urban environments by incorporating treatment into building systems and architectural pools that are the centerpiece of a series of urban plazas. As shown in Figure 5-59, on-site, individual SCMs are used to collect stormwater and use it for sanitary purposes.

FIGURE 5-59 Stormwater is collected and stored on-site in a series of vaults. Water is circulated through a series of biofiltration areas and used for toilets and other mechanical systems in the building complex. Large storms overflow into an adjacent canal. Permission pending.

Menomonee Valley Redevelopment, Wisconsin

The 140-acre redevelopment of abandoned railyards illustrates how a Brownfield site within an existing floodplain can be redeveloped using both on-site and consolidated treatment. As shown in Figure 5-60, consolidated treatment is incorporated into park areas which provide recreation for adjacent neighborhoods and serve as a centerpiece for a developing light industrial area that provides jobs to surrounding neighborhoods. Treatment on individual privately owned parcels is limited to the removal of larger sediments and debris only, making more land available for development. The volume of water that, by regulation, must be captured and treated on individual sites is conveyed through a conventional subsurface system for treatment in park areas.

FIGURE 5-60 Illustrations show consolidated treatment areas in proposed parks. The image on the left illustrates the fair weather condition, the center image the water quality capture volume, and the image on the right the 100-year storm event. Construction was completed in spring 2007.

Noting the Physical Constraints

The specific physical constraints of the watershed terrain and the development pattern will influence the selection and assembly of SCMs. The application of SCMs must be customized in every watershed to reflect its unique terrain, such as karst, high water tables, low or high slopes, freeze–thaw depth, soil types, and underlying geology. Each SCM has different restrictions or constraints associated with these terrain factors. Consequently, the SCM prescription changes as one moves from one physiographic region to another (e.g., the flat coastal plain, the rolling Piedmont, the ridge and valley, and mountainous headwaters).

Developing SCM Guidance and Performance Criteria for the Local Watershed

Based on the foregoing factors, the community should establish specific sizing, selection, and design requirements for SCMs. These SCM performance criteria may be established in a local, regional, or state stormwater design manual, or by reference in a local watershed plan. The Minnesota Stormwater Steering Committee (MSSC, 2005) provides a good example of how SCM guidance can be customized to protect specific types of receiving waters (e.g., high-quality lakes, trout streams, drinking water reservoirs, and impaired waters). In general, the watershed- or receiving water-based criteria are more specific and detailed than would be found in a regional or statewide stormwater manual. For example, the local stormwater guidance criteria may be more prescriptive with respect to runoff reduction and SCM sizing requirements, outline a preferred sequence for SCMs, and indicate where SCMs should (or should not) be located in the watershed. Like the identification of stressors or pollutants of concerns, this step is rarely taken under current paradigms of stormwater management.

Establishing a Trading System

A stormwater trading or offset system is critical to situations when on-site SCMs are not feasible or desirable in the watershed. Communities may choose to establish some kind of stormwater trading or mitigation system in the event that full compliance is not possible due to physical constraints or because it is more cost effective or equitable to achieve pollutant reduction elsewhere in the local watershed. The most common example is providing an offset fee based on the cost to remove an equivalent amount of pollutants (such as phosphorus in the Maryland Critical Area—MD DNR, 2003). This kind of trading can provide for greater cost equity between low-cost Greenfield sites and higher-cost ultra-urban sites.

Ensuring the Safe and Effective Performance of the Drainage Network, Streams, and Floodplains

The urban water system is not solely designed to manage the quality of runoff. It also must be capable of safely handling flooding from extreme storms to protect life and property. Consequently, communities need to ensure that their stormwater infrastructure can prevent increased flooding caused by development (and possibly exacerbated future climate change). In addition, many SCMs must be designed to safely pass extreme storms when they do occur. This usually requires a watershed approach to stormwater management to ensure that quality and quantity control are integrated together, with an emphasis on the connection and effective use of conveyance channels, streams, riparian buffers, and floodplains.

Establishing Community Objectives for the Publicly Owned Elements of Stormwater Infrastructure

The stormwater infrastructure in a community normally occupies a considerable surface area of the landscape once all the SCMs, drainage easements, buffers, and floodplains are added together. Consequently, communities may require that individual SCM elements are designed to achieve multiple objectives, such as landscaping, parks, recreation, greenways, trails, habitat, sustainability, and other community amenities (as discussed extensively above). In other cases, communities may want to ensure that SCMs do not cause safety or vector problems and that they look attractive. The best way to maximize community benefits is to provide clear guidance in local SCM criteria at the site level and to ensure that local watershed plans provide an overall context for their implementation.

Establishing an Inspection and Maintenance Plan

The long-term performance of any SCM is fundamentally linked to the frequency of inspections and maintenance. As a result, NPDES stormwater permit conditions for industrial, construction, and municipal permittees specify that pollution prevention, construction, and post-construction SCMs be adequately maintained. MS4 communities are also required under NPDES stormwater permits to track, inspect, and ensure the maintenance of the collective system of SCMs and stormwater infrastructure within their jurisdiction. In larger communities, this can involve hundreds or even thousands of individual SCMs located on either public or private property. In these situations, communities need to devise a workable model that will be used to operate, inspect, and maintain the stormwater infrastructure across their local watershed. Communities have the lead responsibility in their MS4 permits to assure that SCMs are maintained properly to ensure their continued function and performance over time. They can elect to assign the responsibility to the public sector, the private sector (e.g., property owners and homeowners association), or a hybrid of the two, but under their MS4 permits they have ultimate responsibility to ensure that SCM maintenance actually occurs. This entails assigning legal and financial responsibilities to the owners of each SCM element in the watershed, as well as maintaining a tracking and enforcement system to ensure compliance.

Summary

Taking all of the elements above into consideration, the emerging goal of stormwater management is to mimic, as much as possible, the hydrological and water quality processes of natural systems as rain travels from the roof to the stream through combined application of a series of practices throughout the entire development site and extending to the stream corridor.

The series of SCMs incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required.

There is no single SCM prescription that can be applied to each kind of development; rather, a combination of interacting practices must be used for full and effective treatment. For a low-density residential Greenfield setting, a combination of SCMs that might be implemented is illustrated in Table 5-8. There are many successful examples of SCMs in this context and at different scales. By contrast, Tables 5-9 and 5-10 outline how the general "roof-to-stream" stormwater approach is adapted for intense industrial operations and urban redevelopment sites, respectively. As can be seen, these development situations require a differ combination of SCMs and practices to address the unique design challenges of dense urban environments. The tables are meant to be illustrative of certain situations; other scenarios, such as commercial development, would likely require additional tables.

TABLE 5-8 *From the Roof to the Stream: SCMs in a Residential Greenfield*

SCM	**What it Is**	**What it Replaces**	**How it Works**
Land-Use Planning	Early site assessment	Doing SWM design after site layout	Map and plan submitted at earliest stage of development review showing environmental, drainage, and soil features
Conservation of Natural Areas	Maximize forest canopy	Mass clearing	Preservation of priority forests and reforestation of turf areas to intercept rainfall
Earthwork Minimization	Conserve soils and contours	Mass grading and soil compaction	Construction practices to conserve soil structure and only disturb a small site footprint
Impervious Cover Minimization	Better site design	Large streets, lots and cul-de-sacs	Narrower streets, permeable driveways, clustering lots, and other actions to reduce site IC
Runoff Volume Reduction—Rainwater Harvesting	Utilize rooftop runoff	Direct connected roof leaders	A series of practices to capture, disconnect, store, infiltrate, or harvest rooftop runoff
Runoff Volume Reduction—Vegetated	Frontyard bioretention	Positive drainage from roof to road	Grading frontyard to treat roof, lawn, and driveway runoff using shallow bioretention
	Dry swales	Curb/gutter and storm drain pipes	Shallow, well-drained bioretention swales located in the street right-of-way
Peak Reduction and Runoff Treatment	Linear wetlands	Large detention ponds	Long, multi-cell, forested wetlands located in the stormwater conveyance system
Aquatic Buffers and Managed Floodplains	Stream buffer management	Unmanaged stream buffers	Active reforestation of buffers and restoration of degraded streams

Note: SCMs are applied in a series, although all of the above may not be needed at a given residential site. This "roof-to-stream" approach works best for low- to medium-density residential development.

In summary, a watershed approach for organizing site-based stormwater decisions is generally superior to making site-based decisions in isolation. Communities that adopt the preceding watershed elements not only can maximize the performance of the entire system of SCMs to meet local watershed objectives, but also can maximize other urban functions, reduce total costs, and reduce future maintenance burdens.

TABLE 5-9 From the Roof to the Outfall: SCMs in an Industrial Context

SCM Category	What it Is	What it Replaces	How it Works
Pollution Prevention	Drainage mapping	No map	Analysis of the locations and connections of the stormwater and wastewater infrastructure from the site
	Hotspot site investigation	Visual inspection	Systematic assessment of runoff problems and pollution prevention opportunities at the site
	Rooftop management	Uncontrolled rooftop runoff	Use of alternative roof surfaces or coatings to reduce metal runoff, and disconnection of roof runoff for stormwater treatment
	Exterior maintenance practices	Routine plant maintenance	Special practices to reduce discharges during painting, powerwashing, cleaning, sealcoating and sandplasting
	Extending roofs for no exposure	Exposed hotspot operations	Extending covers over susceptible loading/unloading, fueling, outdoor storage, and waste management operations
	Vehicular pollution prevention	Uncontrolled vehicle operations	Pollution prevention practices applied to vehicle repair, washing, fueling, and parking operations
	Outdoor pollution prevention practices	Outdoor materials storage	Prevent rainwater from contact with potential pollutants by covering, secondary containment, or diversion from storm-drain system
	Waste management practices	Exposed dumpster or waste streams	Improved dumpster location, management, and treatment to prevent contact with rainwater or runoff
	Spill control plan and response	No plan	Develop and test response to spills to the storm-drain system, train employees, and have spill control kits available on-site
	Greenscaping	Routine landscape and turf maintenance	Reduce use of pesticides, fertilization, and irrigation in pervious areas, and conversion of turf to forest
	Employee stewardship	Lack of stormwater awareness	Regular ongoing training of employees on stormwater problems and pollution prevention practices
	Site housekeeping and stormwater maintenance	Dirty site and unmaintained infrastructure	Regular sweeping, storm-drain cleanouts, litter pickup, and maintenance of stormwater infrastructure
Runoff Treatment	Stormwater retrofitting	No stormwater treatment	Filtering retrofits to remove pollutants from most severe hotspot areas
IDDE	Outfall analysis	No monitoring	Monitoring of outfall quality to measure effectiveness

Note: While many SCMs are used at each individual industrial site, the exact combination depends on the specific configuration, operations, and footprint of each site.

TABLE 5-10 From the Roof to the Street: SCMs in a Redevelopment Context

SCM Category	**What it Is**	**What it Replaces**	**How it Works**
Impervious Cover Minimization	Site design to prevent pollution	Conventional site design	Designing redevelopment footprint to restore natural area remnants, minimize needless impervious cover, and reduce hotspot potential
Runoff Volume Reduction—Rainwater Harvesting and Vegetated	Treatment on the roof	Traditional rooftops	Use of green rooftops to reduce runoff generated from roof surfaces
	Rooftop runoff treatment	Directly connected roof leaders	Use of rain tanks, cisterns, and rooftop disconnection to capture, store, and treat runoff
	Runoff treatment in landscaping	Traditional landscaping	Use of foundation planters and bioretention areas to treat runoff from parking lots and rooftops
Soil Conservation and Reforestation	Runoff reduction in pervious areas	Impervious or compacted soils	Reducing runoff from compacted soils through tilling and compost amendments, and in some cases, removal of unneeded impervious cover
	Increase urban tree canopy	Turf or landscaping	Providing adequate rooting volume to develop mature tree canopy to intercept rainfall
Runoff Reduction—Subsurface	Increase permeability of impervious cover	Hard asphalt or concrete	Use of permeable pavers, porous concrete, and similar products to decrease runoff generation from parking lots and other hard surfaces.
Runoff Reduction—Vegetated	Runoff treatment in the street	Sidewalks, curb and gutter, and storm drains	Use of expanded tree pits, dry swales and street bioretention cells to further treat runoff in the street or its right-of-way
Runoff Treatment	Underground treatment	Catch basins and storm-drain pipes	Use of underground sand filters and other practices to treat hotspot runoff quality at the site
Municipal Housekeeping	Street cleaning	Unswept streets	Targeted street cleaning on priority streets to remove trash and gross solids
Watershed Planning	Off-site stormwater treatment or mitigation	On-site waivers	Stormwater retrofits or restoration projects elsewhere in the watershed to compensate for stormwater requirements that cannot be met onsite

Note: SCMs are applied in a series, although all of the above may not be needed at a given redevelopment site.

COST, FINANCE OPTIONS, AND INCENTIVES

Municipal Stormwater Financing

To be financially sustainable, stormwater programs must develop a stable long-term funding source. The activities common to most municipal stormwater programs (such as education, development design review, inspection, and enforcement) are funded through general tax revenues, most commonly property taxes and sales taxes (NAFSMA, 2006), which is problematic for several reasons. First, stormwater management financed through general tax receipts does not link or attempt to link financial obligation with services received. The absence of such links can reduce the ability of a municipality to adequately plan and meet basic stormwater management obligations. Second, when funded through general tax revenues, stormwater programs must compete with other municipal programs and funding obligations. Finally, in programs funded by general tax revenue, responsibilities for stormwater management tend to be distributed into the work responsibilities of existing and multiple departments (e.g., public works, planning, etc.). One recent survey conducted in the Charles River watershed in Massachusetts found that three-quarters of local stormwater management programs did not have staff dedicated exclusively for stormwater management (Charles River Watershed Association, 2007).

Increasingly, many municipalities are establishing stormwater utilities to manage stormwater (Kaspersen, 2000). Most stormwater utilities are created as a separate organizational entity with a dedicated, self-sustaining source of funding. The typical stormwater utility generates the large majority of revenue through user fees (Florida Stormwater Association, 2003; Black and Veatch, 2005; NAFSMA, 2006). User fees are established and set so as to have a close nexus to the cost of providing the service and, thus, are most commonly based on the amount of impervious surface, frequently measured in terms of equivalent residential unit. For example, an average single-family residence may create 3,000 square feet of impervious surface (roof and driveway area). A per-unit charge is then assigned to this "equivalent runoff unit." To simplify program administration, utilities typically assign a flat rate for residential properties (customer class average) (NAFSMA, 2006). Nonresidential properties are then charged individually based on the total amount of impervious surface (square feet or equivalent runoff units) of the parcel. Fees are sometimes also based on gross area (total area of a parcel) or some combination of gross area and a development intensity measure (Duncan, 2004; NAFSMA, 2006).

Municipalities have the legal authority to create stormwater utilities in most states (Lehner et al., 1999). In addition to creating the utility, a municipality will generally establish the utility rate structure in a separate ordinance. Separating the ordinances allows the municipality flexibility to change the rate structure without revising the ordinance governing the entire utility (Lehner et al., 1999). While municipalities generally have the authority to collect fees, some states have legal restrictions on the ability of local governments to levy taxes (Lehner et al., 1999; NAFSMA, 2006). The legal distinction between a tax and a fee is the most common legal challenge to a stormwater utility. For example, stormwater fees have been subject to litigation in at least 17 states (NAFSMA, 2006). To avoid legal challenges, care must be taken to meet a number of legal tests that distinguish a fee for a specific service and a general tax.

Stormwater utilities typically bill monthly, and fees range widely. A recent survey of U.S. stormwater utilities reported that fees for residential households range from $1 to $14 per month, but a typical residential household rate is in the range of $3 to $6 (Black and Veatch, 2005). Despite the dedicated funding source, the majority of stormwater utilities responding to a recent survey (55 percent) indicated that current funding levels were either inadequate or just adequate to meet their most urgent needs (Black and Veatch, 2005).

Both municipal and state programs can finance administrative programming costs through stormwater permitting fees. Municipal stormwater programs can use separate fees to finance inspection activities. For instance, inspection fees can be charged to cover the costs of ensuring that SCMs are adequately planned, installed, or maintained (Debo and Reese, 2003). Stormwater management programs can also ensure adequate funding for installation and maintenance of SCMs by requiring responsible parties to post financial assurances. Performance bonds, letters of credit, and cash escrow are all examples of financial assurances that require up-front financial payments to ensure that longer-term actions or activities are successfully carried out. North Carolina's model stormwater ordinance recommends that the amount of a maintenance performance security (bond, cash escrow, etc.) be based on the present value of an annuity based on both inspection costs and operation and maintenance costs (Whisnant, 2007).

In addition to fees or taxes, exactions such as impact fees can also be used as a way to finance municipal stormwater infrastructure investments (Debo and Reese, 2003). An impact fee is a one-time charge levied on new development. The fee is based on the costs to finance the infrastructure needed to service the new development. The ability to levy impact fees varies between states. Municipalities that use impact fees are also required to show a close nexus between the size of the fee and the level of benefits provided by the fee; a failure to do so exposes local government to law suits (Keller, 2003). Compared to other funding sources, impact fees also exhibit greater variability in revenue flows because the amount of funds collected is dependent on development growth.

Bonds and grants can supplement the funding sources identified above. Bonds and loans tend to smooth payments over time for large up-front stormwater investments. For example, state and federal loan programs (state revolving funds) provide long-term, low-interest loans to local governments or capital investments (Keller, 2003). In addition, grant opportunities are sometimes available from state and federal sources to help pay for specific elements of local stormwater management programs.

Municipalities require funds to meet federal and state stormwater requirements. Understanding of the municipal costs incurred by implementing stormwater regulations under the Phase I and II stormwater rules, however, is incomplete (GAO, 2007). Of the six minimum measures of a municipal stormwater program (public education, public involvement, illicit discharge detection and elimination, construction site runoff control, post-construction stormwater management, and pollution prevention/good housekeeping—see Chapter 2), a recent study of six California municipalities found that pollution prevention activities (primarily street sweeping) accounted for over 60 percent of all municipal stormwater management costs in these communities (Currier et al., 2005). Annual per-household costs ranged from $18 to $46.

Stormwater Cost Review

Conceptually, the costs of providing SCMs are all opportunity costs (EPA, 2000). Opportunity costs are the value of alternatives (next best) given up by society to achieve a particular outcome. In the case of stormwater control, opportunity costs include direct costs necessary to control and treat runoff such as capital and construction costs and the present value of annual operation and maintenance costs. Initial installation costs should also include the value of foregone opportunities on the land used for stormwater control, typically measured as land acquisition (land price).

Costs also include public and private resources incurred in the administration of the stormwater management program. Private-sector costs might include time and administrative costs associated with permitting programs. Public costs include agency monitoring and enforcement costs.

Opportunity costs also include other values that might be given up as a consequence of stormwater management. For example, the creation of a wet pond in a residential area might be opposed because of perceived safety, aesthetic, or nuisance concerns (undesirable insect or animal species). In this case, the diminished satisfaction of nearby property owners is an opportunity cost associated with the wet pond. On the other hand, if SCMs are considered a neighborhood amenity (e.g., a constructed wetland in a park setting), opportunity costs may decrease. In addition, costs of a given practice may be reduced by reducing costs elsewhere. For example, increasing on-site infiltration rates can reduce off-site storage costs by reducing the volume and slowing the release of runoff.

In general the cost of SCMs is incompletely understood and significant gaps exist in the literature. More systematic research has been conducted on the cost of conventional stormwater SCMs (wet ponds, detention basins, etc.), with less research applied to more recent, smaller-scale, on-site infiltration practices. Cost research is challenging given that stormwater treatment exhibits considerable site-specific variation resulting from different soil, topography, climatic conditions, local economic conditions, and regulatory requirements (Lambe et al., 2005).

The literature on stormwater costs tend to be oriented around construction costs of particular types of SCMs (Wiegand et al., 1986; SWRPC, 1991; Brown and Schueler, 1997; Heaney et al., 2002; Sample et al., 2003; Wossink and Hunt, 2003; Caltrans, 2004; Narayanan and Pitt, 2006; DeWoody, 2007). In many of these studies, construction cost functions are estimated statistically based on a sample of recently installed SCMs and the observed total construction costs. Observed costs are then related statistically to characteristics that influence cost such as practice size. Other studies estimate costs by identifying the individual components of a construction project (pipes, excavation, materials, labor, etc.), estimating unit costs of each component, and then summing all project components. These studies generally find that construction costs decrease on a per-unit basis as the overall size (expressed in volume or drainage area) of the SCM increases (Lambe et al., 2005). These within-practice economies of scale are found across certain SCMs including wet ponds, detention ponds, and constructed wetlands. Several empirical studies, however, failed to find evidence of economies of scale for bioretention practices (Brown and Schueler, 1997; Wossink and Hunt, 2003).

Increasing attention has been paid to small-scale practices, including efforts to increase infiltration and retain water through such means as green roofs, permeable pavements, rain barrels, and rain gardens (under the label of LID). The costs of these practices are less well studied compared to the other stormwater practices identified above. In general, per-unit