Pennsylvania Stormwater Best Management Practices Manual

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Section 7
Stormwater Management for Urban Areas

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Section 7 Stormwater Management for Urban Areas

7.1 Introduction

The major population centers of Pennsylvania are highly urbanized, and therefore comprised of landscapes in which a significant fraction of the land area is covered with impervious surfaces (Figure 7-1). These impervious surfaces serve various functions; they provide for residential living space, commercial activities, office and manufacturing, and to convey and store our transportation vehicles. Urban landscapes have undergone significant changes over the last century as the original compacted earth streets covered with cobblestones and bricks were paved, with the advent of the gasoline-driven auto. In the larger cities and older town centers, where the close proximity of buildings was a distinct advantage, the paving of streets in combination with the construction of pedestrian access, completed the development process and resulted in a highly impervious environment.

In terms of stormwater management, the degree or extent of “imperviousness” is directly related to degraded water resources, and specifically highly polluted and greatly increased volumes of runoff. As development has extended out from the urban center into surrounding farmlands, the percentage of impervious surfaces within a given land parcel has generally been regulated, with the assumption that less impervious cover (combined with height limitations) would result in a community that did not have the negative aspects of the more dense urban centers. This has proven not to be the case, especially for stormwater. The suburban commercial center or office park can result in a highly impervious land parcel, in many cases equal to or greater than some older communities, even though

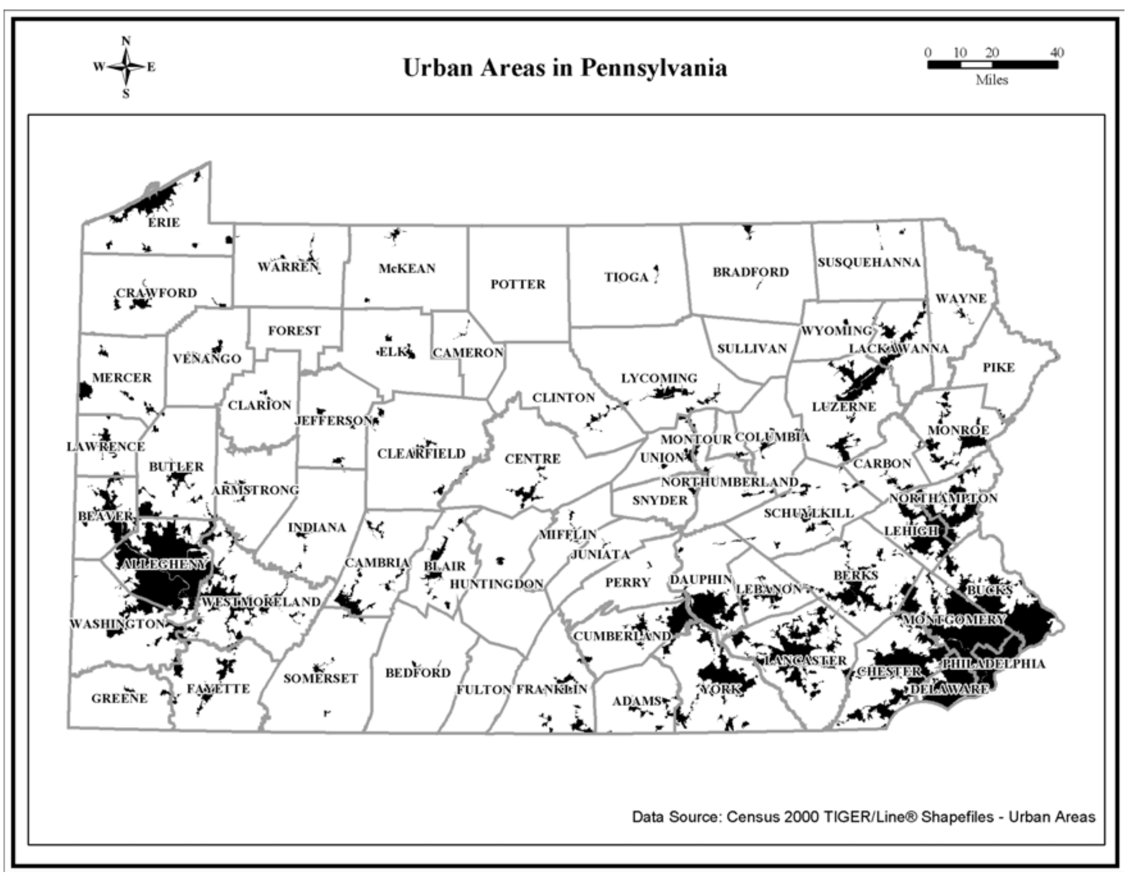

Figure 7-1. Urban lands in Pennsylvania

it exists on an isolated parcel. For residential communities, the impervious cover diminishes with distance from the urban center. Suburban residential developments are generally comprised of far less impervious cover than the urban streets, but still produce a significant pollutant load (Bannerman et al., 1993). This suburban runoff is generated in large measure from the land surface that is not strictly impervious, but has been altered and re-vegetated so that it results in significant stormwater impacts. Thus a low-density suburban residential lot might impact water quality as severely as the row home in center city Philadelphia.

7.2 Urban Water Quality

Several studies (Schueler, 2003) have indicated that the amount of impervious cover in a watershed is a good indicator of degraded water quality. The impacts of urbanization begin when a watershed approaches a level of development that can be measured as 5%, and as this level increases to the 20% impervious cover range, water quality severely degrades. This reduction of stream habitat quality occurs as a combination of increased runoff volumes eroding stream banks, NPS pollutants conveyed with this runoff, and diminished base flow. The pattern of degradation for urban streams is a dramatic increase in magnitude and intensity of runoff and a corresponding reduction in stream flow during much of the year, with drought periods resulting in a transition from perennial to intermittent hydrology. In older urban centers, where the impervious cover can reach 75% or more, the hydrologic cycle has been so severely altered that full restoration seems to be impossible, especially in terms of restoring any original stream networks that often lie in culverts beneath the city streets.

Figure 7-2. Suburban-Urban setting in West Chester, Pennsylvania

The array of suitable stormwater BMPs diminishes as the impervious surfaces increase, and in most highly urban communities the land surface not utilized by building structures or streets becomes quite limited. To add to the problem, the remaining land in surface parking lots or vegetated parks serves as the primary corridor for the full complement of “infrastructure” – sewer, water, gas, steam lines, electrical conduits and a maze of communication cables and services that leave little room in the sub-surface for any type of stormwater management BMPs, especially those that infiltrate. In the more dense urban centers, the use of structural parking is dominant as the value of land eliminates the benefit of surface parking. Many high-rise buildings also extend several floors below grade, further limiting any type of surface infiltration BMP. Nevertheless, the application of these measures should not be immediately ruled out for application, as several case studies illustrate. Even in the heart of the urban center it is possible to mitigate stormwater impacts, but the selection of appropriate BMPs becomes more difficult. The BMPs that utilize the building structures, such as vegetated roofs and capture/reuse measures seem far more suitable as the degree of urbanization increases.

The criterion for volume reduction also seems less feasible in dense urban centers, and rate mitigation becomes more useful, especially in areas with single pipe sewer lines, or combined sewers. Here the water quality impact of rainfall surcharging in the drainage system, and the resultant discharge from relief structures or Combined Sewer Outfalls (CSOs), is substantially greater than simple land runoff. The storage requirements for rate mitigation can also be much less than those intended to prevent downstream flooding or bank erosion, and are driven by the volume of detention required to prevent frequent discharges from the CSOs, usually a fraction of the peak rate criteria. The development of this specific value varies by each urban center, sewer system configuration and point of discharge, requiring hydraulic modeling to determine exact BMP design criteria.

7.3 Urban Land Characteristics That Influence Stormwater Management

The selection of suitable BMPs becomes more difficult as the degree of urbanization increases, simply because the opportunities to build or use many of the measures described here are limited. The selection process begins with an understanding of these characteristics.

Some of the challenges of managing stormwater in urban areas presented by these characteristics include the following:

1. **High densities of imperviousness**, typically greater than fifty percent and sometimes approaching one hundred percent. The developed land cover in urban areas is a mix of roads, buildings, commercial and industrial areas, surface and structured parking lots, residential neighborhoods with little or no yard space, and some limited open space. With a high degree of imperviousness, there are also high volumes of stormwater runoff, often occurring almost instantaneously with even small amounts of precipitation. Urban areas have the most runoff with the least amount of space for BMPs.

2. **High property values on a square foot basis and limited physical space for stormwater BMP's**. There may be build-out conditions, or lot-line to lot-line development, on any given urban site. Most of the property may be privately owned with the right-of-way providing the only opportunity for municipal stormwater management measures of any type. Real estate in urban areas is at a premium, and use of land for stormwater management is costly. Combining stormwater infrastructure with other building program requirements, such as stormwater infiltration located under parking lots (i.e., dual use), or vegetated roofs, recognizes and works within these cost constraints – at least to some extent. Additionally, the limited physical space available in most urban areas further constrains the staging and construction of proposed

Figure 7-3. Imperviousness cover - from building line to building line in the Village of Wayne, Delaware County, PA

Figure 7-4. Rural-Urban Streetscape, McConnellsburg, PA

stormwater management measures. BMP's must be designed with consideration of their constructability in an urban environment.

3. **Previously disturbed soils and site conditions, sometimes including contamination issues**. The soil beneath urban environments has most likely been compacted. Older cities like Philadelphia actually are built on a layer of debris from previous development, which underlies the current surface by many feet. Sometimes the current surface has been built up with fill and then compacted again. In many cases, the natural soil mantle has been altered, virtually eliminating the soil's capacity to infiltrate and/or to support vegetation. Past uses of the site may also have created horizons of soil contamination that must be removed or encapsulated. In some situations, soil restoration measures can be undertaken to improve the permeability of the soil. If contamination has occurred, remediation of various types may be feasible. In any case, soil compaction and quality must be carefully considered in urban BMP designs that incorporate infiltration or vegetation.

Figure 7-5. Urban soils, as found in West Philadelphia above, are generally compacted and disturbed

4. **An extensive network of underground utilities** such as gas lines, electric, steam lines, sanitary sewers, etc. may limit BMP options. Nearby buildings, foundations, and other structures may also require consideration. These underground utilities vary in depth and grade, and usually are constructed by compacting backfill over the utility line, so that little or no infiltration can occur in the surface soil. While the presence of many utilities may eliminate some areas from consideration for stormwater management, coordination is often possible in new or reconstruction. For example, areas underlain by water and sewer utilities may not be suitable for below-grade detention or infiltration BMP's, but may be very suitable for vegetative BMP's on the surface, making double use of the utility corridor. Similarly, groundwater flow and the hydraulic gradient with respect to nearby buildings and basements must be considered, as well as any underground structures and facilities such as steam tunnels.

5. **Severely impacted surface steams, with the original first and second order streams historically buried and enclosed in culverts**. Many urban storm sewers are in fact buried streams, especially first and second-order streams that were enclosed and buried as the urban center expanded in the late 19th century. These buried streams still serve as storm runoff conduits, but the natural movement of groundwater along and into the stream channel also occurs, with water flowing both in and out of these older sewer culverts. In some areas, the fill material above the original channel may eventually wash away, creating subsidence problems as "cave-ins" in urban streets. In other areas, the pipes serve to convey water more rapidly than the original stream would have done, creating downstream flooding or surcharging of both the sub-surface culverts and surface outlets. Deprived of both oxygen and sunlight, the original rate and water quality buffering function of first and second-order streams has been lost and must be mitigated by proposed BMP's.

One aggressive concept that has received considerable attention but little real implementation is the idea of "daylighting" buried streams. This means that the original riparian channel is restored and the culvert removed, with new stream banks cut and revegetated as appropriate. While representing a dramatic measure to restore an urban stream, the reality of fill removal and possible loss of property values along the original channel alignment usually translates into an unacceptable economic impact and disruption in the urban landscape. Even where substantial redevelopment has occurred in older cities, little serious thought has been given to the restoration of buried streams.

Figure 7-6. Headwaters to the Cobbs Creek in Haverford Township, Delaware County.

6. **Elimination of much of the original floodplain through placement of fill and structures**. Where surface streams remain in the urban environment, they have frequently been constrained by channels and structural embankments. The natural floodplain has been filled, eliminating the flow buffering capacity of the riparian section. This practice has been widespread throughout the state, and countless urban streams are now confined to concrete swales and channels. In most of these "channelized" streams, fill has been placed within the floodplain and even the floodway. Where these structures can be modified, removal of floodplain fill and restoration of the natural riparian section can serve as an important BMP.

Figure 7-7. Gabion boxes encroach on the riparian section and constrain the natural floodplain.

7. **Direct connection of impervious surfaces to the storm sewers or combined sewers**. Many urban stormwater collection systems were built with little or no evaluation of pipe capacity, hydraulic conveyance or consideration of increased impervious surfaces within the drainage area. As a result, most urban storm sewers experience substantial overloading and overflow surcharge conditions even in moderate storm events, as evidenced by the frequent "ponding" of inlets. In more severe cases, flooding occurs. Numerous small BMP's, sometimes lot by

lot, can serve to mitigate such flow impacts in urban areas, and are often less costly and less disruptive than replacement of the under-designed stormwater collection system with larger pipes that only serve to convey the stormwater flow problem farther downstream.

Figure 7-8. Direct connection of roof leaders to storm sewers, West Chester, PA.

8. **Combined sanitary-storm sewers** in some older urban areas. Cities with combined sewers and overflow outlets (CSOs), where stormwater collection is combined with wastewater collection, must incorporate a decentralized stormwater approach into their planning. In this case, the focus is likely to shift to short-term storage, with the intent of "holding" stormwater runoff until the storm passes, with gradual release to the treatment plant location. Another option would be to intercept runoff before entering the collection system and simply "shave the peak" to reduce CSO overflows. Once runoff enters inlets, it usually mixes quickly with sanitary sewage, making it impossible to intercept pipe flow and direct it into stormwater elements. Intercepting runoff must be done at the surface so that the flow is "caught" before it joins a sewage flow. Inlets, pipes, and outlet control structures may need to be altered to accomplish this, which can be an important challenge when retrofitting stormwater elements in urban areas.

Figure 7-9. Combined Sewer Overflow to the Darby Creek in Philadelphia.

Figure 7-10. Combined Sewer Overflow to the Brandywine Creek (Wilmington, DE).

9. **High levels of trash and debris**, including concentrated areas of pet waste, characterizes many urban streets. A high degree of imperviousness, combined with a curb and gutter system designed to flush and convey debris, makes the urban landscape produce significant pollutant loads, which in turn are rapidly conveyed to receiving surface streams. The use of various devices to intercept and contain these waste materials offers some measure of pollutant reduction, if maintenance is performed on a regular basis. Street cleaning by vacuum units also presents a very efficient method of pollutant removal, but first cost combined with operation and maintenance makes this BMP a significant investment for any urban community. In one urban center (Santa Monica, CA), the street gutters have been formed with porous concrete and infiltrating underdrains, combined with traps at corner inlets. Less dense residential portions of the urban community may utilize a variation of this approach, where shallow infiltration can be accomplished.

Figure 7-11. Trash and debris accumulate in urban streams.

Figure 7-12. Gas stations are common stormwater hotspots.

10. **A higher density of stormwater "hot spots"** such as gas stations, industrial areas, vehicle service areas, public works storage areas, etc. are found in urban communities, especially in the industrial zones. Smaller facilities, such as fueling islands and dumpster pads, should be treated as separate sources of pollution, and runoff prevented or segregated from surface runoff. On the larger scale, a block-by-block strategy may be appropriate in portions of the community where pollutant-producing activities are concentrated.

11. **Regulations and ordinances that may conflict with current BMP design strategies**. In many urban areas, local codes and regulations may require designs that are contrary to current BMP design. For example, local codes may require that all roof leaders be connected directly to a storm sewer, or that all streets have curbs and gutters. Local code officials may not be familiar with on-going stormwater management efforts. In these instances, early review of local requirements and communication to the appropriate officials is necessary to avoid BMP construction delays or denials. Long-term, review and updating of local ordinances may be warranted, with model urban guidelines developed by PADEP.

12. **Limited economic resources**, and the need to encourage – not discourage- redevelopment in depressed or blighted communities adds an additional dimension to stormwater management. These conditions have led some states (such as New Jersey) to exclude such

communities from new stormwater regulations. The imposition of stringent regulations that are not feasible may serve to direct redevelopment to undeveloped sites outside the urban center. Brownfield parcels with significant residual contamination must be designed carefully to assure that any residual pollutants are not mobilized by stormwater BMPs. Highly contaminated sites may warrant excavation and removal of materials before any BMP can be installed. Stormwater management must not be detrimental to the economic health of urban areas, because this would ultimately be more damaging to the overall water resources of an area.

7.4 Stormwater Control Guidelines and Urban Areas

In many urban areas, Stormwater Control Guideline 1 may be difficult to achieve, especially on sites that are retrofitted for stormwater management, rather than redeveloped from the ground up. Specifically, not increasing runoff volumes for up to the 2-year storm (as compared to natural conditions) may present a physical or financial hardship within the physical constraints of an existing urban site. However, some measure of volume control, as well as water quality improvement and peak rate reduction, is generally achievable. For most urban areas, Stormwater Control Guideline 2, which requires much more limited volume control in comparison with Standard 1, should be achievable.

In many urban areas, the issues of storm sewer surcharging and localized flooding are of great concern. The cost of enlarging the storm sewer infrastructure and installing downstream flood control and water quality measures can be enormous and can significantly exceed the cost of implementing numerous, decentralized BMP's throughout an urban drainage area. City, borough, and municipal officials are encouraged to consider and compare the benefits and costs of localized BMP's as compared to large-scale infrastructure improvements when addressing surcharging, flooding, and water quality issues.

7.5 Water Quality Issues in Urban Areas

Physical pollutants of frequent concern in urban areas include suspended solids, bacteria, phosphorus, nitrate, hydrocarbons, and metals. The runoff from streets is a significant source of pollutants and concern in urban areas (Barrett, et al, 1995) and is the single greatest source of water quality pollutants in the urban environment. In general, rooftop runoff is an order of magnitude less in concentration for most pollutants, and only becomes a problem when it is added to the surface flows, transporting the pollutant load accumulated on pavements, gutters and inlets. Such street runoff is affected by hydrocarbon emissions of different types including leaks from vehicles, nutrients and organics from urban vegetation, bacteria and other pollutants from pet and other animal waste, and the general mix of wastes discarded in urban environments, as well as from atmospheric deposition. Street curb and gutter systems are traditionally designed to convey, not trap, the fine particles associated with street runoff, and will carry the litter and debris directly to surface inlets, the storm sewer system and finally the receiving streams.

Increased temperature is also one of the most significant water quality impacts from urban areas, and can be considered to have a polluting effect on receiving waters, because of the direct connection and discharge of runoff from impervious areas. Although interception/disconnection of stormwater flows (i.e., peak shaving) to pervious areas may provide some limited reduction in temperature impact, opportunities for disconnection are often limited. It should be noted that lack of oxygen in receiving streams (i.e., low dissolved oxygen levels) is related to these temperature impacts of runoff from impervious areas (as temperature increases, effective dissolved oxygen levels decline, with lethal aquatic biota effects). For fish and aquatic life, temperature ultimately can be one of the most critical pollutants, presenting especially difficult challenges in urban areas.

7.6 BMP Selection and Suitability for Urban Areas

The progression of BMP selection in the urban environment is in many ways the opposite of the new development site in a suburban setting. Whereas a new program on an undisturbed and adequately sized parcel in a developing area offers the greatest opportunity to implement many if not most of the BMPS discussed previously, including rainfall infiltration, the urban site is frequently constrained in both dimension and site conditions. For this reason, we begin the BMP design process with the built structures. The implementation of BMP's in urban areas often requires that the BMP's be designed and incorporated into the structural environment – the building itself. Because of site space constraints, there is often little opportunity for large BMP's to be constructed that serve only a single stormwater function. Instead, BMP's may be incorporated into other building program elements. Examples include, but are not limited to, vegetated roof systems, rainfall capture and reuse measures, porous pavement surface parking areas with sub-surface recharge/storage beds, infiltration tree trenches with street trees, stormwater beds located beneath sidewalks, and detention structures built within (or without) the building itself. Additionally, Urban BMPs may be comprised of a number of smaller BMPs instead of a single large system.

In general, BMP's in urban areas fall into one or more of the following broad categories:

- Vegetated roof systems
- Disconnection with storage detention
- Infiltration (usually limited opportunities)
- Capture and Re-Use
- Filtration or Water Quality Treatment (inlet measures, boxes, etc.)
- Peak Rate Reduction Storage
- Preventive Pollutant removal (street vacuuming, inlet cleaning)
- Public educational campaigns

Using this Manual's BMP listings found in Sections 5 and 6, specific BMP's which have been applied successfully in urban areas include:

Reduce parking imperviousness	(Non-Structural)
Rooftop disconnection	(Non-Structural)
Disconnection from storm sewers	(Non-Structural)
Streetsweeping	(Non-Structural)
Vegetated Roof	(Structural)
Rain Garden / Bioretention	(Structural)
Porous Pavement with Infiltration Bed	(Structural)
Subsurface Infiltration Bed	(Structural)
Infiltration Trench	(Structural)
Rooftop Runoff – Capture & Reuse	(Structural)
Water quality filter	(Structural)
Water quality insert	(Structural)

Parking lot, rooftop, etc. as special detention area	(Structural)
Hybrid/other – planter boxes	(Structural)

These BMP's are detailed more thoroughly in Sections 5 and 6, and several applications are discussed below.

Reduce Parking Imperviousness: New parking lots in urban areas can follow the guidelines set out in Section 5 relating to reducing imperviousness as the result of provisions for parking, while rehabilitation of existing parking lots can be designed with some areas of pervious paving, or even re-vegetated areas if the parking spaces are under-utilized.

Rooftop Disconnection: Roof leaders (gutters) in residential, urban areas can be re-configured to drain into Rain Barrels, Planter Boxes, for example. Multiple, smaller stormwater elements placed around the home/structure can be combined to form a flexible design applicable to confined areas. Larger, commercial buildings may have internal drainage systems, which can still be disconnected into larger stormwater elements such as cisterns, planters, or vertical storage.

Disconnect from storm sewers: Disconnecting from existing storm sewers can be accomplished by either adding another inlet slightly up-gradient from the existing inlet to intercept the runoff and redirect it into a storm water feature, or closing off the existing inlet and regrading the area to drain into a stormwater feature, such as an infiltration bed.

Street Sweeping: Streets, roads, and highways constitute large percentages of urban areas, and pollutant loadings are usually greatest from these areas. Runoff from streets may end up at a treatment plant, but is more typically discharged directly to a body of water. Actively sweeping or vacuuming these surfaces can greatly reduce the amount of pollutants entering inlets, and possibly reduce the need for other (usually more costly) water quality measures.

Vegetated Roof: A vegetated roof is one of the most effective (both cost and stormwater – wise) methods to manage stormwater in the urban environment. Many buildings in urban areas have large flat roofs that can be converted into vegetated roofs, which have all the benefits described in Section 6, including a reduction in energy needs for the building. These benefits are much more meaningful in an urban area because of space constraints and the largely impervious land cover. In other countries, such as Germany, the vegetated roof is the primary stormwater BMP in the urban environment, and few if any detention or infiltration measures are used.

Rain Garden/Bioretention: Rain Gardens are excellent urban applications that can be fit into areas of various shapes and sizes. Common locations are parking lot islands, landscaped areas around buildings, and plantings adjacent to streets. Runoff can be directed into these areas either by a "bubbler" inlet or by surface flow graded onto the surface of the rain garden. Curb cuts can be utilized in parking areas and along roads to convey stormwater to these systems.

Porous Pavement with Infiltration Bed: New parking lots in urban areas should follow the guidelines set out in BMP 6.1 for porous pavement with infiltration beds, taking special note of the underlying soils, which have most likely been compacted for many years. Retrofits of existing parking lots to add porous pavement with infiltration beds is somewhat more complicated, specifically in the connection to existing inlets and construction in a "tight", or busy area. Many times, the entire parking lot does not need to be dug up for the infiltration bed. Smaller "strips" of porous pavement with infiltration can be installed in the downhill areas of a parking lot, creating fewer disturbances while still capturing the runoff from the whole parking lot (and possibly adjacent buildings via roof leaders). This space saving technique should be balanced with the infiltration loading rate, as discussed in the Infiltration Procedures Section.

Subsurface Infiltration Bed: Infiltration beds can be constructed under “open space” such as parks, playgrounds, or recreational fields in the same manner as described in Section 6. These areas can have inlets that collect surface drainage and convey runoff beneath the ground surface to the infiltration bed, and/or roof leaders that tie into the beds from adjacent buildings. Inlets in the vicinity can also be directed into the beds (noting special combined sewer precautions) that pick up surrounding impervious surfaces. This will incorporate stormwater management without sacrificing usable open space.

Infiltration Trench: Infiltration trenches are applicable in many urban situations, such as retrofitting street areas where a small “strip” of road can be dug up and a trench installed. The trench can pick up surface road drainage after it passes through the inlets, possibly in combination with some sort of water quality insert as a preliminary filter. A variation on this theme is the installation of tree trenches, which usually takes place along sides of roads, between the road and the sidewalk. Trees are planted in series with their roots being connected by an underground trench. This stone infiltration trench runs the length of the block eventually overflowing into the stormwater system. This system promotes the growth and sustainability of the trees while encouraging the uptake of stormwater runoff by the trees and into the atmosphere (evapotranspiration).

Rooftop Runoff – Capture & Reuse: Rain barrels can be used to capture runoff originally coming from roof leaders, and they are small enough to fit in yards often found in urban residential neighborhoods. Cisterns and vertical storage units can be placed in corners of structured parking lots, inside buildings, on the outside walls of buildings, in adjacent alleys, alongside elevator shafts, and other locations deemed feasible by the designer. Vertical storage is very applicable in urban areas where space is at a premium; the shape and location of this BMP requires very little horizontal land area.

Water Quality Filter: Filters can be used at the end of a drainage area, or at a “hot spot” to treat pollutant filled runoff. They have urban area relevance because of their size – filters can provide substantial water quality treatment in a relatively small container. They are typically used at the end of a drainage area (before it discharges into a body of water) that did not have room up gradient for other water quality measures.

Water Quality Insert: These manufactured devices can be placed in urban area inlets to address water quality, and are appropriate for areas without combined sewers where stormwater is discharged into a receiving stream or water body without other treatment and where removing pollutants before they enter the conveyance system is crucial.

Parking lot, rooftop, etc. as special detention area: Detaining runoff on impervious surfaces does not have any volume benefit, but does reduce CSO impacts by temporarily holding the runoff until after the storm passes, and then slowly releasing the runoff so that the treatment plant can properly treat it, rather than being discharged (combined with raw sewage) into the receiving water body without any treatment. Surface storage can also help reduce the peak rates of a drainage area by increasing the time of concentration for that specific area. This can be useful in areas that require peak rate reductions, or are subject to downstream flooding.

7.7 Case Studies

Case Study 1: Sadie Tanner Mossell Alexander, University of Pennsylvania Partnership School

Location: Philadelphia, PA

Technologies:
- Rain garden
- Porous pavement with infiltration bed
- Subsurface infiltration bed
- Disconnection from storm sewers

The Sadie Tanner Mossell Alexander School, or the "Penn Alexander" School for short, is an exemplary PreK-8 neighborhood public school in West Philadelphia. The product of a joint effort between the University of Pennsylvania and the City of Philadelphia, the Penn Alexander School was completed in the summer of 2001 and held its first classes in the fall. The school's highly urban setting, where green space is limited and combined sewers are prevalent, offered a unique opportunity for innovative and demonstrative stormwater management strategies. Working under a PADEP grant obtained by the Philadelphia Water Department, the design team implemented three distinct systems: a subsurface infiltration bed beneath a playfield, a recharge garden, and a porous asphalt playground with subsurface infiltration. These three strategies constituted an overall program to disconnect the majority of the site runoff from the city's combined sewer system through infiltration measures. Runoff from many of the site's impervious surfaces, including the school building, was directly conveyed either into the subsurface infiltration bed beneath the playfield or into the recharge garden. The subsurface bed not only promotes infiltration, it also retains enough moisture to keep the playfield healthy during dry periods, without the need for irrigation. The recharge garden mimics natural ephemeral pools by filling up when it rains and then gradually draining out, through either infiltration or plant uptake. The porous asphalt playground absorbs direct rainfall, as well as overflow from the recharge garden. This unique approach to stormwater management in an urban setting has so far proven successful in limiting flooding, increasing groundwater recharge, providing habitat for insects and birds, demonstrating stormwater cleansing, and providing invaluable curriculum opportunities.

Figure 7-13. Vegetated playfield with a subsurface infiltration bed.

Figure 7-14. Porous asphalt playground w/ subsurface infiltration bed

Case Study 2: Fencing Academy of Philadelphia

Location: Philadelphia, PA

Technology: Vegetated Roof

In highly urban environments, sometimes the only place for stormwater management is on the roof. **A green roof (also known as an "eco-roof" or "vegetated" roof) cover** is a thin layer of living vegetation installed over a conventional roof. A great example of a green roof project in the U.S. is the Fencing Academy of Philadelphia. Completed in the spring of 1998, the Fencing Academy's 3,000-square-foot green roof was installed over an existing conventional roof. This green roof, as designed and installed by RoofScapes Inc., consisted of a relatively light-weight cover system specifically intended for retrofit installations on existing structures. The Philadelphia Roofmeadow is only 3.0 in (7.6 cm) thick, including the drain layer. (The maximum weight of this system, when fully saturated, is less than 17 pounds per square foot.) The moisture content of the media at field capacity is 45% (volume). The saturated infiltration capacity is 3.5 in/hr (0.0025 cm/sec).

The design was evaluated using the RWS software program developed by Optima, a leading German "roof-greening" firm, affiliated with RoofScapes, Inc. The computer model predicted a 54% reduction in total annual runoff. Further analysis using the same software program predicted peak rate attenuation of 54% and 38% for the standard 2-year and 10-year return-frequency storms, (Miller, 1998). The standard storms were 24-hour events with NRCS type II distributions (USSCS, 1973).

This system immediately improved the aesthetic impact of the roof by creating a meadow-like setting of perennial *Sedum* varieties. These species were selected to withstand the range of seasonal conditions typical of temperate regions without the need for irrigation or regular maintenance. The appearance of the system changes with the seasons. In the spring, fescue grass and sedge, along with *Allium, Burnet* and *Dianthus* accent the cover, while during the summer and fall months, flowering *Sedum* varieties dominate. After only two and one-half years, this vegetated cover reached a mature stage of development and continues to add beauty and function in an otherwise unusable space even today.

Figure 7-15. Sedum cover on the roof of the Fencing Academy of Philadelphia (Source: Roofscapes Inc.)

Case Study 3: Department of Environmental Protection Southeast Regional Office

Location: Norristown, PA

Technologies:
- Capture & Reuse with
- Sustainable Building Strategies

The Pennsylvania Department of Environmental Protection recently opened their new Southeast Regional Office, a state-of-the-art model for sustainable building, in Norristown. The four-story, 85,000-square foot building was designed to dramatically reduce resource consumption while providing a comfortable working environment for approximately 300 employees. The DEP anticipates the achievement of Gold Level status through the Leadership in Energy and Environmental Design (LEED) program. The various “green” elements in the building include highly efficient water fixtures, natural day lighting strategies, and enhanced air quality through low VOC paints, adhesives, sealants, and coatings. But perhaps the most obvious green aspect of the building is a 5,000-gallon wooden cistern connected to roof drains that collect rainwater. The collected rainwater is filtered and then used as gray water to flush toilets in the building. In prolonged dry periods, the cistern can be filled with make-up water from the public water supply. Conversely, during an unusually heavy rainfall, roof runoff can be diverted to the regular storm drain system. The highly visible rainwater cistern provides a focal point of the building’s first-floor atrium, which also includes hardscaping, plantings, and benches.

Figure 7-16. Conceptual rendering of new PA DEP Southeast Regional Office in Norristown, PA.

Figure 7-17. First floor atrium w/ 5,000-gallon wooden cistern on right (Source: PA DEP Southeast home page).

Case Study 4: Ford Motor Company Rouge River Manufacturing Plant

Location: Detroit, Michigan

Technologies:
- Industrial Redevelopment
- Porous Pavement with Infiltration Bed
- Vegetated Roof
- Constructed Wetlands
- Vegetated Swales
- Landscape Restoration
- Soil Amendment & Restoration

The Ford Motor Company's Rouge River Complex in Detroit, Michigan is an excellent example of sustainable redevelopment at an industrial site. In 2000, Ford kick-started its $2 billion Heritage Project, which has since transformed the company's oldest and most notorious manufacturing facility into a global model of sustainability. But the most sustainable thing the Ford Company did was choosing to remain in place and revitalize their ailing site. The first of many stormwater improvements at the Rouge River Plant was the 14-acre porous pavement vehicle storage and staging lot. The design of the porous pavement lot included a subsurface infiltration bed made of decontaminated slag, recycled from on-site, and an adjacent water quality swale to compensate for poorly draining soils. Based on the success of this installation, the world's largest porous pavement lot (67 acres) was installed at the plant. Another major feature of the redevelopment plan was the construction of a 10.4-acre green roof on an assembly building. The green roof system was particularly significant, as it embodied Ford's principle goals for sustainability: the integration of ecological innovation and money-saving benefits. Other green strategies employed at the site included: constructed wetlands and additional water quality swales for enhanced runoff treatment, the creation of over 20 acres of green space through extensive revegetation strategies, and an ambitious phytoremediation test area designed to mitigate historic soil contamination. All of these measures have so far resulted in substantially reduced runoff volumes and pollutant loading from the site.

Figure 7-18. Aerial of Ford Rouge Plant.

Figure 7-19. Porous pavement vehicle staging lot with adjacent water quality swale.

7.8 References

Bannerman et al., 1993.

Barrett, et al, 1995.

Miller, 1998.

Schueler, 2003.

USSCS, 1973.