National Management Measures to Control Nonpoint Source Pollution from Urban Areas

MANAGEMENT MEASURE 4
SITE DEVELOPMENT

4.1 Management Measure

Plan, design, and develop sites to:

- Maintain predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate, or detain runoff;
- Protect areas that provide important water quality benefits or are particularly susceptible to erosion and sediment loss;
- Limit effective impervious area[a] by design and the use of management practices;
- Limit land disturbance activities, such as clearing and grading and cut-and-fill, to reduce erosion, sediment loss, and soil compaction; and
- Preserve natural drainage features and vegetation to the extent possible.

4.2 Management Measure Description and Selection

4.2.1 Description

The goals of this management measure are to reduce the generation of nonpoint source pollution, maintain predevelopment hydrology, and mitigate the impacts of urban runoff and associated pollutants from all site development, including activities associated with roads, highways, and bridges. Included in this section are management practices that can be applied during the site planning and review process to ensure that nonpoint source pollution and increases in the volume and rate of runoff are appropriately managed before, during, and after construction.

Although the goals of Management Measure 3 (watershed protection) are similar, this measure is intended to apply to individual sites at the catchment level (see Figure 1.3) rather than larger watersheds or regional drainage basins. The site development and watershed protection management measures are intended to complement each other and be used together within a comprehensive framework to control runoff and reduce nonpoint source pollution.

[a] Effective impervious area is the portion of total impervious cover that is directly connected to the storm drain network (Sutherland, 1995). These surfaces usually include street surfaces and paved driveways and sidewalks connected to or immediately adjacent to them, parking lots, and rooftops that are hydraulically connected to the drainage network (e.g., downspouts run directly to gutters or driveways).

Programs designed to control increased runoff and nonpoint source pollution resulting from site development should include:

- Predevelopment planning and review processes to ensure watershed/subwatershed and site-level natural resource and performance goals are achieved;

- Guidance on assessing and designing sites to maintain predevelopment site hydrology;

- Appropriate pollution prevention practices to be incorporated into site development and use.

- Site plan review and conditional approval processes to ensure the preservation of environmentally sensitive areas and areas necessary for maintaining natural hydrology and water quality; and

- Requirements for erosion and sediment control plan review and approval prior to issuance of appropriate development permits.

In addition to the preceding provisions, the following objectives should be incorporated into the site development process:

- During site development, disturb only the smallest area necessary to perform current activities to reduce erosion and off-site transport of sediment.

- Avoid disturbance of unstable soils or soils particularly susceptible to erosion and sediment loss.

- Favor sites where development will conserve natural drainage areas and sensitive environmental features, and minimize erosion, sediment loss, and soil compaction.

- Revegetate the site as soon as possible after disturbance, preferably with native vegetation.

- Protect and retain existing vegetation to decrease concentrated flows, maintain site hydrology, and control erosion.

- Minimize imperviousness to the extent practicable.

- Develop and implement inspection and maintenance procedures to ensure that landscapes are maintained to avoid water quality impacts.

- Use natural hydrology as a design element, and avoid alteration, modification, or destruction of natural drainage features.

- Design sites to preserve vegetated or natural buffers adjacent to receiving waters.

– Reforest areas within the same watershed in proportion to the acreage cleared of trees.

– Use porous pavements for areas of infrequent use (see section 5.3.2.3 in Management Measure 5).

The use of site planning and evaluation can significantly reduce the size of controls required to retain runoff and sediment on-site. Long-term maintenance burdens can also be reduced. Good site planning can attenuate runoff from development and can improve the effectiveness of the conveyance and treatment components of an urban runoff management system (Anacostia Restoration Team, 1992).

4.2.2 Management Measure Selection

This management measure was selected because the practices associated with it have been shown to be effective in protecting natural drainage features, reducing runoff quantity, and improving runoff quality. Site evaluation and protection of features that promote infiltration, filtration, and on-site detention will protect receiving water quality, maintain baseflow in receiving waters, and prevent or reduce further degradation of stream channels. Development in and around urban areas is inevitable as population growth puts pressure on suburbs and rural areas. This management measure recommends standards for new development that reduce environmental damage caused by development.

4.3 Management Practices

Many of the management practices in this section are considered "better site design techniques," planning techniques that are intended to be used to guide the layout of new developments to reduce the total effective impervious area, conserve natural habitats, and better distribute and infiltrate runoff. All aspects of an individual site, including soil types, slopes, and the location of environmentally sensitive features such as wetlands, forests, and meadows, should be examined to identify areas that should be preserved or restored. Better site design techniques can be used to identify the most efficient building and infrastructure layouts. It can also be used to develop a comprehensive strategy to reduce the quantity of runoff leaving the site and minimize the amount of pollutants generated on-site.

There are many advantages to better site design. Environmentally friendly site designs are more likely to be accepted by local governments and the community, thereby speeding plan approval. Site designs that preserve community open space also reduce the burden on the local government to provide recreational areas. In addition, better site design techniques reduce the amount and cost of infrastructure, which also in turn reduce engineering and maintenance costs. For example, runoff storage requirements for a low-impact development neighborhood in Pierce County, Washington, were reduced by more than 75 percent and the cost was 20 percent less than for conventional designs. These cost savings resulted primarily from the reduced size of runoff detention structures and the elimination of catch basins and pipes (Zickler, 2002).

Low-impact development practices can provide substantial benefits in terms of reducing the occurrence of combined sewer overflows (CSOs). Temporarily storing runoff in urban areas can greatly reduce the peak flow into storm water systems and provide a cost-effective way to mitigate basement flooding and CSOs (USEPA, 1999). Two communities in Indiana successfully implemented street surface storage of runoff to reduce the occurrence of CSOs in a cost effective manner while also reducing peak flows to wastewater treatment plants. The distributed storage controls also offered some water quality benefits by temporarily detaining runoff during storms (USEPA, 1999).

From a marketing perspective, studies have shown that lots abutting forested or other open space are initially valued higher than lots with no adjacent open space, and over time they appreciate more than lots in conventional subdivisions (Arendt, 1996). For example, lots in an open space subdivision in Amherst, Massachusetts, experienced a 13 percent greater appreciation in value compared to a conventional development after 20 years, even though the lots in the conventional development were twice as large (Arendt, 1996).

From a quality-of-life standpoint, site designs that incorporate pedestrian paths and common open space foster a greater sense of community among residents. House lots are closer together, encouraging communication among neighbors. Additionally, common open space provides recreational opportunities that further encourage community interaction.

Finally, better site design offers environmental benefits, including protection of ecologically significant natural resources, reduction of runoff, and preservation of open space and wildlife habitat. Maintaining open space also increases the opportunity for alternative sewage and wastewater disposal and treatment practices such as land treatment, spray irrigation, and reclamation and reuse. In addition, the flexibility of better site design allows designers to site these wastewater treatment systems in the areas of the development best suited for them.

Overall, the practices presented in this management measure provide many advantages over conventional developments and can be implemented in most communities. In some cases, however, outdated development rules can discourage or prohibit some of these practices. Watershed managers should review the local building codes and regulations that govern new developments to determine whether better site design techniques are allowed or encouraged and work with the appropriate authorities to remove these impediments.

The second edition of the Bay Area Stormwater Management Agencies Association's *Start at the Source*, which was originally published in 1997, is an excellent resource on site design issues for watershed managers. This publication emphasizes the importance of considering runoff quality in the early stages of land planning and design. The new edition has been updated and expanded to include commercial, industrial, and institutional development, as well as a technical section that provides more detailed information on the characteristics, applications, design criteria, maintenance, and economics of the practices discussed in the document. More information about ordering this publication when it becomes available is provided on the Bay Area Stormwater Management Agencies Association's Web site at http://www.basmaa.org/ (BASMAA, no date).

Pembroke Woods Subdivision, Emmittsburg, Maryland

Pembroke Woods is a 43-acre low impact development residential subdivision that the designers hail as the first subdivision designed and under construction using the *Low-Impact Development Design Strategies: An Integrated Design Approach* manual developed by Prince George's County, Maryland (2000a). The designers have identified significant cost savings for this development compared to the traditional development plan created in the 1990s. These include

- Eliminating the need for 2 storm water management ponds that had been envisioned in a prior concept plan for the site, yielding construction cost savings of $200,000.

- In place of those 2 storm water management ponds, 2.5 acres of undisturbed open space and wetlands were conserved, with cost savings realized in eliminating wetland mitigation costs.

- An additional 2 lots were created by revising the site plan, increasing the site yield from 68 to 70 lots and adding $90,000 to the project value.

- Approximately 3,000 linear feet of roads were converted from urban road to rural road, replacing curb & gutter with grass bioswales, yielding a savings of $60,000 in construction costs. Also, reducing the road with from 36 feet to 30 feet in the rural road section of the development reduced paving costs by 17 percent.

A brief project overview and contact information can be found at http://www.buckeyedevelopment.net/lowimpactdevelopment.htm.

4.3.1 Site Planning Practices

4.3.1.1 Select site designs that preserve or minimize impacts to predevelopment site hydrology and topography

Retaining the existing topography of a development site assists in maintaining natural drainage features and depressional storage areas that help infiltrate and attenuate flows and filter pollutants. Depressional storage areas, commonly found as ponded areas after storms or during the wet season, aid in reducing runoff volumes and trapping pollutants. To help preserve natural drainage, a developer can (Goldman et al., 1986):

- Construct buildings and parking areas on existing flat terrain;
- Locate buildings and roads along existing contours;
- Orient long buildings with the major portion parallel to contours;
- Stagger floor levels to adjust to gradient changes; and
- Fit the development to the topography.

4.3.1.2 Protect environmentally sensitive areas

Sites should be developed to avoid destroying wetlands, seeps, bogs, fens, springs, surface water bodies, and catchment areas that are important for sustaining the hydrology of the land. In addition, riparian buffers, both forested and covered with grasses, should be preserved to protect surface water bodies. Steep slopes and highly erodible areas need to be protected to avoid landslides and soil movement into water bodies.

The increase in storm water runoff that results from urban development can dramatically impact the ecology of wetlands and other areas by altering characteristics of hydrology, water quality, and soil (USEPA, 1996). Urban development can also result in ecological changes due to fragmentation and habitat destruction. If the development of a site changes runoff characteristics, measures should be taken to prevent negative impacts to wetlands and other features. For example, Pohlig Builders of Malvern, Pennsylvania, incorporated measures to protect wetlands into its building plan after homeowners opposed the construction of seven high-end homes adjacent to a wetland area. Pohlig designed a vegetative filter strip to buffer runoff from the homes and provide treatment before runoff reached the wetlands. The filter strip was designed to eventually grow into a wooded area to enhance aesthetics and benefit water quality. A level spreader was added to convert concentrated runoff to sheet flow that can be more effectively treated, and extra erosion and sediment control measures were used during construction. The total additional cost of these measures was $30,000 (NAHB, 2003).

4.3.1.3 Practice site fingerprinting

The total amount of disturbed area in a site can be reduced by “fingerprinting” development, i.e., placing development in the most environmentally sound locations on the site and minimizing the size of the disturbed area and ultimate development footprint. Fingerprinting places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), future open spaces and restoration areas, areas with trees to be saved, and temporary and permanent vegetative forest buffer zones. At a subdivision or lot level, ground disturbance is confined to areas where structures, roads, and rights-of-way will exist after construction is complete. Other site-level fingerprinting practices include reducing paving and compaction of highly permeable soils, minimizing the size of construction easements and material storage areas, minimizing impervious areas in the site design, clearly demarcating the disturbance area, maintaining existing topography and drainage divide, and disconnecting impervious areas (Prince George’s County, Maryland, Department of Environmental Resources, 2000a).

4.3.1.4 Use cluster development

Cluster development is used to concentrate development and construction activity on a limited portion of a site, leaving the remainder undisturbed. Figures 4.1 and 4.2 show schematics of a residential cluster development and a rural cluster development. Clustering allows the design of more effective urban runoff management systems and reduces overall site-level erosion and sediment impacts. It also provides a mechanism to preserve environmentally sensitive areas and reduce infrastructure such as wastewater treatment systems, roads, sidewalks, and parking areas.

In addition to its environmental benefits, clustering can result in cost savings for municipalities because clustering and infill development typically require less new infrastructure, such as urban runoff treatment systems. The imposition of density controls may preclude clustering. Although minimum lot size requirements are useful in some instances, such as farmland preservation (see

Management Measure 3), zoning ordinances should not preclude the implementation of clustered development as an alternative to conventional suburban development.

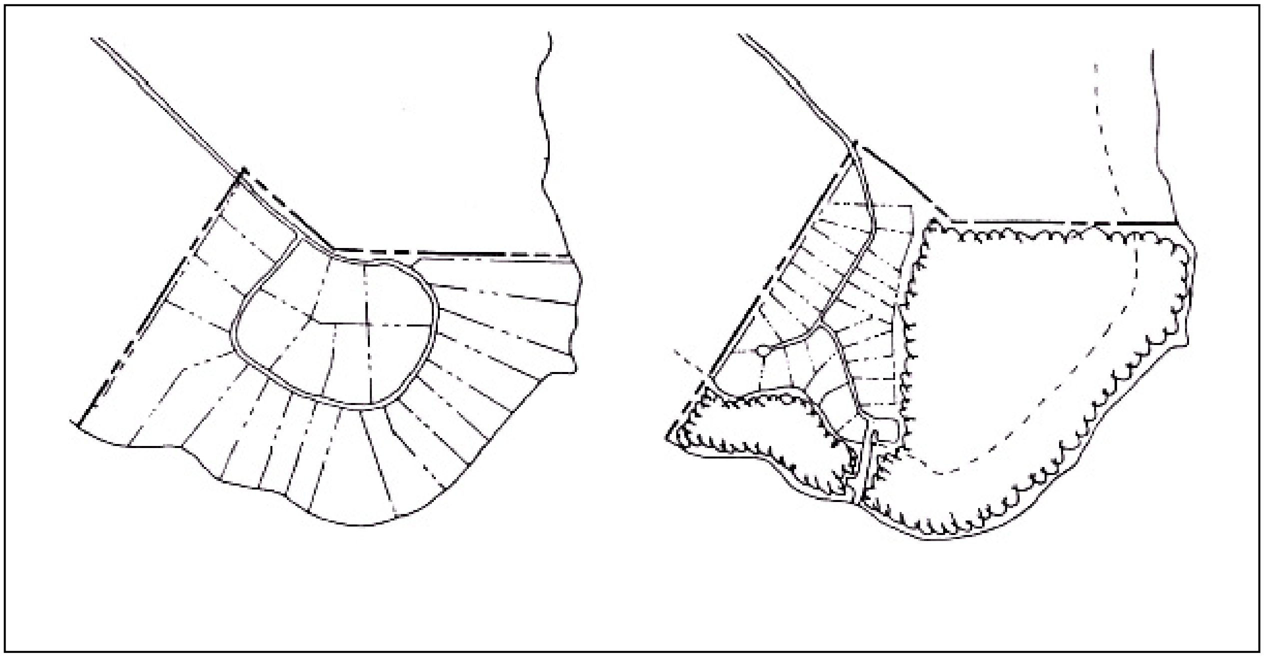

Figure 4.1: Schematic of a residential cluster development (Schueler, 1995).

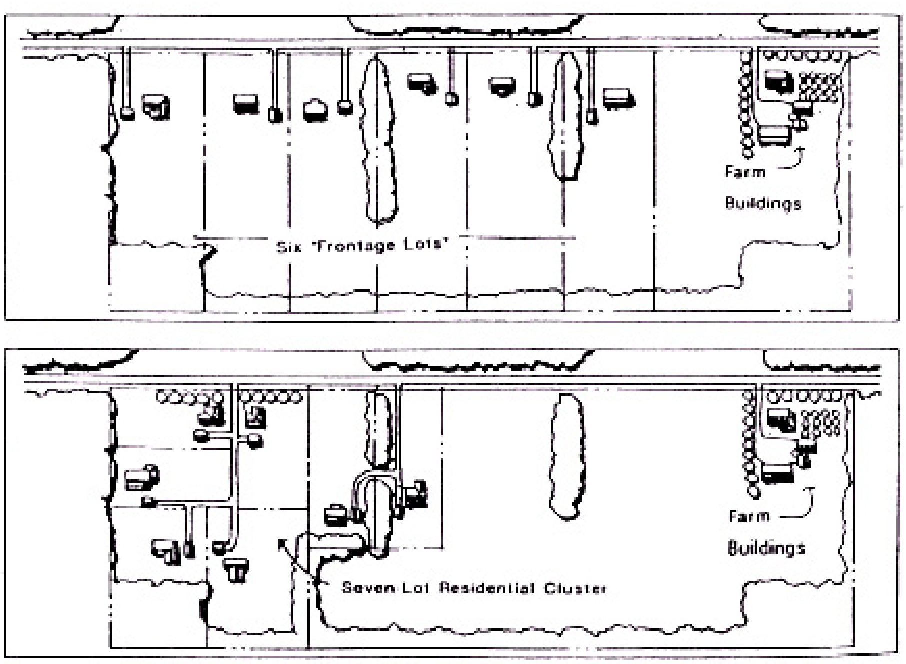

Figure 4.2: Schematic of a rural cluster development (Schueler, 1995).

4.3.1.5 Create open space

Open space development is a technique that concentrates development on one area of a site in exchange for open space in another area. Benefits associated with open space design include:

- A 40- to 60-percent reduction in impervious cover compared to conventional development designs;
- Increased property values;
- Reduced construction and development costs;
- Common recreational facilities (i.e., pedestrian paths, picnic areas, and athletic fields);
- Reduced infrastructure;
- Improved quality of life; and
- The use of community onsite/decentralized systems (see Nutrient Export case study below).

The following are some techniques for conserving open space:

- *By-right open space development*. This technique allows increased density on one portion of a site in exchange for open space on another portion. A large percentage of this open space can be dedicated as conservation land. To encourage open space development, municipalities can draft ordinances so that this is a "by-right" option, as opposed to a special exception or variance.
- *Density compensation*. This technique allows developers to increase housing density to offset potential housing lots lost to on-site buffers or other conservation lands.
- *Storm water credits*. Credit is given for implementation of source controls that reduce runoff volumes and pollutant concentrations before the remaining runoff reaches structural controls. Because performance is typically measured by comparing influent runoff to effluent runoff, storm water credits benefit operators of structural controls because credit for pollutant removal occurs before treatment.
- *Property tax credit*. The property tax credit is a technique for reducing, deferring, or exempting property taxes on conservation land. Typically, conservation easements are exchanged for the property tax credit.
- *Density bonus*. This bonus allows developers to increase density above base zoning density in exchange for conserving natural areas.
- *Off-site mitigation*. This term refers to the restoration or creation of wetlands in a designated off-site area if on-site wetlands are adversely affected and on-site mitigation is not feasible.

Randall Arendt (1996), in his book, *Conservation Design for Subdivisions: A Practical Guide for Creating Open Space Networks*, presents a plain-language, illustrated guide for designing open space subdivisions. This publication is available from Natural Lands Trust, Inc., 1031 Palmers Mill Road, Media, PA 19063; phone 610-353-5587. The following topics are covered:

- Open space vs. conventional developments;
- Economic, social, and environmental benefits of open space designs;
- Roles and responsibilities of stakeholders in site development;
- A stepwise approach to designing an open space subdivision (discussed below);
- Ideas for creating an interconnected open space network;
- Seven case studies;
- Methods to modify existing regulations to encourage open space design;
- Management techniques for conservation lands;
- Sample house plans for open space subdivisions;
- Sample advertisements for developers to capitalize on open space design benefits; and
- Model ordinance provisions.

Arendt's multi-step process for creating conservation subdivisions involves two stages. The first, called the background stage, involves identifying the characteristics of the surrounding landscape and existing development and analyzing and delineating significant features of the site. The second stage involves integrating the site's feature information into a map and prioritizing conservation lands based on the features deemed most important, while maintaining the quantity of land necessary to develop the site to the desired density.

The background stage involves examining the surrounding landscape and existing development to identify conservation areas. It includes the following practices:

(1) *Understanding the locational context*. The layout of new development should consider proximity to traditional small towns or villages; if existing development is nearby, the design of the new community should reflect and extend the historical streetscape and pattern. In rural areas located away from existing development, informal, irregular, "organic" layouts can be used successfully without detracting from the surrounding landscape.

(2) *Mapping natural, cultural, and historic features.* A thorough analysis of a site's special features that may enhance or constrain development is an important step in planning a new development. Special features might already have been identified in a natural resources inventory conducted by local government or land trust organizations. The site analysis should include site visits and identify the conservation areas described in this section.

    The following conservation areas are legally or logistically unbuildable and therefore must be avoided:

    - *Wetlands*. Tidal and non-tidal saltwater and freshwater wetlands and the dry upland buffers surrounding them should be identified as areas to be conserved because they filter runoff, provide critical habitat at the land-water interface, and offer opportunities for recreation and environmental education. Soil survey maps, National

Wetlands Inventory maps, state or environmental agency wetland maps, or on-site delineations can be used to determine the extent of wetland habitat on the site.

- *Floodplains*. The 100-year floodplain, which can be determined from floodplain maps published by the Federal Emergency Management Agency (FEMA) (see Management Measure 2), should be left undeveloped to preserve a continuous riparian greenway and to prevent damage to property from flooding. To preserve views of the water on wooded sites, lower tree limbs can be removed. (This may be a reasonable alternative to developing closer to the water's edge.) Zoning requirements might dictate an additional 50- to 100-foot setback from the 100-year floodplain.

- *Slopes*. Slopes of more than 25 percent should not be developed because of their high potential for erosion. Slopes between 15 and 20 percent can be developed using special site planning but should be avoided when possible. Slope maps can be prepared from USGS topographic maps by an engineer, planner, or landscape architect, but site visits should confirm these conditions.

The following conservation areas typically are legally buildable but are historically or ecologically significant or desirable, and therefore they should be avoided when other land is available for development.

- *Soils*. Soil surveys, whether they are based on existing maps produced by NRCS or data gleaned from on-site testing, identify well-drained soils suitable for treating wastewater, poorly drained soils that might result in leaky basements or wetland conditions, and steep or stony soils that would be difficult to build on. Existing soil survey data might not be detailed enough to characterize site conditions, depending on the spatial variability of soil types in the region. High-intensity soil surveys and site surveys that are accurate to 0.1 acre should be used in highly variable circumstances.

- *Significant wildlife habitats*. Habitat for threatened or endangered wildlife, including travel corridors to food sources, homes, and breeding grounds, should be conserved. An additional buffer of open space is recommended. These habitat locations might have been officially documented already by state or local agencies. Habitat for wildlife species that are not threatened or endangered should also be considered for conservation areas where possible. Continuity in habitat areas is important; land that connects two isolated habitat areas provides a valuable corridor that extends the usable habitat for the species of concern.

- *Woodlands*. Woodlands often provide valuable wildlife habitat and contribute to the aesthetic value of a property. Where areas are mostly forested and clearing is required for site development, however, areas of mature forest or areas with unique species composition should be of higher conservation priority. In areas where woodland is not the predominant land use, as much of the existing tree cover as possible should be conserved on the property. An effort should be made to maintain corridors that connect forested areas to provide as much continuous forested habitat as possible.

- *Farmland*. Agricultural lands can be conserved as open space if desired, although relatively small fields might not be lucrative and could pose a more significant water quality risk compared to residential development due to specific land management practices (tilling, fertilizer application) associated with agriculture. Another option for agricultural fields is to let them succeed to a more natural meadow state with grasses, wildflowers, and shrubs that could provide habitat for many birds and small mammals.

- *Historic, archaeological, and cultural features*. Areas with historic significance can be identified from official lists such as the National Register of Historic Places and state and local inventories of historic and cultural resources. Landowners and local historians should also be consulted for detailed information about a site's history. Although historic areas are not always protected from demolition, if other areas of the property are equally suitable for development, historic resources should be preserved.

- *Views into and out from the site*. Development should be designed to blend well with the surrounding landscape. Because developers typically want to site buildings to take advantage of attractive views, they often build in areas where structures are highly visible. Siting buildings away from the pinnacles of ridges and hills, designing buildings with lower profiles, and preserving or planting trees to shield buildings from view are all techniques that can be used to reduce the visual impact of development on the landscape. Views can be created by cutting a limited number of trees to create "view tunnels," or trimming lower limbs to create "view holes" through the foliage.

- *Aquifers and their recharge areas.* An aquifer recharge area is where water moves downward to the water table. In other words, recharge areas replenish groundwater. Unconfined aquifers are not covered by a layer of impermeable rock and are open to receive water from the land surface. Unconfined aquifers are typically recharged in topographically high areas or through sandy or gravelly soils. These areas should be conserved as open space to maintain ground water recharge. They should also be buffered with vegetation to filter solids and associated pollutants from runoff.

After background information has been obtained, the next step is to integrate the information and prioritize conservation areas. Typically, all of the features mentioned above are drawn onto overlay sheets or entered into a geographic information system (GIS). Once the significant features are shown together, areas most suitable for development become obvious. Where some conservation areas need to be sacrificed to achieve the development objectives, decisions must be made regarding ranking the conservation areas based on how special, unique, irreplaceable, environmentally valuable, historic, or scenic they are. Figure 4.3 shows an example site before development, developed with a conventional strategy, and developed with consideration of locational context and conservation areas (Arendt, 1996).

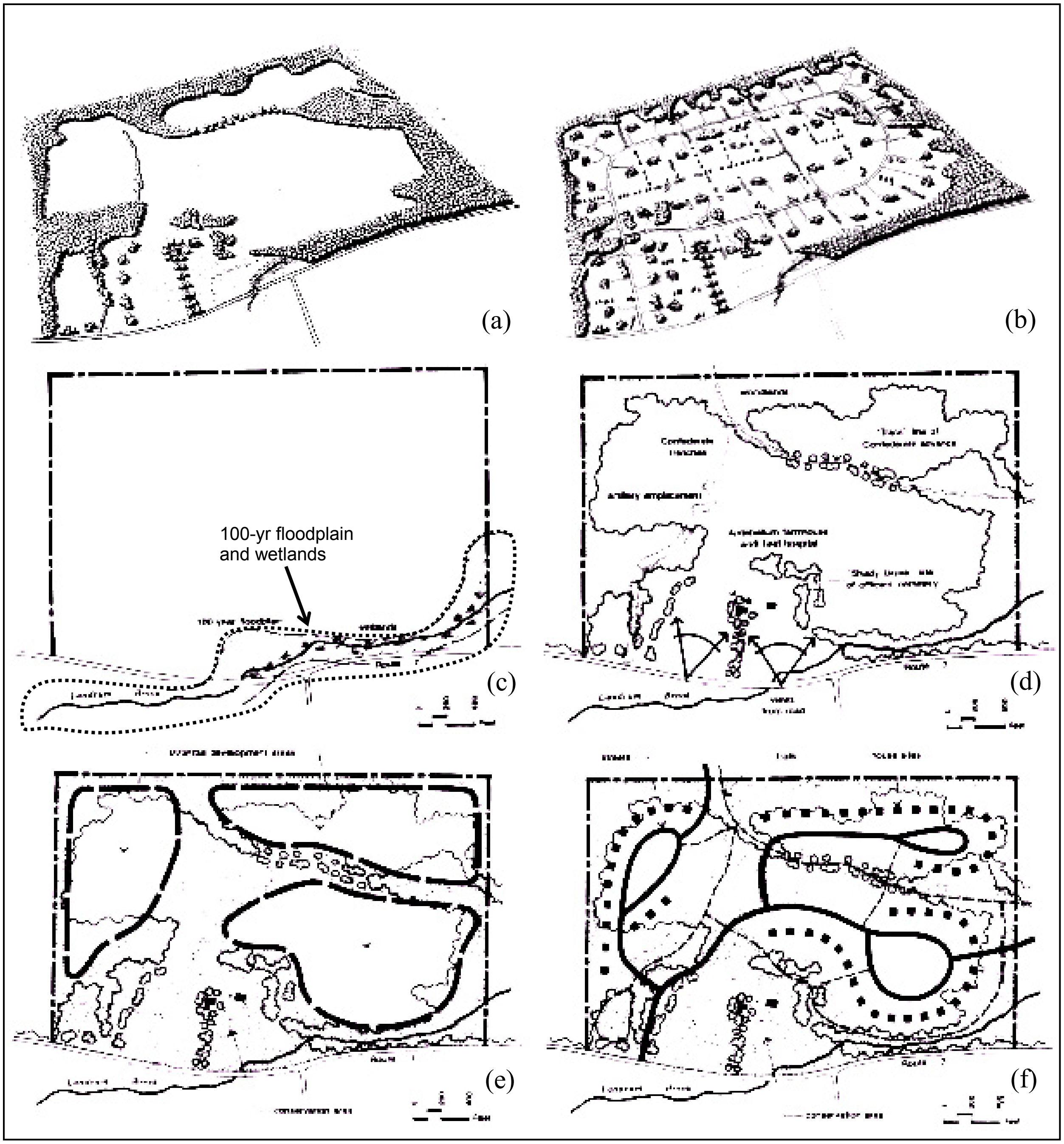

Figure 4.3: Development of a conservation subdivision. The site before development (a) and as designed with conventional development (b); identification of legally unbuildable (c) and legally buildable (d) conservation areas with features to be protected; and delineation of potential development areas (e and f) (adapted from Arendt, 1996).

Comparison of Traditional and Low Impact Development Scenarios in Delaware

The Brandywine Conservancy and the Delaware Department of Natural Resources and Environmental Control presented a case study in *Conservation Design for Stormwater Management* (Delaware DNREC and the Brandywine Conservancy, 1997). The case study compares conventional site development to several alternative, low impact development scenarios at Chapel Run, a 96-acre site in Sussex County, Delaware. The Chapel Run site is located in a rural area and is categorized by Sussex County as a primarily agricultural area where low-density residential development is permitted. Conservation areas that were identified through a site investigation include a large area of woodland, much of which is on well-drained soils that generate little or no runoff, and a small area with steep slopes.

The proposed conventional design dictates dividing the site into 142 lots ½ acre in size. The conventional design does not take into consideration the sensitive areas identified in the site assessment and results in a site with 100 percent of the area disturbed after clearing and grading. Overall site imperviousness under conventional development would be 29 percent, assuming conventional road widths. On-site runoff management would be accomplished by a curb and gutter system that conveys runoff to two detention basins.

Two alternative designs were developed for the Chapel Run site: the parkway design and the village cluster design. Figure 4.4 shows lot layouts for the conventional and conservation designs. Table 4.1 shows a theoretical side-by-side comparison of the three types of developments with respect to lot size and layout, amount of disturbed and impervious area, hydrology, and costs. Table 4.2 shows differences in itemized costs for infrastructure and management practices between conventional and low impact alternative designs.

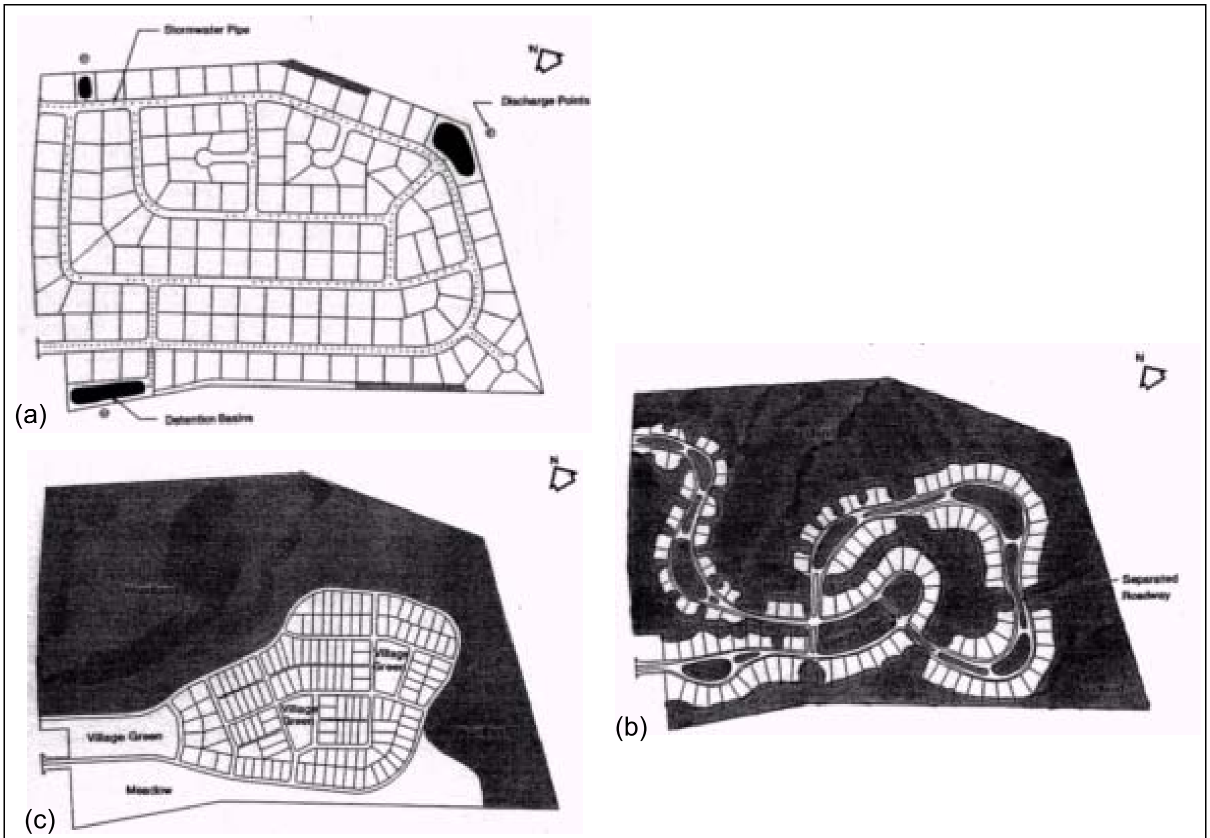

Figure 4.4: Schematic drawings of conventional (a), parkway (b), and clustered (c) development scenarios for the Chapel Run subdivision (Delaware DNREC and the Brandywine Conservancy, 1997).

Comparison of Traditional and Low-Impact Development Scenarios in Delaware (continued)

Table 4.1: Theoretical comparison of conventional and low-impact alternative designs for the Chapel Run site (DE DNREC and the Brandywine Conservancy, 1997). (Reductions are compared to the conventional design.)

Name	Conventional	Village	Parkway
Layout type	Conventional	Condensed cluster	Lots configured along curving road
Number of lots	142	142	142
Lot size	1/2-acre	1/8-acre	1/4-acre
Areas conserved	None	Woodland and high recharge areas	Woodland and high recharge areas
Percent of site in open space	0%	72.7%	49.7%
Impervious cover	29%	17.7%	14.9%
Impervious cover reduction	—	38%	48%
Street width	28 feet	20 feet	Two one-way lanes 12 feet wide with a pervious median
Undisturbed areas	0%	67.5%	59.6%
Runoff management system	Curb and gutter system that conveys runoff underground to two detention basins.	Swale conveyance system along roads that directs runoff to retention/ infiltration areas with level-spreading devices and low berms. These retention/infiltration areas are located throughout the site. Several village greens established on well-drained soils function as both recreation and infiltration areas.	Infiltration of runoff into depressed median (swales) along streets. Wide oval parkway centers used for retention/infiltration. These areas are designed with overflow piping to prevent flooding.
Average curve number[a]	78	66	65
Peak runoff rate for a 10-yr storm[a]	—	53 cfs	51 cfs
Water budget (gal) Precipitation Runoff Recharge Evapotranspiration	 114,082,682 31,584,217 31,280,103 51,223,261	 114,082,682 21,812,868 34,001,079 58,208,796	 114,082,682 17,782,776 35,502,938 60,802,278
Costs [b] Total Per lot	 $2,460,200 $17,325	 $1,174,716 $8,273	 $887,705 $6,259

[a] From USDA-NRCS's TR-55 model.

[b] Total cost for the Parkway design shown here differs from total cost published in DE DNREC and the Brandywine Conservancy (1997). Total cost shown here is based on itemized costs, provided in Table 4.2. These are conservative estimates, as in most cases additional costs such as grading have not been taken into account.

Comparison of Traditional and Low-Impact Development Scenarios in Delaware (continued)

Table 4.2: Theoretical comparison of itemized costs for conventional and low-impact alternative designs for the Chapel Run site (DE DNREC and the Brandywine Conservancy, 1997).

Name	Conventional	Village	Parkway
Street			
Length installed	13,388 ft	11,828 ft	7,800 ft
Unit cost	$150/linear ft	$85/linear ft	$85/linear ft
Total cost	**$2,008,200**	**$1,005,380**	**$663,000**
Storm water detention ponds			
Number installed	3	0	0
Unit cost	$16,000 per pond		
Total Cost	**$48,000**	**$0**	**$0**
Storm water pipe			
Length installed	16,000 ft	2,000 ft	3,000 ft
Unit cost	$22/linear ft	$22/linear ft	$22/linear ft
Total cost	**$352,000**	**$44,000**	**$66,000**
Endwalls/inlets			
Number installed	40	5	10
Unit cost	$1,300 each	$1,300 each	$1,300 each
Total cost	**$52,000**	**$6500**	**$13,000**
Berms			
Length installed	0	1050 ft	1000 ft
Unit cost		$10/linear ft	$10/linear ft
Total cost	**$0**	**$10,500**	**$10,000**
Swales			
Length installed	0	22,570 ft	20,600 ft
Unit cost		$4.50/linear ft	$4.50/linear ft
Total cost	**$0**	**$101,565**	**$92,700**
Check dams			
Number installed	0	90	82
Unit cost		$75 each	$75 each
Total cost	**$0**	**$6771**	**$6150**
Reforestation			
Acres reforested	0	0	12.8
Unit cost			$2,925/ac
Total cost	**$0**	**$0**	**$36,855**
Total [a]	**$2,460,200**	**$1,174,716**	**$887,705**

[a] Total cost for the Parkway design shown here differs from total cost published in DE DNREC and the Brandywine Conservancy (1997). Total cost shown here is based on itemized costs. These are conservative estimates, as in most cases additional costs such as grading have not been taken into account.

4.3.2 On-Lot Impervious Surfaces

4.3.2.1 Reduce the hydraulic connectivity of impervious surfaces

Pollutant loading from impervious surfaces can be reduced by preventing the direct connection of the impervious area to an impervious conveyance system. This can be done in a number of ways, including:

(1) Routing runoff over lawn areas to increase infiltration;

(2) Discouraging the direct connection of downspouts to storm sewers, or the discharge of rooftop downspouts to driveways, parking lots, and gutters;

(3) Substituting swale and pond systems for curbs and gutters to increase infiltration; or

(4) Reducing the use of storm sewers to drain streets, parking lots, and backyards by routing runoff overland using curbless systems, curb cuts, sloped sidewalks, and bioretention cells.

If runoff is directed over lawns, care should be taken to alleviate soil compaction. Urban lawns that are highly disturbed and compacted do not necessarily function as pervious surfaces (for more information on managing runoff from lawns and landscaping, see Management Measure 9).

Figure 4.5 shows schematic representations of impervious areas that are directly connected and not directly connected (BASMAA, 1997).

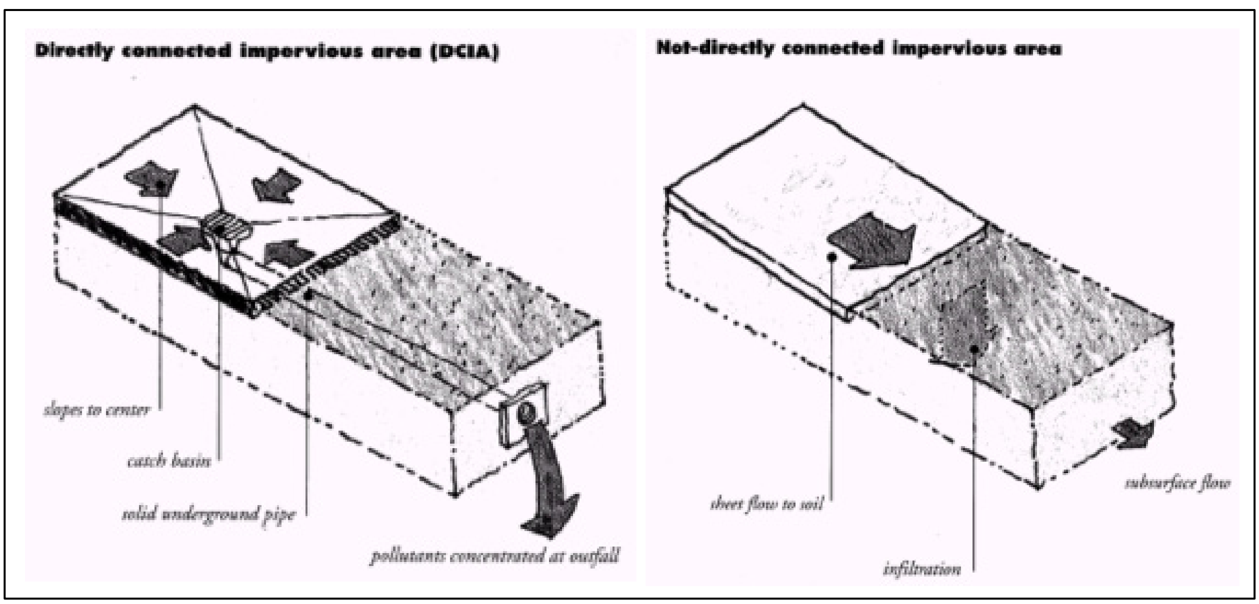

Figure 4.5: Schematic representation of directly connected and not-directly connected impervious areas (BASMAA, 1997).

The Urban Runoff Pollution Mitigation ordinance passed by the City of Santa Monica, California, requires new developments to implement management practices to collect precipitation, increase infiltration, and manage urban runoff on-site rather than after it enters the storm drain system. Infiltration trenches are the most common on-site practices for single-family homes in the city, but biofilters, swales, and porous pavement are also used. Since 1995, when the ordinance came into effect, 600 new developments have implemented management practices, resulting in a 1.2 million-gallon decrease in storm water runoff for each storm of 0.1-inch rainfall or greater (Shapiro, 2003).

In Prince George's County, Maryland, Cheng et al. (no date) measured runoff from adjacent watersheds to compare the effects of conventional versus low-impact subdivision design. One watershed was developed using conventional subdivision design (curb, gutter, and pipe storm drainage), while the other watershed was developed using low-impact development (LID) techniques, including curbless roads, networks of grassy swales to convey runoff, and bioretention areas (with drop inlet structures where necessary to convey concentrated flows during larger storms). After two years of monitoring, the researchers found that the average peak flow rate of the LID site was 56 percent of that of the conventional site, and surface runoff volume for the LID site was 60 percent of that of the conventional site. Only 15 percent of rainfall was converted to runoff in the LID watershed compared to 19 percent in the conventional watershed, and the LID site had delayed runoff hydrographs and a higher frequency of small flow rates compared to the conventional site, which had a higher frequency of larger flow rates.

Gap Creek Low Impact Development Subdivision, Sherwood, Arkansas

The Gap Creek subdivision in Sherwood, Arkansas, was designed using a low impact development approach that involved implementing such practices as street designs that flow with the existing landscape, minimal site disturbance and preservation of native vegetation, preservation of natural drainage features, and a network of buffers and greenbelts that protect sensitive areas. The approach resulted in significant economic benefits arising from lower development costs, higher lot yield, and greater lot values (NRDC, 1999).

The developer took advantage of the open space that was preserved to maximize the number of lots that were adjacent to the uncleared areas, enhancing their marketability and increasing the value of those properties. The LID plan reduced the amount of site clearing and grading, yielding lower site preparation costs.

Additionally, enhancing natural drainage features resulted in less money spent on drainage infrastructure such as piping, curbs, gutters, and other runoff conveyance features. An additional cost savings was realized with shorter and narrower streets, which also reduced imperviousness. For example, the developer reduced street width from 36 to 27 feet and retained trees close to the curb line, resulting in savings of nearly $4,800 per lot.

The greater lot yield and high aesthetic curb appeal also resulted in larger profits. The developer was able to sell lots for $3,000 more than larger lots in competing areas and sold nearly 80 percent of the lots within the first year. Additional benefits can be found in 23.5 acres of green space and parks (Toolbase Services, no date).

The economic benefits are expected to exceed $2 million over original projected profits. Additional benefits of the LID design include lower landscaping and maintenance costs and more common open space and recreational areas.

4.3.2.2 Practice rooftop greening

Rooftop greening has become an increasingly common practice in Europe and other parts of the world. This practice involves growing vegetation on the roofs of businesses and homes to intercept rainfall and promote evaporation rather than runoff (Natural Carpets, 1998). Rooftop mats are typically multilayered and include prevegetated coir fiber mats, a mineral-based substrate, and a synthetic matrix (see Figure 4.6). The coir fiber mat absorbs rainfall; the mineral substrate provides the plants with nutrients; and the synthetic matrix promotes drainage. Mats can be used on roofs with slopes of up to 30 degrees and are capable of reducing runoff by two-thirds (see Figure 4.7). These mats provide benefits other than runoff reduction, including:

- Visual aesthetics
- Protection of roofs from damaging solar radiation, wind, and precipitation
- Insulation
- Noise reduction
- Habitat for wildlife

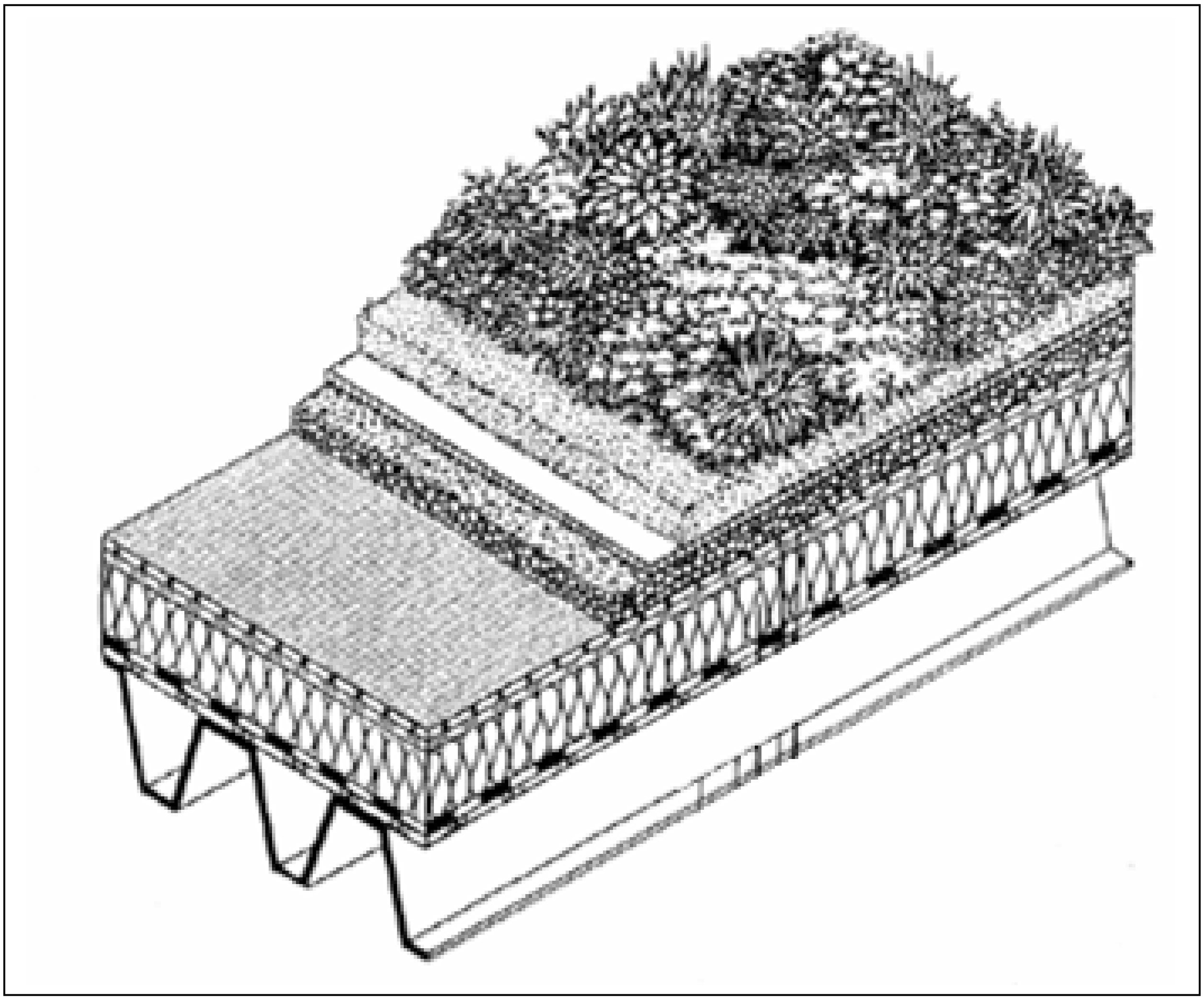

Figure 4.6: Components of the vegetated roof cover (USEPA, 2000).

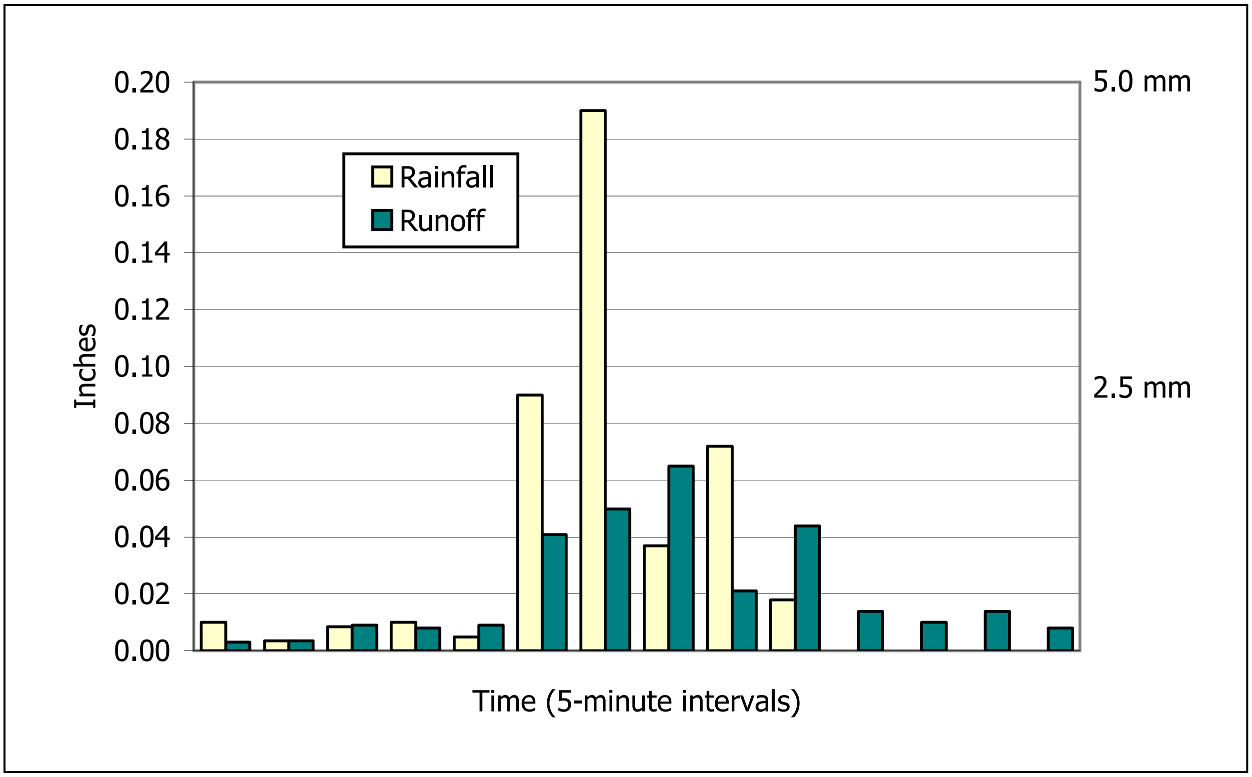

Figure 4.7: Runoff attenuation efficiency for a 0.4-inch rainfall event with saturated media (USEPA, 2000).

- Dust-trapping
- Evaporation and ambient cooling

Vegetation should be well-adapted to the growing conditions of the area where it is installed. Maintenance includes a limited amount of irrigation on steep slopes and periodic fertilization and weeding. Additional roof support might be necessary because the mats, when saturated with water, can add 5 to 17 pounds per square foot.

In response to a court order requiring $3 billion in storm water improvements, Atlanta is targeting commercial buildings for the installation of green roofs, with the anticipation that the resulting decrease in storm water runoff volume will provide water quality benefits. Commercial buildings are being targeted because commercial rooftops cover a huge amount of surface area in the city (Copeland, 2002).

Moran et al. (2004) studied runoff quality from two green roofs installed in North Carolina. They found that each green roof retained approximately 60 percent of the total recorded rainfall during a nine-month observation period. The green roofs reduced average peak flow by approximately 85 percent. Water quality data indicated higher concentrations of total nitrogen and total phosphorus were present in the green roof runoff than in the control roof runoff and in the rainfall at each green roof site. The researchers attribute this to nitrogen and phosphorus leaching from the soil media, which was composed of 15 percent compost. A soil column test of three different green roof soil media indicated that reducing organic matter in the soil media will

Rooftop Meadow Demonstration Project, Philadelphia, Pennsylvania

Rooftop meadows typically use foliage and a lightweight soil mixture to either absorb or filter and detain rainfall (Miller, 1998). Roof meadows are designed to control low-intensity storms by intercepting and retaining or storing water until the peak storm event has passed, while allowing the runoff from higher-intensity storm events to be safely conveyed away from the building. The plants help retain the hydrologic function of intercepting and delaying rainfall runoff by capturing and holding precipitation in the foliage, absorbing water in the root zone, and slowing the velocity of direct runoff by extending the flowpath through the vegetation.

A rooftop meadow demonstration project in Philadelphia, Pennsylvania, consists of a 3,000-ft^2 roof installed and monitored on top of an existing structure. The roof system was intended to mimic natural hydrologic processes of interception, storage, and detention to control the 2-year, 24-hour storm event. There are several distinguishing features of this rooftop meadow: (1) a synthetic underdrain layer that promotes rapid drainage of water from the surface of the roof deck; (2) a thin, lightweight growth medium that permits installation on existing conventional roofs without the need for structural reinforcement; and (3) a meadow-like setting of perennial *Sedum* varieties that have been selected to withstand the range of seasonal conditions typical of the Mid-Atlantic region without the need for regular maintenance.

The installed roof meadow is 3.4 inches thick, including the drainage layer, and weighs less than 5 lb/ft^2 when dry and less than 17 lb/ft^2 when saturated. The moisture content of the medium at field capacity is 45 percent of the volume. The saturated infiltration capacity is 3.5 inches per hour.

The runoff characteristics of the roof were simulated using rainfall records for 1994 from eastern Pennsylvania. The model predicted a 54 percent reduction in annual runoff volume and attenuation of 54 percent and 38 percent, respectively, for the 2- and 10-year, 24-hour Type II storm events. Monitoring of the pilot project for real and synthetic storm events was also conducted for a period of 9 months at 28- and 14-ft^2 trays. The most intense storm monitored was a 0.4-inch, 20-minute thunderstorm. The storm event occurred after an extended period of rainfall had fully saturated the medium. Although 44 inches of rainfall were recorded during this period, only 15.5 inches of runoff were generated from the trays. Runoff was negligible for storm events with less than 0.6 inch of rainfall. This demonstration project shows the advantages of reducing peak runoff rates on overloaded systems for a majority of the storm events and shows that some existing structures can be retrofitted to reduce runoff.

reduce the amount of nutrient leaching. Based on the results of this study, caution should be used when implementing green roofs in nutrient-sensitive watersheds; green roof components such as soil media composition should be selected with consideration of receiving water limitations.

Dunnett and Kingsbury (2004) describe examples of both large-scale and residential applications of green roofs and living walls, and they include technical information about constructing these structures in *Planting Green Roofs and Living Walls.* The authors cover structural engineering concerns as well as factors such as plant selection and environmental considerations that are important for the success of green roofs and living walls. The book is available for purchase at the Timber Press Web site at http://www.timberpress.com.

Another resource for information about green roofs is the proceedings of a conference entitled Green Roofs for Healthy Cities. A CD-ROM of the proceedings can be purchased from http://www.greenroofs.org/portland/proceedings.php and includes information on green roof design and implementation, technical research, and policy developments.

A Better Site Design Approach to Runoff Management: Low Impact Development

The goal of low impact development (LID) is to maintain and enhance the predevelopment hydrologic regime of urban and developing watersheds. LID focuses on managing runoff in small, cost-effective landscape features on each lot rather than conveying runoff to large, costly storm water ponds located at the bottom of large drainage areas. Hydrologic functions such as infiltration, ground water recharge, and depressional storage are maintained using simple, small-scale practices such as bioretention facilities. A key objective of LID is to reduce the hydraulic connectivity of impervious surfaces. For example, instead of allowing storm water to run from a downspout down a driveway and into a storm sewer, direct the runoff onto a lawn or other pervious area. By disconnecting rooftop runoff from the storm drainage system, a community can decrease the volume of water conveyed to a storm drain by as much as 50 percent (Pitt, 1986) and avoid treatment and storage costs, decrease system maintenance costs, and reduce instream impacts. To avoid soggy areas in lawns, water can be directed to specially designed depression storage areas such as bioretention or infiltration areas.

The following is a list of fundamental practices of the LID approach that can be included in runoff management plans. These practices are presented in two publications by the Department of Environmental Resources of Prince George's County, Maryland: *Low-Impact Development Design Strategies: An Integrated Design Approach* (2000a) and *Low Impact Development Hydrologic Analysis* (2000b).

- *Use hydrology as the integrating framework.* Hydrology is used as the key feature when designing a development. Areas that play a critical role in the movement of water (e.g., streams, riparian and buffer areas, floodplains, wetlands, and ground water recharge sites) are identified first. Alternative layout schemes are then evaluated in terms of their impact on site hydrology. Key objectives are to minimize the amount of impervious cover created and to make created impervious areas function as "ineffective" impervious areas that are not directly connected to a storm drain network.
- *Think micromanagement.* Site hydrology is analyzed and dealt with at small scales. Using natural drainage as a design element, integrated management practices are scattered throughout the site, allowing for runoff distribution and the retention of natural hydrologic functions such as infiltration, depressional storage, and interception.
- *Control runoff at the source.* Management of runoff at or near the sources eliminates the need for large-scale runoff management practices such as concrete conveyance systems and storm water ponds.
- *Incorporate safety features into the design of management practices*. LID practices can require diversions or drainage to allow for overflow of runoff from large storms and storm events that occur during saturated conditions. This emergency drainage will protect the longevity of the structural practice against damage from high runoff volumes and flow velocities and enhance the acceptance of LID in the community.
- *Use simple, nonstructural methods.* Natural hydrologic functions rely on simple processes that promote infiltration, depressional storage, and interception of storm water. These characteristics can be implemented throughout the site using simple methods that incorporate native plants, soil, and gravel.
- *Create a multifunctional landscape.* A goal of the LID approach is to create a landscape where runoff is micromanaged and controlled at the source. Runoff management practices and natural landscape features can be used in tandem to reduce postdevelopment runoff volume and maintain the predevelopment time of concentration.

The Prince George's County LID publications can be ordered through the Internet at EPA's National Service Center for Environmental Publications Web site at http://www.epa.gov/ncepihom. They can also be ordered by phone, fax, or mail from USEPA/NSCEP, P.O. Box 42419, Cincinnati, Ohio 45242-2419, toll-free 800-490-9198, fax 513-489-8695.

4.3.2.3 Relax frontage and setback requirements

Developers interested in increasing open space or conservation areas typically increase housing density by creating smaller lots or clustered developments and pool the space "savings" in a large open area accessible to all. This can be accomplished by reducing front, side, and rear yard setbacks and decreasing frontage distances. In addition to increasing housing density for open space development designs, relaxing frontage and setback requirements also decreases impervious cover. This occurs because narrower side yards mean narrower lots, which can in turn lead to shorter subdivision streets; shorter front yard setbacks lead to shorter driveways and sidewalks.

Frontage distance can be reduced by providing garage access through rear alleys. This approach eliminates driveways and allows homes to be sited on narrower lots. This helps reduce road frontage requirements and accommodate more homes on a given amount of road. Because of their limited traffic, the alleys can be paved with alternative treatments to retain more pervious area.

Areas with high potential for significant storm damage, earthquakes, or other catastrophes should take into consideration the appropriate setback distance to ensure emergency access in case of building collapse.

4.3.2.4 Modify sidewalk standards

Many conventional subdivision codes require paved sidewalks on both sides of the street in widths that range from 4 to 6 feet. Communities that want to reduce impervious cover and increase the use of pervious areas for runoff treatment should consider the following (always considering public safety first):

- Allowing sidewalks on only one side of the street or building them only where there is pedestrian demand;
- Increasing the distance between sidewalks and the street so sidewalk runoff has a better chance of infiltrating into the grass border area and not becoming street runoff. This will provide water quality as well as safety benefits;
- Grading sidewalks so that runoff drains into the yard rather than toward the street;
- Reducing the width of very wide sidewalks. Communities should consider the implications of reducing sidewalk widths, including pedestrian demand and wheelchair access, on a case-by-case basis. Three feet will typically allow passage for one wheelchair. Sidewalks in highly commercial areas and government centers should accommodate two wheelchairs abreast, but it may be appropriate for some residential areas to reduce sidewalk width to three feet.
- Maintain sidewalk widths but use porous pavement (see Management Measure 5).

4.3.2.5 Modify driveway standards

In a sense, driveways are small-scale parking lots that are designed to accommodate two to four cars. Typical residential driveways and parking pads often total 400 to 800 square feet. Communities that want to reduce driveway impervious cover should consider:

- Shortening driveway length by shortening front yard setback requirements;
- Narrowing driveway widths;
- Encouraging the use of driveways that are shared by two or more homes; and
- Providing incentives for use of alternative driveway surfaces that allow for infiltration, such as porous pavers, gravel, or a two-track surface with grass in between.

4.3.3 Residential Street and Right-of-Way Impervious Surfaces

The largest percentage of impervious cover in residential neighborhoods is typically associated with the streets, driveways, and sidewalks that together aid in the transport of people to and from their various destinations. Management practices associated with residential streets and their rights-of-way typically are focused on minimizing impervious cover or treating runoff. In general, these objectives can be achieved by developing, updating, or revising codes, ordinances, and standards that determine the size, shape, and construction of residential streets and their rights-of-way.

4.3.3.1 Decrease street pavement width and length

Streets typically make up the largest percentage of transport system impervious cover in residential neighborhoods. Communities can significantly reduce this type of cover in new developments by revising street standards so that street pavement widths are based on traffic volume, on-street parking needs, and other variables rather than requiring all streets to have one universal width. Additionally, communities can encourage developers to design street networks that minimize the total length of pavement. The length of residential streets can be reduced by altering the design and placement of new development. Techniques include:

- Reducing frontage distances and side yard setbacks;
- Allowing narrower lots;
- Clustering smaller lots;
- Reducing the number of non-frontage roads; and
- Eliminating long streets that serve only a small number of homes.

4.3.3.2 Decrease street right-of-way width

A street right-of-way is a public easement corridor through which people, vehicles, runoff, utility services, and other items and materials move in, out, and around the development. A right-of-way usually includes the street itself, its gutters and curbs, and some amount of land on either side of the street, which might contain sidewalks, utility easements, or other components. Options for minimizing right-of-way widths include:

- Eliminating some right-of-way components;
- Placing sidewalks on only one side of the street;
- Running utility pipes, cables, and other infrastructure underneath street pavement (this can result in traffic congestion from road construction if the infrastructure needs to be repaired or replaced); or
- Reducing street and sidewalk widths where appropriate.

On-street parking is a variable that should be closely examined in communities where reducing impervious cover is a goal. Some communities have implemented a concept known as "queuing streets." Queuing streets generally have one travel lane and one or two parking lanes. Cars wait between parked cars until approaching traffic passes before proceeding to the travel lane. This approach also helps slow traffic, which can improve safety.

Street width must provide for utility work (common utilities include water, sewer, gas, cable, phone, power, and fiber optics). If the street width is reduced, utilities can be installed together in a concrete trench with a removable top for maintenance access (Matsuno, 2003).

When considering these options, it is important to remember that public safety should not be compromised and traffic engineering principles must still be a significant design factor. In addition, areas with high potential for significant storm damage, earthquakes, or other catastrophes should take into consideration the appropriate right-of-way width to enable passage of emergency vehicles.

The Headwaters Project: A Sustainable Community

In 1998 the Department of Planning and Development in Surrey, British Columbia, initiated the Headwaters Project to develop a real example of a sustainable community. Part of this project is the *East Clayton Neighbourhood Concept Plan* (The Headwaters Project, 2000), a green infrastructure plan that is an integrated system of "green" streets and affordable housing sites. It has narrow streets that use one-third less blacktop than typical roadways. Storm water management is achieved through natural infiltration, which minimizes runoff and avoids downstream flooding events. Information about East Clayton and a copy of the concept plan are available at http://www.sustainable-communities.agsci.ubc.ca/projects/Headwaters/PDF/toc.pdf

4.3.3.3 Use alternative cul-de-sac designs

Cul-de-sacs (roads with one open and one closed end) are a popular design element in community road networks. The intent of cul-de-sacs is to provide more homebuyers with premium, "end-of-the-road" lots. The typical "bulb" found at the closed end of a cul-de-sac, however, represents a particularly large concentration of impervious cover. Communities can reduce the amount of impervious cover created by bulb-ending cul-de-sacs by

- Eliminating cul-de-sac streets altogether;
- Using alternative designs for turnarounds, such as a T-shaped turnaround or a looped road;
- Reducing the radius of the turnaround bulb; or
- Incorporating a pervious cover island in the center of the turnaround bulb that accepts runoff.

As with modifications of street right-of-way width, public safety should not be compromised and traffic engineering principles must still be a significant design factor for this practice. Existing fire codes may dictate cul-de-sac width. Figures 4.8 and 4.9 show five turnaround options at the end of a residential street and the amount of impervious cover created by each option (Schueler, 1995).

4.3.4 Parking Lot Impervious Surfaces

Parking lots are considered by some to be one of the most damaging land uses in the urban landscape (CWP, 2000). Not only are parking lots very efficient at concentrating and delivering a large amount of runoff to receiving waters, thus exacerbating erosion problems, but they also act as a repository for pollutants associated with automobiles, which include nutrients, trace metals, and hydrocarbons.

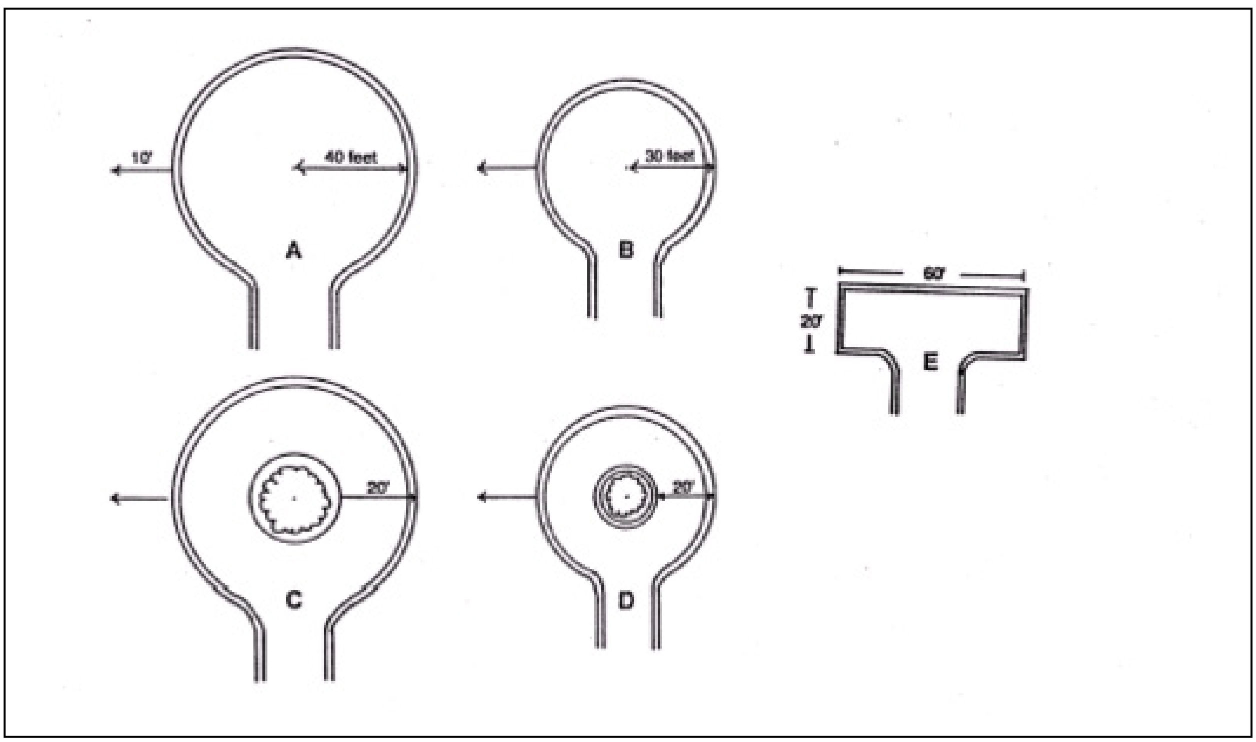

Figure 4.8: Five turnaround options at the end of a residential street (Schueler, 1995).

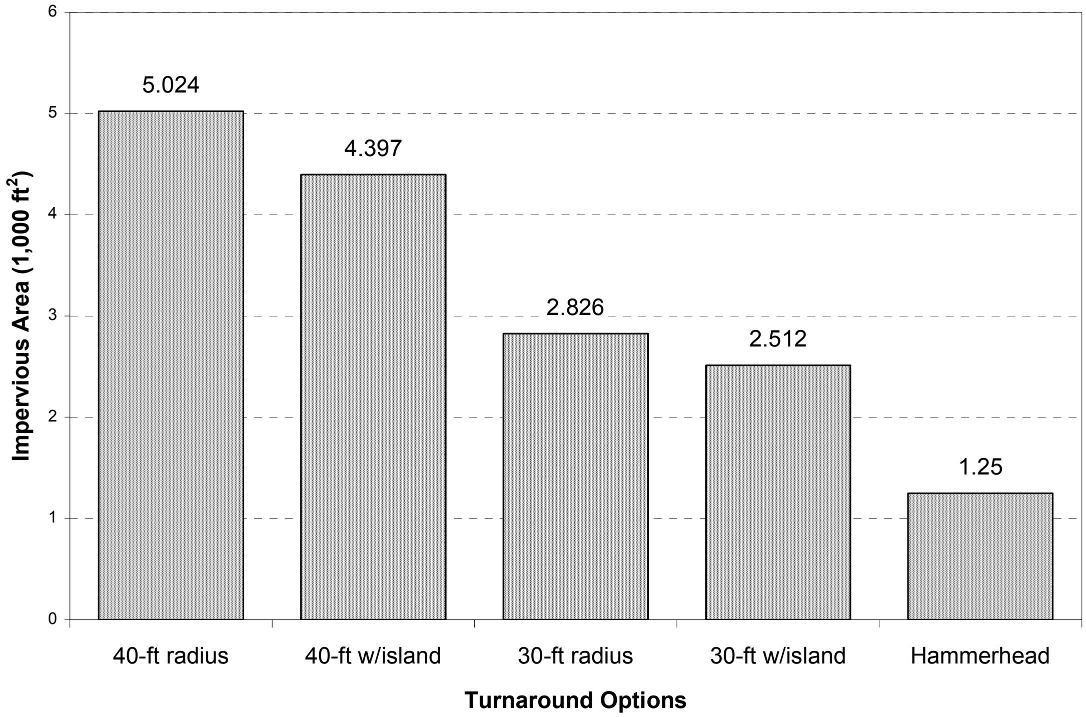

Figure 4.9: Impervious cover created by each turnaround option shown in Figure 4.8 (Schueler, 1995).

Innovative Turf Parking Lot Installation at a Connecticut Shopping Mall

The owners of Westfarms Mall, in the suburbs of Hartford, Connecticut, planned a 310,000-ft^2 expansion that required an additional 4 acres of overflow parking (Wilson et al., 1998). Local zoning boards and members of the community balked at this proposal because of the high ratio of impervious-to-pervious surfaces and concern for the quality and quantity of runoff generated by the new additions.

The traditional solution for handling the increased runoff was to install a large runoff detention pond, which would have cost $1million and was looked upon unfavorably by both the community and the mall owner. A 4-acre turf parking lot was implemented as an alternative and allows rainfall to infiltrate and recharge the ground water supply. To better support automobile traffic, the lot consists of a plastic honeycomb grid filled with sand and soil and laid atop a bed of crushed stone. Additionally, rooftop runoff is diverted to a tank located under the lot and the collected runoff is used to irrigate the turf. The turf would not hold up to everyday traffic, but overflow parking is needed only during the Christmas shopping season when the grass is dormant.

The cost of installing the turf lot was $500,000, which is half the cost of installing a pond. Even though the turf installation was more expensive than traditional pavement installation, the mall owner estimated that the installation would break even within 5 years because of lower maintenance requirements. An additional benefit of this innovative design was for the mall owner to gain the support of community members and local planning commissions.

Traditionally, developers have provided an overabundance of parking as a convenience for shoppers, workers, and landowners. A goal of watershed managers should be to reduce the surface area of parking lots and integrate runoff treatment practices to reduce adverse impacts, while still providing enough spaces to meet the expected parking demand. This reduction can be accomplished by implementing better site design practices, such as:

- Redesigning building and parking area layouts to reduce walking distances and provide more efficient layouts.
- Ensuring that the number of spaces built reflects actual demand. Site planners should design the lot size to correspond to minimum local parking requirements and consider ways in which this requirement can be reduced. For example, less parking is needed if access to public transportation is provided. Also, a parking area can be shared if localities in close proximity have different peak parking times. For instance, a retail establishment with peak demand during weekdays can share parking with a church whose peak demand is on the weekend.
- Sizing parking lot dimensions to meet everyday demand and designating additional "spillover" parking areas to handle peak demand. Because these spillover areas will receive less traffic, alternative paving techniques (see Management Measure 5) can be used to increase infiltration.
- Reducing the dimensions of the normal parking spaces if allowable. Also, developers can designate a percentage of the available parking spaces for use by compact cars and reduce their dimensions correspondingly.
- Building multilevel parking structures when feasible. (Parking structures can sometimes be impractical from a cost standpoint.) Green roofs can be used on these parking garages to reduce imperviousness.
- Converting parking lot islands to bioretention areas (see Management Measure 5).
- Building below-grade parking where it does not affect groundwater or other subsurface resources.
- Working with municipalities to regulate the maximum number of parking spaces allowed in development, rather than a minimum.

When parking area is reduced, functional landscaping can be used to improve the aesthetics of the site and to allow room for the installation of runoff treatment practices such as infiltration basins, filter strips, and dry swales or detention practices like those described in Management Measure 5.

4.3.5 Xeriscaping Techniques

Xeriscaping is a landscaping concept that maximizes water conservation by using site-appropriate plants and an efficient watering system. It involves the use of landscaping plants that need minimal watering, fertilization, and pesticide application, and practices that reduce water demand. For instance, mulching can help retain water and humidity and reduce the need for irrigation. Shading and windbreaks can reduce evaporation, particularly from young plants. In contrast to overhead sprinklers, drip irrigation waters plants directly on the roots without wetting plant leaves, helping to reduce evaporation and control disease. Timers are available that allow automatic watering with drip irrigation systems. Watering early in the morning can also reduce evaporation, and prevent the propagation of disease that often results from leaving foliage wet overnight (Relf, 1996). Xeriscaping can reduce the contribution of landscaped areas to nonpoint source pollution, and it can reduce landscape maintenance by as much as 50 percent, primarily as a result of the following (Clemson University Cooperative Extension Service, 1991):

- Reduction of water loss and soil erosion through careful planning, design, and implementation;
- Reduction of mowing by limiting lawn areas and using proper fertilization techniques; and
- Reduction of fertilization through soil preparation.

The specific benefits resulting from xeriscaping will vary based on the local climate and site conditions.

In 1991 the Florida legislature adopted a xeriscape law that requires state agencies to adopt and implement xeriscaping programs. The law requires that rules and guidelines be adopted for the implementation of xeriscaping along highway rights-of-way and on public property associated with publicly owned buildings constructed after July 1, 1992. Local governments are tasked with determining whether xeriscaping is a cost-effective measure for conserving water. If so, local governments are to work with the state water management districts in developing their xeriscape guidelines. Water management districts will provide financial incentives to local governments for developing xeriscape plans and ordinances. These plans must include:

- Landscape design, installation, and maintenance standards;
- Identification of prohibited plant species (invasive exotic plants);
- Identification of controlled plant species and conditions for their use;
- Specifications for maximum percentage of turf and impervious surfaces allowed in a xeriscaped area;
- Specifications for land clearing and requirements for the conservation of existing native vegetation; and
- Monitoring programs for ordinance implementation and compliance.

The law also includes a provision requiring local governments and water management districts to promote the use of xeriscape practices in existing developed areas through public education programs. California has passed a law requiring all municipalities to consider enacting water-efficient landscape requirements.

Water Conservation and Xeriscaping in Albuquerque, New Mexico

The City of Albuquerque, New Mexico, recently adopted a new strategy to encourage water conservation and to ensure a lasting water supply for years to come (Bennett, 1999). The strategy includes

- Reducing per capita water consumption by 30 percent.
- Developing facilities to treat and distribute city-owned surface water in combination with more limited use of the aquifer.
- Developing systems to use reclaimed wastewater and low-quality shallow ground water to irrigate landscaped areas in specific corridors of the community.
- Aggressive preservation of ground water quality.

The city also developed a new ordinance, the Water Conservation Landscaping and Water Waste Ordinance, that includes the following provisions:

- Prohibits irrigation water from flowing or spraying into streets, storm drains, or adjoining property.
- Limits high-water-use turf to 20 percent of the total landscape for all new developments.
- Establishes design requirements to discourage turf on steep slopes or adjacent to streets.
- Establishes water budget goals for parks and golf courses.
- Requires that new sprinkler systems on large turf areas meet minimum uniformity standards.
- Requires spray irrigation to occur between 6:00 p.m. and 10:00 a.m. from April to September.

The full text of the ordinance can be found at *www.cabq.gov/resources*.

As a result of these changes in Albuquerque's water conservation policy, the city's water consumption has decreased by 24 percent and its irrigation professionals have experienced a substantial increase in business as landowners seek smarter solutions to irrigation problems. Improvements in irrigation technology and increased public awareness are likely to further decrease water consumption.

4.4 Information Resources

In 1991 the Center for Watershed Protection published the *Consensus Agreement on Model Development Principles to Protect Our Streams, Lakes, and Wetlands*, which outlines the series of 22 nationally endorsed principles developed by the Site Planning Roundtable, a national cross-section of diverse planning, environmental, homebuilder, fire, safety, public works, and local government personnel, and details the basic rationale for their implementation. The *Consensus Agreement* can be purchased at http://www.cwp.org/.

The Center for Watershed Protection also published *Better Site Design: A Handbook for Changing Development Rules in Your Community* in 1998. This document outlines 22 guidelines for better developments and provides a detailed rationale for each principle. *Better Site Design* also examines current practices in local communities, details the economic and environmental benefits of better site designs, and presents case studies from across the country. It can be purchased at http://www.cwp.org/.

Wildlife Reserves and Corridors in the Urban Environment: A Guide to Ecological Landscape Planning and Resource Conservation, by Lowell Adams and Louise Dove (1989) reviews the knowledge base regarding wildlife habitat reserves and corridors in urban and urbanizing areas, and it provides guidelines and approaches to ecological landscape planning and wildlife conservation in such areas. It can be purchased from the Urban Wildlife Resources Bookstore at http://users.erols.com/urbanwildlife/bookstor.htm.

In 1997 Randall Arendt of the Natural Lands Trust, Inc., published *Growing Greener: Putting Conservation into Local Codes*. *Growing Greener* is a statewide community planning initiative designed to help communities use the development regulation process to their advantage to protect interconnected networks of greenways and permanent open space. The booklet can be downloaded in PDF format at http://www.dcnr.state.pa.us/growinggreener/growing.pdf.

The Low Impact Development Center was established to develop and provide information to individuals and organizations dedicated to protecting the environment and our water resources through proper site design techniques that replicate preexisting hydrologic site conditions. More information about this organization can be found on the Low Impact Development Center Web site at http://www.lowimpactdevelopment.org/ or by contacting the Center at 301-345-0440.

The Prince George's County, Maryland, Department of Environmental Resources produced two documents, *Low-Impact Development Design Strategies: An Integrated Design Approach* (EPA-841-B-00-003) and *Low-Impact Development Hydrologic Analysis* (EPA-841-B-00-002), that discuss site planning, hydrology, distributed integrated management practice technologies, erosion and sediment control, and public outreach techniques that can reduce storm water runoff from new and existing developments. Both publications can be ordered free of charge through EPA’s National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

Residential Streets, prepared by the American Society of Civil Engineers, the National Association of Home Builders, and the Urban Land Institute (1990), discusses design considerations for residential streets based on their function and their place in the neighborhood.

The publication presents guidance on street widths, speeds, pavement types, streetscapes, rights-of-way, intersections, and drainage systems.

The Institute of Transportation Engineers (ITE) published *Traditional Neighborhood Development—Street Design Guidelines* (1997), in which traditional neighborhood designs that support pedestrian movement over automobile traffic are discussed, and design concepts such as on-street parking, street width, and sight distances are presented. The publication also includes a practical discussion of the time needed for community acceptance and travel behavior changes. ITE also published *Guidelines for Residential Subdivision Street Design* (1993), which presents a discussion of the overall design of a residential subdivision with respect to the adequacy of vehicular and pedestrian access, minimizing excessive vehicular travel, and reducing reliance on extensive traffic regulations. It also provides design considerations for local and collector streets and intersections, including such topics as terrain classifications, rights-of-way, pavements, curb types, and cul-de-sacs. These publications are available through the Institute of Transportation Engineers, 525 School Street, SW, Suite 410, Washington, DC 20024-2797, (202) 863-5486.

Street Design Guidelines for Healthy Neighborhoods is a guidebook intended to help communities implement designs for streets that are safe, efficient, and aesthetically pleasing. This publication can be purchased from the Local Government Commission's Center for Liveable Communities Web site at http://www2.lgc.org/bookstore/topic.cfm?topicId=11.

The Congress for the New Urbanism has compiled a database of jurisdictions across the country that have adopted reduced-width street standards (Cohen, 2000). The database also includes resources related to neighborhood design and transportation. The database can be viewed at http://www.sonic.net/abcaia/narrow.htm.

EPA has compiled a number of resources on its *Low Impact Development (LID)* Web page, with links to Web sites, a literature review, fact sheets, and technical guidance. The Web site is accessible at http://www.epa.gov/owow/nps/lid/.

The Local Government Commission has published a guidebook to assist local communities in overcoming regulatory obstacles to smart growth. *Smart Growth Zoning Codes: A Resource Guide* helps planners design zoning codes that encourage the construction of walkable, mixed-use neighborhoods. The guidebook comes with a CD-ROM containing examples of the best U.S. zoning codes and other resources. The book can be purchased for $25 from http://www2.lgc.org/bookstore/topic.cfm?topicId=1.

Dunnett and Kingsbury (2004) describe examples of both large-scale and residential applications of green roofs and living walls and include technical information about constructing these structures in *Planting Green Roofs and Living Walls.* The authors cover structural engineering concerns as well as factors such as plant selection and environmental considerations that are important for the success of green roofs and living walls. The book is available for purchase at the Timber Press Web site at http://www.timberpress.com.

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MANAGEMENT MEASURE 5
NEW DEVELOPMENT RUNOFF TREATMENT

5.1 Management Measure

By design or performance (a) reduce the postdevelopment loadings of total suspended solids (TSS) so that the average annual TSS loadings[a] are no greater than the predevelopment loadings, or (b) reduce the average annual TSS loadings by a minimum of 80 percent of the influent concentration of TSS[b].

Maintain the postdevelopment average volume and peak runoff rates at levels that are similar to predevelopment[c] levels or, through planning and/or design, control offsite discharges of runoff to prevent erosive impacts to downstream channels or shorelines.

Maintain discharge temperatures in runoff at levels similar to predevelopment levels or at levels that will protect aquatic communities from the thermal impacts of runoff.

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[a] In general, calculations of average annual TSS loadings will be based on TSS loadings from all storms below or equal to a predetermined maximum storm size. The most commonly used upper threshold that states use to calculate annual average TSS loadings is the 2-year, 24-hour storm. However, some states have recently reevaluated the benefits of controlling the 2-year versus the 1-year, 24-hour storm and, as a result, have adopted standards that require the control of all storms less than or equal to the 1-year, 24-hour storm.

EPA interprets predevelopment conditions to mean those conditions that exist prior to the current land use. In situations where the previous land use has resulted in unacceptable erosion and significant sediment movement offsite, a baseline reference condition can be used (e.g., the typical TSS loading rates from forested sites or meadows in the area). Average annual TSS loading calculations also should be based on the TSS discharge concentrations that occur after the site has been permanently stabilized.

[b] It is anticipated that the total TSS reductions will be calculated based on all reductions achieved through a system of structural and nonstructural management practices. The intent of this guidance is to promote the implementation of runoff management programs that protect receiving waters from increases of suspended solids that may, on an individual or cumulative basis, threaten or impair surface waters. Management practices and systems of practices should be selected based on achievement of water quality standards throughout the receiving watershed. TSS loading reduction goals therefore should be determined by assessing the capacity of the receiving water body to assimilate TSS from all contributing sources. EPA acknowledges that, in some jurisdictions, reducing 80 percent of the influent TSS concentration is not reasonable due to the presence of significant concentrations of colloidal particles. EPA also understands that treatment of these particles in many cases is not necessary to protect receiving waters and meet state or local water quality standards. In such cases, design or performance requirements should protect receiving waters from impairment from TSS loadings above the ambient TSS in receiving waters that are not due to anthropogenic sources.

[c] As with the TSS element of the measure, term *predevelopment* refers to runoff rates and volumes that exist on-site immediately before the planned land disturbance and development activities occur. Predevelopment is not intended to be interpreted as that period before any human-induced land disturbance activity has occurred. Watershed managers need to determine an appropriate reference or management condition as an objective to achieve. Also, for the purposes of this element of the management measure, the term *similar* is defined as “resembling though not completely identical.”

5.2 Management Measure Description and Selection

5.2.1 Description

During the development process, both the existing landscape and hydrology are altered. As development occurs, the following changes are likely to occur:

- Soil porosity decreases due to removal of vegetation and compaction of topsoil by construction equipment;
- Impermeable surfaces (paving and rooftops) increase (see Introduction);
- Artificial conveyances such as pipes and concrete channels are constructed;
- Slope angles become less acute;
- Vegetative cover decreases; and
- Surface roughness decreases.

These changes result in increased runoff volume and velocity, which may lead to accelerated erosion of streambanks, steep slopes, and unvegetated areas (Novotny, 1991). The grading of urbanized areas can increase the downward slope to a water body and destroy riparian buffer zones, or developers may level a site to facilitate construction activities. Destruction of in-stream and riparian habitat, increases in water temperature, streambed scouring, and downstream sedimentation of streambed substrates, riparian areas, and estuarine habitats may occur.

Everyday activities that occur after development may cause the discharge of pollutants in runoff that can have harmful effects on waters and habitat. Pollutants related to vehicle petroleum and coolant leaks and overflows, tire and brake wear, pet waste, pesticides, and fertilizers can be carried into estuaries, streams, rivers, and lakes through runoff. Soils and sediment can constitute a significant fraction of the solids on urban surfaces. Weather related erosion and transport of eroded soil (e.g., by wind and rain) increases solids in urban areas. Other sources of solids on urban surfaces are wear of automotive parts (brake pads, tires), combustion products from diesel- and gasoline-fueled engines, fireplaces, construction sites, and industrial facilities. An extensive discussion of these pollutants is presented in Chapter 1.

The goals of the new development runoff treatment management measure are to:

- Retain the predevelopment or pre-disturbance hydrological conditions of both surface and ground water;
- Remove suspended solids and associated pollutants entrained in runoff that result from activities occurring during and after development;
- Decrease the erosive potential of increased runoff volumes and velocities associated with development-induced changes in hydrology;

- Preserve natural systems, including in-stream habitat, riparian areas, and wetlands; and
- Reduce the thermal impacts that result from impervious surfaces and treatment devices with large amounts of surface exposed to sunlight such as wet ponds.

Several issues require clarification to fully understand the scope and intent of this management measure. The watershed protection (3), site development (4), and new development runoff treatment (5) management measures are intended to be used together within a comprehensive framework to reduce nonpoint source pollution. Applied on-site and throughout watersheds, these three management measures can be used together to provide increased watershed protection and help prevent erosion, flooding, and increased pollutant loads generally associated with poorly planned development. Implementation of the watershed protection and site development management measures can help achieve the goals of the new development runoff treatment management measure.

5.2.1.1 Pollutants and total suspended solids

Many pollutants bind to and are entrained in sediment or particulate loadings. Particulates include suspended, settleable, and bedload solids. Metals, phosphorus, nitrogen, hydrocarbons, and pesticides are commonly found in urban sediments. The correlation between total suspended solids (TSS) and specific pollutants may vary (URS Greiner Woodward Clyde, 1999).

TSS is a measure of the concentrations of sediment and other solid particles suspended in the water column of a stream, lake, or other water resource. TSS is an important parameter because it quantifies the amount of sediment entrained in runoff. This information can be used to link sources of sediments to the resulting sedimentation in a stream, lake, wetland, or other water resources. As shown previously, TSS is also an indirect measure of other pollutants carried by runoff, because nutrients (phosphorus), metals, and organic compounds are typically attached to sediment particles. For these reasons TSS was selected as the prime or sole parameter associated with the first element of this management measure.

Sansalone and Buchberger (1997) found that the relative proportional mass of heavy metals (Zn, Cu, Pb) in highway runoff and snowbank samples increased with decreasing particle size. This effect was attributed to the increase in surface area binding sites that were present with smaller particles. In another study, Sansalone et al. (1998) observed that the greatest mass of contaminants in highway runoff is found on particles in the 425 to 850 micron (µm) range. Because average particle size varies across the U.S., it makes sense to address the particle size that most effectively captures the highest percentage of associated pollutants.

The quantity and size range of the suspended particles measured and reported as TSS at any given time depends on many factors including:

- The composition and extent of the sources of suspended solids in the watershed;
- The magnitude and duration of storms or dry weather periods preceding the sampling;

- Flow velocity, turbulence, and other conditions that promote the suspension of solids in the water column; and
- The sampling techniques employed.

Generally, individual particles found in a TSS sample are 62 µm (0.062 µm) or less in diameter and classified as either silts or clays (Table 5.1). Solids greater than 62 µm can also be found in the water column if conditions are turbulent enough to keep them in suspension.

Table 5.1: Sediment particle size distribution (shaded classes are found in a typical urban TSS sample).

General Class	Class Name	Diameter (µm)
Sand	Very coarse sand	2000–1000
	Coarse sand	1000–500
	Medium sand	500–250
	Fine sand	250–125
	Very fine sand	125–62
Silt	Coarse silt	62–31
	Medium silt	31–16
	Fine silt	16–8
	Very fine silt	8–4
Clay	Coarse clay	4–2
	Medium clay	2–1
	Fine clay	1–0.5
	Very fine clay	0.5–0.24
	Colloids	< 0.24

Erosion and entrainment of solids in runoff occur primarily during rainfall. Rainfall varies in magnitude through time, with large rainstorms occurring less frequently than small showers. Collectively, all the rainfall occurring during the year contributes to the annual sediment yield from a site. In order to focus on typical annual yields, however, the management measure states that yield calculations are to be based on the average annual TSS loadings from all storms less than or equal to the two-year, 24-hour storm. Setting this threshold eliminates the need to calculate or integrate the impacts of larger infrequent storms into the average annual sediment yield calculation.

The annual TSS loadings can be calculated by adding the TSS loadings that can be expected during an average one-year period from precipitation events less than or equal to the two-year, 24-hour storm. Removal of 80 percent of TSS can be achieved by reducing, over the course of the year, 80 percent of these loadings.

Critics of the TSS standard suggest that the sampling and analysis protocols employed for this measure do not fully capture the entire range of particle sizes found in some kind of samples. More specifically, TSS protocols tend to under-sample larger solids and therefore yield lower-than-actual values for management practice pollutant removal efficiency. However, under-sampling the larger particles that would easily settle out in a runoff treatment control results in higher overall removal rates of solids and fewer solids discharged to surface waters.

There are alternatives to the TSS method, including turbidity and suspended sediment concentration (SSC). Monitoring turbidity in urban runoff is advantageous because the measurements can be conducted in situ using continuous methods (e.g., Secchi disk). It should be noted, however, that using turbidity as a surrogate for TSS may be appropriate only in instances where a strong statistical correlation has been established, such as in low-energy environments like lakes and estuaries. This correlation should be established on a case-by-case basis if turbidity is to be used as a surrogate.

The SSC method is used by the U.S. Geological Survey (USGS) as the standard for determining concentrations of suspended material in surface water samples (USGS, 2000). Gray et al. (2000) examined the comparability of SSC and TSS measurements. SSC and TSS are the predominant analytical methods used to quantify concentrations of solid-phase material in surface waters. SSC values are obtained by measuring the dry weight of all the sediment from a known volume of a water-sediment mixture. TSS data are produced by several methods, most of which involve measuring the dry weight of sediment from a known volume of a subsample of the original. Analysis of paired SSC and TSS data showed bias in the relationship between SSC and TSS. In samples where sand-size material was greater than nearly a quarter of the dry sediment mass, SSC values tended to be higher than corresponding paired TSS values.

According to Gray, the SSC method produces relatively reliable results for natural water samples, regardless of the amount or percentage of sand-size material in the samples. SSC and TSS are not comparable and should not be used interchangeably. Rather, the authors suggest using the SSC analytical method to enhance the accuracy and comparability of suspended solid-phase concentrations of natural waters (Gray et al., 2000). More information about the SSC analytical method can be found at http://www.astm.org/ by searching for standard number ASTM D 3977-97, *Standard Test Method for Determining Sediment Concentration in Water Samples* (ASTM International, 2002).

5.2.1.2 Runoff

Runoff management programs have traditionally focused on reducing or preventing induced flooding from new development. Performance standards were typically developed to control large storms, e.g., 50- or 100-year storms. Although the control of these large storms is still essential, it has become apparent in the last 20 years that a broad range of storms must be managed to prevent streambed and streambank erosion. Recent research points to the need to control total discharge volumes and rates so that they do not result in stream channel degradation. As a result, some states and local governments have developed performance requirements that are intended to prevent stream channel erosion as well as flooding of downstream properties.

This management measure was written to address the control of both peak runoff rates and average runoff volumes with the intent to maintain postdevelopment runoff characteristics at predevelopment levels. Even though EPA recommends that structural runoff controls be designed to control all storms less than or equal to the two-year, 24 hour storm, state and local governments should determine the locally appropriate storm size threshold to control based on local hydraulics, hydrology, meteorology and other regional and local factors. Watershed managers also should consider the development and implementation of volume and peak discharge performance standards to address problems associated with the frequency and duration of erosive flows (MacRae and Rowney, no date). The use of low-impact development (LID) techniques may be one way to achieve these goals (Prince Georges' County, Maryland, Department of Environmental Resources, 2000a, 2000b).

5.2.2 Management Measure Selection

This management measure was selected because of the following factors:

- Removal of 80 percent of TSS is assumed to control heavy metals, phosphorus, and other pollutants.

- Several states and local governments have implemented a TSS removal treatment standard of at least 80 percent. Table 5.2 presents TSS reduction standards and design criteria for select state and local runoff management programs.

- Analysis has shown that constructed wetlands, wet ponds, and infiltration basins can remove 80 percent of TSS, provided they are designed and maintained properly. Other practices or combinations of practices can also be used to achieve the goal.

- A number of flood control practices can control postdevelopment volume and peak runoff rates and maintain predevelopment hydrological conditions, which will reduce or prevent streambank erosion and stream scouring. Table 5.3 presents peak discharge and volume standards and design criteria for select local runoff management programs.

- Urban streams often experience elevated temperatures due to an increase in impervious areas and a decrease in vegetative cover that would normally provide shading for wetlands and stream channels. Many of the practices presented in this management measure and throughout this guidance, such as infiltration practices, riparian buffers, and urban forestry, help to lower stream temperatures. Practices such as retention ponds may contribute to temperature elevation and should not be used in areas with temperature-sensitive fish or macroinvertebrates unless the other measures are taken to counteract this effect (i.e., plant vegetation to shade ponds, wetlands, or channels).

Table 5.2: Select local and state programs with TSS performance standards (adapted from Watershed Management Institute [WMI], 1997a).

Community/State	Standard	Criteria
Olympia, WA	80 percent removal of suspended solids.	Treat runoff volume of six-month, 24 hr storm
Orlando, FL	Reduce average annual TSS loading by 80 percent.	Treat first half-inch of runoff or the runoff from the first inch of rainfall, whichever is greater.
Winter Park, FL	Reduce average annual TSS loading by 80 percent.	Treat the first inch of runoff by retention.
Baltimore Co., MD	Remove at least 80 percent of the average annual TSS loading.	Treat the first half-inch of runoff from the site's impervious area.
South Florida Water Management District	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 1.0 to 2.5 inches times percent impervious area.

Table 5.2 (continued).

Community/State	Standard	Criteria
Delaware	Remove at least 80 percent of the annual TSS loading.	Treat the first inch of runoff by approved management practices.
Florida	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 0.5 to 1.5 inches depending on the practice.
New Jersey	80 percent reduction in TSS.	Treat runoff volume of a storm of >1.25inches in two hours or the one-yr, 24-hr storm.
South Carolina	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 0.5 to 1.0 inch depending on the practice.

Table 5.3: Select local programs with peak discharge and/or runoff volume performance standards (adapted from WMI, 1997a).

Community/State	Peak discharge	Volume
Alexandria, VA	Postdevelopment rate cannot exceed predevelopment rate for two-yr and 10-yr, two-hr storm.	None
Austin, TX	Postdevelopment rate cannot exceed predevelopment rate for two-, 10-, 25-, and 100-yr, 24-hr storm.	None
Bellevue, WA	Postdevelopment rate cannot exceed predevelopment rate for two- and 10-yr, two-hr storm.	Multiple release rates for detention systems.
Olympia, WA	Postdevelopment rate cannot exceed predevelopment rate for two-yr and 100-yr, 24-hr storm.	Must infiltrate all of the 100-yr vol. on-site if percolation rate greater than 6 inches per hr.
Orlando, FL	Postdevelopment rate cannot exceed predevelopment rate for 25-yr, 24-hr storm.	In closed basins, retain runoff from 100-yr, 24-hr storm.
Washington, DC	Postdevelopment rate cannot exceed predevelopment rate for two-, 10-, and 100-yr, 24-hr storm.	None
Clark Co., WA	Postdevelopment rate cannot exceed predevelopment rate for two-, 10- and 100-yr, 24-hr storm.	Post-development vol. cannot exceed predevelopment vol. for two-yr, 24-hr storm.
SW Florida Water Management District	Postdevelopment rate cannot exceed predevelopment rate for 25-yr, 24-hr storm.	Post-development vol. cannot exceed predevelopment vol. for 25-yr, 24-hr storm.

General Performance Standards for Storm Water Management in Maryland

To prevent adverse impacts from runoff, the Maryland Department of the Environment (MDE, 2000) developed 14 performance standards for development sites. These standards apply to any construction activity disturbing 5,000 or more square feet of land. The following standards are required at all sites where runoff management is necessary:

- Site designs shall minimize runoff generation and maximize pervious areas for runoff treatment.
- Runoff generated from development and discharged directly into a jurisdictional wetland or waters of the State of Maryland shall be adequately treated.
- Annual ground water recharge rates shall be maintained by promoting infiltration through the use of structural and nonstructural methods. At a minimum, the annual recharge from postdevelopment site conditions shall mimic the annual recharge from predevelopment site conditions.
- Water quality management shall be provided through the use of structural and nonstructural controls.
- Structural management practices for new development shall be designed to remove 80 percent and 40 percent of the average annual postdevelopment TSS and total phosphorus loads, respectively. It is presumed that a management practice complies with this performance standard if it is sized to capture the prescribed water quality volume, designed according to the specific performance criteria outlined in the Maryland Stormwater Design Manual (MDE, 2000), constructed properly, and maintained regularly.
- On the Eastern Shore, the postdevelopment peak discharge rate shall not exceed the predevelopment peak discharge rate for the 2-year frequency storm event. On the Western Shore, local authorities may require that the postdevelopment 10-year peak discharge not exceed the predevelopment peak discharge if the channel protection storage volume (Cp_v) is provided. In addition, safe conveyance of the 100-year storm event runoff control practices shall be provided.
- To protect stream channels from degradation, Cp_v shall be provided by 12 to 24 hours of extended detention storage for the 1-year storm event. Cp_v shall not be provided on the Eastern Shore unless the appropriate approval authority deems it necessary on a case-by-case basis.
- Runoff to critical areas with sensitive resources may be subject to additional performance criteria or may need to use or restrict certain management practices.
- All management practices shall have an enforceable operation and maintenance agreement to ensure the system functions as designed.
- Every management practice shall have an acceptable form of water quality pretreatment.
- Redevelopment, defined as any construction, alteration, or improvement exceeding 5,000 square feet of land disturbance on sites where existing land use is commercial, industrial, institutional, or multi-family residential, is governed by special sizing criteria depending on the increase or decrease in impervious area created by the redevelopment.
- Certain industrial sites are required to prepare and implement a storm water pollution prevention plan (SWPPP) and file a notice of intent (NOI) under the provisions of Maryland's Storm Water NPDES general permit. The SWPPP requirement applies to both existing and new industrial sites.
- Runoff from land uses or activities with higher potential for pollutant loadings, sometimes referred to as hotspots, may require the use of specific structural runoff control and pollution prevention practices. In addition, runoff from a hotspot land use may not be infiltrated without proper pretreatment.
- In Maryland, local governments are usually responsible for storm water management review authority. Prior to design, applicants should always consult with their local reviewing agency to determine if they are subject to additional storm water design requirements. In addition, certain earth disturbances may require NPDES construction general permit coverage from MDE.

Delaware Urban Runoff Management Model

The Delaware Department of Natural Resources and Environmental Conservation (2005) developed the Delaware Urban Runoff Management Model (DURMM) to quantitatively estimate how "green technology" management practice designs achieve pollutant removal and flow reductions. Green technology includes the following management practices:

- Conservation site design
- Source area disconnection
- Biofiltration swales/grassed swales
- Terraces
- Bioretention structures
- Infiltration practices

These green technologies address some of the drawbacks of traditional runoff controls, including the following:

- Ponds and wetlands do not necessarily protect against streambank erosion
- Ponds and wetlands do not recharge groundwater.
- Ponds and wetlands require substantial land area
- Ponds and wetlands require significant maintenance.
- Discharges from multiple structural practices can overlap, resulting in downstream flooding.
- Discharges can elevate stream temperatures and sometimes contain high levels of algae.

DURMM provides a quantitative approach to define the benefits of conservation design and quantifies runoff reductions and pollutant reductions from filter strips, biofiltration and grassed swales, terraces, bioretention structures, and infiltration trenches. It also quantifies runoff reductions from source area disconnection. The Delaware Department of Natural Resources and Environmental Conservation is also developing a companion document specifically focused on riparian buffer system design.

Additional information on green technology BMPs or DURMM can be obtained by contacting Delaware's Division of Soil & Water Conservation at 302-739-4411.

5.2.3 General Categories of Urban Runoff Control

Structural practices to control urban runoff rely on several basic mechanisms:

- Infiltration;
- Filtration;
- Detention/retention; and
- Evaporation.

5.2.3.1 Infiltration practices

Infiltration facilities are designed to capture a treatment volume of runoff and percolate it through surface soils into the ground water system. This process:

- Reduces the total volume of runoff discharged from the site, which, in turn, decreases peak flows in storm sewers and downstream waters;

- Filters out sediment and other pollutants by various chemical, physical, and biological processes as runoff water moves through the bottom of the infiltration structure and into the underlying soil; and

- Augments ground water reserves by facilitating aquifer recharge. Groundwater recharge is vital to maintain stream and wetland hydrology. During dry weather, ground water recharge helps to assure baseflow necessary for survival of biota in wetlands and streams.

Treatment effectiveness depends on whether the facility is sited on-line or off-line, and on the sizing criteria used to design the facilities. Online systems receive all of the runoff from an area. Off-line practices receive diverted runoff for treatment and isolate it from the remaining fraction of runoff, which must still be controlled to prevent flooding. Off-line infiltration practices prevent all of the TSS and other pollutants contained in the volume of runoff infiltrated from exiting the site. Thus, the total annual load reduction depends on how much of the annual volume of runoff is diverted to the infiltration structure. On-line infiltration practices, on the other hand, have lower treatment effectiveness, averaging approximately 75 percent removal of TSS (WMI, 1997b).

The overall hydrologic benefits of infiltration practices may also vary depending on site characteristics and the frequency and intensity of storms. Holman-Dodds et al. (2003) modeled the potential for infiltration techniques to reduce the adverse hydrologic effects of urbanization. The study indicated that the greatest reductions in flow are achievable when rainfall is limited and relatively frequent, and when soils are relatively porous.

Infiltration facilities require porous soils (i.e., sands and gravels) to function properly. Generally, they are not suitable in soils with 30 percent or greater clay content or 40 percent or greater silt/clay content (WMI, 1997b). They are also not suitable:

- In areas with high water tables;
- In areas with shallow depth to impermeable soil layers;
- On fill sites, which have low permeability, or on steep slopes;
- In areas where infiltration of runoff would likely contaminate ground water;
- In areas where there is a high risk of hazardous material spills; or
- Where additional groundwater could form sinkholes.

Special protection for ground water is needed when runoff is used as a drinking water source in urban areas (see Management Measure 3—Watershed Protection). Certain types of infiltration facilities, called Class V injection wells, may be regulated as part of the federal Underground Injection Control (UIC) Program, authorized by the Safe Drinking Water Act. Class V wells discharge fluids underground. Class V wells include French drains, tile drains, infiltration sumps, and percolation areas with vertical drainage. Dry wells, bored wells, and infiltration galleries are all Class V wells. Class V wells do not include infiltration trenches filled with stone (with no piping), or excavated ponds, lagoons, and ditches (lined or unlined, without piping or drain tile) with an open surface. Compliance with federal regulations may include submitting basic inventory information about the drainage wells to the state or EPA and complying with specific construction, operation, permitting, and closure requirements (USEPA, 2003). Any questions regarding the applicability of the UIC regulations to a storm water facility should be directed to federal or state UIC contacts. This information is available at http://www.epa.gov/safewater/uic.html.

The effect of infiltration practices on ground water quality is unclear, but a few studies exist that indicate potential ground water quality concerns from infiltrating urban runoff (Pitt, et al., 1994; Fischer, no date; Ging et al., 1997, Morrow, 1999). For example, Fischer (no date) studied the effects of infiltration of urban runoff on ground water quality in the New Jersey Coastal Plain. He found that although many pollutants were removed from runoff before reaching the water table, elevated concentrations and occurrences of certain compounds and ions indicated contributions from urban runoff, implying that infiltration practices could have a detrimental effect on ground water quality. Conversely, Fischer hypothesized that infiltrating runoff would have the beneficial effect of diluting other compounds frequently present in ground water.

Pitt et al. (1994) summarized the potential for 25 pollutants to contaminate ground water, categorizing each as low, low/moderate, moderate, or high. Of these 25 pollutants, only one, chloride, has a high potential, and only fluoranthene and pyrene have a moderate potential. Nitrate, a highly soluble and mobile contaminant, was categorized as having a low/moderate potential for contamination, and the other 21 pollutants had low potential.

Heavy metals and hydrocarbons may pose a low risk of contamination, but several studies have indicated that concentrations of these pollutants decrease rapidly with depth (Barraud et al., 1999; Legret et al. 1999). Similarly, Dierkes and Geiger (1999) found that polycyclic aromatic hydrocarbons (PAHs) in highway runoff were removed in the top four inches of soil.

The presence of volatile organic compounds (VOCs) in ground water is another concern. A USGS study (Ging et al., 1997) analyzed the occurrence and distribution of VOCs in ground water in south-central Texas. Although less than 50 percent of the samples taken had VOC detections, 28 VOCs were detected in samples from 89 wells. Based on the results of this study, VOC contamination in ground water appears to be associated with urban development (Ging et al., 1997).

VOC contamination has also been detected in the ground water of the Lower Illinois River Basin. In 1996, water samples collected from 60 wells in the basin were sampled and analyzed for VOCs. There were only six VOC detections in more than 4,300 analyses of the ground water samples (although at least three of these detections may have been caused by well disinfection practices). Additionally, a VOC was detected in one sample from deep glacial drift, indicating that shallow aquifers may be more susceptible to VOC contamination than deep aquifers. Based on these results, the authors concluded that VOC contamination does not appear to be a major concern for ground water quality in rural areas of the Lower Illinois River Basin (Morrow, 1999).

Several studies have found that the potential for ground water contamination, particularly from heavy metals and hydrocarbons, is low when porous pavement and stone-filled subsurface infiltration beds are used. These systems provide treatment through adsorption, filtration, sedimentation, and biodegradation before runoff reaches the underlying soil (Balades et al., 1995; Legret and Colandini, 1999; Newman et al., 2002; Pratt et al., 1999; Swisher, 2002).

5.2.3.2 Filtration practices

Filtration practices are so named because they filter particulate matter from runoff. The most common filtering medium is sand, but other materials, including peat/sand combinations and leaf compost material, have been used. Filtration systems provide only limited flood storage; therefore, they are most often implemented in conjunction with other types of quantity control management practices. Most filtration techniques require a forebay or clarifier to remove larger particles in runoff from clogging the filter media.

Biofiltration refers to practices that use vegetation and amended soils to retain and treat runoff from impervious areas. Treatment is through filtration, infiltration, adsorption, ion exchange, and biological uptake of pollutants.

5.2.3.3 Detention/retention practices

Runoff *detention* facilities provide pollutant removal by temporarily capturing runoff and allowing particulate matter to settle prior to release to surface waters. Dry detention runoff management ponds are one type of detention facility. Peak flows are reduced in drainage systems/receiving waters downstream of detention facilities.

Runoff *retention* facilities are used to capture runoff, which is subsequently withdrawn or evaporated. Therefore, peak flows and total flow volume can be reduced in downstream drainage systems/receiving waters. Wet runoff management ponds are one type of retention facility. These retention facilities can be designed to accept flow from receiving streams/drainage systems offline.

Both detention and retention facilities can use biological uptake as a mechanism for pollutant removal. Runoff management ponds can be designed to control the peak discharge rates, thereby reducing excessive flooding and downstream erosion in reaches of the drainage system/receiving stream immediately downstream. At some point downstream, however, runoff flow that is not retained will increase the volume of total flow, thereby increasing the risk of flooding and erosion if the receiving stream at that point does not have a stable channel and riparian area or floodplain.

Constructed wetlands are engineered systems designed to employ the water quality improvement functions of natural wetlands to treat and contain surface water runoff pollution and decrease pollutant loadings to surface waters. They can be designed with extended detention to control runoff peak flow and volume. Where site-specific conditions allow, constructed wetlands and retention basins should be located to minimize the impact on the surrounding areas (e.g., in upland areas of the watershed). Ponds, constructed wetlands, and other structural management practices degrade the functions of natural buffer areas and natural wetlands, and they may also interrupt surface water and ground water flow when soils are disturbed for installation. Therefore, the placement of structural management practices in natural buffers and natural wetlands should be avoided where possible.

5.2.3.4 Evaporation practices

Runoff detention and retention facilities and other practices that temporarily store runoff can also evaporate it. Evaporation from runoff detention and retention areas such as rooftops, streets, basins, and ponds can be an important mechanism for runoff management in warm, dry climates.

5.3 Management Practices

Management practices to control urban runoff can be classified in seven categories. The following practices are described for illustrative purposes only. EPA has found these practices to be representative of the types of practices that can be applied successfully to achieve the new development runoff treatment management measure. As a practical matter, EPA anticipates that the management measure can be achieved by applying one or more management practices appropriate to the source(s), location, and climate. Thus, practices that by themselves do not achieve 80 percent TSS removal can be combined with other practices to achieve 80 percent removal (such that x + y + z = 80 percent). This is the “treatment train” approach, in which several types of practices are used together and integrated into a comprehensive runoff management system (WMI, 1997b). The seven categories include:

- Infiltration practices;
- Vegetated open channel practices;
- Filtering practices;
- Detention ponds or vaults;
- Retention ponds;
- Wetlands; and
- Other practices such as water quality inlets.

5.3.1 Infiltration Practices

These practices capture and temporarily store runoff before allowing it to infiltrate into the soil over several days. Design variants include:

- Infiltration basins;
- Infiltration trenches; and
- Pervious or porous pavements.

To prevent premature clogging, these practices must not receive drainage from a construction activity or site. Infiltration practices can be placed in service after the construction activity is complete or the site is stabilized.

5.3.1.1 Infiltration basins

Infiltration basins (Figure 5.1) are impoundments created by excavation or creation of berms or small dams. They are typically flat-bottomed with no outlet and are designed to temporarily store runoff generated from adjacent drainage areas (from 2 to 50 acres, depending on local conditions). Runoff gradually infiltrates through the bed and sides of the basin, ideally within 72 hours, to maintain aerobic conditions and ensure that the basin is ready to receive runoff from the next storm. Infiltration basins are often used as an off-line system for treating the first flush of runoff flows or the peak discharges of the two-year storm.

The key to successful operation is keeping the soils on the floor and side slopes of the basin unclogged to maintain the rate of percolation. This is usually much easier said than done. For example, Schueler (1992) reported infiltration basin failure rates ranging from 60 to 100 percent

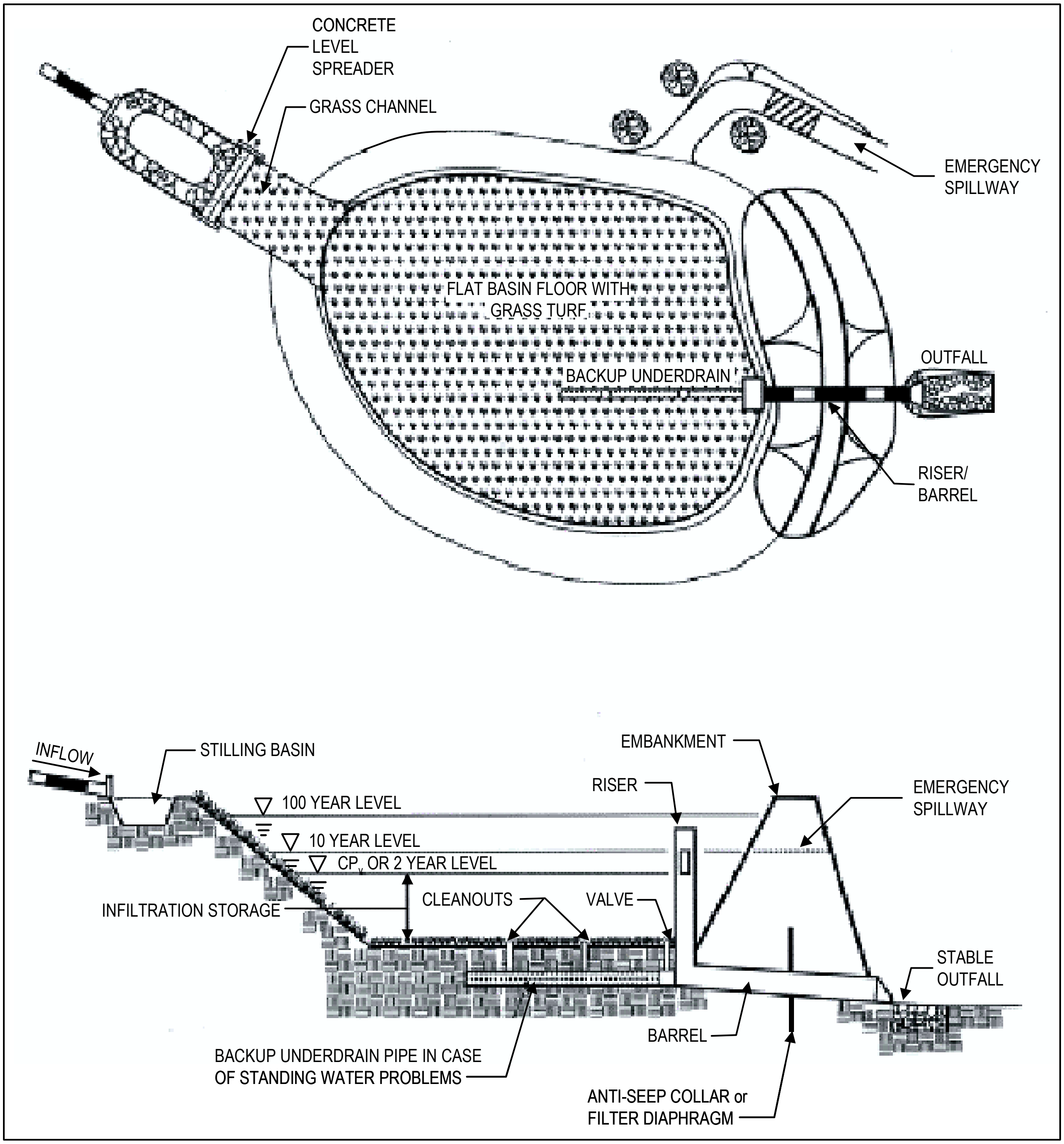

Figure 5.1: Schematic of an infiltration basin (MDE, 2000).

in the mid-Atlantic region. To help keep sediment out of the basin, incoming runoff should be pretreated using vegetated filter strips, a settling forebay, or other techniques. Grasses or other vegetation should also be planted and maintained in the basin. If soil pores become clogged, the basin bottom should be roughened or replaced to restore percolation rates.

5.3.1.2 Infiltration trenches

Infiltration trenches (Figure 5.2) are shallow (2- to 10-feet deep) excavated ditches with relatively permeable soils that have been backfilled with stone to form an underground reservoir. The trench surface can be covered with a grating or can consist of stone, gabion, sand, or a grass-covered area with a surface inlet. Runoff diverted into the trench gradually infiltrates into the subsoil and, eventually, into the ground water. Trenches can be used on small, individual sites or for multi-site runoff treatment. Pretreatment controls such as vegetated filter strips should be incorporated into the design to remove sediment and reduce clogging of soil pores. More expensive than pond systems in terms of cost per volume of runoff treated, infiltration trenches are best-suited for drainage areas of less than 5 to 10 acres, or where ponds cannot be used.

Variations in the design of infiltration trenches include dry wells, which are pits designed to control small volumes of runoff (such as rooftop runoff) and exfiltration trenches. A typical dry well design includes a perforated pipe 3 to 4 feet in diameter that is installed vertically in deposits of gravely/sandy soil. Rock is then backfilled around the base of the well. An exfiltration trench is an infiltration trench that stores runoff water in a perforated or slotted pipe and percolates it out into a surrounding gravel envelope and filter fabric. Dry wells and other infiltration practices that involve subsurface drainage may be regulated by EPA's Underground Injection Control Program. See the EPA's Underground Injection Control Program Web site at http://www.epa.gov/safewater/uic.html for more information.

5.3.1.3 Pervious or porous pavements

Pervious pavement has the approximate strength characteristics of traditional pavement but allows rainfall and runoff to percolate through it. The key to the design of these pavements is the elimination of most of the fine aggregate found in conventional paving materials. There are two types of pervious pavement, porous asphalt and pervious concrete (WMI, 1997b). Porous asphalt has coarse aggregate held together in the asphalt with sufficient interconnected voids to yield high permeability. Pervious concrete, in contrast, is a discontinuous mixture of Portland cement, coarse aggregate, admixtures, and water that also yields interconnected voids for the passage of air and water. Underlying the pervious pavement are a filter layer, a stone reservoir, and a filter fabric. Stored runoff gradually drains out of the stone reservoir into the subsoil. Figure 5.3 shows several types of porous pavement. More information about pervious pavement can be found at http://www.gcpa.org/pervious_concrete_pavement.htm (Georgia Concrete & Products Association, 2003).

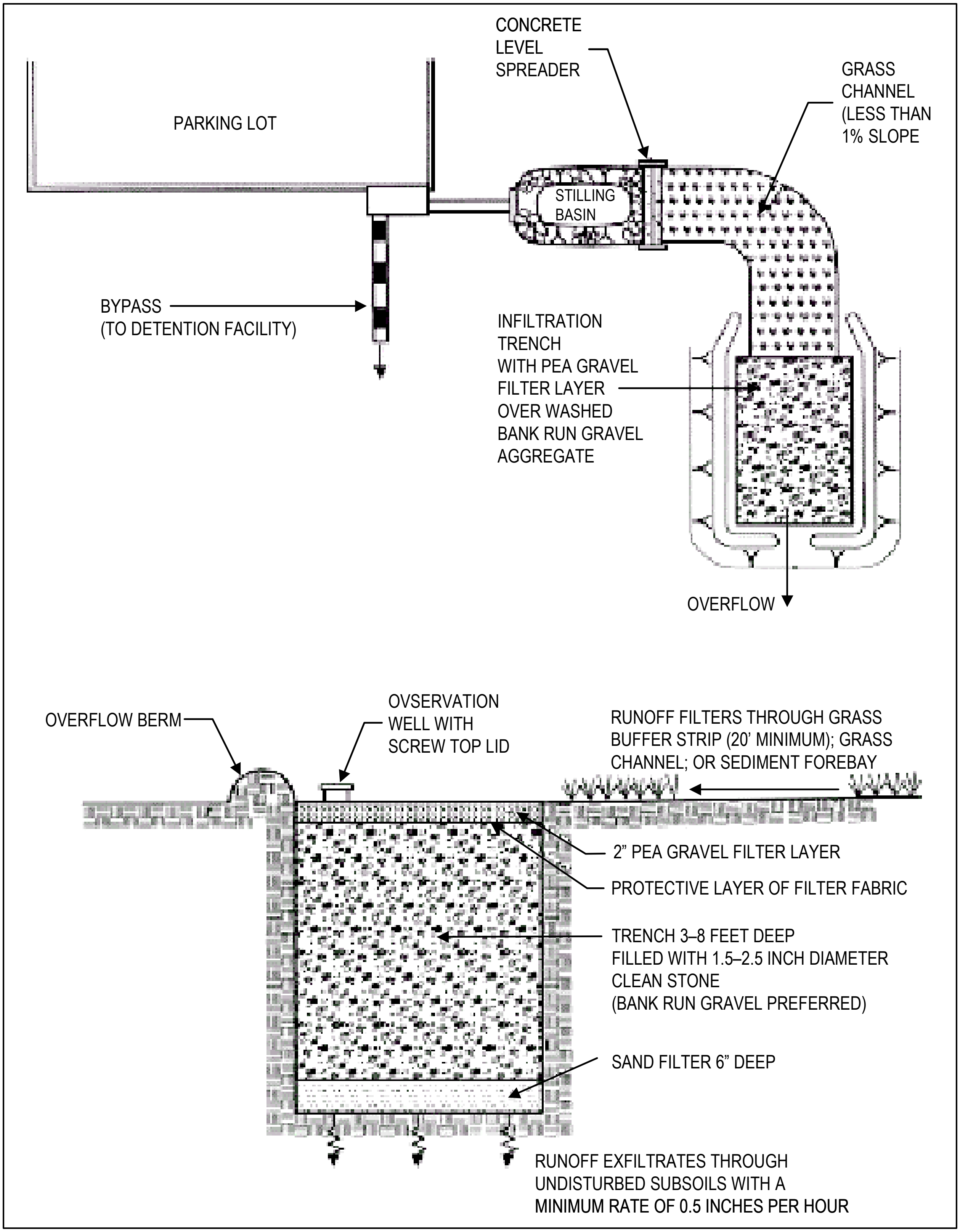

Figure 5.2: Schematic of an infiltration trench (MDE, 2000).

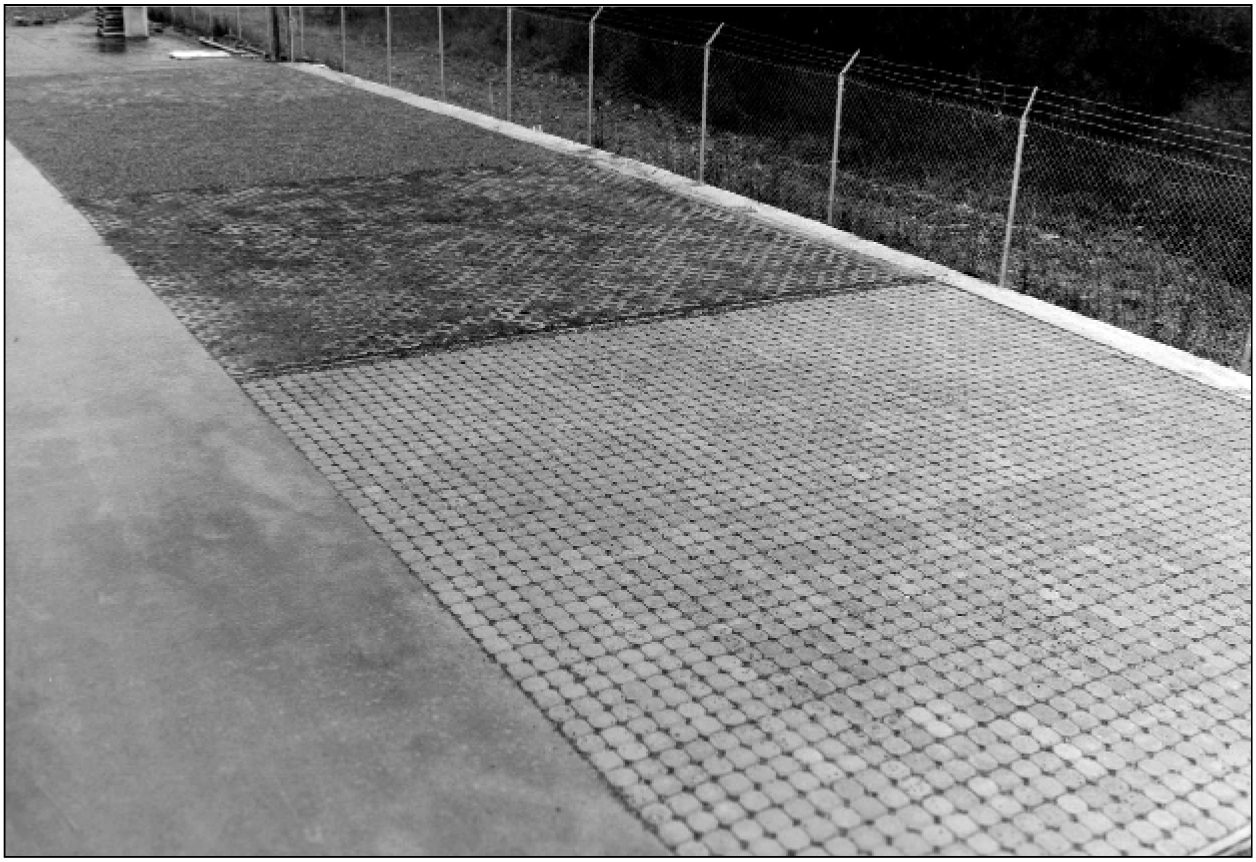

Figure 5.3: Photo showing several types of pervious modular pavement installations.

Modular pavement consists of individual blocks made of pervious material such as sand, gravel, or sod interspersed with strong structural material such as concrete. The blocks are typically placed on a sand or gravel base and designed to provide a load-bearing surface that is adequate to support personal vehicles, while allowing infiltration of surface water into the underlying soils. They usually are used in low-volume traffic areas such as overflow parking lots and lightly used access roads. An alternative to pervious and modular pavement for parking areas is a geotextile material installed as a framework to provide structural strength. Filled with sand and sodded, it provides a completely grassed parking area. More information about concrete pavers can be found at http://www.concretenetwork.com/concrete/porous_concrete_pavers/ (Concretenetwork.com, 2003).

Some states no longer promote the use of porous pavement because it tends to easily clog with fine sediments (Washington Department of Ecology, 1991). If this type of pavement is installed, a vacuum-type street sweeper should be used regularly to maintain porosity. Frequent washing with a high-pressure jet of water can also keep pores clear of clogging sediments. Sites where pervious pavement is to be installed must have deep, permeable soils, slopes of less than 5 percent, and no heavy vehicle traffic.

The City of Kinston, North Carolina, installed a permeable pavement parking lot as a demonstration and research project and to meet the daily parking needs of city employees (Hunt and Stevens, 2001). The final parking lot design included 26 stalls; 20 of the stalls were

The Bath Club Concourse Storm Water Rehabilitation Project, Florida

The Bath Club Concourse is located on a small barrier island community in North Redington Beach, Florida. A combination roadway and parking area, which connects Bath Club Circle and Gulf Boulevard, was previously an impervious slab of concrete pavement. The concourse could not absorb falling rain, which caused runoff to flow directly into a single storm sewer. The sewer would then carry pollutants directly to Boca Ciega Bay. In August 1990, the Water Management District and the town agreed to construct a stormwater rehabilitation project using pervious concrete pavement at the Bath Club Concourse (USEPA, 1999).

The main objective of the rehabilitation project was to reduce nonpoint source pollutant loading by reducing the volume of runoff discharging directly into Boca Ciega Bay. A second objective was to demonstrate an innovative way to treat or improve the quality of runoff in highly urbanized areas, where it can sometimes be difficult or expensive to manage runoff because of land constraints.

To maximize infiltration of runoff and reduce the amount of untreated runoff discharged directly into storm sewers, drainage was directed toward two pervious concrete parking areas. These areas were separated by an unpaved island in the center of the concourse, which also provides infiltration. Engineers installed two 150-foot under-drains to maximize infiltration by allowing subsurface soils to drain beneath the parking areas.

The rehabilitation project resulted in a significant reduction of direct discharge of runoff from the site. Estimates indicate that these improvements resulted in a 33 percent reduction in total on-site runoff volume. Additionally, the volume of surface runoff discharging directly to Boca Ciega Bay was reduced by nearly 75 percent. Overall removal efficiencies for the project, which are based on the pollutant removal efficiency of the under-drain/filter system, indicate that the project can remove 73 percent of lead (Bateman et al., no date). Other removal efficiencies and additional information about the project are available at http://www.stormwaterauthority.org/assets/103BFloridaRetrofits.pdf.

constructed using a concrete block paver filled with and overlaying sand, while the other six were constructed using a plastic grid paver with sandy soil and Bermuda grass. Monitoring results from a two-year study showed a 3- to 5-time reduction in peak runoff for storms greater than 0.5 inches based on calculated runoff coefficients (using the rational method). Of 48 rainstorms, only 11 (less than 25 percent) resulted in runoff generated from the parking lot The researchers found that annual maintenance to scarify the surface of the lot with a street sweeper helps to maximize permeability of the pavement. More information about the study, including several design recommendations, can be found at http://www5.bae.ncsu.edu/programs/extension/wqg/issues/101.pdf.

Brattebo and Booth (2003) examined the long-term effectiveness of permeable pavement by testing four commercially available permeable pavement systems for six years of regular parking use. The systems included the following:

- A flexible plastic grid system with virtually no impervious area, filled with sand and planted with grass;
- An equivalent plastic grid, filled with gravel;
- A concrete block lattice with approximately 60 percent impervious coverage, filled with soil and planted with grass; and

- Small concrete blocks with approximately 90 percent impervious coverage, with the spaces between blocks filled with gravel.

At the end of the study, none of the systems showed major signs of wear. The pavements infiltrated nearly all rainwater, generating almost no surface runoff. The researchers compared the quality of infiltrated water to surface runoff from an asphalt area and found significantly lower levels of copper and zinc in the infiltrated water. Motor oil was not detected in infiltrated water but was detected in 89 percent of samples of surface runoff from asphalt. Measurements of infiltrated rainwater from five years earlier showed significantly higher concentrations of zinc and lower concentrations of copper and lead.

5.3.2 Vegetated Open Channel Practices

Vegetated open channels are explicitly designed to capture and treat runoff through infiltration, filtration, or temporary storage.

A vegetated swale is an infiltration practice that usually functions as a runoff conveyance channel and a filtration practice. It is lined with grass or another erosion-resistant plant species that serves to reduce flow velocity and allow runoff to infiltrate into ground water. The vegetation or turf also prevents erosion, filters sediment, and provides some nutrient uptake benefits. These practices are also known as biofiltration swales. Check dams are often used to reduce flow velocity. When used, sediment that collects behind check dams should be removed regularly.

Two types of channels are typically used in residential landscapes:

- *Grass channels*. These have dense vegetation, a wide bottom, and gentle slopes (Figure 5.4). Usually they are intended to detain flows for 10 to 20 minutes, allowing sediments to filter out.

- *Dry swales*. As with grass channels, runoff flows into the channel and is subsequently filtered by surface vegetation (Figure 5.5). From there, runoff moves downward through a bed of sandy loam soil and is collected by an underdrain pipe system. The treated water is delivered to a receiving water or another structural control. Dry swales are used in large-lot, single-family developments and on campus-type office or industrial sites. They are applicable in all areas where dense vegetative cover can be maintained. Because of a limited ability to control runoff from large storms, they are often combined with other structural practices. They should not be used in areas where flow rates exceed 1.5 feet per second unless additional erosion control measures, such as turf reinforcement mats, are used.

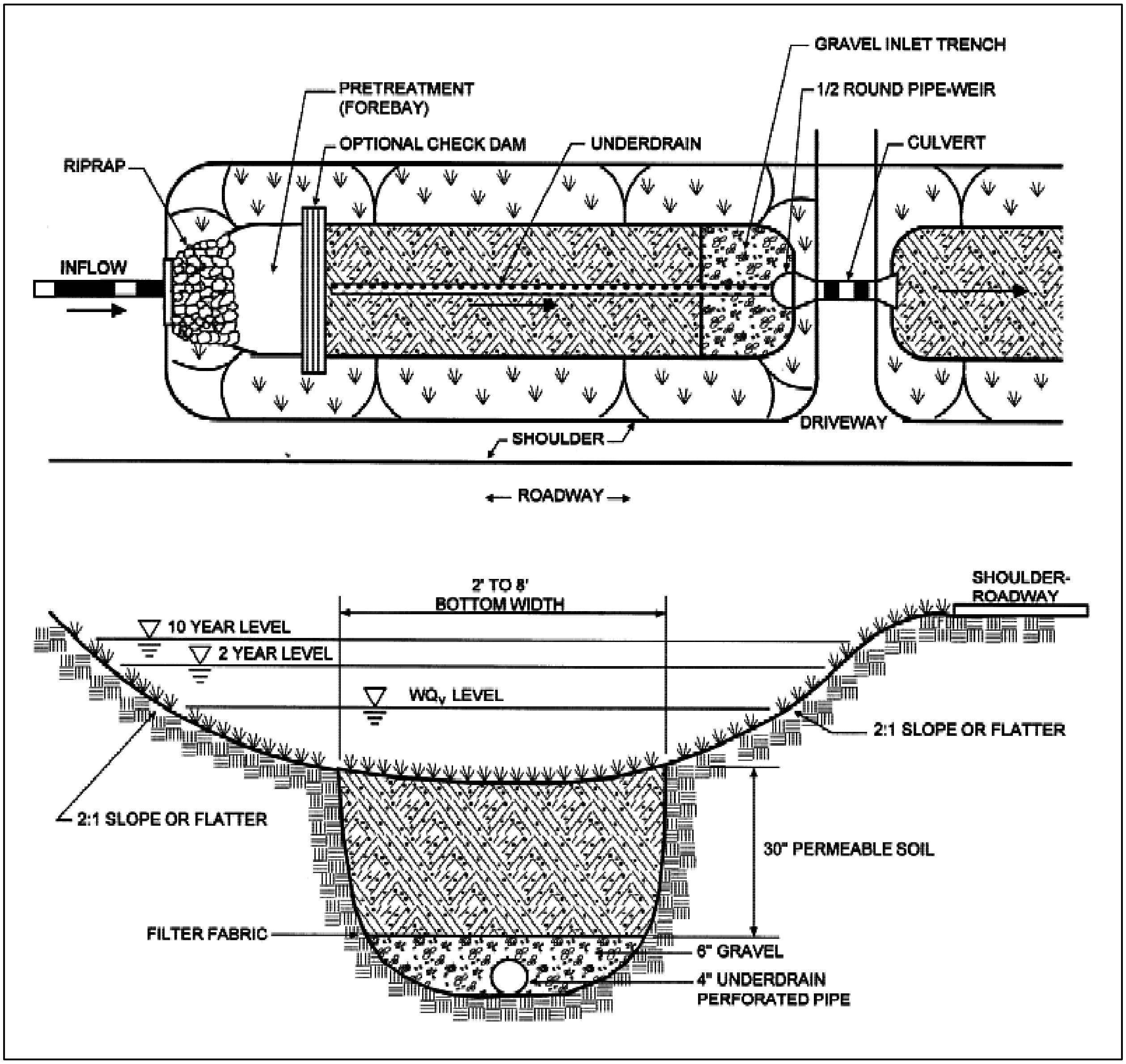

Figure 5.4: Schematic of a grass channel (Claytor and Schueler, 1996).

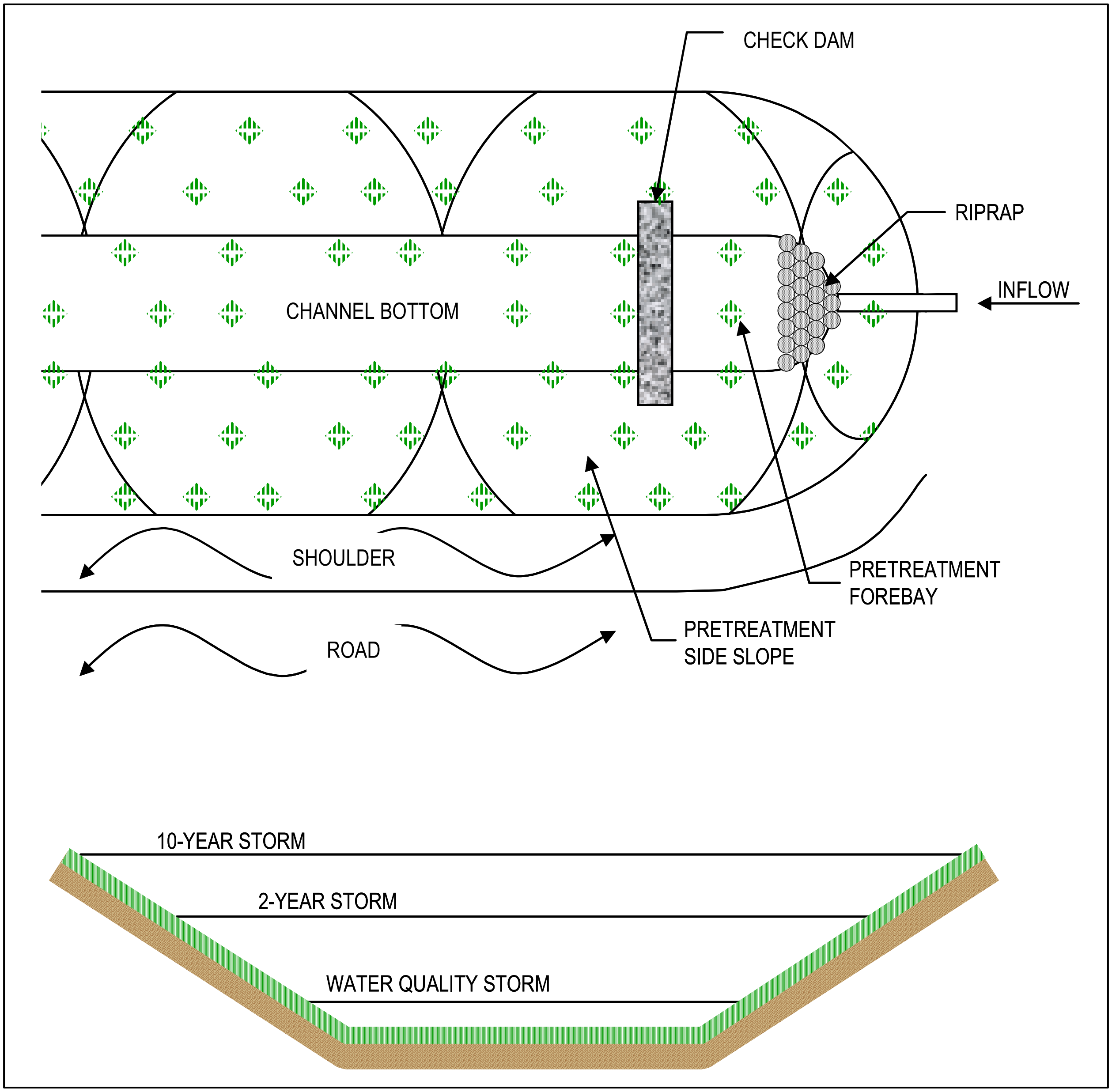

Figure 5.5: Schematic of a dry swale (adapted from MDE, 2000).

In a research study conducted by J.F. Sabourin and Associates (1999), two grass swale/perforated pipe systems and one conventional curb-and-gutter system were compared. Flow monitoring results indicate that much less water reached the outlet of the perforated pipe systems than the conventional system. Peak flows and total runoff volumes from the outlet of the perforated pipe/grass swale system were 2 to 6 percent of those of the conventional system, and total runoff volumes were 6 to 30 percent of conventional system volumes. Water quality monitoring results indicate that for most elements, concentrations measured in the perforated pipes were the same or lower than in the conventional system. Chloride concentrations were found to be higher in the perforated pipe system, most likely from the use of road salt. However, a loading analysis indicated that the perforated pipes released significantly fewer pollutants than the conventional system.

The authors also performed video inspections of the swale/perforated pipe sewershed. These inspections revealed a few interesting issues that can affect the performance of perforated pipe systems. Several unauthorized sanitary sewer connections had been made by some residents, and several raccoons were found living inside the pipes. Both can contribute to nutrient and pathogen problems in receiving waters.

J.F. Sabourin and Associates concluded that infiltration capacities of grass swales are optimum when they allow for proper drainage and hold enough moisture for sustaining grass and plant life. Exfiltration tests indicated that runoff volumes can be reduced by 40 to 60 percent by grass swales and perforated pipe drainage systems. With a direct connection, peak outflows can be 45 percent of the inflow.

5.3.3 Filtering Practices

Filtering practices capture and temporarily store runoff and pass it through a filter bed of sand, organic matter, soil, or other media. Filtered runoff may be collected and returned to the conveyance system, or allowed to exfiltrate into the soil. Design variants include:

- Surface sand filter;
- Underground sand filter;
- Organic filter;
- Pocket sand filter; and
- Bioretention areas.

5.3.3.1 Filtration basins and sand filters

Filtration basins are impoundments lined with a filter medium such as sand or gravel. Runoff drains through the filter medium and through perforated pipes into the subsoil. Detention time is typically four to six hours. Sediment-trapping structures are often used to prevent premature clogging of the filter medium (NVPDC, 1980; Schueler et al., 1992).

Sand filters are usually two-chambered practices: the first is a settling chamber and the second is a filter bed filled with sand or another filtering medium. As runoff flows into the first chamber, large particles settle out and finer particles and other pollutants are removed as runoff flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chambered treatment train (Robertson et al., 1995). All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging site designs (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter). The following are design variations for sand filtration devices:

(1) *Surface sand filter*. The surface sand filter (Figure 5.6) is an aboveground filter design. Both the filter bed and the sediment chamber are aboveground. The surface sand filter is designed as an off-line practice; only the water quality volume is directed to the filter. The surface sand filter is the least-expensive filter option and has been the most widely used.

(2) *Underground sand filter*. The underground sand filter (Figure 5.7) is a modification of the surface sand filter, where all of the filter components are underground. Like the surface sand filter, this practice is an off-line system that receives only flows from small rainstorms. Underground sand filters are expensive to construct but consume very little space. They are well-suited to highly urbanized areas, and often included in groups of practices known as "ultra-urban BMPs."

(3) *Perimeter sand filter*. The perimeter sand filter (Figure 5.8) 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 the only filtering option that is on-line; all flow enters the system, but a bypass to an overflow chamber prevents system flooding. One major advantage of the perimeter sand filter design is that it requires little hydraulic head and thus is a good option in areas of low relief.

(4) Organic media filter. Organic media filters (Figure 5.9) are essentially the same as surface filters, with the sand replaced with or supplemented by another medium. Two examples are the peat/sand filter (Galli, 1990) and the compost filter system. It is assumed that these systems will provide enhanced pollutant removal for many compounds because of the increased cation exchange capacity achieved by increasing organic matter content.

(5) *Multi-chambered treatment train*. The multi-chambered treatment train (Figure 5.10) is essentially a "deluxe sand filter" (Robertson et al., 1995). This underground system consists of three chambers. Runoff enters into the first chamber where screening occurs, trapping large sediments and releasing highly volatile materials. The second chamber provides settling of fine sediments and further removal of volatile compounds and floatable hydrocarbons through the use of fine bubble diffusers and sorbent pads. The final chamber provides filtration by using a sand and peat mixed medium for reduction of the remaining pollutants. The top of the filter is covered by a filter fabric that evenly distributes the water volume and prevents channelization. Although this practice can achieve very high pollutant removal rates, it might be prohibitively expensive in many areas. It has been implemented only on an experimental basis.

(6) *Exfiltration/partial exfiltration.* In exfiltration designs, all or part of the underdrain system is replaced with an open bottom that allows infiltration to the ground water. When the underdrain is present, it is used as an overflow device in case the filter becomes clogged. These designs are best applied in the same soils where infiltration practices are used.

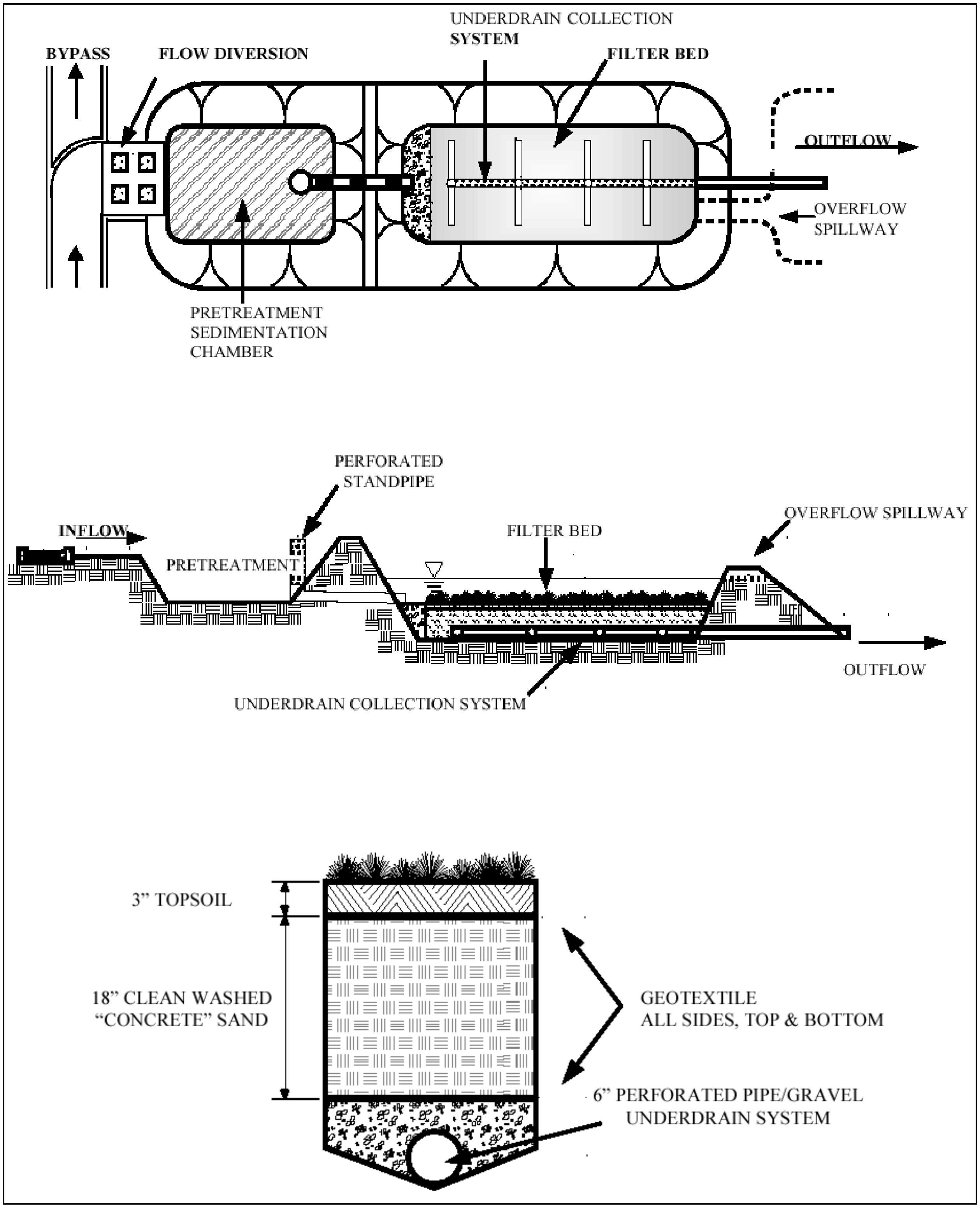

Figure 5.6: Schematic of a surface sand filter (MDE, 2000).

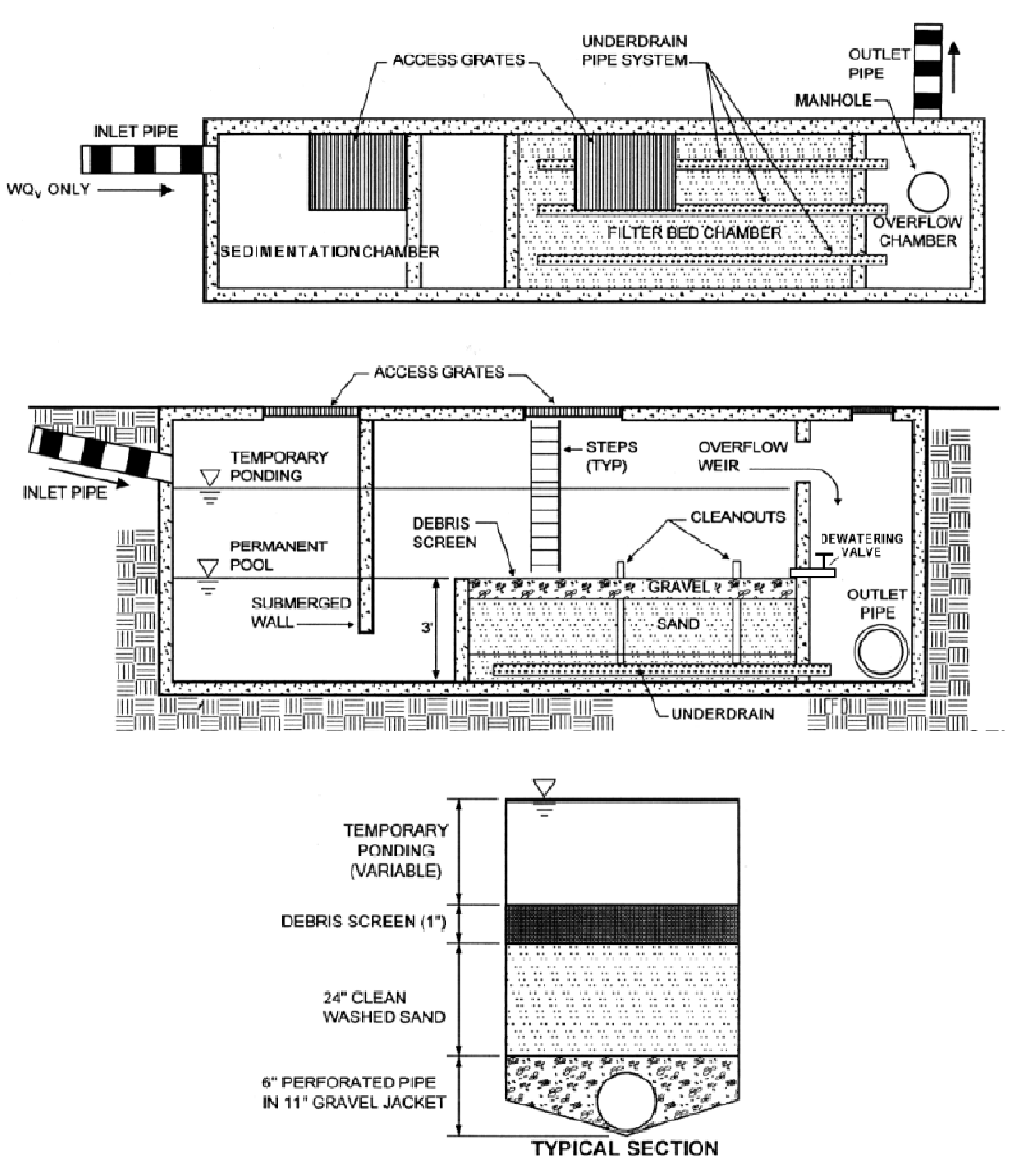

Figure 5.7: Schematic of an underground sand filter (MDE, 2000).

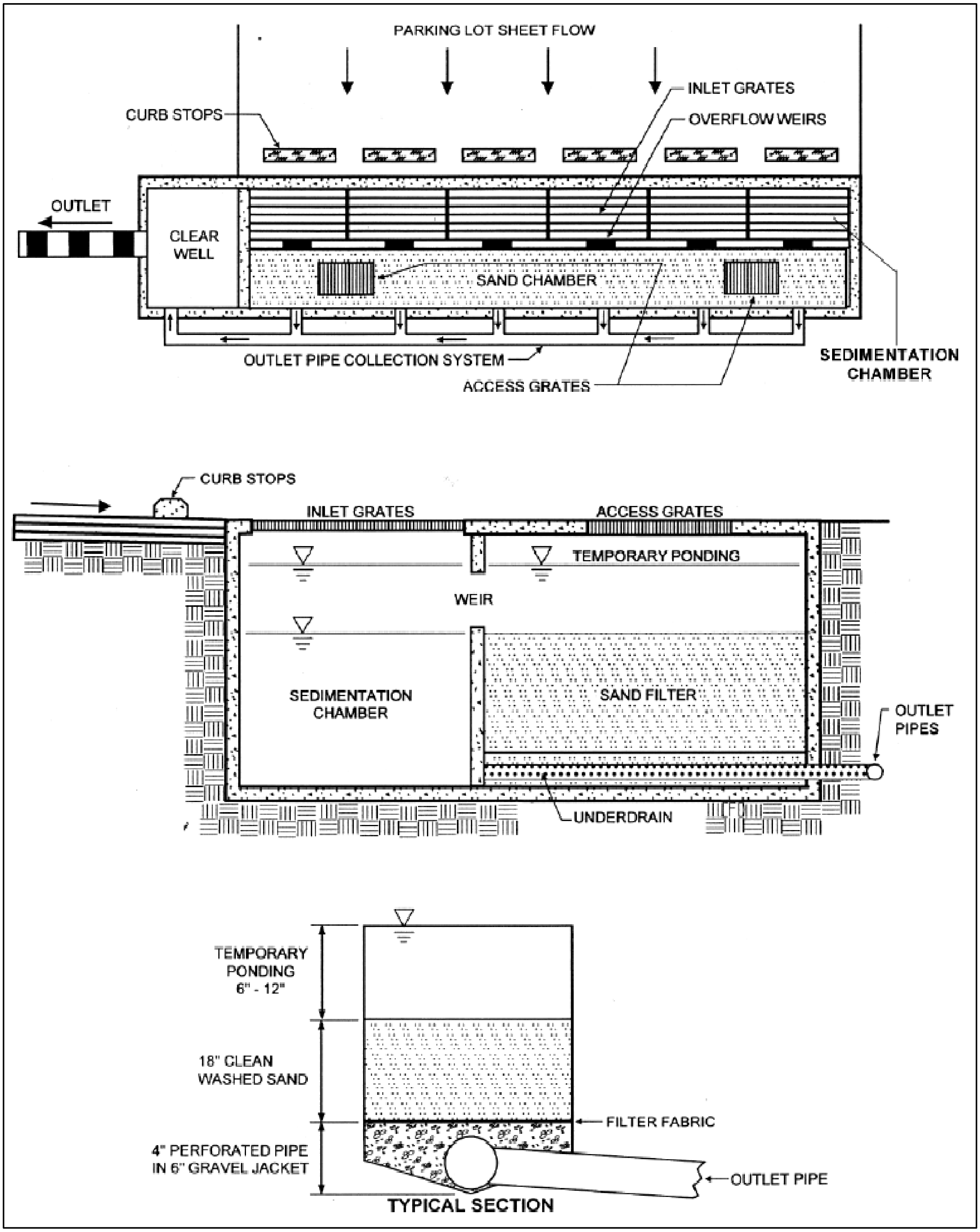

Figure 5.8: Schematic of a perimeter sand filter (MDE, 2000).

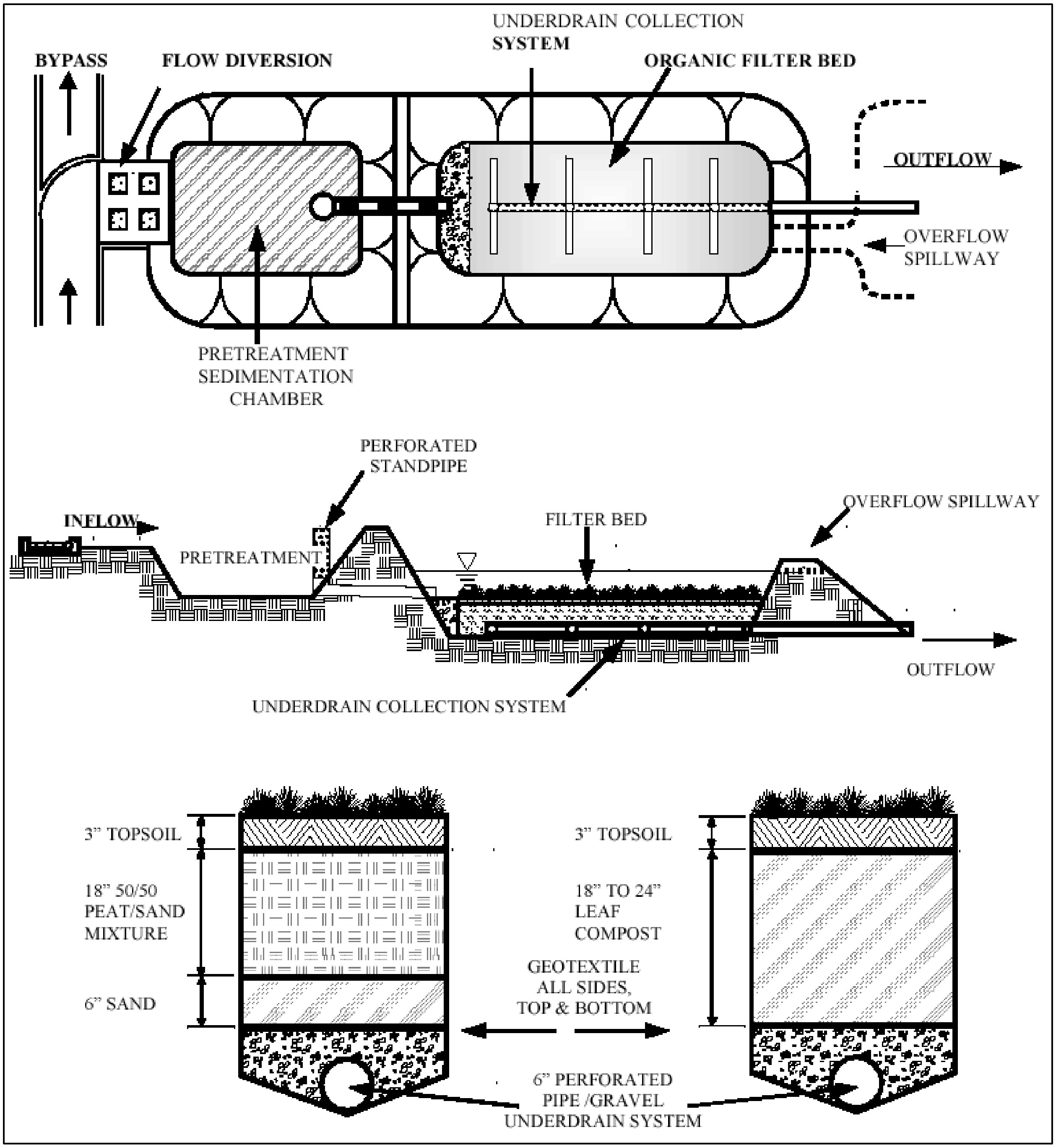

Figure 5.9: Schematic of an organic media filter (MDE, 2000).

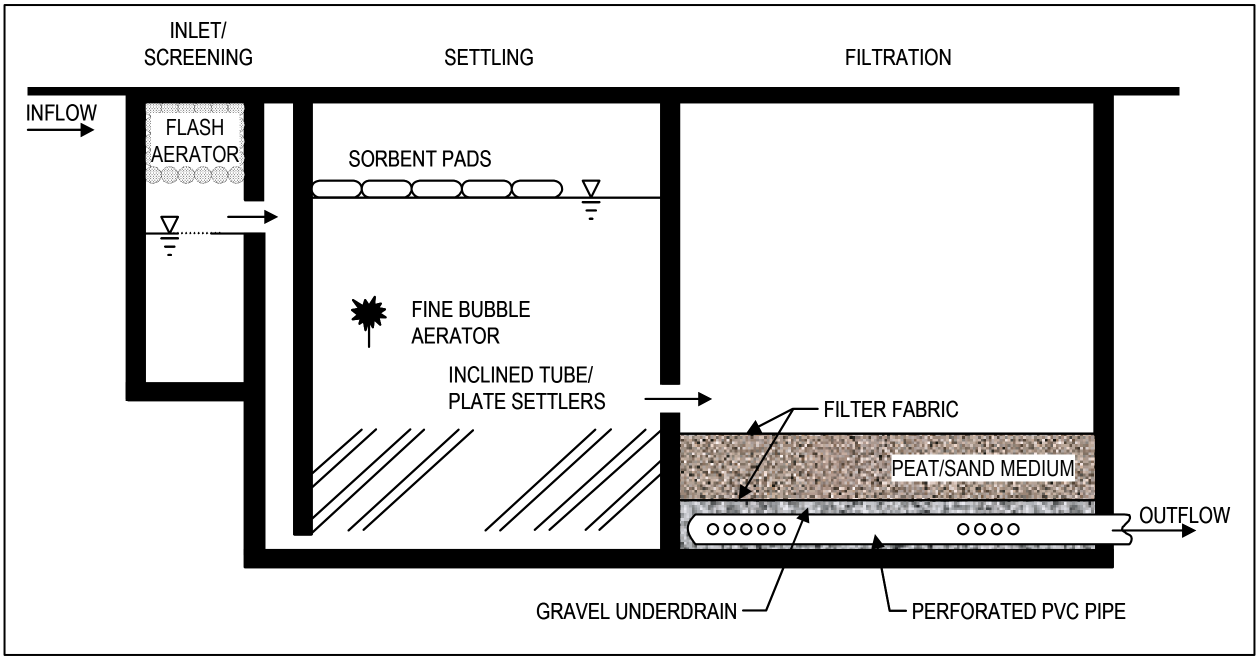

Figure 5.10: Schematic of a multi-chambered treatment train (Pitt, 1996).

5.3.3.2 Media filtration units

Similar to wastewater treatment technology, passive filtration units can be used to capture pollutants from runoff. Media filtration practices commonly use trenches filled with sand or peat. Other media, including types of crushed rock and composted leaves, can also be used. A basin collects the runoff and gradually routes discharge through cartridges filled with filter media. An emergency bypass prevents system flooding during large rainstorms. According to the Unified Sewerage Agency of Washington County in Oregon (WEF, 1998), composted leaf media trap particulates, adsorb organic chemicals, and remove 90 percent of solids, 85 percent of oil and grease, and 82 to 98 percent of heavy metals through cation exchange from leaf decomposition. Similar types of systems with various filter media are available commercially.

Performance of a Compost Storm Water Treatment System in Hillsboro, Oregon

A compost storm water treatment facility was constructed to treat runoff from 3.9 acres of 5-lane arterial road and 70.1 acres of mixed residential land use in Hillsboro, Oregon (FHWA, no date). The system consists of a discharge pipe that conveys runoff from the drainage area into a forebay. Runoff then flows over a wooden baffle into two consecutive cells filled with Portland leaf compost material. After runoff filters through the compost medium, it is discharged to a rock drainbed separated from the compost by a layer of filter fabric.

Monitoring of the effluent between 1991 and 1994 showed average mass balance pollutant removals of 81 percent for oils and grease, 84 percent for petroleum hydrocarbons, 58 percent to 94 percent for nutrients, and 68 percent to 93 percent for metals. See Table 5.4 for additional pollutant removal results. More details on the design and performance of this study are available at http://www.fhwa.dot.gov/environment/ultraurb/5mcs5.htm.

Table 5.4: Pollutant removal efficiencies for the compost storm water treatment facility from 1991 to 1994.

Parameter		1991-1992	1992-1993	1993-1994
Turbidity	Combined	84.2 %	78.4 %	78.4 %
	First Flush	93.4 %	85.3 %	81.4 %
Total Suspended Solids	Combined	94.8 %	88.5 %	86.0 %
	First Flush	98.3 %	91.4 %	89.0 %
Chemical Oxygen Demand	Combined	66.9 %	76.3 %	74.0 %
	First Flush	89.5 %	82.1 %	79.8 %
Total Phosphorus	Combined	40.5 %	53.2 %	65.5 %
	First Flush	67.3 %	68.9 %	72.9 %
Total Kjeldhal Nitrogen	Combined	55.9 %	50.5 %	66.7 %
	First Flush	84 %	60.8 %	69.0 %
Iron	Combined	89 %	95.5 %	79.6 %
	First Flush	94 %	97.5 %	82.9 %
Chromium	Combined	61.2 %	74.5 %	64.3 %
	First Flush	92.4 %	80.8 %	72.8 %
Copper	Combined	66.7 %	63.5 %	64.1 %
	First Flush	83.7 %	73.9 %	70.7 %
Lead	Combined	N/A	85.1 %	81.4 %
	First Flush	N/A	89.0 %	84.0 %
Zinc	Combined	88.3 %	75.8 %	79.9 %
	First Flush	92.8 %	83.1 %	83.1 %

5.3.3.3 Bioretention systems

Bioretention systems (Figure 5.11 and Figure 5.12) are suitable to treat runoff on sites where there is adequate soil infiltration capacity and where the runoff volumes that are not infiltrated do not present a safety or flooding hazard. Typical applications for bioretention include parking areas with or without curbs, traffic islands, and swales or depressed areas that receive runoff from impervious areas.

Bioretention system designs are very flexible, can be adapted to a wide range of commercial, industrial, and residential settings, and can be linked in series or combined with structural devices to provide the necessary level of treatment depending on expected runoff volumes and pollutant loading. A common technique is to use bioretention areas to pre-treat sheet flow before it is channelized or collected in an inlet structure.

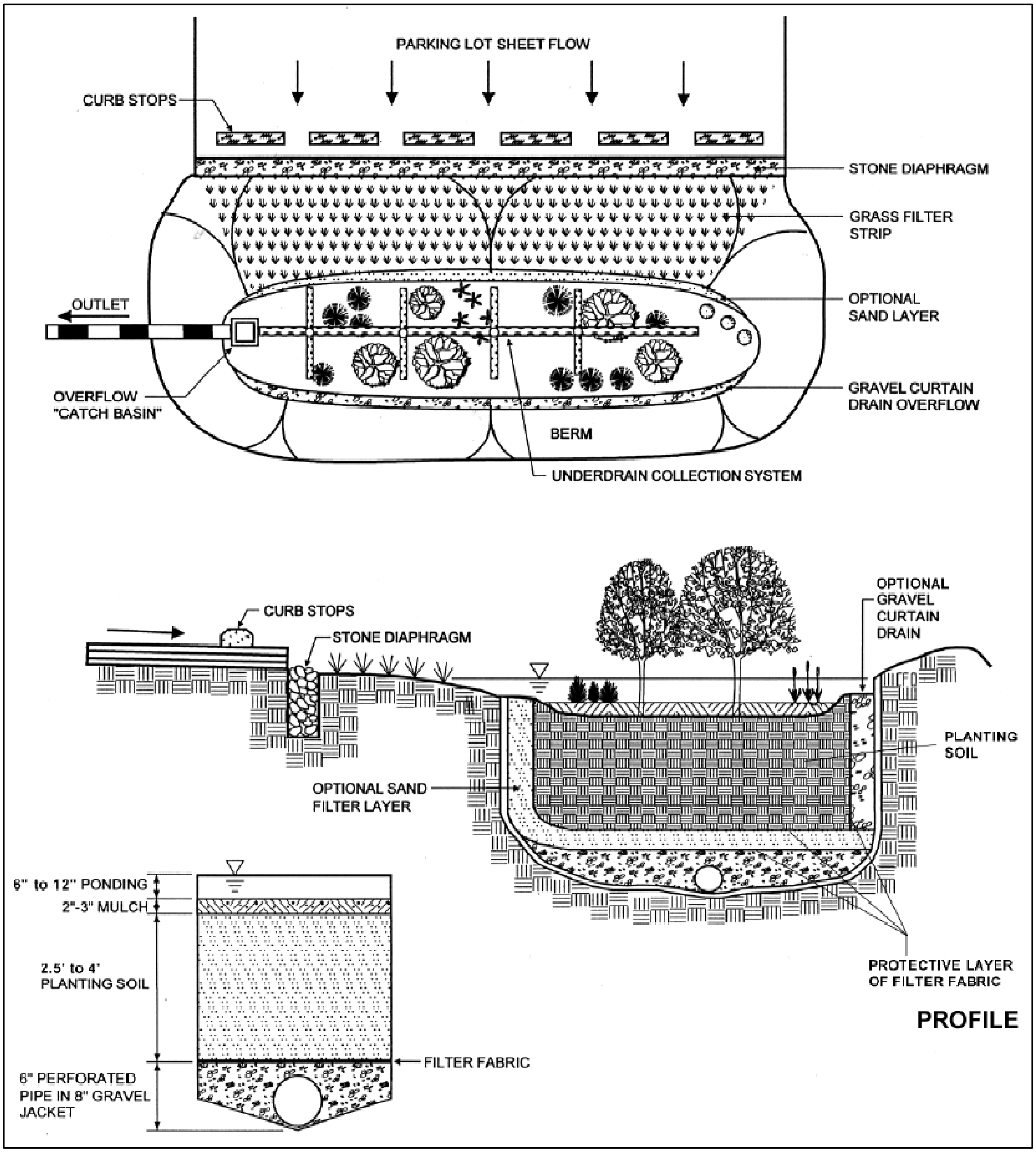

Figure 5.11: Schematic of a bioretention system (MDE, 2000).

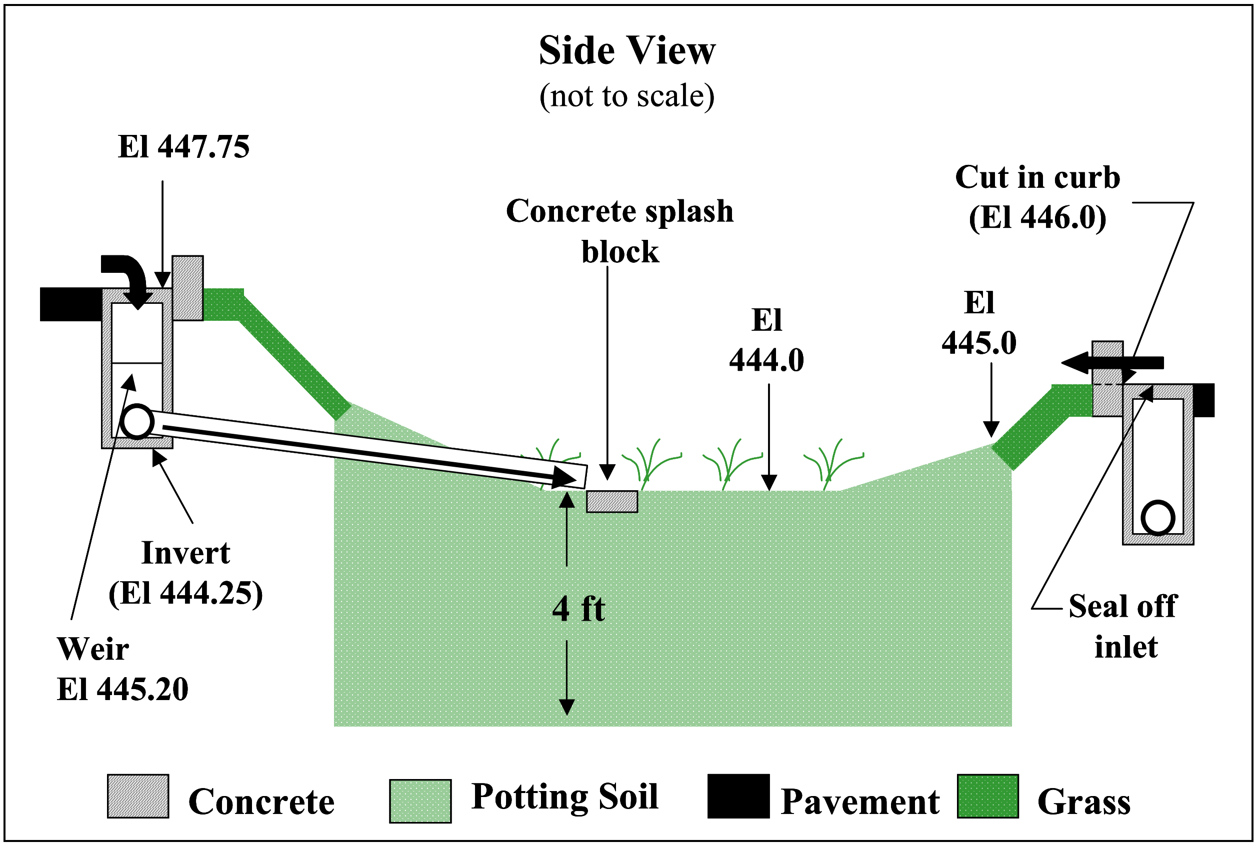

Figure 5.12: Schematic of a bioretention parking lot island (Traver, 2003).

Bioretention should not be used in areas:

- With mature trees;
- With slopes greater than 20 percent;
- With a water table within 6 feet of the land surface;
- With easily erodible soils;
- Below outfalls;
- Where concentrated flows are discharged; or
- Where excavation or cutting will occur.

To determine the appropriate design of the bioretention area with respect to the amount of runoff it receives, Prince George’s County, Maryland, Department of Environmental Resources (1993), suggests a design based on a four-day maximum ponding period (appropriate for the Mid-Atlantic region). This four-day period is based on hydrologic, horticultural, and maintenance constraints such as plant tolerance of flooded conditions and mosquito-breeding concerns. Other considerations include infiltration rates for the root zone, sand layer, and in-situ material.

There is some flexibility with respect to size, shape, and placement of vegetation within the bioretention area. Other elements that should be incorporated into the design of the bioretention system include curb openings, a ponding area suitable to handle runoff from larger storms, amended planting soil that provides the desired infiltration rate, and an under-layer sand or gravel bed or underground perforated pipe that facilitates infiltration.

Regular maintenance, including soil pH testing, mulching and repairing eroded areas, inspecting vegetation, ensuring that runoff is infiltrating as designed, and checking for damage caused by large storms, will help to ensure the longevity of bioretention areas. More information about the design, operation, and maintenance of bioretention systems can be found in Coffman and Winogradoff (1999) or Prince George's County, Maryland, Department of Environmental Resources (1993).

As for the performance of bioretention areas, in one research study, simulated runoff was pumped continuously into an area of 5.3 m^2 in six bioretention cells, and effluent samples were collected from the perforated drainpipes underlying the bioretention media. All six bioretention facilities showed greater than 99 percent removal efficiency for oil and grease. Total lead removal efficiency decreased when the TSS level in the effluent increased because lead was adsorbed onto the surface of the solids. TSS removal ranged from 72 to 99 percent, and lead removal rates ranged from 80 to 100 percent. For total phosphorus, the removal efficiency was found to be highly variable, ranging from 37 to 99 percent. Nitrate-nitrogen and ammonium-nitrogen removal efficiencies ranged from 2 to 7 percent and 5 to 49 percent, respectively. Overall, the bioretention cells contributed significantly to water quality improvement (Hsieh and Davis, 2003).

The developer of Somerset Community, a typical suburban development in Prince George's County, Maryland, incorporated bioretention areas into each lot to control runoff quantity and quality. The bioretention areas eliminated the need for a wet pond, allowed the development of six extra lots, and resulted in a cost savings of more than $4,000 per lot. Somerset residents have enthusiastically accepted their bioretention areas, are actively maintaining them, and have lodged few complaints. Safety issues and mosquitoes have not been a problem (Daniels, 1995, and Curry and Wynkoop, 1995).

The Inglewood Demonstration Project in Largo, Maryland, involved retrofitting an existing parking facility with bioretention areas and comparing the pollutant removal efficiency of a bioretention cell in a laboratory setting to that of a comparable facility constructed in a parking lot. This study showed the feasibility of retrofitting an existing parking facility and demonstrated the consistency of laboratory and field pollutant removal performance. Results showed that the runoff temperature was lowered 12 degrees Celsius, lead levels were lowered 79 percent, zinc levels were lowered 78 percent, and numerous other pollutant levels were also considerably reduced. The retrofit cost $4,500 to construct, while usual methods would have cost $15,000 to $20,000 and involved fewer environmental benefits and higher maintenance costs. Also, bioretention areas offer the ancillary benefit of aesthetic enhancement. It is interesting to note that a drought occurred after the installation of the plants, and although many of the other plants in the parking lot died or experienced severe drought stress, those in the bioretention facility survived because of the retained water supply (USEPA, 2000a).

Using Landscaped Rain Gardens to Control Runoff

The city of Maplewood, Minnesota is seeking to improve drainage in its older neighborhoods through the use of rain gardens. A successful pilot project, which was implemented in 1995, was the starting point for the current citywide rain garden initiative. Rain gardens from the pilot project have prevented runoff from flowing out of the area, containing 100 percent of the flow. City officials decided to expand the project when they recognized the aesthetic and environmental benefits resulting from the pilot project rain gardens.

The city is focusing on demonstration, education, and outreach to convey the benefits of using rain gardens for runoff management, rather than requiring homeowners to participate. Although rain gardens can be a solution for people who are opposed to adding curbs and gutters to their streets, some are concerned that rain gardens may attract and breed mosquitoes. Before beginning a street improvement project for a specific neighborhood, the city holds neighborhood meetings and distributes a comprehensive educational mailing and questionnaire to homeowners. These materials contain a fact sheet that explains the purpose of rain gardens, how they are designed, how they work, their benefits, and the plants best suited for a variety of hydrologic conditions. A questionnaire is also included to ascertain existing drainage problems and to determine whether the homeowner would be willing to agree to use a rain garden.

Once a homeowner has decided that they want a rain garden, they choose the location and size. The city works with homeowners to make these types of decisions and to help them comply with restrictions on garden placement caused by existing trees, natural drainage, or the presence of gas and water mains and other utilities. Homeowners may choose from three standard rain garden sizes (12-foot by 24-foot, 10-foot by 20-foot, and 8-foot by 16-foot) and from one of six different garden themes, including an easy shrub garden, easy daylily garden, sunny garden, sunny border garden, butterflies and friends garden, Minnesota prairie garden, and shady garden.

To begin construction, the city's contractor excavates a gently sloping depression to collect the water. Rain garden depths vary depending on garden size and topography. The contractor digs a sump 42 inches wide and 3 feet deep at the deepest part of the garden to accommodate a geotextile filter fabric bag, which is filled with clean crushed rock. The sump promotes rapid infiltration to reduce the standing time of water in the rain garden. After the infiltration sump is in place, the contractor adds at least 8 inches of bedding material (typically a mixture of salvaged topsoil and clean organic compost) and covers the area with 3 to 4 inches of shredded wood mulch. Residents are provided with all necessary plants and a landscape plan at no additional cost. However, many Minnesota municipalities charge residents a street assessment to cover a percentage of the project cost.

The city's rain garden street improvement project typically costs 75 to 85 percent of a traditional curb and gutter project. Costs are kept low because most of the existing street material is recycled to use as the base aggregate. Additionally, plants are obtained at a reasonable cost and residents are responsible for the planting. Other long-term savings, which are difficult to quantify, result from the reduced demand on the city's downstream sewer infrastructure, which is not characteristic of conventional storm systems. The city may also be able to reduce the need for downstream storm sewer system upgrades and construction, including detention and treatment facilities designed to prevent pollution, erosion, and flooding problems.

More information about Maplewood's rain garden project is available from Chris Cavett, Assistant City Engineer, at 651-770-4554 or chris.cavett@ci.maplewood.mn.us (Terrene Institute, 2001).

5.3.4 Detention and Retention Practices

5.3.4.1 Detention ponds and vaults

These practices temporarily detain runoff to ensure that the postdevelopment peak discharge rate is equal to the predevelopment rate for the desired design storm (e.g. two-, 10-, or 25-year). These practices may also be used to provide temporary extended detention to protect downstream channels from erosion (e.g., 24-hour extended detention for a one-year storm).

Extended detention (ED) ponds (Figure 5.13) are an example of this type of facility. ED ponds temporarily detain a portion of urban runoff for up to 24 hours after a storm, using a fixed orifice to regulate outflow at a specified rate and allowing solids and associated pollutants time to settle out. ED ponds are normally dry between storm events and do not have any permanent standing water. These basins are typically composed of two stages: an upper stage, which remains dry except after larger storms, and a lower stage, which is designed for typical storms. Enhanced ED ponds are equipped with plunge pools or forebays near the inlet, a micropool at the outlet, and an adjustable reverse-sloped pipe as the ED control device (NVPDC, 1980; Schueler et al., 1992). Most ED ponds use a riser with an anti-vortex trash rack on top to control large floating solids.

Detention tanks and vaults are underground structures used to control peak runoff flows. They are usually constructed out of concrete (vaults) or corrugated metal pipe (tanks). Underground detention can also be achieved by retrofitting the over-capacity storm drain pipes with baffles. The baffles allow water to be stored in the pipes so it can be released at a slower rate. Pretreatment structures such as water quality inlets and sand filters can be used to treat runoff and remove trash and debris.

These systems are primarily applicable where space is limited and there are no other practical alternatives. Concrete vaults are relatively expensive and are often used to control small flows where system replacement costs are high. Corrugated metal pipe systems are less expensive and are often used to control larger volumes of runoff in parking lots, adjacent to rights-of-way, and in medians. These systems should be located where maintenance can be conducted with minimal disturbance.

Underground detention structures provide runoff quantity control but do not provide significant water quality control without modifications. Corrugated metal pipe systems can work in conjunction with infiltration to provide additional runoff treatment. This is accomplished by adding perforations to the pipe to allow it to store the water until it can be released into the soil (FHWA, no date).

5.3.4.2 Retention ponds

These practices use a permanent pool, extended detention basin, or shallow marsh to remove pollutants and can include:

- Micropool extended detention ponds;
- Wet ponds;
- Wet extended detention ponds; and
- Multiple pond systems.

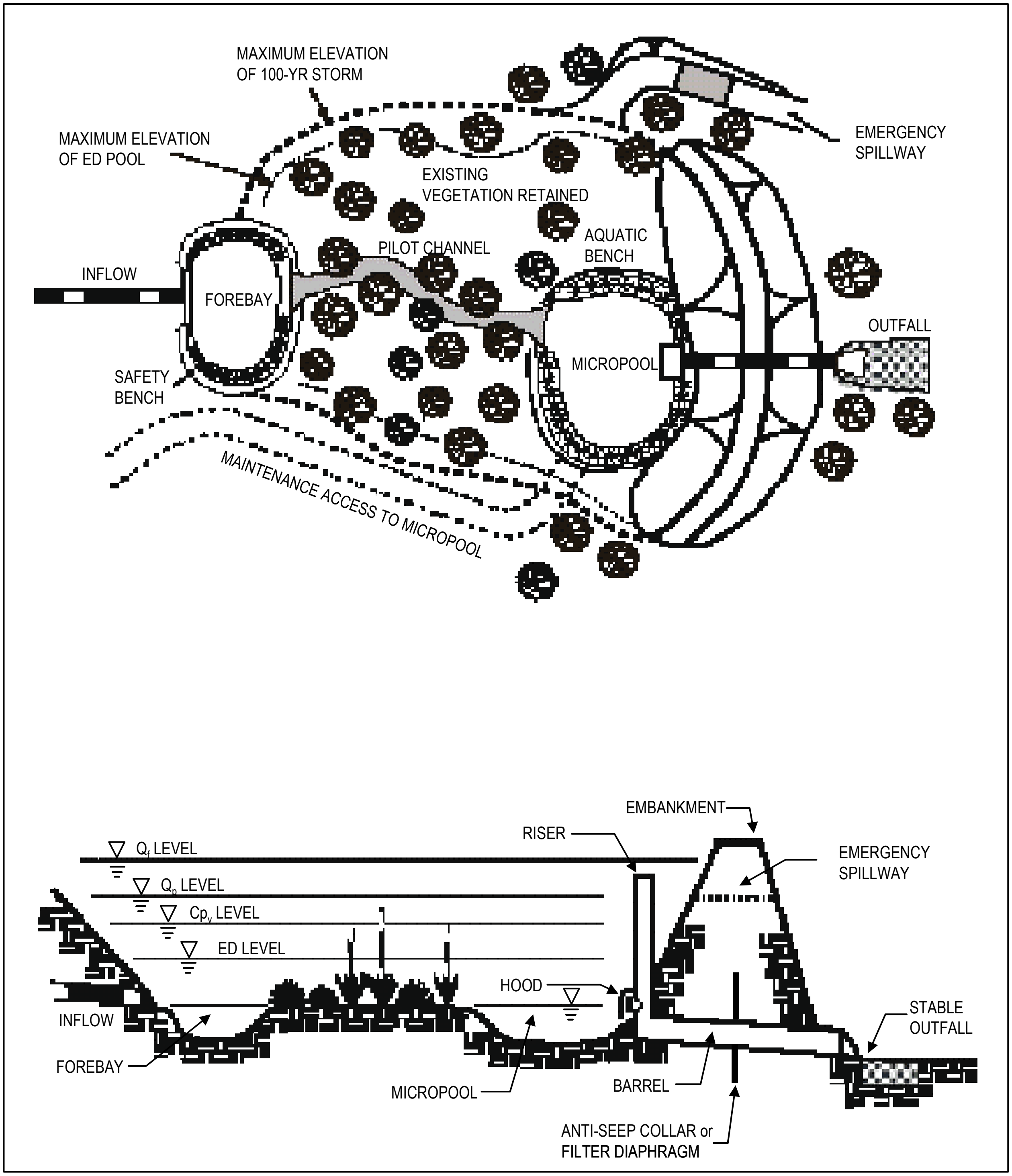

Figure 5.13: Schematic of a dry extended detention pond (MDE, 2000).

Ponds (Figure 5.14) are basins designed to maintain a permanent pool of water and temporarily store runoff (ED wet pond), which is released at a controlled rate. Ponds allow particulates to settle and can provide biological uptake of pollutants such as nitrogen or phosphorus. Enhanced designs include a forebay to trap incoming sediment where it can easily be removed. Often, a

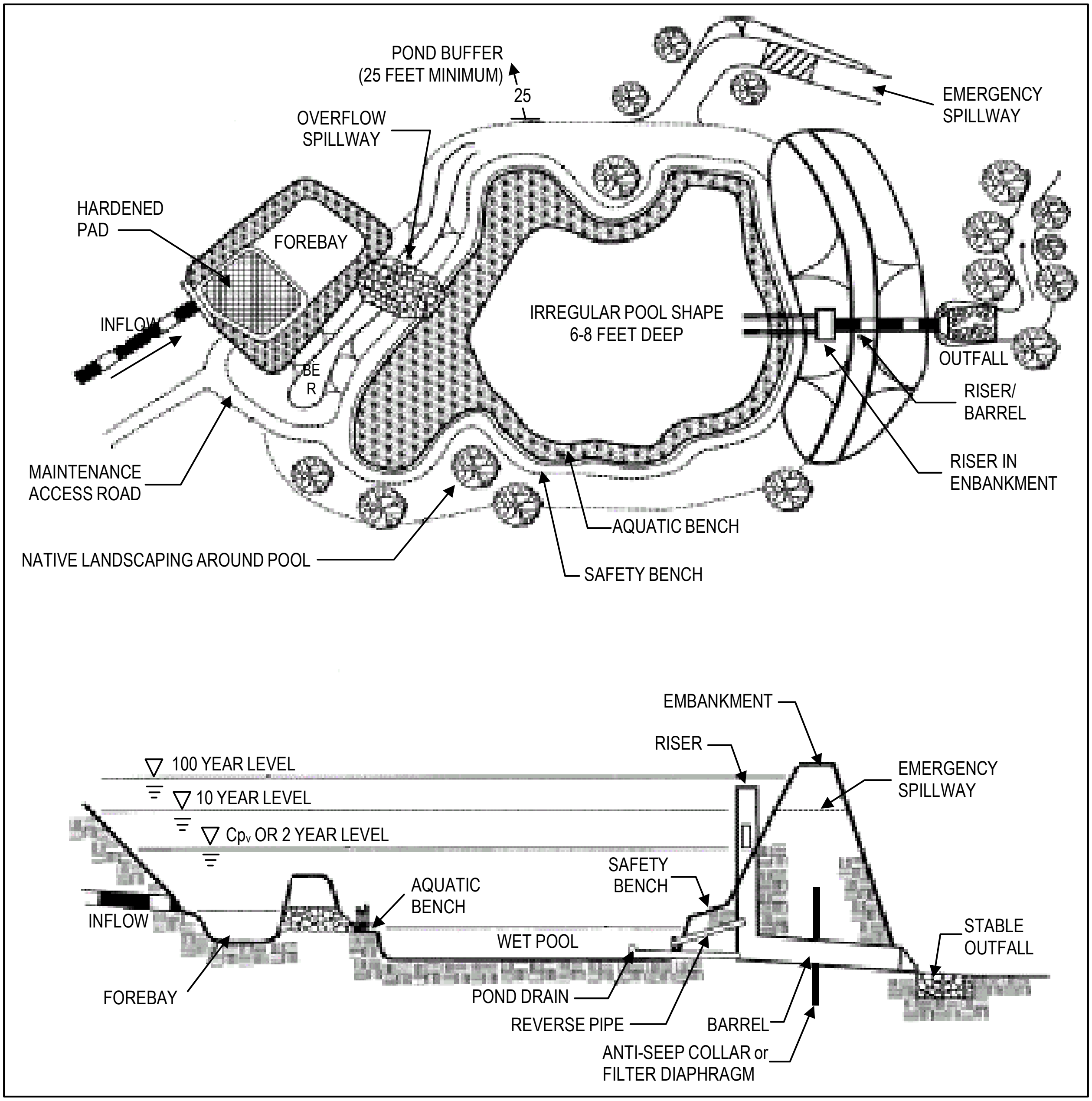

Figure 5.14: Schematic of a wet pond (MDE, 2000).

fringe wetland is installed around the perimeter of the pond to increase the habitat, aesthetic, and pollutant removal values of the facility. An outlet riser, sometimes combined with an anti-vortex trash device, is a common design modification. The design of wet ponds should account for the infiltration of ground water when the wet pond intercepts the water table. Table 5.5 presents several design considerations for ponds.

Table 5.5: Design considerations for ponds and wetlands (MDE, 2000).

Design Consideration	Ponds	Wetlands
Watershed Design Requirements		
Streams in intensely developed areas	Drainage area may limit the applicability of ponds except for pocket ponds.	Drainage area may limit the applicability of ponds except for pocket wetlands.
Cold-water streams	An offline design is recommended. Maximize shading of open pool areas.	An off-line design is recommended. Maximize shading of open pool areas.
Streams in sparsely developed areas	Require additional storage to ensure adequate downstream channel protection.	Require additional storage to ensure adequate downstream channel protection.
Aquifer protection	May require a liner depending on soil type.	May require a liner depending on soil type.
Reservoir protection	Require additional storage to ensure adequate downstream channel protection.	Require additional storage to ensure adequate downstream channel protection.
Shellfish beach located downstream	Provide moderate bacteria removal. Should be designed to prevent geese problems. Should provide permanent pools.	Provide 48-hr extended detention for maximum bacterial die-off.
Terrain Factors		
Low relief	The maximum normal pool depth should be 4 feet (dugout).	Wetlands are suitable for low-relief areas.
Karst	Require a poly or clay liner and geotechnical tests.	Require a poly or clay liner and geotechnical tests.
Mountainous	Embankment heights are restricted.	Embankment heights are restricted.
Physical Feasibility		
Soils	Depending on pond type, they may or may not require a liner or testing.	Certain soils may require a liner.
Water table	Must be at least 2 feet above water table if near a potentially contaminated “hotspot” or if underlain by an aquifer. Pocket ponds by definition are below the water table.	Must be at least 2 feet above water table if near a potentially contaminated “hotspot” or if underlain by an aquifer.
Drainage area	Minimum drainage area is 10 to 25 acres depending on type of pond. Pocket pond has a 5-acre maximum.	Minimum of 25 acres except pocket wetlands, which have a 5-acre maximum.
Site slope	Slopes should always be less than 15%	Slopes should be less than 8%.
Head	A 6- to 8-foot head is needed for all ponds except pocket ponds, which require a 4-foot head.	A 3- to 5-foot head is needed for most wetlands except pocket wetlands, which require a 2- to 3-foot head.
Ultra urban	Only pocket ponds are practical.	Pocket wetlands are sometimes practical; all others impractical.
Runoff Treatment Suitability		
Ground water recharge	No	No
Channel protection	Yes	Yes
Runoff Treatment Suitability (continued)		
Ground water recharge	No	No
Channel protection	Yes	Yes
Water quantity control	Yes	Yes
Large space requirements	Less space	More space
Community and Environmental Factors		
Maintenance	Easier	More difficult
Community acceptance	More acceptable	Less acceptable
Affordability	More affordable	Less affordable
Wildlife habitat	Yes	Yes

Used in combination with on-site and nonstructural practices, regional ponds are an important component of a runoff management program. The costs and benefits of regional, or off-site, practices compared to on-site practices should be considered as part of a comprehensive management program. For example, regional ponds can be located to treat runoff from existing development, and will result in overall net reductions on pollutant loads for the watershed (Fairfax County Environmental Coordinating Committee, 2002). Regional facilities can incorporate more advanced treatment technologies than on-site facilities (Maupin and Wagner, 2003). They can also provide community recreation and wildlife benefits, reduce peak and total flow, and be easier to maintain than dispersed controls. The City of Fairfax, Virginia, found that maintenance costs for a regional pond were about one-sixth those of on-site ponds (Fairfax County Environmental Coordinating Committee, 2002). Maintenance responsibilities and liability for regional runoff facilities belong to the municipality (Maupin and Wagner, 2003).

A study of 43 wadeable streams in Austin, Texas, showed that several indicators of stream health (ephemeroptera-plecoptera-trichoptera (EPT) richness and percent EPT abundance) were higher in streams with storm water ponds protecting 60 to 95 percent of their catchments than in streams with no storm water controls (Maxted and Scoggins, 2004). This trend was only significant in fully developed watersheds (having greater than 40 percent impervious cover). In watersheds with less than 40 percent impervious cover, storm water ponds had no significant impact on EPT richness or percent EPT abundance. The researchers attributed the lack of effects of storm water ponds to urban development in the reference watersheds and to the nature of the biological index used to gauge stream health, which was not tailored to the specific environmental conditions of the Austin area.

Research has shown that storm water ponds can increase property values. A survey in Columbia, Maryland, found that 75 percent of homeowners felt that permanent bodies of water such as storm water ponds added to real estate values. Seventy-three percent were willing to pay more for property located in a neighborhood with storm water control basins designed to enhance fish or wildlife uses (Adams et al., 1984; Tourbier and Westmacott, 1992; USEPA, 1995). Residents of a Champaign-Urbana, Illinois, neighborhood with storm water ponds stated that lots adjacent to a wet pond were worth an average of 21.9 percent more than comparable non-adjacent lots in the same subdivision. The same survey revealed that 82 percent would in the future be willing to pay a premium for a lot adjacent to a wet pond (Emmerling-DiNovo, 1995). In Alexandria, Virginia, condominiums alongside a 14-acre runoff detention pond sold for $7,500 more than comparable units not adjacent to the pond (USEPA, 1995).

Regional ponds do not, however, provide protection in contributing drainage systems, including upstream tributaries. These can experience damage from increased peak flow and flow volume. In addition, placement of regional ponds in low-lying areas may harm natural wetlands, and the ponds may create safety and liability issues. Siting ponds or other structural management practices within natural buffer areas and wetlands degrades their functions and may interrupt surface water and ground water flow when soils are disturbed for installation.

5.3.4.3 Constructed wetlands

Constructed wetlands (Figure 5.15) are engineered systems designed to treat runoff. They are typically designed to provide some of the functions of natural wetlands, e.g., wildlife habitat, in

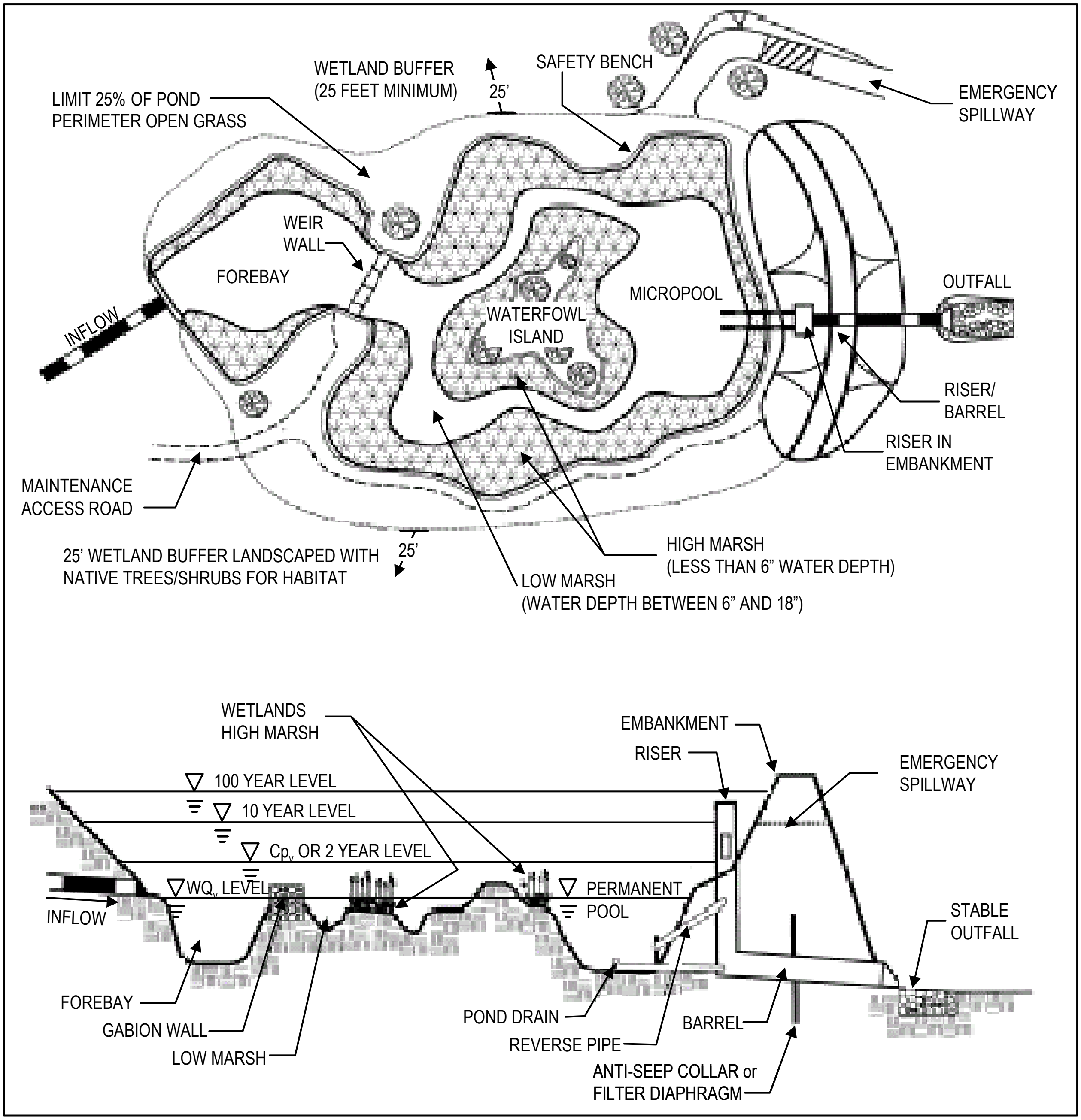

Figure 5.15: Schematic of a shallow wetland (MDE, 2000).

addition to controlling runoff volumes and pollutant loadings. There are many variations of constructed wetlands, such as shallow wetlands, extended detention wetlands, pond/wetland systems, and small isolated "pocket" wetlands. Constructed wetlands may contain some or all of the following elements: shallow vegetated areas, permanent pools, sediment forebays, transition areas, and weirs. Designs are intended to slow flow through the wetlands and provide maximum contact with wetland vegetation.

It should be noted, however, that constructed wetlands rarely replicate the functions of natural wetlands and should not be used for compensatory mitigation of natural wetlands and buffers.

Furthermore, constructed wetlands should be designed to receive periodic maintenance to ensure the wetland continues to function as designed.

Constructed wetlands are feasible at most sites and drainage areas where there is enough rainfall and/or snowmelt to maintain a permanent pool. In areas with highly permeable soils, other impermeable barriers, such as synthetic liners or clay, sometimes can be used to maintain enough water or moisture to support the wetland. Constructed wetlands should be located contiguous to existing wetlands wherever possible, unless there is concern about contaminants that may pose a threat to wildlife. Although it is technically feasible to construct a wetland on a small site (less than 1 acre), alternative control strategies should be considered when land constraints are present.

Constructed wetland systems can take several forms, including wet ponds with a wetland fringe, swale/ditch wetland depressions, and large-scale constructed wetlands used as mitigation wetlands or treatment wetlands. The choice of wetland designs depends on watershed characteristics, spatial and geomorphic constraints, runoff treatment requirements, and community and environmental factors. These considerations are outlined in Table 5.5.

In the San Diego Creek Watershed in southern California, constructed wetlands are being used as a regional runoff control technique. This approach, called the Natural Treatment System (NTS) Plan, is part of a watershed-wide management effort to meet total maximum daily load (TMDL) requirements for the San Diego Creek, which is impaired by sediment, nutrients, pathogens, heavy metals, and pesticides. The results of water quality modeling that accounted for the combined effects of the 44 planned facilities indicated that the TMDL for total nitrogen in base flows would be achieved, total phosphorus targets would be met in all but the wettest years and the fecal coliform target would be met in the dry season. While the NTS Plan is not meant to meet the TMDL for sediment, it will capture 1,900 tons annually, and the wetlands are estimated to remove 18 percent of the total zinc and 11 percent of the total copper and lead in runoff (Strecker et al., 2003).

New York City Bluebelt

The New York City Department of Environmental Protection (NYCDEP) has taken an innovative approach to solving drainage problems that have long plagued southern Staten Island. Instead of installing a conventional piped storm sewer system that would destroy the existing wetlands through drainage or filling, NYCDEP proposed to use a natural drainage system to convey, store, and filter runoff. The plan involves both preserving and restoring wetlands. In 1991, the agency began purchasing land along wetland corridors, and soon this network of property was termed the Bluebelt, because it mirrors the role a Greenbelt plays for open space areas by protecting water resources. The Bluebelt area is a total of 10,000 acres and includes 16 watersheds.

The constructed wetlands in the Bluebelt range from 0.5 to 2 acres in area and have a permanent pool that ranges from 12 to 24 inches deep. The wetlands are intended to provide water quality, flood control, and flow attenuation benefits for the region. More than 100 management practices were screened for their applicability, and in addition to constructed wetlands, meandering streams and outlet stilling basins were installed. Meandering streams convey runoff in open channels, providing a basis for the establishment and preservation of riparian areas. Outlet stilling basins mitigate the high velocities of runoff exiting conventional pipes. In the past 12 years, approximately half of the 89 planned management practices have been designed (Vokral et al, 2003).

Desert Wetlands

A constructed wetland demonstration project is being tested in the Sonoran Desert to improve the New River, which consists primarily of wastewater from Mexico and agricultural drain water from California's Imperial Valley (Fortner, 2000). Without these two sources of water, the New River would run dry. Near Imperial, California, about halfway along the New River, 68 acres of wetlands were constructed as a demonstration project. These wetlands use a series of six cells to remove sediments and other pollutants from irrigation drain water. A few miles downstream, in Brawley, California, a similar project will treat water that is diverted directly from the New River. The site for this project consists of 7 acres and three cells. The two sites are collectively referred to as the Brawley Constructed Wetlands Demonstration Project.

The project is described as one of the most challenging constructed wetlands projects in the United States and will help researchers determine the best design for treating river and agricultural drain water. Scientists are aware that it will be challenging to construct a wetland to treat a severely impaired waterbody in a desert area. They will monitor the performance of the test sites before additional wetlands are built. Once the data is obtained, the Citizens' Congressional Task Force for the New River (comprised of citizens and representatives from environmental groups, local community organizations, and state and federal agencies) will decide whether to expand the project.

Wetlands and other runoff control systems should not be sited in areas where they disrupt or significantly alter the predevelopment hydrology unless restoration objectives apply. When designing the wetland, a variety of physical characteristics should be used to promote multiple wildlife and habitat functions. For example, an irregular shape increases the perimeter of the system and provides a greater variety of microhabitats along the shoreline. Also, an irregular shoreline can extend the perimeter of a constructed wetland by 10 to 20 percent with no increase in land requirements.

Shallow-water wetlands do not contain a large volume of water per surface area as would a typical wet pond. In general, the wetland should have a shallow slope with a permanent pool in the middle. To enable growth of emergent vegetation, static water depths should not exceed 2 to 3 feet. Depths greater than 2 to 3 feet are conducive to the growth of submerged aquatic vegetation. The use of deeper water (>3 feet) in an area that is easily accessible for small children should be discouraged. No area of the pond should have a depth greater than four feet. In general, 50 percent of the pond should have depths less than one foot, 30 percent should be 1 foot to 2 feet deep, and 20 percent should be 2 to 4 feet deep. Greater depths are allowable for the inflow forebay and around the outlet structure.

The Maryland Department of the Environment (2000) requires that the first inch of runoff from the site must be controlled and released over a 24-hour period to provide water quality treatment, while peak discharge control of the two- and 10-year storms must be provided for water quantity control. Local requirements should be used when designing the treatment capacity of a constructed wetland. Other factors such as steep slopes may necessitate deeper ponds to obtain adequate runoff control.

Individual soil analyses should be done during the site design phase to determine if a clay or plastic liner is needed to maintain a wetland environment. Wetland vegetation cannot usually survive unless a base flow is available to provide a permanent pool to keep plants wet. Rapid infiltration will remove this needed pool. If a liner is needed, it should have at least 1 foot of

The Use of Wetlands to Reduce Fecal Coliform

Unusually high levels of fecal coliform have been found in an area of Laguna Niguel, California. Runoff from a neighborhood is washing into Aliso Creek and then to the Pacific Ocean. In response to a cleanup order issued by state water regulators, city officials built a series of wetlands to filter fecal coliform out of runoff. The natural water treatment system will work in combination with an existing wetland, which has already been proven successful in cleaning waters to a level acceptable for swimming.

Upon completion, water will flow through a series of four stepped ponds, spread out, and remain in the wetlands for hours or days of treatment. It is estimated that it will take a year for all vegetation to grow in and nearly two years to attain maximum removal of bacteria. When the wetlands system is complete, the existing wetland will treat 35 to 40 percent of the runoff and the new wetlands will treat 35 percent of the runoff. The city hopes that the new wetlands will work as well as the existing wetlands in reducing fecal coliform from urban runoff (Vardon, 2000).

clean fill material placed on top of it for wetland plant growth (the fill material will also reduce the potential for puncture).

An island placed in the wetland can extend the length of the flow path that runoff must travel to traverse the pond. This increased flow path enhances the pollution removal function of the constructed wetland. The highest elevation of the island should be above that reachable by storage of the first inch of runoff. Islands in wetlands may attract geese, which can be undesirable in some urban settings, but there are ways to minimize habitat for geese in a constructed wetland. Because most runoff management ponds are fairly small compared with a natural marsh system, they do not provide the long glide path preferred by geese for landing and takeoff. Planting woody vegetation or allowing areas around the pond to grow without mowing also tends to discourage goose residency.

The following are typical elements of a constructed wetland:

(1) *Sediment forebays*. It is important that sediment forebays be placed at all locations where runoff enters the wetland. A forebay is designed for vehicle access to facilitate sediment removal while preventing disturbance of substrate that could disrupt wetland functions. The forebay should constitute approximately 10 percent of the total basin volume and should have a maximum depth of 4 feet. Where there are multiple inlets to the constructed wetland, the total volume of all the forebays should be 10 percent of the basin volume, with individual inlet forebays sized with respect to the percentage of contributing flow they receive. The use of stone riprap in the forebay will reduce the velocity of flow into the wetland portion of the basin and minimize resuspension of deposited sediments. An access to the forebay should be provided for cleanout equipment. An area adjacent to the constructed wetland should be set aside for disposal of the sediments that become trapped and are removed during periodic maintenance.

    The cleanout frequency of sediment forebays depends on the sediment load entering the constructed wetland. Each forebay should be inspected annually to ensure cleanout is being conducted as needed. Once the forebay has been filled to approximately 50 percent of its total volume (every 10 to 15 years), sediment should be removed, placed in an appropriate upland location, and stabilized. Costs for sediment forebay maintenance, including periodic inspection and cleaning, should be budgeted as a long-term operating expense if this practice is selected.

(2) *Diversion weir*. Diversion weirs may be needed for designs where the entire runoff volume is not directed to the constructed wetland. This diverted fraction of the runoff is often routed to collection systems or inlets. The amount of rainfall that may be diverted will vary according to local requirements and design objectives.

(3) *Outlet*. As is the case with all ponds having a normal pool of water, algae can clog outlets with small orifices that are needed for extended detention. A below-surface withdrawal structure may reduce or eliminate this problem.

(4) *Transition zone*. The maximum slope of the transition zone on wetland side slopes should be no greater than 10:1 (horizontal:vertical) and should extend at least 20 feet from the design pool of the constructed wetland. This area will be temporarily flooded whenever runoff is temporarily detained. Planting trees in the transition zone enhances nutrient uptake; the shading reduces temperature increases common in open water areas; and the trees provide habitat for wildlife. The transition zone should be mowed no more than once a year in late fall. Optimally, to promote the growth of woody vegetation, the transition area should not be mowed at all unless the pond is an embankment pond, in which case it should be mowed annually to prevent woody vegetation on the embankment.

(5) *Vegetation*. Placement of organic soils on the bottom of the pond will provide faster growth of planted or volunteer vegetation. Constructed wetlands should initially be planted with emergent plants and woody shrubs, and the wetlands should be allowed to succeed to a system dominated by woody shrubs and trees. The emergent wetland plants that are chosen should have tops that rise above the normal pool level.

It is important to consult local ecologists/plant specialists to choose suitable wetland species and to design a landscaping plan with appropriate vegetation density and spacing. Local specialists can also provide information regarding the optimal time to plant vegetation and help to design a maintenance schedule based on vegetation requirements. Native species should be used where feasible because they are well-adapted to local conditions. The USDA has a database (see http://www.plants.usda.gov/) of invasive and noxious species, which should be avoided.

The following specifications are provided as an example and apply to the Mid-Atlantic region (MDE, 2000):

- At least two aggressive species should be planted in the constructed wetland; their purpose is to rapidly spread to other unplanted areas of the wetland. In addition, at least three secondary species should be planted to increase the diversity, wildlife values, and appearance of the wetland. Ideally, plantings should include a mix of perennial and annual species.

- Plants should cover approximately 30 percent of shallow areas, with particular attention paid to areas adjacent to the shoreline. Plants should be spaced 2 to 3 feet apart, and the same species of plants should be planted in a single area to avoid interspecies competition.

- Species that are not recommended for any use in a constructed wetland are *Phragmites australis* (common reed), *Lythrum salicaria* (purple loosestrife), and *Phalaris arundinacea* (reed canary grass). Periodic inspections are important to ensure that exotic or other pest species do not dominate the plant community. In certain situations where there is an initial invasion of an aggressive, undesirable species, selective removal of the plants might be warranted, especially if the plant community that was introduced has not had time to adequately establish itself.

- Depending on site conditions, planting *Typha latifolia* (cattail) may or may not be recommended. Despite the fact that it is considered an exotic species, cattail will eventually dominate the wetland community. Additionally, cattail is an excellent plant for water treatment from a filtration and sedimentation standpoint.

- Planting will be more successful if the water level can be drawn down immediately prior to planting. This drawdown will leave the soils saturated, a condition necessary for the plants, and will improve visibility, especially when a number of people are involved in planting. The potential for damaging previously planted vegetation is reduced if the plants are clearly visible. Upon completion of planting, the outlet structure drain valve should be closed so either storm or base flow can reestablish the normal pool elevation.

- Harvesting wetland plants is only appropriate in areas such as the southern United States where plant growth is the most important mechanism for nutrient uptake. Harvesting is not needed where microbial activity is the dominant pollutant removal mechanism.

Like wet ponds, wetlands can increase adjacent property values. One study in Boulder, Colorado, found that lots located alongside a constructed wetland sold for up to a 30 percent premium over lots with no water view (USEPA, 1995). In Wichita, Kansas, a developer enhanced existing wetlands rather than filling them, and the waterfront lots sell for a premium of up to 150 percent of comparable lots (USEPA, 1995).

5.3.5 Other Practices

Other practices used to control urban runoff have not been studied as extensively as those above but have been used with varying degrees of success. They include:

- Water quality inlets;
- Hydrodynamic devices;
- "Baffle boxes;"
- Catch basin inserts;
- Vegetated filter strips;
- Street surface storage;

- On-lot storage; and
- Microbial disinfection.

In some cases, these practices are used for pretreatment or are part of an overall runoff management system, which is sometimes referred to as a "treatment train." For example, water quality inlets, catch basin inserts, and vegetated filter strips installed upslope of a wet pond or filtration practice will help remove a portion of the pollutants present in runoff before it enters the pond or filtration practice. These other practices in the treatment train improve runoff quality and can help extend the longevity of the filtration practice and wet pond.

5.3.5.1 Water quality inlets

Water quality inlets are underground retention systems designed to remove settleable solids. There are several water quality inlet designs. In their simplest form, catch basins are single-chambered urban runoff inlets in which the bottom has been lowered to provide 2 to 4 feet of additional space between the outlet pipe and the structure bottom for collection of sediment. Some water quality inlets include a second chamber with a sand filter to provide additional removal of finer suspended solids by filtration. The first chamber provides effective removal of coarse particles and helps prevent premature clogging of the filter medium.

Other water quality inlets include an oil/grit separator. Typical oil/grit separators consist of three chambers. The first chamber removes coarse material and debris; the second chamber provides separation of oil, grease, and gasoline; and the third chamber provides safety relief if blockage occurs (NVPDC, 1980). Although water quality inlets have the potential to perform effectively, they are not recommended because they are usually designed to bypass high flows, which can resuspend captured pollutants and flush them through the water quality inlet. Frequent maintenance and disposal of trapped residuals and hydrocarbons are necessary for these devices to continuously and effectively remove pollutants.

5.3.5.2 Hydrodynamic devices

A variety of engineered hydrodynamic devices, also called swirl separators or swirl concentrators, are available for removing pollutants from runoff. Swirl separators are modifications of the traditional oil-grit separator and include an internal component that creates a swirling motion as runoff flows through a cylindrical chamber. The concept behind these designs is that sediments settle out as runoff moves in this swirling path. Additional compartments or chambers, with or without pads, are sometimes present to trap oil and other floatables. Typically these devices are prefabricated and come in a range of sizes targeted at specific flow rates. At least two technologies are available. One is designed to remove suspended particles, oil, and grease during low flow conditions. The device removes particulate and floatable pollutants from runoff through settling of solids and floating of oils, greases, and litter. Higher runoff flows are diverted around the treatment unit so that scour and increased velocity do not carry the collected pollutants out of the treatment chamber. Maintenance requirements include the periodic removal of oil, greases, and sediments, typically by using a vacuum truck.

A second type of hydrodynamic device uses centrifugal motion to remove litter and debris and, potentially, larger sediment particles from runoff. This technology is designed to capture trash rather than pollutants, and therefore it is most applicable in coastal areas and areas that receive heavy trash loads such as leaf litter, plastics, and cans. Prefabricated units are currently available with capacities up to 300 cubic feet per second (cfs). The devices are constructed so that a vacuum truck can regularly remove the floatable and settleable debris collected in the treatment chamber.

Limited data are available on the performance of these devices, and independently conducted studies suggest marginal fine particle and soluble pollutant removal. Therefore, swirl separators should not be used as a stand-alone practice for new development. Also, these devices require regular maintenance. Communities may reduce maintenance costs by sharing a vactor truck. Swirl separators are best installed on highly impervious sites. These products have application as pretreatment to another runoff treatment practice and in a retrofit situation where space is limited.

5.3.5.3 Baffle boxes

Sediment control devices called “baffle boxes” have been used in Brevard County, Florida, as an “end of pipe” treatment method (England, 1996). They are concrete or fiberglass boxes, typically 10 to 15 feet long and 6 to 8 feet high, which are placed at the end of existing storm drain pipes. The box is divided into multiple chambers by weirs set at the same level as the pipe invert to minimize hydraulic losses. Trash screens are incorporated in the design to remove floating debris. Baffle boxes have been shown to have a removal efficiency of up to 90 percent for sand or sandy clay at entrance velocities of up to 6 feet per second, and 28 percent removal efficiency for fly ash at the same velocity. Baffle box designs can be modified to serve as a retrofit installation at curb or manhole inlets or beneath grates. Regular maintenance, especially removal of sediment and debris, is essential to maintain the effectiveness of this practice.

5.3.5.4 Catch basin inserts

Catch basin inserts consist of a frame that fits below the inlet grate of a catch basin and can be fitted with various trays that target specific pollutants. Typically the frame and trays are made of stainless steel, cast iron, or aluminum to resist corrosion. The trays may contain a variety of media. Often more than one tray is included in the design with the first tray filtering out sediment. Subsequent trays typically address a specific targeted pollutant, (e.g., wood fiber or other absorbent materials for oils and grease, or activated carbon for organics, fertilizers, and pesticides). The device is typically designed to accept the design flow rate of the inlet grate with bypasses as the trays become clogged with debris. The media require routine maintenance for replacement, cleaning, or regeneration. Catch basin inserts are typically used for smaller drainage areas. Usually the media need replacement on a quarterly basis.

The City of Santa Monica installs catch basin inserts that catch trash and debris in areas of high pedestrian traffic. Catch basin screens attach to the face of the curb and block trash from the storm drain, allowing debris to be easily removed by maintenance personnel or a street sweeper. Inserts that also filter hydrocarbons are installed on streets with automotive businesses. The city has found these practices to be effective when they are chosen carefully to suit site characteristics and are carefully installed and maintained (Shapiro, 2003).

5.3.5.5 Alum

Alum, which is an aluminum sulfate salt, can be added to storm water to cause fine particles to flocculate and settle out (USEPA, 2001a). It can help meet downstream pollutant concentration loads by reducing the concentrations of fine particles and soluble phosphorus. Alum can be added directly to or just before a pond or lake inlet, and booms can be used to ensure quiescent settling. When alum is injected into runoff it forms the harmless precipitates aluminum phosphate and aluminum hydroxide. These precipitates combine with heavy metals and phosphorus, causing them to be deposited into the sediments in a stable, inactive state. The collected mass of alum pollutants, precipitates, and sediments is commonly referred to as “floc.” Frequent maintenance and disposal of the floc is required for continuous and effective operation.

5.3.5.6 Vegetated filter strips

Vegetated filter strips (VFSs) (Figure 5.16) are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. Dense vegetative cover facilitates sediment attenuation and pollutant removal. Unlike grassed swales, vegetated filter strips are effective only for overland sheet flow and provide little treatment for concentrated flows. Grading and level spreaders can be used to create a uniformly sloping area that distributes the runoff evenly across the filter strip (Dillaha et al., 1989). Vegetated filter strips are often used as pretreatment for other structural practices, such as infiltration basins and infiltration trenches.

Typically, VFSs are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area the practice treats but the length of flow leading to it. As runoff flows over the ground surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets that are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip.

VFSs should be designed on slopes between 2 and 6 percent. Steeper slopes encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff ponds on the surface on slopes flatter than 2 percent, creating potential mosquito-breeding habitat. Filter strips should not be used on soils with high clay content because they require infiltration for proper treatment. Very poor soils that cannot sustain a grass cover crop are also a limiting factor. Filter strips should be separated from the ground water by 2 to 4 feet to prevent contamination and to ensure that they do not remain wet between storms.

The design of VFSs is straightforward because they are not much more than a grassed slope. However, the following design features are critical to ensure that the filter strip provides some minimum amount of water quality treatment:

- A pea gravel diaphragm or stone drop should be used at the top of the slope. The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.

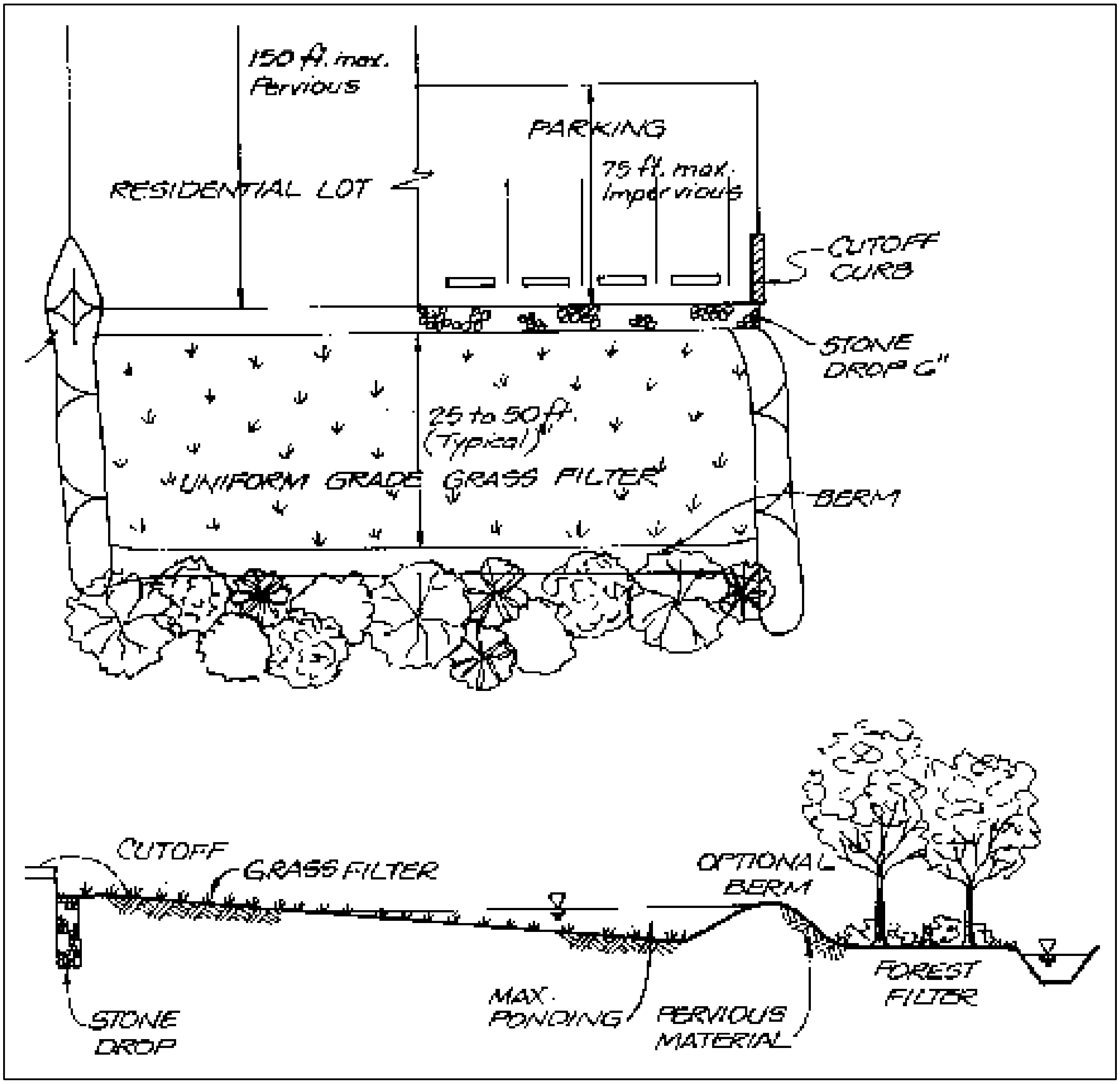

Figure 5.16: Schematic of a vegetated filter strip (Claytor and Schueler, 1996).

- The filter strip should be designed with a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm. The volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal in the practice. Typical water quality volumes are the runoff from a 1-inch storm or ½-inch of runoff over the entire drainage area to the practice.

- The filter strip should have a length of at least 25 feet to provide water quality treatment.

– Vegetation must be able to withstand relatively high velocity flows and both wet and dry periods.

– The slope should have a flat top and toe to encourage sheet flow and prevent erosion.

5.3.5.7 Street surface and subsurface storage

Figure 5.17: Runoff pooling on a street surface designed for temporary storage.

Runoff can be temporarily stored on and below the surface of streets in urban areas, as shown in Figure 5.17, to reduce peak flows to the storm sewer system (Carr et al., 1999). Runoff can be retained on and below the street using a combination of berms, flow regulators, and below-surface storage. Berms resemble speed bumps or speed humps but are broader and gentler; they retain water in a shallow pool on the street surface upstream of the berm. In some cases, this type of surface storage is inappropriate because it can result in damage to roadways. An alternative is subsurface storage in tanks or large sewer pipes. Both above- and below-ground storage systems, when combined with flow regulators that allow only a limited amount of runoff to enter the sewer system, mitigate basement flooding, combined sewer overflows, sanitary sewer overflows, and surface flooding. These systems should be designed with public safety in mind to minimize hydroplaning and icing in cold climates.

Two suburban Chicago, Illinois, towns—Skokie and Wilmette—implemented street-surface storage of runoff. The Skokie system has 2,900 flow regulators, 871 berms, 10 off-street storage facilities, 83 subsurface facilities, and several new storm and combined sewers (USEPA, 2000b). Wilmette's runoff storage system is composed of essentially all street storage. These systems have been effective in preventing flooding and overflows and are less expensive than other alternatives such as sewer separation and relief sewers. More information about these studies can be found at http://www.epa.gov/ednnrmrl/publications/reports/epa600r00065/epa600r00065.htm.

5.3.5.8 On-lot storage practices

The term "on-lot storage" refers to a series of practices that are designed to contain runoff from individual lots. The purpose of most on-lot practices is to manage rooftop or parking area runoff. The primary advantage of managing runoff from rooftops and parking lots is to disconnect these impervious surfaces, reducing the effective impervious cover in a watershed.

Johnston et al. (2003) modeled the downstream hydrologic and economic impacts of on-site runoff storage based on flood risk reduction on property values and costs of storm drainage infrastructure. They found that use of reduced runoff practices provided property value benefits due to decreased flood risk of $21,600 to $36,300 per acre using countywide assessed values, or $17,540 to $29,240 per acre using U.S. Census Bureau census block median housing values. Benefits in avoided costs for storm drainage infrastructure (road culverts) totaled $247 to $836 per developed acre.

Although there are many on-lot treatment options, they can all be classified into one of three categories: (1) practices that infiltrate runoff; (2) practices that divert runoff to a pervious area; and (3) practices that store runoff for later use. The best option depends on the goals of a community, the feasibility at a specific site, and the preferences of the property owner.

Rooftop Runoff

Rooftop runoff, particularly in residential areas, generally has low pollutant concentrations compared with other urban sources (Schueler, 1994). Information on green rooftops can be found in Section 4.3.2.2. The practice most often used to infiltrate rooftop runoff is the dry well. In this design, the storm drain is directed to an underground rock-filled trench that is similar in design to an infiltration trench. French drains or Dutch drains can also be used for this purpose. In these designs, the relatively deep dry well is replaced with a long trench with a perforated pipe within the gravel bed to distribute flow throughout the length of the trench. Chamber systems, a widely marketed proprietary product, can be used in a similar manner.

Runoff can be diverted to a pervious area or to a treatment area using site grading or channels and berms. Treatment options can include grassed swales, bioretention cells, or filter strips. The bioretention design can be simplified for an on-lot application by limiting the pretreatment filter and in some cases eliminating the underdrain. Alternatively, rooftop runoff can simply be diverted to pervious lawn areas instead of discharging it directly to the street or a pipe drainage system.

Practices that store rooftop runoff, such as cisterns, chambers, and rain barrels (Figure 5.18), are the simplest designs for on-lot treatment systems. Some of these practices are available commercially and can be applied in a variety of site conditions. Cisterns and rain barrels are particularly valuable in the arid Southwest, where water is at a premium, rainfall is infrequent, and reuse for irrigation can save homeowners money.

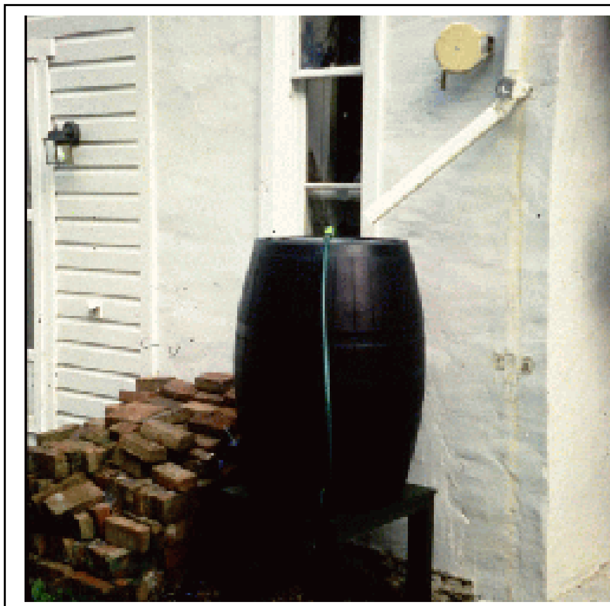

Figure 5.18: A rain barrel that collects runoff from a roof gutter downspout.

Rain barrels typically range in cost from $60 to $135. These prices do not always include the cost of additional parts needed to link the rain barrel to a downspout. These parts generally range in cost from $5 to $18, depending on the manufacturer and the design of the rain barrel (Gardener's, 2001; Jade Mountain, 2000; Midwest, 2001; Spruce Creek, 2001). If homeowners want to save money, they can build their own rain barrel, which costs approximately $15 if recycled drums are available.

Information about building a simple rain barrel is available from the Maryland Green Building Program at http://www.dnr.state.md.us/ed/rainbarrel.html (MDNR, no date). Information is also available in *How to Make a Rain Barrel*, which was published by the city of Ottawa, Ontario (no date). The manual is available by contacting the city of Ottawa toll-free at 866-261-9799, or by e-mailing info@city.ottawa.on.ca.

It is important for municipalities planning to start a rain barrel program to consider water quality issues, climate, algae and mosquito control, homeowner attitudes and willingness, and the protection of home foundations. Rain barrels can be a reliable source of water for garden and lawn watering, but if the water is intended for consumption it is crucial that the roof materials and gutter system be examined for asbestos, lead paint, and bird droppings (Sands and Chapman, 2003).

The Milwaukee Metropolitan Sewerage District (MMSD) undertook a rain barrel project in response to problems with combined sewer overflows. The project involved 40,000 single-family homes with roof areas of approximately 1,200 square feet. Two 90-gallon rain barrels were installed at each home. The MMSD found the reduction in runoff volume attributed to rain barrels to be approximately 243 million gallons. While the effort did not reduce combined sewer overflow volumes for the MMSD, it did result in savings on treatment plant costs and increased environmental awareness. The MMSD plans to continue to incorporate rain barrels into an integrated management plan that might include additional on-lot treatment practices (Sands and Chapman, 2003).

On-lot treatment practices can be applied to almost all sites with very few exceptions (e.g., very small lots or lots with no landscaping). There are currently at least two jurisdictions that offer "credits" in exchange for the application of on-site runoff management practices. In Denver, Colorado, sites designed with methods to reduce "directly connected impervious cover," including disconnection of downspout runoff from the storm drain system, are permitted to use a lower impervious area when computing the required storage of runoff management facilities (DUDFC, 1992). Similarly, new regulations for Maryland allow designers to subtract each rooftop that is disconnected from the total site impervious cover when calculating required storage in runoff management practices (MDE, 2000).

Although most residential lots can incorporate on-lot treatment, the best option for a site depends on design constraints and the preferences of the homeowner. On-lot infiltration practices have the same restrictions regarding soils as other infiltration practices. If other design practices are used, such as bioretention or grassed swales, they need to meet the siting requirements of those sites. Of all of the practices, cisterns and rain barrels have the fewest site constraints. In order for the practice to be effective, however, homeowners need to have a use for the water stored in the practice, and the design must accommodate overflow and winter freezing conditions.

Although these runoff management practices are simple compared with many others, their design needs to incorporate the same basic elements. Pretreatment is important for all of these practices to ensure that they do not become clogged with leaves or other debris. Infiltration practices may

Santa Monica Urban Runoff Program

Santa Monica's comprehensive urban runoff program combines pollution prevention and on-site practices with a runoff recycling program designed to improve water quality and harvest dry weather runoff as a resource. By protecting existing water resources, increasing infiltration on-site, and harvesting runoff for reuse, the city is maximizing the use of storm water as a resource and decreasing the demand for imported water. The city's pollution prevention program protects water quality with education, municipal housekeeping, lawn care and landscaping practices, and an ordinance that requires good housekeeping practices on construction sites. On-site practices are required by the Urban Runoff Pollution Mitigation Ordinance and include infiltration practices, porous pavement, and other low impact development techniques. The city has also installed catch basin inserts and screens to capture trash, debris, and some soluble pollutants. Finally, the Santa Monica Urban Runoff Recycling Facility (SMURRF) harvests and treats dry weather runoff and makes it available for reuse as irrigation water or for indoor toilet flushing (Shapiro, 2003).

be preceded with a settling tank or, at a minimum, a grate or filter in the downspout to trap leaves and other debris. Rain barrels and cisterns also often incorporate some sort of pretreatment, such as a mesh filter at the top of the barrel or cistern.

Both infiltration practices and storage practices should incorporate some type of bypass so runoff from larger storms flows away from the house. With rain barrels or cisterns, this bypass may be a hose set at a high level within the device that directs runoff away from both the device and the building foundation. These practices also include a hose bib set at the bottom of the device so the homeowner can use the stored water for irrigation or other uses by attaching a standard garden hose to the hose bib.

One important design requirement for on-lot infiltration practices is locating the infiltration area sufficiently far from the house (at least 10 feet) to prevent undermining of the foundation or seepage into the basement.

Infiltration practices require regular removal of sediment and debris settled in the pretreatment area, and the infiltration medium needs to be replaced when it becomes clogged. Rain barrels and cisterns require minimal maintenance, but the homeowner must ensure that the hose remains elevated during the winter to prevent freezing and cracking. In addition, the tank requires cleaning approximately once a year.

On the basis of cost per unit area treated, on-lot practices are relatively expensive compared with other runoff storage and treatment options. It is difficult to make this comparison, however, because the cost burden of on-lot practices is borne directly by homeowners. Typical costs are $100 for a rain barrel and $200 for a dry well or French drain. Often, homeowners can reduce costs by creating their own on-lot practice rather than purchasing a commercial product.

Parking Lot Runoff

Standard parking lots typically drain rapidly through curb and gutter systems to prevent flooding. This practice, however, does little to improve water quality or protect receiving waters from high flows during and after storms. Innovative designs for parking lots incorporate pervious areas for drainage, whether at the perimeter or in various islands within the lot. These pervious areas should be designed to infiltrate runoff at rates that prevent excessive ponding, which could appear unsightly or create safety issues and nuisance mosquito habitat. In cases where existing soils have poor infiltration capacity, better-drained soils should be imported or perforated under-drains installed to store infiltrated runoff underground.

The use of large-diameter underground pipes constructed of concrete, corrugated steel, or high-density polyethylene (HDPE) is becoming a more common practice for large parking areas such as shopping malls and mixed-use developments. These underground pipes and vaults as well as chamber systems can store large quantities of runoff that can be reused as needed or released at rates that will not damage natural conveyance systems.

5.3.5.9 Microbial disinfection

Other practices can be used to treat runoff for specific pollutants other than sediment. For instance, in areas where microbial pollution is an issue, runoff can be treated using ozone or ultraviolet light to prevent disease and reduce exceedances of water quality due to pathogen contamination. The City of Encinitas, California, was concerned about the number of public health warnings at its primary seaside attraction, Moonlight Beach, due to high enterococcus and coliform bacteria counts. The main source of the microbial pollution was dry weather runoff from Cottonwood Creek, which discharges at Moonlight Beach. Despite extensive evaluation of the Cottonwood Creek drainage area to identify and reduce bacterial loading, public health warnings continued to be posted. In anticipation of a total maximum daily load for bacteria under development for the region, and to reduce or eliminate the number of beach postings, the City chose to install an ultraviolet (UV) disinfection facility with partial funding from California's Clean Beach Initiative. The UV treatment facility was designed to treat 150 gallons per minute of Cottonwood Creek's dry weather flow, with 15% of the creek's flow diverted around the facility to maintain biological connectivity between upstream and downstream waters. During times of high flow (i.e., during and after storms) and high turbidity, when the system's treatment effectiveness would be reduced, the system is shut down and flow is passed through without treatment. Early monitoring results showed a significant decrease in bacterial counts downstream of the treatment facility, with a removal efficiency of more than 99.9 percent that yielded an effluent quality of 2 bacteria per 100 mL. Filters built into the system were also effective at removing suspended sediment, reducing turbidity from an average of 14.0 mg/L in the influent to 5.0 mg/L in the effluent.

5.4 Performance and Cost Information for Management Practices

Some advantages, disadvantages, and costs of specific runoff control practices described above are listed in Table 5.6. Site-specific information, regional limitations, operation and maintenance burdens, and longevity for these practices are listed in Table 5.7.

Table 5.6: Advantages and disadvantages of management practices (MDE, 2000).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Runoff control ponds			
Wet pond	– Can provide peak flow control – Can serve large developments; most cost-effective for larger, more intensively developed sites – Enhances aesthetics and provides recreational benefits – Little ground water discharge – Permanent pool in wet ponds helps to prevent scour and re-suspension of sediments – Provides moderate to high removal of both particulate and soluble urban runoff pollutants	– Not economical for drainage area less than 10 acres – Potential safety hazards if not properly maintained – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors – Requires considerable space, which limits use in densely urbanized areas with expensive land and high property values – Not suitable for hydrologic soil groups “A” and “B” (USDA-NRCS classification) unless a liner is used – With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life – Hydrologic damage to stream channels and aquatic habitat is possible due to flow volume.	Moderate to high compared to conventional runoff detention
Infiltration practices			
Infiltration basin	– Provides ground water recharge – Can serve large developments – High removal capability for particulate pollutants and moderate removal for soluble pollutants – When basin works, it can replicate predevelopment hydrology more closely than other BMP options – Basins provide more habitat value than other infiltration systems	– Possible risk of contaminating ground water – Only feasible where soil is permeable and there is sufficient depth to bedrock and water table – Fairly high failure rate – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors – Regular maintenance activities cannot prevent rapid clogging of infiltration basin	Construction cost moderate but rehabilitation cost high

Table 5.6 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Infiltration trench	– Provides ground water recharge – Can serve small drainage areas – Can fit into medians, perimeters, and other unused areas of a development site – Helps replicate predevelopment hydrology, increases dry weather baseflow, and reduces bankfull flooding frequency	– Possible risk of contaminating ground water – Only feasible where soil is permeable and there is sufficient depth to bedrock and water table – Since not as visible as other BMPs, less likely to be maintained by residents – Requires significant maintenance	– Cost-effective on smaller sites – Rehabilitation costs can be considerable
Concrete grid pavement	– Can provide peak flow control – Provides ground water recharge – Provides water quality control without additional consumption of land	– Requires regular maintenance – Not suitable for areas with high traffic volume – Possible risk of contaminating ground water – Only feasible where soil is permeable, there is sufficient depth to bedrock and water table, and there are gentle slopes	Information not available
Filtering practices			
Filtration basin	– Ability to accommodate medium-size development (3–80 acres) – Flexibility to provide or not provide ground water recharge – Can provide peak volume control	– Requires pretreatment of runoff through sedimentation to prevent filter media from premature clogging	Information not available
Bioretention	– Provides ground water recharge	–	
Open channel practices			
Grassed swale	– Requires minimal land area – Can be used as part of the runoff conveyance system to provide pretreatment – Can provide sufficient runoff control to replace curb and gutter in single-family residential subdivisions and on highway medians – Economical	– Low pollutant removal rates – Leaching from culverts and fertilized lawns may actually increase the presence of trace metals and nutrients	Low compared to curb and gutter
Structural management practices that do not consistently remove 80% TSS			
Vegetated filter strip	– Low maintenance requirements – Can be used as part of the runoff conveyance system to provide pretreatment – Can effectively reduce particulate pollutant levels in areas where runoff velocity is low to moderate – Provides excellent urban wildlife habitat – Economical	– Often concentrates water, which significantly reduces effectiveness – Ability to remove soluble pollutants highly variable – Limited feasibility in highly urbanized areas where runoff velocities are high and flow is concentrated – Requires periodic repair, regrading, and sediment removal to prevent channelization	Low

Table 5.6 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Water quality inlet Catch basins with sand filter	– Provide high removal efficiencies of particulates – Require minimal land area – Flexibility to retrofit existing small drainage areas – Higher removal of nutrient as compared to catch basins and oil/grit separator	– Not feasible for drainage areas greater than 5 acres – Only feasible for areas that are stabilized and highly impervious – Not effective as water quality control for intense storms	Information not available
Water quality inlet Oil/grit separator	– Captures coarse-grained sediments and some hydrocarbons – Requires minimal land area – Flexibility to retrofit existing small drainage areas and applicable to most urban areas – Shows some capacity to trap trash, debris, and other floatables – Can be adapted to all regions of the country	– Not feasible for drainage area greater than 1 acre – Minimal nutrient and organic matter removal – Not effective as water quality control for intense storms – Concern exists for the pollutant toxicity of trapped residuals – Require high maintenance	High, compared to trenches and sand filters
Extended detention dry pond with micropool	– Can provide peak flow control – Possible to provide good particulate removal – Can serve large development – Requires less capital cost and land area when compared to wet pond – Does not generally release water or anoxic water downstream – Provides excellent protection for downstream channel erosion – Can create valuable wetland and meadow habitat when properly landscaped	– Removal rates for soluble pollutants are quite low – Not economical for drainage area less than 10 acres – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors	Lowest cost alternative in size range

[a]Comparative cost information from Schueler, 1992

Table 5.7: Regional, site-specific, and maintenance considerations for management practices (USEPA, 1993; Caraco and Claytor, 1997; Schueler, in press).

Management Practice and Specifications	Cold Climate Restrictions (Caraco and Claytor, 1997)	Arid and Semi-Arid Regional Restrictions (Schueler, in press)
Infiltration basins *Size of drainage area*: Moderate to large *Site requirements:* Deep, permeable soils *Maintenance burdens*: High *Longevity:* Low	– Avoid areas with permafrost – Monitor ground water for chlorides – Do not infiltrate road/parking lot snowmelt if chlorides are a concern – Increase percolation requirements – Use 20 foot minimum setback between road subgrade and practice	– No recharge in hot-spot areas – Do not treat pervious areas – Use multiple pretreatment – Soil limitations exist in arid areas
Infiltration trenches *Size of drainage area*: Moderate *Site requirements:* Deep, permeable soils *Maintenance burdens*: High *Longevity:* Low	– Avoid areas with permafrost – Monitor ground water for chlorides – Do not infiltrate road/parking lot snowmelt if chlorides are a concern – Increase percolation requirements – Use 20-foot minimum setback between road subgrade and practice	– No recharge in hot-spot areas – Do not treat pervious areas – Use multiple pretreatment – Soil limitations exist in arid areas
Vegetated filter strips *Size of drainage area*: Small *Site requirements:* Low-density areas with low slopes *Maintenance burdens*: Low *Longevity:* Low if poorly maintained	– Small setback may be required between filter strips and roads when frost heave is a concern – Avoid areas with permafrost – Use cold- and salt-tolerant vegetation – Plowed snow can be stored in-practice	– Use drought-tolerant vegetation
Grassed swales *Size of drainage area*: Small *Site requirements*: Low-density areas with <15% slope *Maintenance burdens*: Low *Longevity:* High if maintained	– Avoid areas with permafrost – Use cold- and salt-tolerant vegetation – Plowed snow can be stored in the practice – Increase underdrain pipe diameter and size of gravel bed – Provide ice-free culverts – Ensure soil bed is highly permeable	– Not recommended for pollutant removal in arid areas – Of limited use in semi-arid areas – Ensure adequate erosion protection of channels
Porous pavement *Size of drainage area*: Small *Site requirements*: Deep permeable soils, low slopes, and restricted traffic *Maintenance burdens*: Moderate to high *Longevity:* Low	– Only use on non-sanded surfaces – Pavement may be damaged by snow plows – Maintenance is essential	
Filtration basins and sand filters *Size of drainage area*: Widely applicable *Site requirements*: Widely applicable *Maintenance burdens*: Moderate *Longevity:* Low to moderate	– Reduced treatment effectiveness during cold season – Underground filters only effective if placed below the frost line – Peat/compost media ineffective during winter and may become impervious if frozen	– Preferred in both arid and semi-arid areas. Arid area filters require greater pretreatment
Bioretention	– Reduced treatment effectiveness during cold season – Pretreatment should be used to prevent “choking” of vegetation	

Table 5.7 (continued).

Management Practice and Specifications	Cold Climate Restrictions (Caraco and Claytor, 1997)	Arid and Semi-Arid Regional Restrictions (Schueler, in press)
Water quality inlets *Size of drainage area*: Small *Site requirements:* Impervious catchments *Maintenance burdens*: Cleaned twice a year *Longevity:* High	– Few restrictions	
Extended detention dry ponds *Size of drainage area*: Moderate to large *Site requirements:* Deep soils *Maintenance burdens*: Dry ponds have relatively high burdens *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Preferred in arid climates and acceptable in semi-arid climates
Wet ponds *Size of drainage area*: Moderate to large *Site requirements*: Deep soils *Maintenance burdens*: Low *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Not recommended in arid areas and of limited use in semi-arid areas
Wetlands *Size of drainage area*: Moderate to large *Site requirements:* Poorly drained soils, space may be limiting *Maintenance burdens*: Annual harvesting of vegetation *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Not recommended in arid areas and of limited use in semi-arid areas

Table 5.8 presents pollutant removal efficiency statistics for the management practices discussed in this section. These values originate from the *National Pollutant Removal Performance Database for Stormwater BMPs* (Caraco and Winer, 2000). The database was compiled through a comprehensive literature search focusing on runoff treatment practice monitoring sites from 1990 to present. In addition, approximately 60 previously collected monitoring studies from 1977 and 1989 were included in the database. All 139 studies meet the two following criteria: (1) the researchers used automated equipment that enabled flow or time-based composite samples; and (2) they documented the method used to compute removal efficiency. With respect to the number of storms sampled, more than three-quarters of the studies were based on five or more storm samples. The sample size was not reported in the remaining studies.

Table 5.8: Effectiveness of management practices for runoff control (adapted from Caraco and Winer, 2000).

Runoff Treatment or Control Practice Category or Type	Median Pollutant Removal (Percent)							
	No. of studies	TSS	TP	OP	TN	NOx	Cu	Zn
Quality Control Pond	3	3	19	N/A	5	9	10	5
Dry Extended Detention Pond	6	61	20	N/A	31	-2	29	29
Dry Ponds	9	47	19	N/A	25	3.5	26	26
Wet Extended Detention Pond	14	80	55	69	35	63	44	69
Multiple-Pond System	1	91	76	N/A	N/A	87	N/A	N/A
Wet Pond	28	79	49	39	32	36	58	65
Wet Ponds	43	80	51	65	33	43	57	66
Shallow Marsh	20	83	43	66	26	73	33	42
Extended Detention Wetland	4	69	39	59	56	35	N/A	-74
Pond/Wetland System	10	71	56	37	19	40	58	56
Submerged Gravel Wetland	2	83	64	14	19	81	21	55
Wetlands	36	76	49	48	30	67	40	44
Organic Filter	7	88	61	30	41	-15	66	89
Perimeter Sand Filter	3	79	41	68	47	-53	25	69
Surface Sand Filter	7	87	59	N/A	31.5	-13	49	80
Vertical Sand Filter	2	58	45	21	15	-87	32	56
Bioretention	1	N/A	65	N/A	49	16	97	95
Filtering Practices[a]	18	86	59	*57*	38	-14	49	88
Infiltration Trench	3	100	42	100	42	82	N/A	N/A
Porous Pavement	3	95	65	10	83	N/A	N/A	99
Ditches[b]	9	31	-16	N/A	-9	24	14	0
Grass Channel	3	68	29	32	N/A	-25	42	45
Dry Swale	4	93	83	70	92	90	70	86
Wet Swale	2	74	28	-31	40	31	11	33
Open Channel Practices	9	81	34	*1.0*	*84*	31	51	71
Oil-Grit Separator	1	-8	-41	40	N/A	47	-11	17

Shaded rows show data for groups of practices (i.e., dry ponds include quality control ponds and dry extended detention ponds).
Numbers in italics are based on fewer than five data points.
[a] Excludes vertical sand filters
[b] Refers to open channel practices not designed for water quality.
TSS=total suspended solids, TP=total phosphorus, OP=ortho-phosphorus, TN=total nitrogen, NOx=nitrate and nitrite nitrogen, Cu=copper, Zn=zinc.

Strecker et al. (2000) identified problems with comparing different management practice effectiveness studies. They suggested that inconsistent study methods, lack of associated design information, and multiple reporting protocols make wide-scale assessments of management practices difficult. Also, differences in monitoring strategies and data evaluation methods contribute significantly to the wide range of reported management practice effectiveness.

EPA recognizes that 80 percent TSS removal efficiency cannot be achieved for each storm event and understands that TSS removal efficiency will fluctuate above and below 80 percent for individual storms. Researchers have noted that efficiency estimation is often based on pollutant loads into and out of the management practice on a storm-by-storm basis. Therefore, a multiple-study analysis or summary is based on the assumption that all storms are equal when computing average pollutant removal. Storm-by-storm comparisons are probably not effective because many storms are not large enough to displace the permanent pool volume. They recommend that effectiveness be evaluated using statistical characterizations of the inflow and outflow concentrations because if enough samples are collected, total loads into and out of the management practice can be used reliably.

Strecker et al. (2000) also analyzed the use of effluent data to measure the influence of certain design criteria on management practice efficiency. Some studies suggest that management practices can only treat runoff to a specified pollutant concentration. However, if relatively clean water enters a practice, performance data based on removal efficiency might not fully characterize whether the practice is well designed and effective. Therefore, pollutant removal efficiency, when it is expressed as percent removal, might not be an accurate representation of

Verifying the Performance of Environmental Technologies

EPA's Environmental Technology Verification (ETV) Program, which began in October 1995, was instituted to verify the performance of innovative technical solutions to problems that threaten human health and the environment. ETV was created to significantly accelerate the entrance of new environmental technologies into the domestic and international marketplaces. The program operates through public and private testing partnerships to evaluate the performance of environmental technology in all media, including air, water, soil, ecosystems, waste, pollution prevention, and monitoring. More information about the ETV Program is available at http://www.epa.gov/etv (USEPA, 2001b).

Another method for evaluating technology is the Environmental Technology Evaluation Center (EvTEC), which was established by the Civil Engineering Research Foundation (CERF) through EPA's ETV Program. EvTEC is an independent, market-based approach to technology verification and was established to accelerate the adoption of environmental technologies into practice. More information about EvTEC is available at http://www.cerf.org/evtec (CERF, 2001).

EPA and NSF International, an independent, nonprofit testing organization, have developed a testing protocol to determine the viability of runoff treatment technologies and other wet weather flow controls, including runoff, combined sewer overflow (CSO), and sanitary sewer overflow (SSO). NSF International will also test and verify high-rate separation/clarification and high-rate disinfection technologies, flow monitoring equipment, and wet weather models.

Participants in the study include vendors who want to demonstrate the effectiveness of their technologies. Results of the pilot will be useful to a variety of stakeholders including municipalities, businesses, vendors, consulting engineers, and regulatory agencies. Once verification reports have been completed, vendors may use the results in their marketing efforts. Results will be made publicly available through EPA's and NSF's Web sites at http://www.epa.gov/etv and http://www.nsf.org/business/ETV_EPA_NSF/index.asp?program=ETVEPANSF, respectively. More information about the program is available at http://www.wateronline.com/content/news/article.asp?docid={17DDF263-29B8-11D5-A770-00D0B7694F32} (Water-Online, 2001).

International Stormwater Best Management Practices Database

The American Society of Civil Engineers, in cooperation with EPA, has compiled the *International Stormwater Best Management Practices Database*, which contains performance data from more than 200 management practice studies. Information provided for the management practices includes test site location, researcher contact data, watershed characteristics, regional climate statistics, management practice design parameters, monitoring equipment types, and monitoring data such as precipitation, flow, and water quality. More information on the database's purpose, design, and documentation can be found at http://www.bmpdatabase.org/.

how well a management practice is performing. Although more research is necessary to accurately determine the effectiveness of management practices, Strecker et al. recommend that standard methods and detailed guidance on data collection be used to improve data transferability.

Table 5.9 presents information concerning the costs associated with selected structural practices. The sources of these data are publicly available articles (some are a compilation of numerous studies).

Table 5.9: Costs of selected management practices (Claytor and Schueler, 1996; Brown and Schueler, 1997).

Management Practice	Construction Costs[a]	Useful Life (years)	Total Annual Costs
Infiltration basin[b]			
Average	$0.55/ft^3$ storage	25[c]	–
Report range	$0.22–$1.31/ft^3$	–	$0.03–$0.05/ft^3$
Probable range	$0.44–$0.76/ft^3$	–	–
Infiltration trench[b]			
Average	$4.36/ft^3$ storage	10[c]	–
Report range	$0.98–$10.04/ft^3$	–	$0.03–$0.10/ft^3$
Probable range	$2.73–$8.18/ft^3$	–	–
Infiltration practices[d]			
Average	$2.99/ft^3$ storage	–	–
Report range	$2.13-4.27/ft^3$ storage	–	–
Vegetated swales[b]			
Established from seed			
Average	$7.09/linear ft	50[e]	$1.09/linear ft
Report range	$4.91–$9.27/linear ft	–	–
Established from sod			
Average	$21.82/linear ft	50[e]	$2.18/linear ft
Report range	$8.73–$54.56/linear ft	–	–
Porous pavement[b]			
Average	$1.64/ft^2$	10[f]	$0.16/ft^2$
Report range	$1.09-$2.18/ft^2$	–	–
Concrete grid pavement[b]			
Average	$1.09/ft^2$	20	$0.05/ft^2$
Report range	$1.09–$2.18/ft^2$	–	–
Filtration basins[b]			
Average (probable)	$5.46/ft^3$ storage	25[g]	–
Report range	$1.09–12.00/ft^3$	–	$0.11–$0.87/ft^3$
Probable range	$2.18–9.82/ft^3$	–	–
Bioretention practices[d]			
Average	$6.83/ft^3$ storage	–	–
Filtration practices[d]			
Average	$2.63/ft^3$ storage	–	–
Range	$2.13-6.40/ft^3$ storage	–	–
Water quality inlet[b,h]			
Average	$2,182 each	50	$164 each
Report range	$1,200–3,273 each	–	–
Probable range	–	–	–
Water quality inlet with sand filter[b,h] Average (probable)	$10,900/drainage acre	50	$764/drainage acre

Table 5.9 (continued).

Management Practice	Construction Costs[a]	Useful Life (years)	Total Annual Costs
Oil/grit separator[b,h]			
Average	$19,640/drainage acre	50	$1,091/drainage acre
Report range	$16,370–$21,820/drainage acre	–	–
Stabilization with ground cover[b,h]			
From existing vegetation			
Average	$0	50	Natural: $109/acre
Report range	–	–	Managed: $873/acre
From seed			
Average	$436/acre	50	Natural: $131/acre
Report range	$218–$1,091/acre	–	Managed: $900/acre
From seed and mulch			
Average	$1,637/acre	50	Natural: $218/acre
Report range	$872–$3,819/acre	–	Managed: $982/acre
From sod			
Average	$12,330/acre	50	Natural: $764/acre
Report range	$4,910–$52,375/acre	–	Managed: $1,528/acre
Ext. Detention Dry Pond[b,h]			
Average	$0.55/ft^3 storage	50	–
Report range	$0.05–$3.49/ft^3	–	$0.008–$0.33/ft^3
Probable range	$0.10–$5.46/ft^3	–	–
Wet Pond and Extended Detention Wet Pond[b]	$0.55/ft^3 storage	50	$0.009–$0.08/ft^3
Storage vol. < 1 million ft^3	$0.05–$1.09/ft^3	–	–
Average	$0.55–$1.09/ft^3	–	–
Report range	$0.27/ft^3 storage	50	–
Probable range	$0.05–$0.55/ft^3	–	$0.009–$0.08/ft^3
Storage vol. > 1 million ft^3	$0.11–$0.55/ft^3	–	–
Average (probable)			
Report range (probable)			
Probable range			

[a]Costs updated using the Bureau of Labor Statistics Inflation Calculator.
[b]Claytor and Schueler, 1996.
[c]References indicate the useful life for infiltration basins and infiltration trenches at 25-50 and 10-15 years, respectively. Because of the high failure rate, infiltration basins are assumed to have a useful life span of 25 years and infiltration trenches are assumed to have a useful life span of 10 years.
[d]Brown and Schueler, 1997.
[e]Useful life is assumed to equal the life of the project, assumed to be 50 years.
[f]No information was available for porous pavement. It is assumed to be similar to infiltration trenches.
[g]No information was available for filtration basins. It was assumed to be similar to infiltration basins.
[h] These practices do not meet the 80 percent TSS removal, thus it is recommended that they be used with other management practices in a treatment train.

5.5 Managing Structural Controls to Reduce Mosquito-Breeding Habitat

In recent years, concern has been raised that storm water management facilities have been breeding grounds for mosquitoes (Conlon, 2002). This is a public health concern because mosquitoes are known vectors for disease-causing arboviruses such as malaria, yellow fever, dengue fever, St. Louis encephalitis, and West Nile virus, to name a few. The relationship between storm water management and mosquito breeding exists because the presence of standing and sometimes stagnant water facilitates the two aquatic stages of a mosquito's life cycle—the egg and larval stages.

Not all mosquito species are vectors for disease, but control is still warranted because, even if not a health risk, mosquitoes are considered a nuisance. Mosquito species have different habitat preferences, and two basic groups can breed in the urban environment: permanent water species and floodwater species (Metzger et al., 2002). Permanent water species would be likely to propagate in storm water management facilities that always contain water, such as wet detention ponds and constructed wetlands. Floodwater species would likely inhabit "dry" systems such as extended detention dry ponds that have fluctuating water levels.

This issue has caused a fair amount of controversy because mosquito-breeding habitats are prevalent in urban and suburban environments. Metzger et al. (2002) identified a few of the numerous manmade mosquito-breeding habitats in urban and suburban environments:

> Urban environments provide mosquitoes with a vast array of new habitats: humid and arid, above and below ground, small water-holding containers and large ponds, polluted and clean water. Aquatic habitats are found around people's homes (birdbaths, jars, flower pots, neglected pools and Jacuzzis and clogged rain gutters), in unregulated waste dumps (used tires, barrels, bottles, and cans), in parks (ponds, lakes, and streams), and in the city's own infrastructure (storm drains, sewer systems, catch basins, and culverts). Many of these sources are replenished frequently by stormwater and urban runoff (e.g., irrigation, washing cars). Adding to this, increasingly stringent urban stormwater runoff regulations have recently mandated the construction of structural practices for both volume reduction and pollution management, many of which have created additional sources of standing water. This abundance of habitats has favored mosquitoes and allowed many species to greatly expand their range and increase in number.

Although storm water management facilities are not the sole source of standing water, public concern has raised the question of how these facilities can be managed, redesigned, or otherwise modified to reduce the creation of disease vectors close to urban population centers.

The California Department of Health Services' Vector-Borne Disease Section (2002), in cooperation with the California Department of Transportation (Caltrans), undertook a study to evaluate retrofit opportunities for storm water management. Part of this study investigated the mosquito production of 37 structural management practices in southern California. Eight categories of practices were constructed and examined as part of the study: (1) biofiltration strips and swales; (2) filtration devices (Austin-type and Delaware-type sand media filters, multi-chambered treatment train sand media filters, and a proprietary canister filter); (3) extended detention basins; (4) infiltration devices (basins and trenches); (5) continuous deflective separators (CDSs); (6) an oil/water separator; (7) drain-inlet inserts; and (8) a constructed wetland (retention pond). The study consisted of comprehensive surveillance and monitoring of each practice for mosquito production, as well as follow-up monitoring after modifications had been made to reduce the potential to produce mosquitoes. Of the eight different technologies implemented by Caltrans, those that maintained permanent sources of standing water in sumps or basins (MCTT, CDS, and the retention pond) provided excellent habitat for immature mosquitoes and frequently supported large populations relative to other structural designs. In contrast, practices designed to drain rapidly (i.e., biofiltration swales and strips, Austin-type sand media filters, infiltration basins and trenches, and extended detention basins) provided less-suitable habitats and rarely harbored mosquitoes.

The project was expanded to a nationwide investigation using phone and mail surveys and site visits to 150 agencies in 28 states. Of the 72 agencies that completed a questionnaire, 86 percent reported mosquito production associated with storm water management facilities. The survey found that inadequate maintenance resulted in accumulation of trash and other constituents (e.g., sediment, vegetation, organic debris).

The Southwest Florida Water Management District conducted a study to determine the extent to which storm water management facilities were breeding mosquitoes and offer recommendations for minimizing mosquito production (Livingston, no date). After examining more than 200 management practices with both permanent pools and intermittent pools, they found that 76 percent of all practices were mosquito productive, and that 66 percent of the permanently flooded practices and 69 percent of the intermittently flooded practices bred mosquitoes. Larval density was smaller and more dispersed in wet detention systems than in intermittently flooded systems. The wet detention systems that did not breed mosquitoes shared a paucity of vegetation, abundant fish, and good aeration. The intermittently flooded dry detention pond systems that did not produce mosquitoes were those that drained or dried within 72 hours.

The Florida researchers also investigated several pesticides and found them to be between 91 and 100 percent effective at controlling existing larval infestations in intermittently flooded systems within 24 hours of treatment, although one treatment in a system with high organic content was found to be ineffective against dense larval populations. The researchers also found that sustained-release materials such as pellets were effective for up to five weeks after application, whereas short-term controls required regular application.

Regular monitoring for mosquito adults and larvae, retrofitting and maintenance of practices to reduce the likelihood for breeding, and pesticide application where needed are the three key actions for eliminating mosquito breeding in storm water facilities. The Centers for Disease Control and Prevention discussed the role of pesticides that kill adult mosquitoes (adulticides) in mosquito management and recommended that their use be incorporated into an integrated pest management program that includes surveillance, source reduction, chemical control (larvicide and adulticide), biological control, and public relations and education (Rose, 2001).

Surveillance programs track diseases in bird populations, vector-borne pathogens in mosquitoes, mosquito populations, larval habitats, mosquito traps, biting counts, and reports by the public (Rose, 2001). Control activities are initiated when threshold populations are exceeded, and predictions are made from seasonal records and weather data.

Source reduction entails eliminating or altering larval habitats. This can be achieved through public education campaigns, with outreach to both children and adults. Additionally, state and local mosquito control agencies can alter the hydrology of open water and marshy areas to reduce or prevent the proliferation of mosquito larvae. Rose (2001) suggests techniques in which mosquito-producing areas in marshes are connected by shallow ditches to deep-water habitats to allow drainage or fish access, and minimally flooding the marsh during the summer but flap-gating impounded areas to reintegrate them to the estuary for the rest of the year.

Biological control can be achieved using various predators such as dragonfly nymphs and predacious mosquitoes (Rose, 2001). Mosquito fish are the most commonly used agents for biological control because they are easily reared, although they also feed on non-target species. Other types of organisms that might be used for mosquito control include several fish types other than *Gambusia*, as well as fungi, protozoans, nematodes, and predacious copepods.

It is essential that storm water managers and public works crews who maintain storm water management facilities be educated in integrated pest management. They should be trained to identify design flaws or maintenance needs that might create mosquito-breeding habitat, and they should know the procedures for reporting and remedying the problem. Pesticide handlers should have the required training under the Federal Insecticide, Fungicide, and Rodenticide Act and all chemicals should be applied at rates recommended on the packaging. Treated areas should be monitored after application to determine the efficacy of the applications and identify where pesticide resistance might be occurring.

There are steps that a storm water manager can take to reduce the likelihood that mosquitoes will breed in storm water management facilities. From a design standpoint, most management practices other than wet retention ponds are intended to drain within 72 hours. This is a safe drainage time because mosquitoes need at least that long for their aquatic life stages. Additionally, Metzger et al. (2002) found that several design features of storm water management practices contributed to vector production, including the use of sumps, catch basins, or spreader troughs that did not drain completely; the use of loose riprap that could hold small amounts of water; pumps or motors designed to “automatically” drain water from structures; and effluent pipes with discharge orifices prone to clogging because of their small diameter.

Livingston (no date) recommends the following design considerations to minimize mosquitoes:

- Designs must be based on site characteristics to ensure that the most appropriate type of storm water management facility is selected. Vegetated dry retention systems should be designed as off-line systems. They should be used only where the soil and water table conditions will assure that the system drains or dries within 24 to 36 hours, and where the seasonal high water table is at least two feet below the bottom of the system. If on-line retention areas are used, they should be designed to be dry within three days of a 25-year, 24-hour storm.

- Dry retention systems need to be carefully constructed to avoid compacting the soil and reducing its infiltration rate. They also should have flat bottoms to avoid having areas of standing water.

- To minimize decaying organic matter, the grass or other vegetation in dry retention areas should be regularly mowed and the clippings removed and composted.

- The littoral zone of wet detention areas should be planted with aquatic macrophytes such as *Sagittaria latifolia* (duck potato), *Sagittaria lancifolia* (lance-leaf arrowhead), *Juncus effusus* (soft rush), *Pontedaria lancifolia* (pickerelweed), *Juncus roemerianus* (needle rush), *Scirpus californicus* (giant bulrush), and *Scirpus validus* (soft stem bulrush). Cattails (*Typha* spp.) should never be planted in or allowed to remain in storm water systems as they grow very profusely, creating a large quantity of decaying matter.

- Wet detention systems should be stocked with native *Gambusia* spp. minnows (mosquito fish) to foster biological predation of mosquito larvae. If needed because of site conditions, a “minnow sump” should be excavated in the deepest part of the pond to assure permanent habitat and survival during droughts.

- Sustained-release larvicides should be used whenever necessary with systems known to be mosquito productive treated before the onset of the mosquito life cycle.

- Regular inspection and maintenance of storm water systems is essential to ensure that the facility drains as designed. Such maintenance involves removing submerged vegetation and clearing sediments away from inlets, outlets, and the bottom of the pool or holding area.

5.6 Information Resources

The *Technology Review: Ultra-Urban Stormwater Treatment Technologies* (Brueske, 2000) was compiled to provide a review of "ultra-urban" storm water treatment technologies. These types of technologies are designed to remove pollutants from runoff in highly developed areas where land values are high and available space is limited. Ultra-urban technologies differ from traditional runoff treatment controls in that they are very compact and can be retrofitted into existing runoff collection systems. The document specifically analyzes four types of treatment technologies: gravity separation, swirl concentration, screening, and filtration. Technology review findings were then used to develop a design protocol for selecting and installing ultra-urban treatment technologies. This document can be downloaded in PDF format from http://depts.washington.edu/cuwrm/research/ultraurbn.pdf.

The California Department of Transportation (Caltrans) prepared two handbooks on storm water quality as an updated version of the *Construction Contractor's Guide and Specifications*. These new manuals are the *Construction Site Best Management Practices (BMPs) Manual* and the *Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP) Preparation Manual*. The two manuals provide background information on Caltrans' program to control water pollution, offer instructions for selecting and implementing construction site best management practices, and help to standardize the process for preparing and implementing the SWPPP and the WPCP. Caltrans requires contractors to prepare and implement a program to control water pollution during the construction of all projects. The manuals are available for download at http://www.dot.ca.gov/hq/construc/stormwater/manuals.htm.

The Milwaukee Metropolitan Sewerage District developed a manual entitled "Surface Water and Storm Water Rules Guidance Manual" in 2002 that is available on their Web site at http://www.mmsd.com/stormwaterweb/Startpg.htm. The document includes an extensive discussion of the principles of storm water management, descriptions of both structural and nonstructural measures to control storm water, and sizing procedures for detention basins, among other topics.

In August 1998 the Center for Watershed Protection published *Better Site Design: A Handbook for Changing Development Rules in Your Community*. The publication covers everything from basic engineering principles to "actual versus perceived" barriers to implementing better site designs. The handbook outlines 22 guidelines for better developments and provides a detailed rationale for each principle. *Better Site Design* also examines current practices in local communities, details the economic and environmental benefits of better site designs, and presents case studies from across the country. The document is available for purchase from the Center for Watershed Protection at http://www.cwp.org/.

In 2000 the Maryland Department of the Environment published the *Maryland Stormwater Design Manual*. The manual was designed to protect Maryland waters from the adverse impacts of urban runoff, to provide design guidance on the most effective structural and nonstructural management practices for development sites, and to improve the quality of management practices that are recommended by the state of Maryland. The first volume of the manual contains information on management practice siting and design on new development sites to comply with Maryland's 14 storm water performance standards. A unique feature is the use of storm water credits for rewarding innovative storm water management designs. The second volume contains detailed technical information on runoff control practices, including step-by-step design examples. Both volumes are available for download at http://www.mde.state.md.us/environment/wma/stormwatermanual.

In 1995 the Metropolitan Washington Council of Governments (MWCOG) published *Site Planning for Urban Stream Protection*, which presents a watershed approach to site planning and examines new ways to reduce pollutant loads and protect aquatic resources through nonstructural practices and improved construction site planning. The book also provides insight into the importance of imperviousness, watershed-based zoning, concentration of development, headwater streets, stream buffers, green parking lots, and other land planning topics. The document is available for purchase from MWCOG at http://www.mwcog.org/ic/95708.html.

The *Texas Nonpoint SourceBOOK* is an interactive Web tool that was designed to provide runoff management information to public works professionals and other interested parties in Texas and elsewhere. This site, which can be accessed at http://www.txnpsbook.org/, includes a beginner's guide to urban nonpoint source management issues, a discussion of water quality issues in Texas, elements of a storm water management program, information on storm water utilities, tips for assessing and selecting management practices, a comprehensive listing of links to other sites, frequently asked questions, and nonpoint source news.

In 1999 the Denver Urban Drainage and Flood Control District published the *Urban Storm Drainage Criteria Manual*. The manual was designed to provide guidance for local jurisdictions, developers, contractors, and industrial and commercial operators in selecting, designing, implementing, and maintaining management practices to improve runoff quality. The third volume of this manual is primarily targeted at developing and redeveloping residential and commercial areas. The manual is available for purchase at http://www.udfcd.org/.

In 1995 EPA published *Economic Benefits of Runoff Controls* (EPA-841-S-95-002), which contains a description of studies that document increases in property values and rental prices when properly designed runoff controls are used as visual amenities. The document is available for download from EPA's National Environmental Publications Internet Site (NEPIS) at http://www.epa.gov/ncepihom/nepishom.

EPA published the *Preliminary Data Summary of Urban Storm Water Best Management Practices* in 1999. The document summarizes existing information and data on the effectiveness of management practices to control and reduce pollutants in storm water. The report also provides a synopsis of what is currently known about the expected costs and environmental benefits of management practices, and identifies information gaps. The document is available for download in PDF format at http://www.epa.gov/ost/stormwater/usw_a.pdf.

In 1992 the Washington State Department of Ecology published its *Stormwater Management Manual for the Puget Sound Basin*. The manual is divided into five documents: Volume I: Minimum Technical Requirements; Volume II: Construction Stormwater Pollution Prevention; Volume III: Hydrologic Analysis and Flow Control Design; Volume IV: Source Control BMPs;

and Volume V: Runoff Treatment BMPs. All five volumes are available for download at http://www.ecy.wa.gov/biblio/9911.html.

The Washington State Department of Ecology's Water Quality Program has developed a Nonpoint Source Pollution home page. This Web site, accessible at http://www.ecy.wa.gov/programs/wq/nonpoint, contains nonpoint source program information, posters, resources, and references. The Department of Ecology has also made available a copy of the draft of *Instream Flows in Washington State: Past, Present, and Future*. The document is available at http://www.olympus.net/community/dungenesswc/InstreamFlowversion12.PDF.

The Metropolitan Council of St. Paul/Minneapolis developed the *Urban Small Sites Best Management Practices (BMP) Manual* to provide assistance to communities in planning for storm water management for sites of less than 5 acres located in cold climates. The document focuses on low-impact development practices that promote the restoration and preservation of natural hydrology. The manual includes information on the selection of BMPs and model storm water ordinances and contains a regulatory analysis for watershed programs. The document is available at http://www.metrocouncil.org/environment/Watershed/bmp/manual.htm.

An excellent discussion of the design of infiltration techniques in limestone/carbonate bedrock areas can be found in a new design manual developed for the Lehigh Valley Planning Commission (LVPC) by Cahill Associates. The manual, *Technical Best Management Practice Manual and Infiltration Feasibility Report: Infiltration of Stormwater in Areas Underlain by Bedrock in the Little Lehigh Creek Watershed,* is available from the LVPC at 961 Marcon Boulevard, Suite 310, Allentown, Pennsylvania, 18109, 1-888-627-2626 (toll free), lvpc@lvpc.org.

The Virginia Municipal League published an article titled "Stafford County helps pioneer low impact design movement" describing the process by which Stafford County, Virginia, incorporated low-impact design into its development codes. The article includes links to Builders for the Bay, an organization that provides assistance to local communities wishing to update their codes, as well as several other helpful resources for communities. The article can be downloaded at http://www.vml.org/VTC/VTC3908-2.html.

The American Mosquito Control Association's Web site, located at http://www.mosquito.org/, offers information about mosquitoes and their control along with links, frequently asked questions, and West Nile virus information.

American Rivers developed a report on low impact development techniques for the Great Lakes region called *Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management.* The report includes an overview of many runoff control techniques, including pros and cons of each practice. The report can be downloaded in PDF format from the American Rivers Web site at www.americanrivers.org (visit the "Resources" link and choose to view a complete list of publications).

The Villanova University Stormwater Partnership conducts research on management practices to control urban runoff. The organization has established a "Stormwater BMP Park" with a constructed wetland, a biofiltration traffic island, and a porous concrete site. Research results and outreach materials can be found at http://www3.villanova.edu/VUSP/.

The EPA "Final Action for Effluent Guidelines and Standards for the Construction and Development Category" can be found at http://www.epa.gov/fedrgstr/. The Technical Development Document (EPA-821-B-04-001), which contains information on costs and technologies, is available from US EPA/NSCEP. P.O. Box 42419, Cincinnati, Ohio 45242-2419, (800) 490-9198 or http://www.epa.gov/waterscience/guide/construction.

EPA's *The Use of Best Managment Practices (BMPs) in Urban Watersheds* evaluates design, effectiveness, and cost considerations for storm water management practices. The document canbe downloaded in PDF format from http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184.pdf (cover and table of contents) and http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap1.pdf (Chapters 1–6).

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MANAGEMENT MEASURE 10
EXISTING DEVELOPMENT

10.1 Management Measure

Develop and implement watershed management programs to reduce runoff pollutant concentrations and volumes from existing development and redevelopment:

- Identify opportunities to reduce pollutants in priority local and/or regional watersheds (e.g., improvements to existing urban runoff control structures, including the addition of infiltration, filtration, retention, and detention practices).
- Devise a schedule for implementing appropriate runoff controls.
- Limit destruction of natural conveyance systems.
- Where appropriate, preserve, enhance, or establish buffers along surface water bodies and their tributaries.
- Promote redevelopment that reduces runoff volumes and pollutants.

10.2 Management Measure Description and Selection

10.2.1 Description

The purpose of this management measure is to protect or improve surface water quality by developing and implementing watershed management programs that pursue the following objectives:

- Reduce surface water runoff pollution loadings from areas where development has already occurred.
- Reduce the volume and peak runoff rates of surface water runoff to reduce runoff flow, increase infiltration, and minimize habitat degradation and sediment loadings from erosion of streambanks and other natural conveyance systems.
- Preserve, enhance, or establish buffers that provide water quality benefits along water bodies and their tributaries.

Maintaining water quality becomes increasingly difficult as urbanization occurs and areas of impervious surface increase. Increased peak runoff volumes from impervious surfaces result in alteration of stream channels, natural drainageways, and riparian habitat. This alteration, in turn, results in elimination or reduction of predevelopment aquatic flora and fauna and degradation of predevelopment water quality. Other effects include increased bank cutting, streambed scouring, embedded cobbles, siltation, increases in instream water temperature, decreases in dissolved oxygen, and changes to the natural structure and flow of the stream or river.

Protecting water quality in urbanized areas is difficult because of many factors, including diverse pollutant loadings, large runoff volumes, limited areas suitable for surface water runoff treatment systems, the high implementation costs associated with structural controls, and the destruction or absence of buffer zones that can filter pollutants and prevent the destabilization of streambanks and shorelines.

An important nonstructural component of many watershed management plans is the establishment and preservation of buffers and natural systems (e.g., by policy, code, or ordinance). These areas help to maintain and improve surface water quality by filtering and infiltrating urban runoff. In areas of existing development, natural buffers and conveyance systems may have been altered as urbanization occurred. Where possible and appropriate, additional impacts on these areas should be minimized, and if the areas are degraded, their functions should be restored. Establishing and protecting buffers is most appropriate along surface water bodies and their tributaries where water quality and the biological integrity of the water body are dependent on the presence of an adequate buffer or riparian area. Buffers may be necessary where the buffer or riparian area:

- Reduces significant nonpoint source pollutant loadings;
- Provides habitat necessary to maintain the biological integrity of the receiving water;
- Reduces undesirable thermal impacts on the water body; or
- Reduces erosion.

Structural practices may be a suitable option to decrease the nonpoint source pollution loads generated from developed areas in addition to nonstructural controls (see Management Measure 9: Pollution Prevention). In such situations, a watershed plan can be used to integrate the construction of new surface water runoff treatment structures and to retrofit existing surface water runoff management systems.

Retrofitting is a process that involves the modification of existing surface water runoff control structures or surface water runoff conveyance systems that were initially designed to control flooding, not to serve a water quality improvement function. By enlarging existing surface water runoff structures, changing the inflow and outflow characteristics of such devices, and increasing runoff detention and retention time, sediment and associated pollutants can be removed from the runoff. Retrofit of structural controls is often the only feasible alternative for improving water quality in developed areas. Where existing development or financial constraints limit treatment options, targeting or identifying priority pollutants and selecting the most appropriate retrofits that will result in the greatest improvement to water quality may be necessary.

Once key pollutants have been identified, an achievable water quality target for the receiving water should be set to improve current levels based on an identified objective or to prevent degradation of current water quality. Extensive site evaluations should then be performed to assess the performance of existing surface water runoff management systems and to pinpoint low-cost structural changes or maintenance programs for improving pollutant removal efficiency. Where flooding problems exist, source controls, low-impact development (LID), and infiltrative controls should be incorporated into the design of surface water runoff controls. Available land is often limited in urban areas, and the lack of suitable areas frequently restricts the use of conventional pond systems. In heavily urbanized areas, sand filters, biofilters, or water quality inlets with oil/grit separators might be appropriate for retrofits because they do not limit use of the land.

10.2.2 Management Measure Selection

The first and second components of this management measure were selected to encourage communities to develop and implement watershed management programs. Local conditions, availability of funding, and problem pollutants vary widely among communities. Watershed management programs allow communities to select and implement the practices that best address local needs. Prioritizing local and/or regional pollutant reduction opportunities and setting schedules for implementing appropriate controls were selected as logical starting points for establishing an institutional framework to address nonpoint source pollutant reduction. The first two parts of Section 10.3: Management Practices, “Identify, Prioritize and Schedule Retrofit Opportunities” and “Implement Retrofits as Scheduled” address these two components.

The third and fourth components of this management measure were selected to preserve, enhance, and establish areas within existing development, such as natural streams, ponds, and wetlands and aquatic buffers, that provide positive water quality benefits. These natural systems provide efficient runoff conveyance as well as aesthetic benefits. These components are addressed by the third, fourth, and fifth parts of Section 10.3: Management Practices: “Restore and Limit the Destruction of Natural Runoff Conveyance Systems,” “Restore Natural Streams,” and “Preserve, Enhance, or Establish Buffers.”

The fifth component is addressed by part 5 of Section 10.3: Management Practices, “Revitalize Urban Areas.” This component was selected to encourage redevelopment of urban areas that may be contributing to water quality problems via impervious surfaces, contaminated soils, or land uses that result in poor runoff quality or increased runoff volumes. Multiple goals such as surface water and ground water quality improvement, soil remediation, and quality-of-life enhancements may be simultaneously achieved using such an approach.

The Brownfields program, managed by EPA under the authority of the Small Business Liability Relief and Brownfields Revitalization Act of 2002 (USEPA, 2002b), promotes redevelopment of these areas and also can be an effective source of funding and expertise to achieve the above goals. The Act

- Provides legislative authority for the Brownfields program including grants for assessment and clean-up;
- Expands the current Brownfields program by increasing its funding authority up to $200 million per year including up to $50 million per year to assess and clean up brownfields with petroleum contamination;
- Expands eligibility for assessment and clean-up grants;
- Includes a new provision for direct clean-up grants of up to $200,000 per site;
- Streamlines current requirements for the brownfields clean-up revolving loan fund and makes funding available to nonprofit organizations;

- Applies the Davis Bacon Act, which maintains local wage and labor standards for federal construction work, on the same terms as the authority for the current program; and

- Makes funds available for technical assistance, training, and research.

More information about the Small Business Liability Relief and Brownfields Revitalization Act can be found at http://www.epa.gov/brownfields/sblrbra.htm.

Cost was a major factor in the selection of this management measure. EPA acknowledges the following constraints to implementing nonpoint source controls for existing development:

- High costs and other limitations inherent in treating existing sources to levels consistent with the standards set for developing areas;

- Frequent lack of suitable areas for structural treatment systems that can adequately protect receiving waters;

- Lack of universal cost-effective treatment options;

- Frequent lack of funding for mandatory retrofitting; and

- Extraordinarily high costs associated with implementing retention ponds and exfiltration systems in developed areas.

10.3 Management Practices

10.3.1 Identify, Prioritize, and Schedule Retrofit Opportunities

In the watershed assessment phase of the urban runoff management cycle, watershed managers should identify water bodies that have been degraded by urban runoff and prioritize them for restoration based on the costs and benefits for watershed stakeholders. One method to halt further degradation and initiate water body recovery is to retrofit existing runoff management practices or conveyance structures. It is important for watershed managers to have clear goals and realistic expectations for retrofitting existing structures. Each retrofit project should be planned in the context of a comprehensive watershed plan, and managers should have a clear set of objectives to ensure that the project results in measurable improvements in hydrologic, habitat, and/or water quality indicators.

10.3.1.1 Evaluate existing data

The first step in identifying candidate sites for storm water retrofitting is to examine existing data. These data can include results from a watershed assessment, topographic maps, land use or zoning maps, property ownership maps, aerial photos, and maps of the existing drainage network. For example, results from a watershed assessment can be used to identify areas with good habitat and water quality that should be protected, as well as areas with poor habitat and water quality that need to be improved. Topographical maps can be used to delineate drainage units within the watershed at the subwatershed and catchment levels. Land use or zoning maps can be used to estimate areas of high impervious cover to target areas that contribute a large amount of runoff to receiving waters, while property maps provide land ownership data. Finally, aerial photographs can be used to identify open spaces that can be more easily developed into runoff management facilities. According to the Center for Watershed Protection (CWP, 1995a), the best retrofit sites:

- Are located adjacent to existing channels or at the outfall of storm drainage pipes;
- Are located within an existing open area;
- Have sufficient runoff storage capacity;
- Are feasible for diverting runoff to a potential treatment area (forested or vegetated area) or structural management practice; and
- Have a sufficient drainage area to contribute meaningfully to catchment water quality.

Specific areas well-suited for new runoff controls include undeveloped parkland and open space, golf courses, wide floodplains, highway rights-of-way, and edges of parking lots.

Information for potential retrofit sites, such as location, ownership, approximate drainage area, utility locations, and other pertinent details, can be compiled in a retrofit inventory sheet (CWP, 1995a). A site visit can provide information on site constraints, topography, adjacent sensitive land uses, receiving water conditions, utility crossings, and other considerations that would affect the feasibility of implementing the management practice. At this point, a conceptual sketch for rerouting drainage and siting management practices should be drawn and preliminary cost estimates made for each site.

10.3.1.2 Choose appropriate management practices based on site conditions

The choice of one potential retrofit site over another for management practice implementation can be based on several different factors in addition to site limitations and cost. For instance, the preliminary goals of a retrofit program may be to preserve streams or reaches known to have high-quality habitat or exceptional water quality. The goal of another program may be to restore poor habitat and degraded water quality. The program may elect to target particular land uses thought to contribute the majority of pollutants to receiving waters. Retrofit facilities also can be installed to treat runoff from large parts of a watershed or subwatershed (regional controls), thereby requiring fewer overall projects. Once retrofit sites are identified and prioritized, a schedule for installing new facilities or updating old facilities should be devised.

10.3.1.3 Incorporate low-impact development practices into existing development

In many cases, sites that are already developed can be retrofitted with low-impact development practices such as biofilters, rain barrels, rooftop greening, and cisterns (see Management Measure 5 for a more detailed discussion of these practices). Soil rehabilitation and tree planting can also contribute to the reduction of runoff. All of these practices can be designed on a small scale to accommodate space constraints that may be present on developed sites. The use of these practices will aid in retaining runoff on-site and help to reduce the total volume of runoff reaching receiving waters. For example, in Washington, DC, trees have saved $4.74 billion in gray infrastructure costs per 30-year construction cycle, and reduced the need for storm water retention structures by 949,000 ft^3 (NALGEP, 2003).

The City of Chicago has incorporated low-impact development practices such as rooftop greening and downspout disconnection into its urban runoff management strategy. The City Hall Rooftop Garden is a $1.5 million retrofit project to demonstrate the benefits of green roofs. The city has published *A Guide to Rooftop Gardening* (http://www.cityofchicago.org/Environment/GreenTech/pdf/GuidetoRooftopGardening.pdf) to communicate the lessons learned from this project and provide information to the public on green roof development. The city is also targeting flood-prone areas for its downspout disconnection campaign, distributing door hangers and brochures to residents, and encouraging the use of rain barrels (Murante, 2003).

The *Low-Impact Development Design Strategies: An Integrated Design Approach* (Prince George's County, Maryland, Department of Environmental Resources, 2000) and the Low Impact Development Center Web site (http://www.lowimpactdevelopment.org/) can provide more information about these and other practices appropriate for existing developments. Additionally, a search for "urban forestry" on the USDA Forest Service's Web site (http://www.fs.fed.us/) produces many good references about how trees can be used to reduce runoff volume and improve runoff quality.

10.3.1.4 Identify undeveloped and privately owned land for acquisition

In addition to the installation of conventional storm water management practices, the acquisition and preservation of open space in developed watersheds can protect against the threat of further development, reduce runoff volume, and provide storm water treatment. This practice involves the identification of parcels in a developed watershed that are undeveloped or privately owned and can be protected or restored to provide storm water benefits by attenuating additional runoff volume and peak flow. This watershed-wide planning effort involves mapping open space, cadastral data (e.g., property boundaries, subdivision lines, buildings), drainage systems, urban forests, floodplains, and other land use data. The planning effort also involves selecting sites based on their proximity to receiving waters, the condition of the soil and vegetation, and ease of purchase. Selected parcels are purchased, restored if necessary, and modified to receive and retain more runoff using berms or diversions (O'Leary, 2003). For more information on land acquisition, see Management Measure 3: Watershed Protection.

10.3.1.5 Use routine maintenance as an opportunity for retrofitting existing infrastructure

One of the major challenges in controlling runoff from existing development is the potentially high cost of retrofitting infrastructure to reduce runoff quantity and improve quality. One way to reduce costs is to modify runoff controls during routine maintenance procedures. Retrofits can be constructed as part of the routine maintenance and repair of urban infrastructure. This approach requires less capital outlay for retrofit compared to large-scale, capital-intensive approaches. For example, pervious surfaces can be installed when resurfacing parking areas, and newly disturbed areas can be restored to the desired vegetative condition (e.g., forest or meadow). When storm water ponds are dredged every few years, sediment forebays can be redesigned to improve performance.

Retrofitting Catch Basins for On-Street Runoff Storage

An example of a retrofit to reduce downstream impacts of urbanization can be found in the towns of Skokie and Wilmette, Illinois. These towns are urban areas that are served by a combined sewer system (CSS). Both communities wanted to control CSS surcharge but did not want to build expensive relief sewers. As a result, they were willing to try alternative approaches. The towns decided to modify street cross sections and storm drain inlets to allow runoff to be stored temporarily on the street surface during storm events to reduce hydraulic loading to CSSs. The street surface storage projects combined the following elements (USEPA, 2000b):

- Street storage.
- Downspout disconnection.
- Flow regulators.
- Subsurface storage.
- New storm and combined sewer systems.
- Improvements to existing storm and combined sewer systems.

The projects involved installing a system of street berms, 7 to 9 inches high, at the curb line to detain water on the street. Flow regulation devices were installed at catch basin outlets to reduce the rate of storm water flow to the CSS. Both the street surface and the inlet structure were used for storage. Subsurface storage facilities were also installed in the street right-of-way and in other public areas at critical points in the system and in pedestrian walkways, parking areas, and high-traffic areas, where ponding was unacceptable.

The project resulted in a number of benefits. Researchers estimated a cost savings from using street storage rather than conventional sewer separation systems. Estimated costs for the Skokie system are approximately 38 percent of conventional sewer separation system costs. Berm costs are a small fraction of the overall cost of the CSS surcharge relief project. Another benefit of the storage system is traffic control. Berms can function as speed humps and help control traffic. The street storage system also reduces the volume and frequency of combined sewer overflows, resulting in less runoff-related pollution entering receiving waters. Icing of ponded areas during the winter was not a problem because retention times were relatively short (less than 30 minutes), but consideration should be given to safety hazards associated with ponded water during periods of high rainfall.

10.3.2 Implement Retrofit Projects as Scheduled

CWP (1995b) describes six common types of retrofitting projects:

- Modifying existing runoff management facilities;
- Constructing new management practices at the upstream end of road culverts;
- Constructing new management practices at storm drainage pipe outfalls;.
- Constructing small instream practices in channels;
- Constructing management practices at the edge of large parking areas and
- Constructing new management practices in highway rights-of-way.

10.3.2.1 Retrofit existing runoff management facilities

Many older dry detention basins were designed for the singular purpose of flood control. In some cases, a facility of this type can be converted into an extended detention pond/wetland or a conventional wet pond. If this retrofit is designed well, it will increase pollutant removal capabilities and aquatic habitat functions without losing any of its flood control benefits. This modification also typically results in only minimal impacts on the surrounding environment. Dry detention ponds can be modified to accommodate a greater variety of species by transforming them into constructed wetlands or installing aquatic platforms, which are shallow benches on which aquatic vegetation can be planted (see Section 5.3.1.3 for more information about constructed wetlands; Fairfax County Environmental Coordinating Committee, 2002).

The retrofit process often includes:

- Analyzing existing hydraulic characteristics and the flood control design specifications of the facility;
- Determining whether there is available storage for water quality treatment;
- Excavating the pond bottom to create permanent pool storage (for pond and wetland systems) if water quality storage is available;
- Raising the embankment or modifying the outlet structure to obtain additional storage if extended detention is needed;
- Increasing the flow path from inflow point to discharge point by using baffles or earthen berms or by regrading the pond's contours to increase particulate settlement; and
- Addressing safety considerations, such as fencing and adding underwater benches or shallow fringe areas along shorelines, to reduce the risk of drowning.

Bioengineering to enhance water quality benefits

The City of Griffin, Georgia, constructed a bioengineering system within the North Griffin Regional Detention Pond and within a forested wetland area downstream of the pond to improve water quality in the receiving waterbody, Flint River. The bioengineering system is comprised of specific species of vegetation that provide natural filtration and breakdown of pollutants in runoff. The wetland plants selected include cattail, bulrush, pickerel weed, soft rush, wool grass, southern cutgrass, and shallow sedge. Experts chose these species based on their anticipated ability to break down and filter various pollutants commonly found in runoff. The system has low maintenance requirements and relatively low construction and operating costs in comparison to conventional treatment facilities. In addition to water quality benefits, the system will enhance wildlife habitat (City of Griffin, no date). The Consulting Engineers Council of Georgia recognized the project design and performance success with an Engineering Excellence Award in February 2000. The Georgia Environmental Protection Division and USEPA Clean Water Act (CWA) Section 319(h) Program also acknowledged the project's achievement (Greuel and Feldner, 2001). A detailed summary of this project is available in EPA's Section 319 Success Stories, Vol. III at http://www.epa.gov/owow/nps/Section319III/GA.htm.

10.3.2.2 Modify the upstream end of road culverts

A good retrofit opportunity can sometimes be found at the upstream end of a road culvert. A gabion, concrete weir structure, or riser/barrel control structure can be installed to create a small, permanent micropool excavated to provide water storage, water quality, and habitat benefits. This method can be used to provide a dry extended detention basin with a maximum depth of 6 feet above the culvert invert. If the upstream area is open floodplain, it might be possible to construct a wet pond or extended detention pond/wetland retrofit.

Cost-Effectiveness Study of Retrofitting Runoff Treatment Facilities

EPA's Office of Research and Development investigated retrofitting wet-weather flow treatment facilities to determine their feasibility and cost-effectiveness (Moffa et al., 2000). The following retrofit scenarios were analyzed:

- Converting or retrofitting primary settling tanks with dissolved air flotation and lamellae (thin, flat membranes or layers) and/or microsand-enhanced plate or tube settling units.
- Retrofitting existing wet-weather flow storage tanks to provide enhanced settling/treatment and post-storm solids removal.
- Converting dry ponds to wet ponds for enhanced treatment.
- Retrofitting wet-weather flow storage tanks for dry-weather flow augmentation.
- Using storage for sanitary sewer overflow control.
- Retrofitting for industrial wastewater control in a combined sewer system.
- Bringing outdated/abandoned treatment plants back on-line as wet-weather flow treatment facilities.

The cost-benefit analysis examined site-specific, operational, cost, and design parameters. Each retrofit scenario was analyzed over a range of flow and/or volume conditions. The study revealed that in certain circumstances, retrofitting existing wet-weather flow treatment facilities is technically feasible and can be more cost-effective than construction of new conventional control and treatment facilities. The authors concluded that these results were highly site-specific and recommended that retrofitting existing control facilities be identified as one of several alternatives to reduce impacts from storm events. The full report is available at the Office of Research and Development's Web site at http://www.epa.gov/ednnrmrl/news/main.htm.

Because roadways are not constructed as runoff management embankments, special measures might be necessary to ensure that these facilities meet dam safety specifications for seepage control and passage of the 100-year storm. Consideration and evaluation of secondary impacts, such as modification of the 100-year floodplain, creation of fish migration barriers, and changes to the wetland hydrologic regime is also warranted with this type of retrofit.

10.3.2.3 Modify storm drainage pipe outfalls

A volume of runoff can be diverted at or near a storm drainage pipe outfall to a sand filter, peat-sand (or other medium) filter, bioretention system, centrifugal deflection system, off-line wetland or pond system, or other water quality treatment facility for treatment before it reenters a receiving water.

10.3.2.4 Add retention structures to channelized streams

Small weir walls or check dams can sometimes be placed in small, previously channelized streams to retain sediments and create a ponding area for wetland vegetation. This type of retrofit is usually easy to install and can provide moderate pollutant removal benefits. Because it can potentially affect channel design flows and the floodplain, however, careful analysis must be conducted before the instream practice is implemented. In addition, cleanout frequency should be considered before selecting this practice, as regular maintenance will be needed to remove trapped sediments.

10.3.2.5 Install runoff management practices in or adjacent to large parking areas

Retrofit practices can be installed near large parking lots to capture, detain, and/or treat runoff. Infiltration practices such as bioretention areas, porous pavement, sand filters, and underground vaults are good candidates. Two examples of successful use of bioretention areas can be found at http://www.epa.gov/owow/nps/bioretention.pdf (USEPA, 2000a). In addition, a case study illustrating the effectiveness of porous pavement in reducing runoff is provided at http://www.epa.gov/owow/nps/pavements.pdf (USEPA, 2000b).

10.3.2.6 Construct new practices in highway rights-of-way

Existing highway systems can have significant open spaces for the installation of various practices. For example, cloverleaf open space can be an ideal location for storm water wetlands and pond systems if drainage areas and patterns allow. Care must be taken to avoid creating a safety hazard for traffic, and maintenance access should be an integral part of the design.

10.3.2.7 Install trash-capturing devices

Trash racks are inclined metal grates that trap floatables as water passes through. The racks can be installed at storm sewer inlets or outfalls or in the stream itself. These structures effectively remove trash from the water, but they require a high level of maintenance (inspection for damage or clogging after storms and regular trash removal). If these racks are poorly maintained, their effectiveness decreases and they can clog, which can cause a flood hazard. A less-expensive alternative to metal trash racks is plastic mesh trash collectors with floating piers that stretch across the width of the stream. They are easier to maintain because they are simply removed and replaced with a new collector.

The applicability of these trash collection methods is limited to small streams with relatively low flow and low-level trash inputs. More substantial trash collection methods, such as vortex devices that use centrifugal force to separate floatables from water, can be installed to handle larger flows or high trash loads.

10.3.2.8 Install inlet and grate inserts

A wide variety of inserts that trap oil and grease from parking lots, maintenance yards, and streets are also commercially available. These can be used with or without trash capture in storm drain inlets and grates. Inspection and maintenance one to four times per year (depending on pollutant concentrations in runoff) is usually recommended. Catch basin inserts are discussed in more detail in Management Measure 5 (section 5.3.5.4).

10.3.3 Restore and Limit the Destruction of Natural Runoff Conveyance Systems

Existing development has likely resulted in a modification of natural drainage patterns as compared to predevelopment conditions. As a result, increases typically occur in imperviousness, runoff, peak flows during storm events, erosion, and pollutant transport. The use of traditional runoff management technology, such as piping, channeling, and curbing, has aggravated these impacts.

Efforts should be made to restore previously developed or redeveloping sites so they more closely mimic predevelopment hydrologic conditions. The predevelopment condition should be estimated based on historical records and existing slopes, soils, and natural drainage features. Consideration should be given to the time of concentration—the time it takes water to travel from the farthest point in a subwatershed to the outlet. (Sites might contain multiple subwatersheds and multiple outlets.) Paving and curbing substantially reduce time of concentration, resulting in high peak flows during storms. Time of concentration can be increased substantially by modifying drainage patterns and installing infiltration and detention practices. The practices presented in this section can be used to increase time of concentration on a particular site. Additional technical guidance for restoration practices can be found at EPA's River Corridor and Wetland Restoration Web site at http://www.epa.gov/owow/wetlands/restore (USEPA, 2002a). Another resource is *Stream Corridor Restoration: Principles, Processes, and Practices* (FISRWG, 1998), which can be downloaded at http://www.nrcs.usda.gov/technical/stream_restoration/newgra.html or ordered by contacting the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; telephone 703-605-6000 or 800-553-NTIS; e-mail orders@ntis.fedworld.gov.

10.3.3.1 Disconnect impervious areas

Roof downspouts can be disconnected from streets and culverts and runoff diverted over vegetated areas or infiltration systems (for treatment) or into cisterns or rain barrels (for reuse; see Management Measure 5 for more information on these practices). Also, roadway runoff can be converted to sheet flow and directed to vegetated buffers, infiltration devices, or other pervious areas.

Rooftop runoff also can be controlled with a vegetated roof cover. These systems consist of a high-quality waterproof membrane covered by drainage material, a planting medium, and vegetation. Vegetated roof covers use foliage and a lightweight soil mixture to absorb, filter, and detain rainfall. The systems are designed to control high-intensity storms by intercepting and retaining water until the rainfall peak passes (USEPA, 2000d). Additionally, vegetated roof covers improve insulation and reduce the amount of reflected solar radiation, resulting in lower temperatures in urban areas. More information about vegetated roof covers can be found at http://www.epa.gov/owow/nps/roofcover.pdf.

The City of Portland, Oregon, encourages residents to reduce the connectivity of impervious surfaces through its Downspout Disconnection Program, originally established in 1996 to address problems with combined sewer overflows. Through an interagency agreement, the local plumbing code was revised to allow downspout disconnection without a permit. The program has developed safety standards that establish criteria for the feasibility of a disconnection, as well as an inspection and maintenance program to ensure safety. Homeowners can choose to have the city disconnect a downspout free of charge, or they can disconnect it themselves and receive a cash incentive. Since the start of the program, nearly 17,000 homes have been disconnected and data have been collected on an additional 20,000 potential disconnections (Hottenroth, 2003).

More information about the Downspout Disconnection Program can be found at http://www.portlandonline.com/oni/index.cfm?c=28992.

10.3.3.2 Encourage overland sheet flow

Concentrated flow of runoff during storms results in decreased time of concentration, decreased infiltration, and increased erosion due to high runoff velocity. Careful regrading to reduce steep slopes slows runoff, promotes infiltration, and reduces erosion. (Note that regrading efforts should not result in increased compaction; if compaction has occurred, soil amendments and rehabilitation may be necessary.) A level spreader, which typically consists of a shallow, gravel-filled trench that receives concentrated flows and converts them to sheet flow, can be installed to convey runoff to vegetated areas. A flat, grassy area can also be used to promote overland flow.

10.3.3.3 Increase flow path

Increasing the path of runoff results in increased storm water detention and increased travel time. Directing concentrated flows from impervious areas to infiltration areas, swales, dry wells, cisterns, or bioretention facilities increases the time it takes for runoff to leave the site and mitigates peak runoff flows.

10.3.3.4 Use open swales in place of traditional storm drain systems

Grassed swales are an effective and natural means of conveying runoff. Because the water comes into contact with vegetation, the runoff velocity decreases, which promotes infiltration, reduces erosion, and lengthens time of concentration. Because grassed swales are wider and shallower than conventional channels, runoff is less concentrated. They are especially appropriate alongside roadways or on the border of a site. Swales can be combined with terraces and infiltration devices to enhance runoff retention. Swale installation requires a minimum amount of excavating and regrading. Vegetation should be established immediately to prevent excessive erosion; while vegetation is being established, geotextiles or turf reinforcement mats can be used to stabilize exposed soils in the swale.

One neighborhood in Seattle, Washington, underwent a transformation from conventional to natural drainage systems as part of a pilot project, called “SEA Street” (for Street Edge Alternatives), conducted by Seattle Public Utilities. Monitoring before and after the installation of swales indicated a decline from approximately 5,000 cubic feet of runoff from 8 inches of rain to only 132 cubic feet of runoff from 9 inches of rain. The project, which cost approximately $800,000, was equivalent to the cost of a conventional curb-and-gutter system and provides additional water quality benefits and an anticipated boost to property values (Taus, 2002). More information about this project can be found at http://www.ci.seattle.wa.us/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Street_Edge_Alternatives/index.asp.

10.3.3.5 Establish vegetation throughout the site

Vegetation intercepts rainfall, decreases runoff velocity by increasing surface roughness, and promotes infiltration. Establishing vegetated areas in strategic locations that currently receive runoff from impervious areas requires minimal effort, especially when native plant species are used. Excess compaction of these areas by heavy equipment should be avoided. To enhance the benefits of vegetated areas, part of a site can be regraded during redevelopment activities to direct runoff to these areas. See Management Measure 3: Watershed Protection (section 3.3.3.8) for a discussion of urban forestry practices that can help in achieving these goals.

10.3.3.6 Reestablish ground water recharge

Traditional development techniques that focus on quickly conveying runoff off-site have resulted in decreased infiltration of rainfall to ground water. This ground water deficit results in a lowered water table and decreased seepage and baseflow in streams during dry periods. Infiltration practices can be installed to promote ground water recharge. Such practices include infiltration trenches, infiltration basins, sand filters, biofiltration systems, and vegetated areas underlain by permeable soils (see Management Measure 5: New Development Runoff Treatment).

A Watershed Restoration Plan for the Norwalk River Watershed

Habitat quality and water quality in the Norwalk River watershed of southeastern Connecticut have been degraded by erosion, sediment, pesticides, excessive algae growth, driftwood and other impoundments, and other types of pollution associated with increased watershed urbanization (NWRI, 1998). In 1997 federal, state, and local government agencies, environmental groups, and concerned citizens formed the Norwalk River Watershed Initiative (NRWI) to halt further degradation and promote water quality recovery. Subcommittees were tasked with developing goals for four key issues: (1) habitat restoration; (2) land use, flood protection, and open space; (3) water quality; and (4) stewardship and education.

The NWRI assessed existing water quality and riparian conditions based on data collected by the Connecticut Department of Environmental Protection, U.S. Geologic Survey, and U.S. Department of Agriculture. They also identified land uses that contribute to water quality problems, areas where stream channels had been modified by dams or flood control projects, and point sources such as municipal wastewater treatment facilities.

Based on the results of the assessment, the NWRI developed the Norwalk River Watershed Action Plan, which describes specific objectives and action items to accomplish those objectives for each of the four key areas listed above. Each objective contains a list of specific tasks with the implementing group clearly identified, the proposed time line for each task, and a measure of the tasks' success. The NWRI also developed an outreach program to foster stewardship and to educate watershed residents about the impacts of daily activities that contribute to the degradation of the Norwalk River watershed.

For more information on the Watershed Action Plan or to obtain a copy of the plan, contact the Norwalk River Watershed Coordinator, Connecticut Department of Environmental Protection, Bureau of Water Management, 79 Elm Street, Hartford, CT 06106; telephone 860-424-3096; e-mail tessa.gutowski@po.state.ct.us.

Restoration in the Anacostia River Watershed

The Anacostia River has been cited nationally as exemplifying urban watershed problems (AWRC, 1998). These problems are typified by

- Conversion of natural drainage networks into man-made channels.
- Increased runoff and urban pollutants from impervious surfaces.
- Channel erosion and associated loss of aquatic habitat from changes in land use.
- Sediments laden with toxic substances and other pollutants from motor vehicles.
- Electrical transformers, past applications of persistent pesticides, poorly timed applications of fertilizers, combined sewer overflows, atmospheric deposition, and pet waste.
- Thousands of tons of trash and debris.

As a result of this degradation, in 1987 a concerted effort to restore and protect the Anacostia watershed was initiated in the form of the Anacostia Watershed Restoration Agreement and the establishment of the Anacostia Watershed Restoration Committee (AWRC), which involved the District of Columbia, Montgomery and Prince George's counties in Maryland, the State of Maryland, the U.S. Army Corps of Engineers, the Metropolitan Washington Council of Governments, and the Interstate Commission on the Potomac River Basin. The cooperative effort was expanded in 1996 with the creation of the AWRC's Anacostia Watershed Citizens Advisory Committee (AWCAC). The AWCAC has brought formal recognition of the importance and need for citizen input and involvement in the restoration.

The AWRC established a framework to guide long-term restoration efforts and identified 580 restoration projects to correct existing environmental problems and enhance overall ecosystem quality. As of 1997 approximately $20 million had been spent on implementing roughly 29 percent of the 580 identified projects, with additional millions of dollars spent on planning, design, land acquisition, and maintenance. An additional $54 million had been spent on engineering controls designed to reduce the impacts of combined sewer overflows on the tidal river and of leaking, aging sewer lines on tributary streams. As a result of the restoration efforts, the submerged aquatic vegetation once absent from the river is beginning to reappear, signaling some improvement in water clarity, as the volume and concentrations of pollutants from urban runoff have been reduced. The successes have required the identification of problems and associated solutions, coordination of programs, and the mobilization of critical government, political, and financial resources. Key features in the success of the Anacostia program have been the development of common watershed restoration goals and the identification and establishment of partnerships.

More information about the Anacostia Watershed Restoration Project can be found at http://www.anacostia.net/awrc.htm.

10.3.3.7 Protect sensitive areas

Areas that should be considered for preservation and restoration at sites with existing development include riparian areas, 100-year floodplains, wetlands, woodlands and valuable trees, and areas with permeable soils. Steep slopes and erosive soils should be protected and stabilized to the extent possible.

10.3.4 Restore Natural Streams

Streams degraded by prior urbanization should be restored, if possible, using preexisting conditions as a goal or guideline. Eight restoration tools can be applied to help restore urban streams. These tools are intended to compensate for stream functions and processes that have been diminished or degraded by prior watershed urbanization. Best results are usually obtained when the tools are applied together; otherwise, the same sources that degraded the stream remain unchanged, causing similar effects.

A resource for information about restoring natural streams is *Stream Corridor Restoration: Principles, Processes, and Practices* (FISRWG, 2000), which is available for purchase or download at http://www.usda.gov/stream_restoration/newgra.html. Another resource is *Urban Stream Restoration: A Video Tour of Ecological Restoration Techniques* (Riley, 1998b), which is available for purchase at http://www.noltemedia.com/nm/urbanstream/index2.html. Finally, the Center for Watershed Protection developed 11 manuals, collectively called the Urban Subwatershed Restoration Manual Series, that present the information needed to restore small urban watersheds in a format that can easily be accessed by watershed groups, municipal staff, environmental consultants, and other users. The manuals are available for a fee in hard copy or as a download at http://www.cwp.org/USRM_verify.htm.

10.3.4.1 Partially restore the predevelopment hydrologic regime

The primary objective of storm water management is to reduce the frequency of bankfull flows and other erosive events in the contributing watershed. This is often done by constructing upstream storm water retrofit ponds that capture and detain increased storm water runoff for up to 24 hours before release (i.e., extended detention). Extended detention systems are often designed to control the one-year, 24-hour storm. Storm water retrofit ponds are often critical in the restoration of small and mid-sized streams, but they might be less cost-effective in larger streams and rivers unless implemented on a watershed basis.

10.3.4.2 Stabilize channel morphology

Over time, urban stream channels can become enlarged and are subject to severe bank and bed erosion. Therefore, it is important to stabilize the channel and, if possible, restore equilibrium to the channel geometry. In addition, it is useful to provide undercuts or overhead tree canopy to improve fish habitat. Depending on the stream order, the impervious cover in the watershed, and

Restoring Channel Morphology in a North Carolina Stream

Long Leaf Creek is located in an urbanized watershed along coastal North Carolina (Sotir, 2000). The stream had deepened and widened as a result of increased runoff and severe storms, including hurricanes. The changes resulted in reduced aesthetic value, damaged riparian vegetation and aquatic and terrestrial habitats, and degraded water quality. Managers selected a soil bioengineering approach over other alternatives after considering such issues as erosion control, streambank stabilization, safer and healthier environment, flood control, timely project completion, environmental and aesthetic improvement, property loss minimization, hydraulic efficiency, and cost feasibility. They installed live fascines, brush layer/live fascine combinations, joint planting, and vegetated geogrids.

The survival rates of the live vegetation ranged from 60 to 80 percent depending on the species used; maintenance proved to be a key factor in survival rates. Several important needs were identified, including studying bed conditions in areas that have had high deposits of mobile materials, employing sophisticated grade control structures, following installation procedures and maintenance schedules, and encouraging communication and cooperation between engineers and wetland scientists.

the height and angle of eroded banks, a series of different tools can be applied to stabilize the channel and prevent further erosion. Bank stabilization measures include revegetated riprap and soil bioengineering methods (see Management Measure 7) such as willow stakes, brush bundles, bio-logs, lunker structures, and rootwads.

10.3.4.3 Restore instream habitat structure

Most urban streams have poor instream habitat structure, often typified by indistinct and shallow low-flow channels within a much larger and unstable storm channel. The goal is to restore instream habitat structure that has been blown out by erosive floods. Key restoration elements include creating pools and riffles, confining and deepening the low-flow channels, and providing greater structural complexity across the streambed. Typical tools include installation of log check dams, stone wing deflectors, and boulder clusters along the stream channel.

Urban Stream Restoration in the Waukegan River, Illinois

An urban stream restoration project is underway in the Waukegan River in Illinois to repair channel instabilty caused by runoff from impervious surfaces and lack of storm water controls. The project uses biotechnical bank restoration to stabilize streambanks and low stone weirs to restore pool and riffle sequences. A habitat monitoring design was also used to document water quality changes. The project has improved biological diversity through pool and riffle restoration, yet it did not significantly improve stream fisheries. For more information about the project, refer to *Section 319 Nonpoint Source National Monitoring Program: Successes and Recommendations* (NCSU, 2000).

10.3.4.4 Reestablish riparian cover

Riparian cover is an essential component of the urban stream ecosystem. Riparian cover is necessary to stabilize banks, provide large woody debris and detritus, and provide shade to maintain water temperatures. Reestablishment of the riparian cover plant community along the stream network is often essential to achieve the goals and objectives of the program. This can entail active reforestation of native species, removal of exotic species, or changes in mowing operations to allow gradual succession. Establishment of an urban stream buffer can achieve many of these objectives (see section 3.3.3.6 of Management Measure 3 for a discussion of setbacks/stream buffer zones).

Citizen Involvement in Planting Riparian Forests

In Lexington, Kentucky, a unique program is underway to restore riparian areas to local streams. Because the city’s limited budget does not allow for an expensive riparian planting effort, Reforest the Bluegrass was established as a cooperative effort by local private and nonprofit organizations, citizen groups, and government agencies. Reforest the Bluegrass provides training for citizen volunteers to participate in replanting efforts. The program provides public education for participants and for local residents through outreach, while significantly reducing program costs. Participants are taught the value of riparian systems in protecting water quality, combating the “urban heat island” effect, and providing habitat for wildlife. As of April 2002, nearly 4,000 volunteers had planted 108,000 seedlings. The program was financed with $85,000 from local government and $50,000 from private donations, compared with an estimated cost $675,000 if the project had been completed by contractors (Gabbard and Poe, 2003).

Restoring Atlanta's Watersheds

The International Life Sciences Institute's Risk Science Institute (RSI) was tasked with assessing the condition of streams in Atlanta, Georgia; developing a watershed management implementation plan; and identifying specific watershed restoration activities that would improve riparian habitat and water quality in four example subwatersheds (RSI, 1998). They identified several habitat and water quality impacts that can be attributed to urbanization, including

- Increased magnitude and frequency of bankfull and subbankfull events.
- Stream channel dimensions out of equilibrium with hydrologic regime.
- Enlarged, highly modified channels.
- Increased sediment load due to upstream channel erosion.
- Decreased baseflow.
- Decreased wetted perimeter.
- Degraded in-stream habitat structure.
- Reduced large woody debris.
- Increased number of stream crossings, which are potential barriers to fish migration.
- Fragmentation and narrowing of riparian forests.
- Degraded water quality.
- Increased summer stream temperatures.
- Reduced aquatic diversity.
- Combined sewer overflows.

To address these issues, RSI developed a watershed management program for the Atlanta region that includes the following elements:

- Creation of an institutional framework for watershed management (Management Measure 1).
- Development of a comprehensive storm and surface water control program.
- Establishment of erosion and sediment control programs.
- Establishment of detention pond requirements.
- Expansion of the tree canopy.
- Management of buffers, sensitive areas, and floodplains.
- Establishment of land development provisions.
- Daylighting of streams.
- Relocation of utilities.
- Eradication of invasive and exotic species.
- Development of a public education and outreach campaign.

RSI also developed several objectives for the watershed management program and identified environmental indicators that can be used to gauge the effectiveness of management activities (see Management Measure 2). Finally, RSI examined four subwatersheds to identify specific management practices that can be used to fulfill the objectives of the watershed management program. In each case study, they identified the activities in the subwatershed that were contributing to resource degradation and suggested methods, such as separating storm and sanitary sewers and improving storm water infiltration, that would reduce runoff to prevent further waterbody degradation. These methods would also increase the effectiveness of in-stream and riparian restoration activities. RSI then identified site-specific restoration activities such as streambank stabilization, riparian buffer management, and creation or restoration of in-stream habitat.

For more information about the Watershed Management Program for Atlanta or to receive a copy of RSI's report, contact the Risk Science Institute, International Life Sciences Institute, 1126 16th Street, NW, Washington, DC 20036-4810; e-mail rsi@ilsi.org.

10.3.4.5 Protect critical stream substrates

A stable, heterogeneous streambed is often a critical requirement for fish spawning and secondary production by aquatic insects. The bed of an urban stream, however, is often highly unstable and clogged by deposits of fine sediment. It is often necessary to mechanically restore the quality of stream substrates at points along the stream channel. Often, the energy of urban storm water can be used to create cleaner substrates through the use of flow concentrators and other manufactured devices. (See Management Measure 5 for more information about these practices.) If thick deposits of sediment have accumulated on the bed, mechanical sediment removal might be needed.

10.3.4.6 Promote recolonization of the aquatic community

It may be difficult to reestablish the fish community in an urban stream if downstream fish barriers prevent natural recolonization. In these instances it is important to seek the judgment of a fishery biologist to determine whether downstream fish barriers exist, whether they can be removed, or whether selective stocking of native fish is needed to recolonize the stream reach.

10.3.4.7 Daylight streams

Daylighting involves returning a stream that has been buried in a pipe or culvert to the surface. In many cases the stream can be restored to its original channel, but sometimes a new channel must

Daylighting Jolly Giant Creek, Arcata, California

A classic example of daylighting is Arcata, California's Jolly Giant Creek (Pinkham, 1998). The daylighting and stream restoration project was initiated in 1991 by a high school biology teacher, Lewis Armin-Hoiland, and Humboldt State University students Melissa Bukosky and Tom Hagberg. They initially started the project to provide environmental education to high school and college students on stream ecology and restoration, but Bukosky continued to gather data and designed a new channel and restoration plan for the creek.

The Redwood Community Action Agency, a nonprofit regional development organization, obtained a grant from the California Department of Water Resources Urban Streams Restoration Program. Other funding sources included U.S. Fish and Wildlife Service Challenge Cost-Share, the city of Arcata, and donations from a local heavy equipment contractor and the National Tree Trust. A substantial amount of volunteer labor was used for revegetation and to conduct assessment and monitoring. Funding for the project totaled $120,000.

The first phase of the stream restoration project included removing nearly 100 feet of culvert; installing a sedimentation basin, a ⅓-acre pond, and 75 feet of new stream channel; providing bank stabilization and flow control measures; and rerouting the stream through an older dry channel with existing riparian vegetation. The second phase involved creating a new channel within the old, wider channel at an abandoned mill site; creating berms around part of the property; restoring more than 400 feet of the Jolly Giant Creek; and providing a seasonal wetland and wet weather detention pond with substantial runoff storage capacity.

For more information contact Richard Pinkham, Senior Research Associate, Rocky Mountain Institute, 1739 Snowmass Creek Road, Snowmass, CO 81654; telephone 970-927-3807; e-mail rpinkham@rmi.org.

be engineered. Flow control structures and flood control measures can be incorporated into the design of the new or restored channel. Planting, restoring, and maintaining streambank vegetation and providing a diversity of instream habitat for submerged aquatic vegetation, fish, and aquatic insects are important aspects of the stream restoration project.

Daylighting typically requires a large capital investment for acquiring permits, engineering designs and expertise, equipment and labor for excavation, and plantings and labor to establish desirable stream morphology. Because communities are typically in favor of daylighting projects, many of these costs can be offset by recruiting sponsors such as property owners, community groups, housing associations, municipalities, environmental groups, and contractors. The benefits of a daylighting project for a particular stream reach should be carefully considered and weighed against the cost to determine whether the project is worthwhile.

A source of information is *Daylighting: New Life for Buried Streams*. In addition to summary findings, recommendations, and conclusions, the report provides information about completed and proposed daylighting projects (Pinkham, 2000).

10.3.5 Preserve, Enhance, or Establish Buffers

Stream buffers may be present as part of previous development, but it is unlikely that existing buffers were established or maintained to maximize pollutant removal. As the intensity of surrounding development increases, runoff and pollutant loads increase and can result in damage to the buffer. If the buffer is not protected from disturbance or excessive traffic, it can deteriorate over time. Buffers serve several important functions: they help improve soil and water quality, stabilize streambanks, decrease flood severity, replenish ground water supply, and provide wildlife habitat (Schultz et al., 1996). Some steps that can be taken to preserve or enhance existing buffers include:

- Delineating buffer boundaries and establishing management zones within the buffer (streamside, middle, and upland zones);
- Developing vegetative and use strategies within these zones;
- Establishing provisions for buffer crossings;
- Integrating structural runoff management practices where appropriate to protect the buffers and to augment their performance; and
- Developing buffer education and awareness programs.

A buffer can be established in the area between the stream and existing development when buildings are set back from the stream to prevent damage from flooding. These areas can be mapped and buffer boundaries established based on runoff and pollutant loadings. In some cases, impervious surfaces in the buffer need to be removed or parts of the buffer regraded to ensure maximum pollutant removal efficiency. The buffers are then divided into three zones—the streamside, middle, and upland zones—that contain different types of vegetation and accomplish pollutant removal in different ways (Herson-Jones et al., 1995). Design considerations for stream buffers are discussed in more detail in Management Measure 3.

10.3.6 Redevelop Urban Areas to Decrease Runoff-Related Impacts

10.3.6.1 Encourage infill development

Infill development is a tool planners use to encourage siting of new development on unused lands in existing urban areas. Infill development usually works in tandem with community redevelopment initiatives to foster revitalization of existing neighborhoods by replacing dilapidated buildings and underused properties with new housing or businesses. However, from a water quality perspective, if infill development is promoted on unused lands in existing developed areas, sites should be selected that result in decreased pollutant loadings and runoff volumes. Open space that provides valuable flood control and pollutant removal functions should be preserved or enhanced if possible. Trees within existing developments should be protected or replanted as necessary.

Infill and redevelopment can be employed in either large or small projects. One impediment to more widespread implementation of infill projects is the existing condition of a potential redevelopment site in terms of environmental constraints. The restrictive nature of many land use regulations and pressing social and economic issues may also impede implementation. Faced with these constraints, local governments often need to modify local zoning or building codes to make infill development and redevelopment more inviting to developers. Experience has shown that citizen involvement has often been a catalyst for leveraging funding or revising codes for this type of renewal.

10.3.6.2 Assess vacant, abandoned lots and areas of potentially contaminated soils to promote redevelopment

In many urbanized areas, changes in development patterns and economic decline have resulted in deterioration or abandonment of industrial and commercial sites. Many of these sites have contaminated and compacted soils that discharge polluted runoff during and after storms. These underused areas can be identified and assessed to determine if redevelopment or remediation can result in significant reductions in pollutant loadings or flow to improve surface water or ground water quality. Social and economic benefits may also accrue. Redevelopment plans can include the use of practices such as disconnection of impervious areas to reduce the total effective impervious area (see section 4.3.2) or infiltration practices including bioretention and onsite runoff storage.

EPA's Office of Solid Waste and Emergency Response has a brownfields initiative that encourages the redevelopment of abandoned, lightly contaminated industrial sites in economically stressed communities (USEPA, 1999). The program provides funding and guidance to help communities locate potential brownfields redevelopment sites, to perform soil and ground water assessments to determine the nature and extent of contamination, and to promote environmental clean-up and redevelopment of these sites. The program includes tax incentives for potential redevelopers and waivers of liability for past contamination. It encourages federal, state, and local coordination of enforcement activities and stakeholder and community involvement to identify and plan new uses for brownfields to promote environmental health and safety, environmental justice, and economic growth for economically depressed communities.

The brownfields initiative has several advantages for communities with underused, potentially contaminated sites. It provides a catalyst for assessment of urban areas for sites in need of clean-up and redevelopment to improve the community's surface water and ground water quality, quality of life, and property values. Redeveloping properties that have already been disturbed helps to prevent development of greenfields—undeveloped suburban areas—and slows the growth of imperviousness in the outskirts of urban areas. It also provides an incentive for communities to alleviate soil and ground water contamination and to convert abandoned, eyesore lands to viable businesses, recreational facilities, or other uses.

In 2002, the brownfields program was expanded and strengthened through ratification of the Small Business Liability Relief and Brownfields Revitalization Act (see http://www.epa.gov/brownfields/sblrbra.htm for more information). More information about EPA's Brownfields Initiative is available at http://www.epa.gov/brownfields.

Chicago Calumet Initiative

Calumet is located on the southeast side of Chicago along the Calumet River, adjacent to Lake Michigan, that has been subject to more than 120 years of heavy industrial activity. Calumet currently has thousands of acres of contaminated brownfields located amongst open space that serves as habitat for many types of wildlife, including birds listed by the state as endangered or threatened.

In 2000 Chicago mayor Richard Daley and former Governor George Ryan launched the "Calumet Initiative," a revitalization project that involves brownfields clean-up, the preservation of land and wetlands, urban forestry, renewable energy, and low impact development. The City is working in partnership with the Illinois Department of Natural Resources, the U.S. Forest Service, EPA, the Fish and Wildlife Service, the Illinois Environmental Protection Agency, and 15 other governmental partners.

The Initiative includes plans to redevelop 3,000 acres of brownfields into a region with sustainable industries such as a new Ford Motor Company supplier park that uses low impact development techniques and minimizes runoff to adjacent waterbodies. The Calumet Tax Increment Financing District was established to encourage industries to relocate to the revitalized area.

The Calumet Open Space Reserve will provide 4,800 acres of rehabilitated and preserved wetlands and crucial habitat for the 700 plant and 200 bird species that occupy the land currently. The property will be managed through a watershed-based ecological management strategy combined with land acquisition and preservation (NALGEP, 2003).

10.4 Information Resources

The *Anacostia Watershed Restoration Progress and Conditions Report 1990–1997* summarizes accomplishments and ongoing projects of the Anacostia Watershed Resoration Committee as they relate to their six restoration goals. In addition, the report provides recommendations to the committee for future actions to sustain and further promote the restoration effort.

The Federal Interagency Stream Restoration Working Group (2000), which is a collaboration among of 15 federal agencies including EPA and USDA, published *Stream Corridor Restoration: Principles, Processes, and Practices*. This document covers background information about stream corridors, including processes, characteristics, and disturbances; development of a stream corridor restoration plan; and application of restoration principles to stream corridor projects. *Stream Corridor Restoration: Principles, Processes, and Practices* can be purchased or downloaded in PDF format at http://www.nrcs.usda.gov/technical/stream_restoration/newgra.html.

Riparian Buffer Strategies for Urban Watersheds (Herson-Jones et al., 1995) provides guidance on riparian buffer programs used to mitigate the impact of urban areas on nearby streams. The document uses the results of a national survey of riparian buffer programs as well as a comprehensive review of riparian buffer literature to make recommendations on buffer design. It also analyzes buffer pollutant removal potential and pollution prevention techniques via chemical, biological, and physical processes. It is available for purchase at http://www.mwcog.org/ic/95703.html.

The Save Our Streams Program is a national watershed education and outreach program by the Izaak Walton League (no date). The league offers many stream-related resources, including information on stream projects and publications such as *A Citizen's Streambank Restoration Handbook*. The Save Our Streams Program can be reached by e-mail at sos@iwla.org, by calling 1-800-BUG-IWLA, or by visiting the Web site at http://www.iwla.org/sos.

The Natural Resources Conservation Service's National Conservation Buffer Initiative Web site (http://www.nrcs.usda.gov/feature/buffers/) contains information about buffers, links to technology information, and buffer initiative contacts (NRCS, no date).

Urban Restoration: A Video Tour of Ecological Restoration Techniques (Riley, 1998b) is a video tour of six urban stream restoration sites. It includes background information on how the projects were funded and organized with community involvement and the history and principles of restoration. Additionally, examples are presented of stream restoration in very urbanized areas, recreating stream shapes and meanders, creek daylighting, soil bioengineering, and ecological flood control projects. A companion to the video is *Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens* (Riley, 1998a). This book includes detailed information on all relevant components of stream restoration projects, from historical background to hands-on techniques. The book and video can be purchased at http://www.noltemedia.com/nm/urbanstream/index2.html.

EPA and the LID Center conducted a literature review of LID studies to assess the state of knowledge about LID practices (USEPA, 2000c). The final report contains a brief overview of LID principles and programmatic issues such as use, ownership, and cost. The heart of the document is a summary of the information available regarding the pollutant removal effectiveness of the most common LID practices. The report is available for download in PDF format at http://www.epa.gov/owow/nps/lidlit.html. This page also contains links to low-impact development fact sheets on bioretention, vegetated roof covers, permeable pavements, and street surface storage of runoff.

EPA's River Corridor and Wetland Restoration Web site contains general information about restoration and its benefits, a list of restoration guiding principles that cover the entire life of a restoration project from early planning to postimplementation monitoring, restoration project descriptions, and links to other restoration resources. The site is located at http://www.epa.gov/owow/wetlands/restore.

The Center for Watershed Protection developed 11 manuals, called the Urban Subwatershed Restoration Manual Series, that present the information needed to restore small urban watersheds in a format that can easily be accessed by watershed groups, municipal staff, environmental consultants, and other users. The manuals are available for a fee in hard copy or as a download at http://www.cwp.org/USRM_verify.htm.

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MANAGEMENT MEASURE 11
OPERATION AND MAINTENANCE

11.1 Management Measure

Develop a program for regular inspection and maintenance of urban runoff management practices.

- Develop and implement an operation and maintenance plan for urban runoff management practices. The plan should include scheduled inspections, scheduled maintenance activities, and scheduled evaluations of operation and maintenance practices.
- Inspect, maintain, and repair runoff treatment controls to maintain design treatment capacity.
- Inspect, maintain, and restore riparian buffers.

11.2 Management Measure Description and Selection

11.2.1 Description

The maintenance of storm water controls is essential to ensure that overall program goals are met and that each management practice or set of practices continues to function as designed. Storm water controls need to be periodically inspected and maintained as necessary to fine-tune performance, prevent malfunction, and address any problems that may arise. Although maintenance issues should be a major consideration during the management practice selection process, they are often overlooked and inadequately planned for and budgeted. As a result, many management practices fail to perform as intended.

An operation and maintenance (O&M) plan is one way to systematically ensure that scheduled inspections, maintenance, and practice evaluations occur. Formalizing an operation and maintenance plan also can be helpful in determining and securing the funding necessary to properly operate and maintain runoff management practices.

Program managers should consider incorporating the following elements in their operation and maintenance programs:

- Scheduled inspections (based on climate, precipitation, and runoff management practice);
- Scheduled maintenance activities, such as removal of forebay sediment;
- Use of maintenance checklists to systematize and document the inspection process; and
- Initial and follow-up monitoring of management practices to establish performance baselines and trends to guide maintenance activities.

Maintenance activities may vary by management practice. For example, vegetation management is necessary for some extended detention wet ponds and constructed wetlands to maintain optimal removal efficiency, to avoid the net export of nutrients during winter, and to maintain design flow patterns. Removal of sediment build-up is essential to maintain properly functioning practices. Infiltration devices must be protected and maintained to prevent pore clogging and loss of infiltration capacity.

Preventative maintenance may also be necessary to protect the performance of management practices. Run-on sedimentation from off-site areas may need to be addressed through stabilization measures to prevent unnecessary maintenance expenditures.

The incorporation of maintenance considerations into management practice designs will often reduce subsequent maintenance costs and repairs and help to avoid failures. For example, the removal of material from sediment traps can be facilitated by designs that allow easy access to accumulated sediments without specialized equipment. Safe and convenient access to inlet and outlet structures can reduce maintenance costs and prevent nuisance flooding. Finally, the use of proper construction techniques and phasing can reduce the potential for initial clogging of infiltration devices during the construction process.

Enforcement of inspection and maintenance programs is crucial to their success. A 1992 study in Maryland evaluated 250 storm water practices to determine whether they were being maintained in compliance with the state's Stormwater Management Act. The researchers found that after a few years, approximately one-third of the practices were not functioning as designed, and most required maintenance. Approximately one-half of the facilities were undergoing sedimentation and many had problems with clogging (Lindsey et al., 1992). Implementing the practices described under this management measure can help develop an effective O&M program for continued effectiveness and longevity of runoff management practices.

11.2.2 Management Measure Selection

This management measure was selected because improper operation and maintenance of runoff control practices can result in poor performance and increased discharge of pollutants to downstream waters. Flooding may occur and downstream channel stability could be jeopardized. Poorly maintained runoff systems also may increase risks to public safety and the potential for property damage.

To prevent these potential impacts, effective maintenance programs should include standards for the inspection and maintenance of runoff controls. The entities responsible for maintaining runoff controls must be clearly identified and adequate resources must be provided to conduct the necessary maintenance activities. Because maintenance issues are critical to successful program implementation, they should be planned for at the outset of the runoff management program and conducted continuously for the lifespan of the practice(s).

The following section contains descriptions of specific O&M requirements for various types of management practices.

11.3 Management Practices

11.3.1 Establishing an Operation and Maintenance Program

The following section outlines several practices that will facilitate development of a runoff control O&M program.

11.3.1.1 Establish a runoff control operation and maintenance ordinance

One way for local governments to ensure that maintenance of runoff control facilities is performed is to establish an ordinance that mandates these activities. The O&M language in a runoff control ordinance can specify that runoff management practices must be designed to facilitate easy maintenance and require that regular maintenance activities be performed.

EPA (2000) has provided model ordinance language (at http://www.epa.gov/nps/ordinance) that includes consideration of maintaining runoff control management practices. Ordinance language examples from across the country are provided, including a sample maintenance agreement, a sample easement and right-of-way agreement, an inspection checklist, and a performance bond.

It is important for O&M ordinances to contain language that requires the identification of the specific entity or entities responsible for long-term maintenance and requires regular inspection visits. The ordinance also should provide design guidelines that can help ease the maintenance burden, such as the inclusion of maintenance easements. Note that runoff control ordinance language regarding the maintenance of erosion and sediment control practices differs from that regarding maintenance of postconstruction controls because of the short-term nature of the former.

The City of Alexandria, Virginia has incorporated inspection and maintenance requirements into the Alexandria Zoning Ordinance. The ordinance requires the submission of a long-term inspection and maintenance plan that identifies all maintenance requirements and responsible parties. A standard maintenance and monitoring agreement approved by the city council is required for urban runoff practices in Alexandria and cannot be modified without council approval (Bell, 1997).

11.3.1.2 Make provisions for maintenance in the design and construction of management practices

Because maintenance programs play such an important role in ensuring the proper operation of most structural practices and some source controls, emphasis should be given to maintenance issues when identifying management practices under any runoff management program. Making provisions for maintenance at the design and construction phase involves identifying the urban runoff practices to be used when designing a new facility. Practices should be designed so that maintenance equipment (mowers and vacuum trucks) can easily access the site. Many practices have been designed with inadequate pre-treatment (i.e., without a sediment basin at the inlet), and they have not performed as anticipated. Inlet and outlet structures also tend to clog easily without proper design and maintenance. Adequate size and storage volume based on expected sediment loads from the contributing drainage area should be factored into the design of inlets and pre-treatment structures.

11.3.1.3 Identify mechanisms for program funding

It is important to identify the entity responsible for operating and maintaining structural runoff control practices. The responsible party can be a property owner, homeowners' association, certified contractor, or local government agency. Local governments may assume the responsibility of maintaining privately owned facilities. When private entities do not fulfill their maintenance responsibilities and the facilities fail, the burden of maintaining runoff control and performing downstream restoration may ultimately fall under the local government's responsibility. Public financing for maintenance of both public and private facilities can be generated from general tax revenues, storm water utility fees, inspection or permit fees, or dedicated contributions. Sources of funding should be dedicated to runoff program budgets and or maintenance programs whenever possible. A discussion of these and other financing options for maintenance of runoff control facilities is provided in Chapter 8 of the Watershed Management Institute's *Operation, Maintenance, and Management of Stormwater Management Systems* (1997).

It is important that the funding source for maintenance of runoff control facilities be supported by the public. The Watershed Management Institute (1997) stresses the importance of public education to inform citizens about the locations and functions of runoff control facilities and the importance of regular maintenance. The institute believes that citizens and government officials will be more willing to allocate funds to projects that they know will provide tangible benefits to the community. The institute also recommends that funding programs for maintenance activities have the following attributes:

- Be based on a stable source of consistent funds that will ensure a long-term commitment of personnel, equipment, and materials;
- Be compatible with the local organizational structure to allow use of existing billing, collection, and bookkeeping operations;
- Include provisions for four essential operations: (1) program administration; (2) accounting and budgeting; (3) revenue management; and (4) information management;
- Be based on an equitable, understandable, and defensible fee or rate structure;
- Be continually reviewed and updated to meet the changing maintenance needs of the runoff control program; and
- Be consistent with applicable state laws and regulations.

11.3.1.4 Plan regular inspections

Inspections are essential to maintain the successful operation of the facility. Inspectors should have on hand equipment necessary for taking measurements and making minor repairs, be trained in identifying and remedying problems, and have a set of standard inspection procedures from which to work. An inspection schedule and checklist for each type of management practice should be developed and followed. Inspections and maintenance should be conducted both on a regular schedule and following storms to identify and repair any damage.

11.3.1.5 Schedule maintenance, cleaning, and debris removal to avoid sediment accumulation

Sediment and debris can contain hazardous contaminants and can clog filtration and infiltration practices, reducing their effectiveness over time. In addition to major structural controls, maintenance programs should include measures for cleaning catch basins and drainage channels. Establishment of an effective O&M program should include the creation of maintenance logs and identification of specific maintenance triggers for each class of control (e.g., removing sediment from forebays every year and retention ponds every five years, cleaning catch basins at least annually prior to the rainy season, removing litter from channels twice a year). If maintenance activities are scheduled infrequently, regular inspections should be made to ensure that the control is operating adequately. Additionally, maintenance should be performed following significant storms.

11.3.1.6 Make provisions for monitoring treatment criteria

Regularly monitoring the influent to and effluent from structural management practices will support program goals by facilitating development of a database to track the effectiveness of these practices, which can help guide future decisions about management practice implementation. These data will make it easier to quantify the performance of the practice and determine the behavior of the system as a result of regular maintenance.

11.3.1.7 Implement training and certification programs to provide educational opportunities for management practice operators

Training and certification programs are gaining popularity around the country at both the state and local levels. Municipalities sometimes use contractors to conduct inspections and maintenance because resources are not available to purchase equipment and hire dedicated staff. Good training programs can ensure that inspections and maintenance activities are carried out in a thorough and consistent manner. Also, training programs can be customized to address local concerns and conditions such as high flows, highly erodible soils, or invasive species.

11.3.1.8 Disposal of residuals

Runoff can carry both natural and anthropogenic pollutants and materials to receiving waters. Natural materials, such as leaves and soils, can accumulate in the system and cause localized flooding. Anthropogenic sources, which include oil and grease, heavy metals, deicing materials, and litter, can become adsorbed to leaf litter and sediments (Lenhart and Harbaugh, 2000). The mixed composition of solids that are removed from the storm drain system (termed residuals) can require special handling and treatment, which increases disposal costs (Field and O’Shea, 1994). The characteristics of residuals tend to vary with season and land use. Table 11.1 summarizes the results of a number of studies analyzing residuals in runoff (Field and O’Shea, 1992; Marquette University, 1982; Schueler and Yousef, 1994).

Table 11.1: Properties of urban storm water solids/residuals (adapted from USEPA, 1999).

Properties of Residuals	Wet Ponds[1]	Sediment Basin[2]	Swirl and Helical Bend Solids Separators[3]	In-Line Upsized Storm Conduit[4]	Urban Storm Water Runoff Residuals[5]
Solids					
Volatile Suspended Solids	6%	104–155 mg/l	107,310 mg/l	25,800 mg/l	90 mg/l
Total Suspended Solids	43%	233–793 mg/l	344–1,140 mg/l	161,000 mg/l	415 mg/l
Nutrients					
Phosphorus	583 mg/kg	< 5 mg/l	<5 mg/l	0.3–2,250 mg/l	502–1,270 mg/kg
Total Kjeldahl Nitrogen	2,931 mg/kg	<5 mg/l	<5 mg/l	0.3–2,250 mg/l	1,140–3,370 mg/kg
Heavy Metals					
Zinc	6–3,171 mg/kg				302–352 mg/kg
Lead	11–748 mg/kg				251–294 mg/kg
Chromium	4.8–120 mg/kg				168–458 mg/kg
Nickel	3–52 mg/kg				69–143 mg/kg
Copper	2–173 mg/kg				251–294 mg/kg
Cadmium	No detect–15 mg/kg				
Iron		6.1–2,970 mg/l	6.1–2,970 mg/l	6.1–2,970 mg/l	
Hydrocarbons	2,087-12,892 mg/kg				

[1] Scheuler and Yousef, 1994
[2] Marquette University, 1982 (Racine, Wisconsin)
[3] Marquette University, 1982 (Boston, Massachusetts)
[4] Marquette University, 1982 (Lansing, Michigan)
[5] Field and O'Shea, 1992

A system for managing residuals in runoff should address the proper handling and disposal of both liquid and solid residuals. Ponds, infiltration practices, vegetative controls, and catch basin inserts have different removal mechanisms, and the type of residuals generated from these practices will vary. All residuals should be tested for contamination (unless the management entity has determined that residuals from an individual practice or category of practices pose no hazard), and maintenance employees should be trained in properly identifying and handling contaminated waste according to the requirements of the Resource Conservation and Recovery Act (RCRA) and state and local regulations (USEPA, 1999). Removal mechanisms and requirements for specific practices are described below.

Non-hazardous solids in residuals can be recycled, sent to a landfill, or applied to land. Land application involves spreading the material on designated land at approved application rates. The material should not be applied to cropland, but application to a nonagricultural vegetated area may be appropriate (USEPA, 1999). Disposal of the waste in a landfill may be the most expensive option because of travel costs, testing requirements, and disposal fees (Lenhart and Harbaugh, 2000).

There are a number of low-cost options for recycling. Coarse sand and gravel can be used for road base, and road sand can be recycled for winter maintenance activities. The City of Olympia, Washington uses dried solids from treatment systems by mixing them with cement. The organic portion of residuals can be composted after removing the coarse inorganic materials. These organic residuals can then be combined with yard debris, leaves, straw, or soil. The Washington Department of Transportation mixes solids with mulch and bark for use as topsoil along roadsides (Lenhart and Harbaugh, 2000). In general, urban runoff residuals have very low nutrient content and thus require mixing with high nutrient content organic matter to provide fertilization benefits (Field and O'Shea, 1994).

Additional considerations for the disposal of residuals include air and noise pollution from machinery operation at the disposal site, unpleasant odors, possible ground water or surface water contamination, and public health. To address these issues, local and state agencies should address the following when developing guidelines for disposal of residuals: application rates, treatment requirements, site suitability, and proximity to schools, parks, and residential areas (Field and O'Shea, 1994).

The City of Everett, Washington uses a source separation system that requires operators of vacuum trucks to determine whether contamination of residuals is suspected based on sheen, odor, and color. Residuals suspected of contamination are handled in accordance with state and local regulations. Otherwise, materials are collected and recycled as aggregate material on medians and selected roadsides after being tested for contamination (Lenhart and Harbaugh, 2000).

11.3.2 Source Control Operation and Maintenance

11.3.2.1 Infrastructure

(1) *Street sweeping.* Street cleaning reduces pollutants carried in runoff from street surfaces. The frequency of cleanings should reflect the rate of pollutant buildup and should increase just before the rainy season. An effective program requires that street sweeping be conducted on a regular basis. Sweeper operators require training, and equipment needs to be maintained regularly to ensure that it is functioning as designed. Finally, parking restrictions can be implemented to guarantee adequate cleaning despite on-street parking. Table 11.2 shows O&M costs associated with street sweeping. See Management Measure 7 for more information about types of street sweepers (brush vs. vacuum sweepers and their relative effectiveness, section 7.3.5.1) and roadside trash removal (section 7.3.5.4).

Table 11.2: Street sweeper O&M costs (adapted from CWP, 1998).

Maintenance Considerations		Sweeper Type	
		Mechanical Sweeper	**Vacuum-Assisted Sweeper**
O&M costs (1998 dollars)	Cost ($/curb mile)	30	15
	Weekly sweeping ($)	1,680	946
	Biweekly sweeping ($)	840	473
	Monthly sweeping ($)	388	218
	4 times per year sweeping ($)	129	73
	Twice per year sweeping ($)	65	36
	Annual sweeping ($)	32	18
Expected life (years)		5	8

(2) *Storm drain flushing*. This practice is used to remove deposited materials from storm drain pipes to maintain their flow capacity. The flushing schedule should be designed to prevent excessive buildup based on estimated inputs from the contributing drainage areas, cleaning history, and visual inspections. Flushing is performed either at or upstream from problem areas. There are costs to consider for collecting and disposing of sediments, debris, and flush water, in addition to supplying flush water and treating sediment-laden water if the storm drains are being flushed to a receiving water body.

(3) *Catch basin cleaning*. Cleaning catch basins removes excess pollutants, thereby reducing high pollutant concentrations in a storm's first flush, preventing clogging, and restoring sediment-trapping capacity. Maintenance should target areas with the greatest pollutant loading and those near sensitive water bodies. A maintenance log should be kept to track progress. If there are many catch basins in a community, mechanical cleaners (vacuums or bucket loaders) may be required; otherwise, hand cleaning will suffice. Proper record-keeping, waste disposal, and safety procedures are essential for a successful program.

(4) *Highway, bridge, and road maintenance*. Maintenance of roads and bridges can be a significant source of pollutants. Some methods to prevent materials from contaminating runoff are limiting the use of salts; using suspended tarps, vacuums, or booms to reduce pollutant drift onto waters from scraping and painting; and training road crews in proper waste control and disposal methods. Treatment controls also can be used on-site to reduce the amount of polluted runoff that enters receiving waters. Runoff reduction, conveyance, and treatment practices (e.g., infiltration swales in median strips) can be incorporated into the design of new roadways and bridges to help contain pollutants from traffic as well as from

Sediment Removal from Catch Basins

The Delaware County, New York, Department of Public Works, with the assistance of the Catskill Watershed Corporation, purchased a vacuum truck capable of removing sediment from culverts and catch basins. The truck, which has a 30-foot pipe reach and a 12 cubic yard storage capacity, is available for use by neighboring counties based on need and availability. In the first month of operations, approximately 700 cubic feet of sediment was removed. The sediment s disposed of without posing a threat of contamination to the Cannonsville and Pepacton reservoirs. The County will be sampling sediment in an attempt to quantify the amount of contaminants removed (Delaware County Departments of Planning and Public Works, 2003).

maintenance activities. For more information about runoff management practices for roads, highways, and bridges, see Management Measure 7: Bridges and Highways.

11.3.2.2 Trash in channels and creeks

Clean-up of trash from streams and storm water conveyance infrastructure can reduce pollutant levels in downstream waters. Areas where dumping occurs frequently can be identified and inspected regularly, and "no littering" or "no dumping" signs can be posted to deter future dumping. Steep fines for dumping may also discourage potential transgressors. Associated costs for these practices are the purchase of signs and equipment, paying personnel to conduct inspections and clean-up, and providing landfill space to dispose of recovered items. Cost savings can be achieved through community or volunteer clean-up programs.

11.3.3 Treatment Control Operation and Maintenance

Runoff treatment controls require periodic inspection and maintenance to ensure that sediment, trash, and overgrown vegetation are not impeding their performance. Regular inspections should be performed along with routine maintenance. Nonroutine maintenance may be required to repair structures, control erosion, and remove unwanted vegetation. Table 11.3 and the following practices describe maintenance costs, activities, and schedules for several categories of urban runoff treatment practices.

Table 11.3: Maintenance costs, activities, and schedules for runoff control practices in 1998 dollars (Adapted from CWP, 1998).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Detention ponds or vaults	Dry ponds	~1%	$1,200	– Cleaning and removal of debris after major storms (>2" rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repair of embankment and side slopes – Repair of control structure	Annual or as needed
				– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle

Table 11.3 (continued).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Ponds	Extended detention ponds, wet ponds, multiple pond systems, "pocket" ponds	3%–6%	$3,000–$6,000	– Cleaning and removal of debris after major storm events (>2" rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repair of embankment and side slopes – Repair of control structure	Annual or as needed
				– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle
Wetlands	Shallow wetlands, pond wetlands, "pocket" wetlands	~2%	$3,800	– Cleaning and removal of debris after major storm events (>2" rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repair of embankment and side slopes – Repair of control structure	Annual or as needed
				– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle

Table 11.3 (continued).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Infiltration practices	Infiltration trench	5%–20%	$2,300–$9,000	– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle
	Infiltration basin	1%–3%	$150–$450	– Cleaning and removal of debris after major storm events; (>2" rainfall) – Mowing and maintenance of upland vegetated areas – Sediment cleanout	Annual or as needed
		5%–10%	$750–$1,500	– Removal of accumulated sediment from forebays or sediment storage areas when 50% of the original volume has been reduced	3- to 5-year cycle
Open channel practices	Dry swales, grassed channels, biofilters	5%–7%	$200–$2,000	– Mowing and litter/debris removal – Stabilization of eroded side slopes and bottom – Nutrient and pesticide use management – Dethatching of swale bottom and removal of thatching – Discing or aeration of swale bottom	Annual or as needed
				– Scraping of swale bottom, and removal of sediment to restore original cross-section and infiltration rate – Seeding or sodding to restore ground cover (use proper erosion and sediment control)	5-year cycle

Table 11.3 (continued).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Filtration practices	Sand filters	11%–13%	$2,200	– Removal of trash and debris from control openings – Repair of leaks from the sedimentation chamber or deterioration of structural components – Removal of the top few inches of sand, and cultivation of the surface, when filter bed is clogged	Annual or as needed
				– Clean-out of accumulated sediment from filter bed chamber once depth exceeds approximately ½ inch, or when the filter layer will no longer draw down within 24 hours – Clean-out of accumulated sediment from sedimentation chamber once depth exceeds 12 inches	3- to 5-year cycle
	Bioretention	5%–7%	$3,000–$4,000	– Repair of erosion areas – Mulching of void areas – Removal and replacement of all dead and diseased vegetation – Watering of plant material	Biannual or as needed
				– Removal of mulch and application of a new layer	Annual
	Filter strips	$320/acre (maintained)	$1,000	– Mowing and litter/debris removal – Nutrient and pesticide use management – Aeration of soil on the filter strip – Repair of eroded or sparse grass areas	Annual or as needed.

11.3.3.3 Ponds and wetlands

Extended dry detention ponds are submerged only during storms and are dry between storms. Depending on the type of vegetative cover used, they may require mowing at least once a month to maintain turf grass cover, or once a year to prevent the establishment of woody vegetation. Sediments should be removed when they are dry and cracked to separate them from vegetation more easily. Pilot or low-flow channels require inspection to prevent undermining of concrete channels and overgrowth of stone channels. Inlets and outlets should be cleared of sediment and debris to prevent clogging.

Wet ponds are susceptible to algae blooms as a result of high nitrogen levels and may need to be cleaned periodically. Sediments that accumulate in the pond inlet or forebay should be removed more frequently than fine sediment, which collects near the pond outlet. Sediment removal requires draining the pond (some water to maintain fish populations should be left), collection of solids, and drying and testing of the residuals before disposal. Pond water should be disposed of in a locally approved manner; it should be tested for pollutants and released to the receiving water, if allowed, or pumped and hauled to a disposal facility. During the period in which the stockpiled materials are drying, erosion controls should be implemented to prevent sediment loss. All structures and surrounding areas should be inspected for leakage, seepage, corrosion, and wear and tear. Inspectors and crews should pay special attention to structural integrity to ensure that ponds operate safely.

Constructed wetlands should be inspected approximately four times per year to determine if they are retaining and discharging storm water at an appropriate rate and whether maintenance is needed. Constructed wetlands require periodic cropping; removal of trash, weeds, invasive species, or woody vegetation; repair of animal burrows in embankments; and clearing of inlets and outlets. Side slopes should be stabilized with vegetative cover to prevent erosion. Wetland plants should be thinned and transplanted as necessary to maintain adequate cover throughout the wetland. In general, semiannual sediment removal is recommended to ensure that treatment capacity is maintained. Mosquitoes may be a problem in some areas, and introducing natural predators such as mosquito fish (*Gambusia*) can be one method of control. Consultation with a wetland scientist is recommended to ensure that the constructed wetland functions as intended.

11.3.3.4 Infiltration practices

Infiltration practices, such as basins, trenches, vegetated swales, and porous pavement, are subject to clogging from sediment, oil, grease, and microbes. Clogging impairs their effectiveness in reducing runoff volume and pollutant loading to downstream waters. When clogging occurs, standing water tends to collect. Seasonal water table fluctuations or ground water mounding can also cause standing water. Facility inspection during dry periods will identify whether standing water is present and provide clues to the possible causes. Inspections should include a site assessment of the contributing drainage area because sediment accumulation in a facility stems from erosion in surrounding areas that can be prevented if the areas are adequately stabilized. The frequency of required maintenance depends on loads from the contributing drainage areas.

If clogging results in pooling, sediment can be removed to restore the facility to its original capacity. If the standing water results from high water table conditions, the facility owner should consider converting the site to a permanent pool facility such as a constructed wetland or detention pond. For systems designed with filter fabric to collect sediments, periodic inspections can identify when and where the mesh should be replaced. In cold climates where street sanding occurs in the winter, the filter fabric in infiltration devices adjacent to roads and parking lots should be replaced prior to spring.

Promotion of a vegetative cover will help to maintain percolation rates, slow runoff velocity, and minimize ground water pollution. To maintain aeration and permeability, nonvegetated basins require tilling or disking and leveling after sediment is removed. Vegetated filters adjacent to infiltration trenches should be cleared of sediments periodically to prevent sediment loading to the trench.

Regular monitoring of infiltration rates after storms will indicate when maintenance is required to maintain the system's treatment design capacity.

11.3.3.5 Filtration practices

Filtration practices include media filters (typically sand) and biofilters. Sand filters contain two phases: a sedimentation chamber and a filtration chamber. The sedimentation chamber can be inspected by measuring to determine if the deposited sediments are becoming deep enough to interfere with the filtration chamber. Different types of sand filters require different levels of maintenance. The Austin sand filter system usually requires maintenance every five to 10 years, depending on the stability of soils in the contributing areas, and can be treated like a dry detention facility. The filter component can be raked of fine sediments or skimmed with a shovel to restore permeability. The Washington and Delaware sand filter sedimentation chambers, which maintain a pool of water, should be vacuumed to remove sediment when inspections identify accumulation greater than 75 percent of capacity. Filtration chambers for these systems may need to be cleaned of fine particles as frequently as twice per year to maintain their efficiency and prevent overflows. A flat-bottomed shovel can be used to remove the sediment-laden filter media and roughen surfaces to improve permeability.

Each system should be inspected for vandalism, leaks, cracks, or damage to concrete at least once per year. These problems should be remedied immediately. Forebays should be pumped or cleaned as necessary. All materials removed from the systems should be tested for contamination and to identify how the material should be disposed of (e.g., as clean fill, in a landfill, or as a hazardous waste).

Biofiltration system vegetation should be mowed periodically to maintain an optimum height (2 to 6 inches) that maximizes infiltration and minimizes runoff velocity. Special effort should be made to promote native species and exclude invasive species, which can grow too vigorously and reduce treatment capacity. Some natural vegetation replacement is desirable, such as wetland plants that colonize a low-lying biofilter. Inspection and maintenance records should reflect these changes.

Biofiltration facilities should be inspected and maintained regularly. Sediment removal is an important and sometimes expensive part of biofilter maintenance. Sediment should be removed when it fills 20 percent of the design depth in any spot or starts to cover vegetation. Efforts should be made to return the system to its original topographic and vegetative condition once the sediment has been removed. Inlets and outlets should be cleared of particles and debris to prevent backups and overflows. Biofiltration systems may also need periodic replacement or amendment of system soils if clogging has occurred.

Maintenance equipment for the tasks described previously, along with purchase and rental costs, is presented in Table 11.4.

Table 11.4: Typical O&M equipment and material costs (WMI, 1997).

Equipment	Purchase	Rent (per day)
Grass Maintenance		
Hand mower	\$300–\$500	\$25–\$50
Riding mower	\$3,000–\$7,000	\$75–\$150
Tractor mower	\$20,000–\$30,000	\$150–\$450
Trimmer/edger	\$200–\$500	\$25–\$35
Spreader	\$100–\$200	\$20–\$30
Chemical sprayer	\$200–\$500	\$25–\$40
Vegetative Cover Maintenance		
Hand saw	\$15–\$20	\$5
Chain saw	\$300–\$800	\$15–\$35
Pruning shears	\$25–\$40	\$5
Shrub trimmer	\$200–\$300	\$25–\$35
Brush chipper	\$2,000–\$10,000	\$100–\$300
Sediment, Debris, and Trash Removal		
Vactor truck	\$100,000–\$250,000	\$700–\$1,200
Front-end loader	\$60,000–\$120,000	\$250–\$500
Backhoe	\$50,000–\$100,000	\$250–\$500
Excavator	>\$100,000	\$400–\$1,000
Grader	>\$100,000	\$400–\$1,000
Transportation		
Van	\$18,000–\$30,000	\$50–\$100
Pickup truck	\$15,000–\$25,000	\$50–\$100
Dump truck	\$40,000–\$80,000	\$100–\$200
Light-duty trailer	\$3,000–\$6,000	\$50–\$100
Heavy-duty trailer	\$10,000–\$20,000	\$100–\$250
Miscellaneous		
Shovel	\$15	\$5
Rake	\$15	\$5
Pick	\$20	\$5
Wheelbarrow	\$100–\$250	\$15–\$25
Portable compressor	\$800–\$2,000	\$50–\$150
Portable generator	\$750–\$2,000	\$50–\$150
Concrete mixer	\$750–\$1,500	\$50–\$100
Welding equipment	\$750–\$2,000	\$50–\$100
Materials		
Topsoil	\$35–\$50/cubic yard	
Fill Soil	\$15–\$30/cubic yard	
Grass seed	\$5–\$10/pound	
Soil amenities	\$0.10–\$0.25/square foot	

Table 11.4 (continued).

Equipment	Purchase	Rent (per day)
Materials (continued)		
Chemicals	$10–$30/gallon	
Mulch	$25–$40/cubic yard	
Dry mortar mix	$5/50-pound bag	
Concrete delivered	$60–$100/cubic yard	
Machine/motor lubricants	$5–$10/gallon	
Paint	$20–$40/gallon	
Paint Remover	$10–$20/gallon	

11.4 Information Resources

The South Carolina Department of Health and Environmental Control (2000) published *A Citizen's Guide to Stormwater Pond Maintenance in South Carolina*, which is available for download in PDF format at http://www.scdhec.net/eqc/admin/html/eqcpubs.html. The booklet is intended as a guide for homeowners' associations and others responsible for the proper maintenance of storm water ponds. Photos and descriptions of nuisance aquatic plant species are presented in the guide to aid in identifying these species and removing them from ponds. Copies of the guide are available from Ward Reynolds at 843-747-4323.

The Stormwater Manager's Resource Center (CWP, no date) has sample O&M checklists available for download from its Web site (http://www.stormwatercenter.net/). When at the site's homepage, click on "Manual Builder" and choose "Construction and Maintenance Checklists" from the pull-down list. There are checklists for the following practices: ponds, infiltration trenches, infiltration basins, bioretention facilities, sand filters, and open channel practices.

11.5 References

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