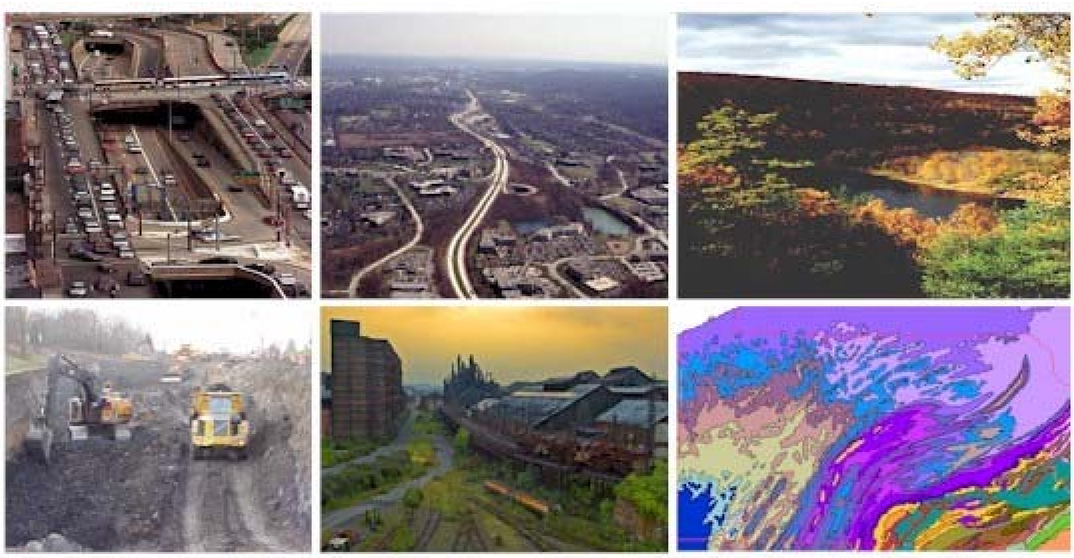
Pennsylvania Stormwater Best Management Practices Manual

Chapter 7

Special Management Areas

(Brownfields, Highways and Roads, Karst Areas, Mined Lands, Water Supply Well Areas, Surface Water Supplies and Special Protection Waters)



363-0300-002 / December 30, 2006

Chapter 7. Special Management Areas

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7.1 Introduction

The non-structural and structural BMPs described in the preceding Chapters provide measures that mitigate the additional volume, pollutant load and increased rate of runoff produced by land development. Some land surfaces, however, will not be compatible with the application of certain BMPs. Successful compliance with the Control Guidelines described in Chapter 3 should still be possible for most new land development sites, but the range of measures available may be limited. In fact, some types of BMPs may be totally unsuitable for consideration in these special land areas and should be excluded from application.

The land use types considered as "Special Management Areas" are very different from each other, but all are places where land disturbance can alter the original natural environment. This land use type, past or present, above or below the surface, will dictate which BMPs are suitable.

7.2 Brownfields

Brownfields are real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of hazardous substances, pollutants, or contaminants. Cleaning up and reinvesting in these properties takes development pressures off of undeveloped, open land, and both improves and protects the environment. (Source: http://www.epa.gov/brownfields/)

Pennsylvania encourages private cleanups of contaminated properties and the return of those sites to productive use. It has developed programs such as the Act 2 – Land Recycling Program, which was envisioned as an integral part of a sound land use policy that would help prevent the needless development of prime farmland, open space areas and natural areas; and the Brownfield Action Team, which expedites the remediation, reclamation, reuse and redevelopment of brownfield lands. It is important to point out that this section of the manual is applicable to all cleanup sites, not just those that enter the Act 2 Program – which is a voluntary program.

Smart growth encourages the redevelopment of brownfield properties as pedestrian friendly, transit-accessible properties, built compactly with a mixture of land uses, and with access to public spaces, parks or plazas. Use of smart growth principles in brownfield redevelopment can create greater benefits from the reuse of infill sites, reduce demand for land for development on the urban fringe, and improve the air and water quality of the regions in which they are applied. Brownfield redevelopment is an essential component of smart growth, as both seek to return abandoned and underutilized sites to their fullest potential as community and economic assets.

Brownfield sites have a wide range of complexity, primarily dependent on previous, existing and proposed land use. Land development at brownfield sites normally occurs in two stages: (1) site remediation and (2) redevelopment. Planning, design and construction work associated with these two stages typically involve separate consultants and/or contractors. There are very few practitioners who perform both stages of work. This bifurcation of responsibility can potentially lead to miscommunication, mistakes and problems. It is critical that both parties coordinate and are mutually agreeable to the proposed activities at the site.

When applying for permits for a brownfield site (for either stage), it is imperative that the applicant provide full disclosure, including but not limited to the following information:

1. Existing and previous land uses
2. Potential pollutants, along with a summary of sampling data.
3. Source and location of the potential pollutant(s) on the Erosion and Sediment Control (E&S) Plan drawings,
4. A description of what measures are proposed to manage and control discharges of these pollutants to eliminate the potential for pollution to surface waters of the Commonwealth.

7.2.1 Site Remediation (i.e. Cleanup)

The site remediation stage does not typically generate new impervious surfaces. In fact, remediation may reduce impervious area through the demolition of buildings and other impermeable surfaces. These areas, along with other earthmoving related to the cleanup, are usually temporarily stabilized until the site is redeveloped. As a result, this stage of land recycling does not typically require structural infiltration stormwater BMPs. The focus of site remediation routinely involves earthmoving to address soil and groundwater contamination. The stormwater management portion of this work is normally limited to non-structural BMPs, consisting of detailed construction sequencing or other measures to prevent the transport of contaminated runoff from the site.

How stormwater is managed on brownfield sites depends largely on how the site was remediated. Contaminated soil can be completely removed from the site, contaminated soil can be isolated and capped, or contaminated soil can be blended with clean soil so that it meets state standards for public health and safety. For more information on site remediation, go to: www.depweb.state.pa.us.

7.2.2 Site Redevelopment

Most of the site improvements occur in the redevelopment stage. It is imperative that this stage of the project does not disturb any completed work from the site remediation stage (e.g. a cap or other cleanup remedy). Conflicts most frequently arise during the foundation work or utility work phases of a project. Utility lines, in particular, are often overlooked and can have a major impact by opening new preferential pathways for contaminants to migrate. Each stage should be considered independently; ideally, the remediation work should be completed prior to commencing redevelopment work.

The redevelopment stage is where any net increase of impervious area would be expected to occur; thereby leading to increases in the rate and volume of stormwater runoff. Even where there is no net increase in impervious area, the existing site is usually devoid of any notable stormwater management BMPs. This is the stage where post-construction stormwater management must be addressed.

All stormwater management options are available for use on brownfield sites where the contaminated soil has been completely removed from the site. Emphasis should be placed on minimizing the amount of earth disturbance area and soil compaction, minimizing the creation of impervious area, maximizing stormwater infiltration, and dispersing runoff to a number of BMPs scattered around the site rather than conveying and concentrating runoff to just a few locations.

For the less severe cases, a brownfield redevelopment can follow the same track as a conventional land development project, provided that certain precautions are taken. To facilitate this process, the applicant should clearly identify on their plan drawings where "hot spot" areas are known to exist and any associated remediation that may have occurred. The project consultants should prepare this vital information during the site remediation stage. Except for structural stormwater infiltration BMPs, the stormwater management options listed in this manual are also available for use on brownfield sites where contaminated soil is isolated and sealed, or the contaminated soil was blended with clean soil. Since soil contaminants are still present at these sites, the use of structural stormwater infiltration BMPs should be used only if the residual soil contaminants are non-soluble pollutants.

Precipitation and some runoff can be infiltrated through lawn and landscaped areas. These areas should be designed to have a layer of topsoil at least 8 inches thick. The topsoil should contain sufficient decomposed organic material (10 percent by dry weight is recommended in the Stormwater Management Manual for Western Washington) to provide cation exchange capacity to remove pollutants.

Bio-retention provides good options for water quality BMPs on all sites, including brownfield sites. Bio-retention coupled with infiltration should be considered on brownfield sites where all soil contaminants have been removed during remediation, or where only non-soluble contaminants remain. On brownfields where soluble contaminants are still present in the soil, bio-retention BMPs should be designed so that all water passing through the planting soil is directed to an overflow and not permitted to infiltrate.

Vegetated roofs can be used effectively on brownfield sites to retain much of the rainwater that falls on the roof. This BMP is very effective in areas where subsurface systems are not feasible. Stormwater can also be retained in basins or landscaped ponds and allowed to evaporate.

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 particularly applicable to urban areas where space is at a premium. The shape and location of this BMP requires very little land area. Water collected this way can be re-used for things such as fire suppression, drip irrigation, lawn sprinkling, cooling buildings, toilet flushing and recreational water.

Chapter 6 of this manual provides more detailed information on these structural BMPs.

7.3 Highways and Roads

The purpose of this section is to consider the most suitable BMPs for managing runoff from roadways. Consideration of roadway design, construction, and maintenance should be included in the selection of BMPs that minimize the rate and volume, and enhance the quality of roadway runoff.

Mitigating the impacts of runoff from highways and roads is a concern for highway managers (such as PennDOT and the PA Turnpike Commission) and for municipalities; particularly those tasked with stormwater management and NPDES Phase II responsibilities. Highways and roads face specific challenges in managing stormwater, including:

- The need to manage stormwater while maintaining safe road conditions
- Limited available space and the need to locate BMPs within the right-of-way, if possible.
- Drainage area imperviousness greater than 50 percent, and sometimes 100%.
- Areas of extensive disturbance and compaction of soils (cut and fill).
- The potential for spills of hazardous materials.
- The use of deicing chemicals and salts as well as anti-skid materials, and the need to dispose of removed snow.
- Higher concentration of pollutants as compared to many other land uses.
- Thermal impacts to receiving streams in both summer and winter.

Pennsylvania ranks eighth in the country in terms of "total road and street" miles (http://www.fhwa.dot.gov), with a total of over 120,000 road miles, including over 18,000 miles of dirt and gravel roads. The intersection of these roads with the 86,000 miles of rivers and streams in Pennsylvania warrants careful consideration by stormwater managers and roadway designers alike.

7.3.1 Roadway Runoff Quality Issues

Highway and roadway runoff has been identified as a significant source of stormwater pollutants (Bannerman, et al 1993), as well as a significant source of thermal pollution to receiving waterways (Bush, et al 1974). The chemical constituents of roadway runoff are highly variable. The Federal Highway Administration (FHWA, 1999, Ultra-urban) identifies a number of roadway runoff pollutants and possible sources (Table 7-1). The FHWA also summarizes the concentrations of typical constituents found in highway runoff as outlined in Table 7-2. In comparison to other land uses and impervious surfaces, roadway runoff tends to have higher levels of sediment and suspended solids, which must be taken into consideration when selecting BMPs. Roadway runoff may also contain salts, deicing materials, and metals that can affect both receiving waters and vegetation and must be considered in BMP selection.

In addition to the chemical water quality issues associated with roadway runoff, exaggerated temperatures may also affect water quality. Roadway systems may deliver large amounts of warm or cold water directly and rapidly to receiving streams and wetlands, resulting in significant temperature extremes that could be harmful to fish and other aquatic life. Studies have shown that the runoff from summer storm events may exceed 90 degrees F, and winter runoff may be 37 degrees F colder than the receiving stream ambient temperature (Galli, 1990, Pluhowski, 1970). Such wide temperature differentials can have profound impacts on the aquatic systems of a receiving stream, and significantly alter and reduce the native aquatic life and its diversity. Stormwater collection and conveyance systems, and stormwater BMPs, should be designed with consideration of the potential thermal impacts on receiving waters due to runoff from road surfaces. Extended detention basins, in particular, should be designed to reduce this potential as discussed below.

*Table 7-1 Constituents and Sources in Highway Runoff **

Constituent	Source
Particulates	Pavement wear, vehicles, atmospheric deposition, maintenance activities
Nitrogen, Phosphorus	Atmospheric deposition and fertilizer application
Lead	Leaded gasoline from auto exhausts and tire wear
Zinc	Tire wear, motor oil and grease
Iron	Auto body rust, steel highway structures such as bridges and guardrails, and moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear and insecticide application
Chromium	Metal plating, moving engine parts, and brake lining wear
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, bushing wear, brake lining wear, and asphalt paving
Manganese	Moving engine parts
Cyanide	Anti-caking compounds used to keep deicing salts granular
Sodium, Calcium Chloride	Deicing salts
Sulphates	Roadway beds, fuel, and deicing salts

* From FHWA Stormwater Best Management Practices in an Ultra-Urban Setting

Table 7-2. Constituents of Highway Runoff

Parameter	Concentration (mg/L)
Total Suspended Solids (TSS)	45 - 798
Volatile Suspended Solids (VSS)	4.3 - 79
Total Organic Carbon (TOC)	24 - 77
Chemical Oxygen Demand (COD)	14.7 - 272
Biochemical Oxygen Demand (BOD)	12.7 37
Nitrate + Nitrite (NO_3 + NO_2)	0.15 - 1.636
Total Kjeldahl Nitrogen (TKN)	0.335 - 55.0
Total Phosphorus as P	0.113 - 0.998
Copper (Cu)	0.022 - 7.033
Lead (Pb)	0.073 - 1.78
Zinc (Zn)	0.056 - 0.929
Fecal coliform (organisms/100 ml)	50 - 590

7.3.2 BMP Considerations for Roadways

While many of the BMPs discussed in this manual are appropriate for use in managing roadway runoff, these BMPs should be designed and implemented with consideration to the nature of runoff from road surfaces. Specifically:

1. Roadway runoff generates higher levels of suspended solids than most other urban land uses. Roadway runoff should not be discharged directly to infiltration systems without first reducing sediment loads. Infiltration BMPs are appropriate for roadway systems but must be designed in conjunction with a measure (structural or non-structural) that reduces the amount of sediment in roadway runoff prior to infiltration. There are a variety of options that will reduce sediment loads, including:

   a. Vegetated systems such as grassed swales, filter strips, and bioretention;
   b. Structural elements such as catch basin inserts, filters, and manufactured treatment units; and
   c. Maintenance measures such as street sweeping and vacuuming.

   Using some or all of these measures before discharging to an infiltration BMP will minimize the accumulation of sediment that could lead to failure of an infiltration BMP. All measures for sediment reduction require regular maintenance.

2. Vegetative BMPs such as grassed swales and filter strips can be highly effective in reducing pollutant loads from roadways but must be properly designed in terms of slope, flow velocity, flow length, and vegetative cover (Barrett, et al, 1997). Improperly designed or maintained systems may contribute to pollutant load, rather than reduce it.

3. The potential for spills must be considered. It is cost prohibitive to design for spill containment on all sections of roadway, but the designer should certainly consider the potential for spills and the necessary action should a spill occur. Subsurface systems, infiltration systems, or vegetative systems may require replacement should a spill occur. While this may seem to be a limiting factor in the use of such systems, many existing storm sewers from roadways discharge directly to receiving streams with no opportunity to contain or mitigate a spill before discharge to a receiving stream. Therefore, while BMP restoration may be required after a spill, the potential for a direct stream discharge of the contaminated substance will be greatly reduced or eliminated.

4. The use of deicing materials and salts, as well as anti-skid materials, may affect vegetation, soil conditions, and water quality. Consideration should be given to the types of vegetation used in vegetative BMPs, as high chloride levels may adversely affect some vegetation as well as the soil microbial community. Proximity to water supply sources should also be considered when designing infiltration BMPs, and the potential for groundwater chloride levels to be impacted by roadway runoff should be considered. Consideration must also be given to the disposal of snow removed from roadways. This snow may ultimately be deposited in BMP areas and may contain higher concentrations of roadway salts and sediments. The potential impacts of this material on the BMP should be considered in the design process.

5. Temperature extremes of runoff from roadways can significantly affect receiving stream aquatic habitat. Roadways, especially asphalt roadways, tend to absorb heat and lack cooling vegetation. Many existing storm sewers from roads discharge directly and immediately to receiving waters. New discharges should provide mitigation for temperature impacts prior to discharge to the receiving water. This may involve:

   a. Vegetated systems and buffers to replace sections of concrete swales or pipes that impart heat to runoff. Use of multiple small drainage elements that use vegetated swales for conveyance can help reduce the temperature impacts from roadway runoff.

b. If extended detention systems, wet ponds, or constructed wetlands are used for peak rate mitigation, the discharge from these systems should be further mitigated by the use of vegetated swales or buffers, as these impoundments may also create adverse temperature impacts (SWRCB 2002; Oberts 1997). The discharge from an extended detention system should be conveyed by a vegetated swale, or dispersed through a level spreader, wherever practicable. Discharges should not be routinely piped directly into receiving streams or wetlands.

c. Extended detention systems should include design elements (Table 7-3) to attenuate runoff temperature. Recommended techniques (FHW, Young, et al 1996) include:
    1. Designing the system with minimal permanent pool;
    2. Preserving existing shade trees and planting fast growing trees along the shoreline, but not on the constructed embankment;
    3. Aligning ponds in a north-south direction; and
    4. Avoiding excessive riprap and concrete channels that impart heat to runoff.

Table 7-3. Impacts and Mitigation Measures for use of extended detention basins (Young, et al. 1996)

Environmental Issue	Diligent Responses
Need to avoid an existing wetland	Perform wetland delineation before sitting pond.
	Select pond systems with minimal permanent pool.
	Adjust pond configuration.
	Install parallel pipe system to divert runoff around wetland to pond site sited further downstream.
	Construct ponds around the wetland.
Need to preserve mature forest or habitat area	Configure pond to minimize the removal of specimen trees.
	Limit the area of disturbance.
	Mandate tree protection measures during construction.
	Plant native trees and shrubs to replicate habitat functions lost due to pond.
Concern about the thermal impact of pond on downstream fishery	Select system with minimal permanent pool.
	Preserve existing shade trees, plant fast-growing shade trees along the shoreline.
	Align pond north-south direction.
	Avoid excessive riprapping and concrete channels that rapidly impart heat to runoff.
	Maximize detention and/or increase first flush amount to runoff greater than first 13 mm of rain.
Need to protect stream reach above pond from urban storm flows	Install parallel pipe system along the upstream reach to convey excessive storm flows.
	Install plunge-pools at terminus of storm drains to reduce runoff velocities.
	Use bioengineering techniques and check dams to stabilize the stream reach.

PENNDOT Program and Recommendations

As the primary state agency charged with construction, operation and maintenance of the major roadways in the Commonwealth, the PA Dept. of Transportation has worked to develop a strategy to address two related issues. The immediate impact created by earthwork and disturbance during new construction, considered as Erosion and Sediment Control (E&S), is the subject of the recent Manual produced by the Department (PENNDOT E&S Manual, 2004). The long-term problems of stormwater runoff, discussed here, remains as a major issue. In discussions with PADEP, a set of strategies have been developed as follows:

- Use sod-forming grasses adjacent to the roadway shoulders and for vegetated swales to serve as filters for suspended solids and metals.
- Use non-invasive native species vegetation (or plant species that are known to take up and store certain contaminants) in lawn areas, on slopes and within wetland reconstruction/banking areas to enhance water uptake and the storage of certain pollutants in plant tissue.
- Limit the use of curb-gutter sections as much as practical for filtering and temperature considerations.
- Limit the use of storm sewers as much as practical for filtering and temperature considerations.
- Consider bioretention capability in the design of new detention basins (Dry Extended Detention Basin design).
- Monitor the effectiveness of existing constructed wetlands, updating the current design practices as necessary.
- Consider alternative methods of energy dissipation (in-lieu of rock pads) at culvert and storm sewer outfalls for temperature considerations.
- Where practical, discharge storm sewers into wetland areas or vegetated swales instead of discharging directly to streams for filtering and temperature considerations.
- Consider vegetated islands in-lieu of concrete islands (where practical for maintenance considerations) for filtering and temperature considerations.
- Consider the inclusion of infiltration berms and retentive grading in areas that are down slope of the roadway.
- Continue efforts to monitor and minimize the volume of winter maintenance materials utilized to minimize pollutant loadings within the runoff and into the groundwater.
- Continue efforts to protect all salt storage and loading areas from weather influences in efforts to minimize pollutant loadings.

- Consider practices to dilute flows where high concentrations of salts are anticipated to minimize pollutant loadings.
- Consider porous pavement and other subsurface infiltration methodologies on Department park-and-ride sites and for Department building site parking areas.
- Consider dry wells and other subsurface infiltration methodologies for Department building roof drains.

7.3.3 Specific BMP Considerations:

Limited Access Highways, Interstates and Turnpikes (Principal Arterials)

Highways are usually designed with shoulders and often include vegetated medians, presenting prime areas for BMP implementation. Infiltration opportunities may be limited due to compaction and fill, as the right-of-way is often subject to significant grading changes to meet highway design standards. However, infiltration should not be precluded, and should be considered on a case-by-case basis.

The use of vegetated swales and buffer strips is highly recommended to reduce sediment loads from highways, but the possible impact on sight distances and roadway visibility must be considered, with planting design sensitive to this height issue. Vegetated swales and buffer strips can be combined with subsurface infiltration trenches or small infiltration/bioretention basins for volume reduction and temperature mitigation. For example, strips of vegetated swales that are underlain by infiltration trenches can provide both quality treatment and volume reduction, and replace concrete channels and pipe systems. Numerous small bioretention systems can provide peak rate mitigation and be incorporated into the right-of-way.

New Streets and Residential Roads

New streets and roads in residential and commercial developments provide the greatest opportunity to incorporate both non-structural and structural BMPs to address road runoff. Non-structural BMPs include:

- Reduced street widths
- Reduction or elimination of curbs and gutters
- Reduction of storm sewer infrastructure

Structural residential road systems include:

- Vegetated swales and infiltration trenches along the right-of-way
- Bioretention areas along the roadway
- Bioretention or bio-infiltration in cul-de-sacs
- Porous pavement
- Infiltration trenches along the contour that are perpendicular to the road
- Catch basin inserts or treatment devices

In new development, the roads and driveways often comprise the greatest amount of impervious area, sometimes as much as 70% of the total impervious area. Techniques that seek to manage the roadway runoff where it is generated, and reduce piping and conveyance of stormwater, should be implemented to the greatest extent possible.

Bridges

Grit and oil removal BMP's should be considered for addressing stormwater discharging from scuppers serving bridge decks. If the inclusion of grit and oil removal BMP's is not feasible due to design constraints, more frequent "street cleaning" of the bridge deck should be made part of the project's Operation and Maintenance plan.

7.3.4 Dirt and Gravel Roads

A significant portion of the state is served by unpaved roadways constructed of various types of gravel base, constructed over time and with locally available materials. While not constructed with AC impervious pavement, theses roadways serve as stormwater conveyance pathways, creating significant erosion in the process and requiring constant maintenance to restore shoulders.

Pennsylvania has over 18,000 miles of unpaved roads. These roads consist of dirt and or gravel, and have historically been undermaintained compared to paved roads. These roads are frequently a source of pollution to streams and rivers in a drainage area, especially for sediment. This pollution occurs as precipitation carries sediment eroded from these roads and adjacent banks along the road surface and into open water. Statewide, while runoff from these roads is not the major source of pollution in streams, close proximity of rural roads to high quality streams is common, and these roads often parallel streams and discharge directly into them. Others have culverts that convey large amounts of water before discharging at high rates, following long downhill grades to a stream crossing. Adequate drainage is essential to the longevity of these roads, but environmentally sensitive practices for discharge of this drainage will benefit the health of the surrounding environment.

Pennsylvania's Dirt & Gravel Road Pollution Prevention Program was formed in 1997 to "fund environmentally sound maintenance of unpaved roadways that have been identified as sources of dust and sediment pollution." This program strives to reduce erosion, sediment, and dust pollution by using improved maintenance techniques that benefit both dirt and gravel roads and the environment. This program is centered on using local control as a method of stopping pollution. To date, at least 1400 projects have been completed under this program, and over 3,500 people have participated in the program's two day "Environmentally Sensitive Maintenance." Training course. Eligible dirt and gravel road sections are those identified by County Conservation District personnel as having a sediment source from the road polluting a stream.

Program initiatives include identifying and replacing pipes running beneath unpaved roads that are undersized and contribute to "ponding" on the road. The program also has developed a GIS (Geographical Information Systems) database, which tracks the location and status of all the dirt and gravel roads in PA, and allows the local entities to submit electronic reports directly to the State Conservation Commission. In 2000, data from over 17,000 miles of unpaved roads was compiled and resulted in over 11,000 verified pollution sites found. In addition to this, the program is undergoing an aggregate study in Centre County, PA to determine the most economical and durable stone for gravel roads.

Local Municipalities and state agencies have jurisdiction of over 90% of dirt and gravel roads, and because the cost of paving these roads is often too high for the road owner, there are several best maintenance practices that can be employed to maintain an unpaved road in an environmentally sensitive manner. Recommendations include:

- Working with the natural landscape in the design of roads (minimize cut and fill)
- Identifying existing drainage patterns and designing to minimize disturbance
- Crowning the road to drain the water away from the center
- Using graders with scarified blades as preferred equipment to reshape a road
- Sizing roadside ditches appropriately and outletting appropriately within an infiltration design
- Driving Surface Aggregate mix should have increased abrasion resistance, be angular on the surface with increased fines to provide stability and facilitate compaction (stone quality matters)
- Vegetating roadside banks to prevent erosion
- Using snowplow shoes when clearing snow and re-shaping the road after snow season
- Preserving soil stabilizing vegetation in ditches and observing appropriate roadside vegetation management practices along road corridors
- Limiting driving speeds

Reduced road maintenance costs (grading, regrading, & re-graveling), and reduced sedimentation in water affecting aquatic life and drinking water reservoirs, should result from the implementing these measures, and are consistent with the various BMPs discussed in this manual. A detailed listing of technical bulletins and further information on “Environmentally Sensitive Maintenance” practices for dirt and gravel roads is available from the Center for Dirt and Gravel Road Studies at Penn State University (www.dirtandgravelroads.org).

7.4 Karst Areas

7.4.1 The Nature of Karst

Surface-Water Interaction: Water is a key to sinkhole collapses. Taking water away from where it was or putting a new, concentrated source of water where it wasn’t before can speed the development of sinkholes. Examples of new sources of water could be drainage from rain gutters, pavement, collection ditches and ponds. Treatment basins or lagoons must be diligently lined in karst to prevent a sudden drainage out of the bottom and into the groundwater. Leaky water and sewer pipes can cause the soil underneath to wash away and are often the trigger for sinkholes. However, an existing sinkhole under a pipe can cause the initial leak. The greater the volume of water and the faster it moves into the karst system, the more soft material is washed from the voids. Weather events can also trigger sinkholes. In Pennsylvania, sinkholes can “pop” when a heavy rain event comes after a prolonged drought.

Karst areas present problems to those attempting to work with conventional hydrologic models. Typically, modeling of a karst site or watershed via SCS or other traditional methods provides poor representation of runoff rates, with regard to both flooding and over-design of conduits and stormwater management facilities. This is largely because standard hydrologic modeling methods lack allowances for losses into sinkholes, fractures, crevices or caves that may exist in the carbonate units. Neither do models typically account for the stormwater that joins surface runoff as “interflow” when the collective capacity of interconnected conduits and cavities in the subsurface is exceeded. (Source: **Technical Bulletin No. 2** Virginia Department of Conservation and Recreation - Hydrologic Modeling and Design in Karst)

Karst loss is a term given to surface runoff loss into bedrock strata in areas underlain by limestone formations. Unlike other calculation factors, such as curve numbers (which deal with characteristics of the land surface), a karst loss factor is intended to depict projected losses into bedrock. The determination of karst potential in any given area may be simplified by the observation of noticeable indicators such as caves, crevices, limestone outcrops, sink holes, ponds that appear to lack sufficient contributing area, and disappearing streams. In other cases, karst infiltration areas may be difficult to identify since definitive karst features are not always obvious. Generally, a lack of natural drainage way erosion or inadequately sized drainage ways (for the size of the contributing area) may be clues to karst loss. Other observations may include undersized drainage conduits that never run full.

Thick sequences of carbonate bedrock (limestone and dolomite) underlie a sizeable area in - central and southeastern Pennsylvania. Folding and faulting have extensively fractured this bedrock. Over millions of years, chemical weathering of the deformed carbonate units by weakly acidic water along points of weakness has produced a subdued, but deeply developed karst (Wilshusen and Kochanov, 1999). The process of carbonate bedrock dissolution results in a distinct landscape called karst topography. Karst topography includes features such as sinkholes, surface depressions, and caves. Other notable characteristics are significant changes in the depth to bedrock or groundwater table within a short distance and “losing” streams that disappear into the subsurface.

Karst development is a water-driven system; whereby the enlargement of fractures creates a natural system of “pipes and drains” that serves to transport groundwater, surface water and surficial material. Karst drains are typically covered with a mantle of soil. Surface and/or groundwater can mobilize these sediments into subsurface voids, resulting in sinkholes or closed depressions. Variations in the volume of water entering the karst system can increase the rate at which sinkholes develop.

Karst aquifers are vulnerable to contamination when the natural filtration capability of soil is bypassed due to thin soils, sinkholes or subsurface open fractures and voids. Contaminants can enter the karst system and travel long distances over a relatively short period of time.

When addressing stormwater management issues, **the complexities of a karst system demand a more rigorous scrutiny than other geologic settings**. In areas that undergo land-use changes, stormwater, which once had established infiltration routes into the ground, may then be captured and redirected into a variety of artificial drainage ways and catchment areas. This change creates an imbalance that can result in increased subsidence and sinkhole activity, potential groundwater contamination, and could affect the quantity and quality of the karst aquifer system (Knight, 1971; Newton, 1987; White and others, 1986).

7.4.2 Infiltration vs. non-infiltration

A decision must be made to either promote infiltration at a karst site (recommended, but may not be feasible in all areas) or eliminate infiltration altogether as an attempt to curb sinkholes or contamination liability. This decision must be based on a sound site assessment and consideration of potential contaminants that can be introduced by the proposed project. The worst scenario is to ignore karst features entirely and thus significantly increase the potential for costly delays, repairs, catastrophes and legal proceedings.

Stormwater control plans that utilize infiltration in karst are more common in areas such as Kentucky (Crawford, 1989) and Tennessee (McCann & Smoot, 1999) but have generally been avoided by hesitant or inexperienced developers in Pennsylvania. Non-infiltration plans may seem safer and more economical even with the increased cost, but, an additional, long-term "cost" is associated – lowering of the groundwater table, reducing the potential groundwater resources of an area, and increasing the risk of a sudden, catastrophic ground collapse (via a failed impoundment, swale, retention structure, etc.). Use of infiltration BMPs, especially watershed-wide, is the best method for stormwater control in most karst areas. (Crawford, 1989)(McCann & Smoot, 1999) Future research in this area should identify additional innovative solutions to these stormwater management challenges.

7.4.3 Basic Principles

Successful stormwater management in karst areas can be achieved by developing a strategy for the site that will be best suited to function within the tolerance limits of the natural system. Every effort should be made to maintain the pre-development hydrologic regime and utilize existing karst drainage features in a safe way. The risk of sinkholes, subsidence problems and potential groundwater contamination issues should be of utmost consideration. As previously noted in Chapter 3, watershed-wide stormwater planning that considers and incorporates the existing karst drainage will achieve the best overall results.

The following basic principles must be considered in karst areas:

Identification, understanding and consideration of geologic information are crucial.

- An initial site assessment is critical to identify karst and existing drainage features. It is recommended that a broader area be reviewed to spot regional trends in geology and drainage. A thorough site assessment should include, but not be limited to, the following:
    - Review of aerial photographs, geologic literature, sinkhole maps, borings (if available), existing well data, and municipal wellhead or aquifer protection plans.
    - Site reconnaissance, including a thorough field examination for features such as limestone pinnacles, sinkholes, closed depressions, fracture traces, faults, springs and seeps. Special attention should be paid to confirmation of features located during literature review.
    - Drilling of boreholes.
    - Determination of groundwater elevations, especially with respect to the bedrock surface, and flow direction. To assess seasonal changes, it is necessary to obtain groundwater measurements over several months to a year.
    - Geophysical surveys to locate subsurface anomalies. Consult a professional experienced in geophysical methods and karst areas before conducting these tests.
- Observe the site under different weather conditions especially during heavy rain events and through different seasons. Identify and map the natural drainageways.
- A site design in karst areas should be supported by a geotechnical or hydrogeologic report conducted by a qualified and/or licensed professional (i.e., soil scientist, geologist, hydrogeologist, geotechnical engineer, etc.). The report should include:
    - Site reconnaissance discussion.

- Identification and mapping of karst features and hydrogeologic conditions of the site.
- Identification and mapping of existing drainage patterns and features.
- Discussion of groundwater hydrology.
- Survey of soil characteristics and thickness and analysis of the site's capability for infiltrating stormwater.
- A discussion of how infiltration will be handled to avoid contamination of the groundwater aquifer.
- A plan view drawing of the site, noting the locations of important features. This plan should delineate areas available for infiltration, areas not suitable for infiltration and areas where development should not occur.
- A contingency plan to be used if unexpected conditions or unmapped karst features are encountered during site excavation.

Refer to the Case Studies in karst areas contained in Chapter 9 for examples. More information is available from Virginia DCR Technical Bulletin No. 2, Memon and others, 1999 and Ralston, and others, 1999)

Maintain natural conditions within the stormwater plan to the maximum extent possible.

- Maintain the natural water balance for surface flows and groundwater recharge. (See also section 5.4.3). Existing drainage patterns and features, both natural and artificial, should be taken into consideration. Use these pre-development drainage ways to the maximum extent possible. Avoid building on or adjacent to these drainage features.
- Maintain groundwater levels and hydrostatic pressure to the maximum extent possible – avoid large groundwater withdrawals, elimination of recharge areas or concentrated injection (in reference to time as well as location). Fluctuating groundwater levels will undermine the structural stability of the subsurface.
- Establish a buffer zone around karst features that are not used for infiltration - areas of historic or active sinkholes or surface depressions and related geologic features such as fracture zones and faults - grading water away from these features. Establish filter berms (with gabions or vegetation, for example), etc. to prevent contamination from overland flow and discourage access to these areas. (McCann & Smoot, 1999)
- Designate aquifer recharge areas. Promote safe infiltration. Direct recharge into groundwater aquifers without proper filtration of sediments and pollutants is prohibited. *Improved* sinkholes may be utilized as injection wells, but must be properly constructed. Casing must be firmly seated into competent bedrock and grouted into place. Sediment and pollution controls must be incorporated. EPA categorizes these structures as Class 5 Underground Injection Wells. With adequate planning and design, these infiltration structures can be used successfully in karst areas (McCann & Smoot, 1999, case studies). A permit from EPA must be obtained to construct and operate a Class 5 Underground Injection Well.
- Replicate natural hydrologic loading rates as much as possible when designing infiltration BMPs. Minimize impervious surfaces. Drastically increasing or decreasing the loading rate may promote or accelerate sinkhole development. (Loading rate is the ratio of drainage area to infiltration area.)

Avoid Concentrating Water.

- Employ methods to reduce runoff volumes and velocity.

- Implement numerous infiltration BMPs throughout the site instead of just one.
- Stormwater should not be conveyed into concentrated runoff flow paths. Broad and shallow flow dispersion is most effective. Minimizing impervious surfaces should aid in decreasing runoff, in general. (Virginia DCR)
- Impounded water causes soil saturation and loss of cohesion, and produces stress from the weight of the water. Differences in hydraulic head and steep hydraulic gradients can result in sinkhole development. For these reasons, shallow basins with overflow channels are preferred over one large, deep basin. Basins, if they must be used, must have synthetic liners to prevent failure and sudden loss of water into a subsurface drain.

Diligence and site maintenance can influence the ultimate success of the stormwater plan.

- Seal all exploratory boreholes to eliminate surface water entry.
- Minimize earth disturbance when installing stormwater structures. Disturbing the upper, cohesive soils can lead to subsidence and future collapses. (Newton, 1987)
- Management of stormwater structures usually ends after construction. In karst, however, BMPs need to be inspected, cleaned, maintained, and possibly repaired. Sinkholes should be promptly and properly repaired. Inspection and maintenance schedules must be addressed in the plans.
- Pay specific attention to the integrity of piping of all types. Evidence of pipe leakage or sagging should be immediately addressed because these areas quickly become the focus for soil loss into subsurface voids that leads to subsidence and sinkhole collapse.
- All stormwater management designs for karst areas must include details for sinkhole repair during and after construction. The sinkhole repair plan should appear on the construction drawings and also be made a part of the site's Operation and Maintenance Plan. The sinkhole repair plan should be flexible to accommodate a variety of failure modes and locations. A qualified individual should oversee the repair work.

7.4.4 BMP Considerations

The conventional stormwater BMPs presented for traditional development activities are generally applicable and effective in karst areas. However, these are not necessarily the *most* effective or appropriate. (McCann & Smoot, 1999) (Virginia DCR) The following are some conventional examples of karst area BMPs:

Increased storage

- Dry detention pond
- Wet retention with lined settling ponds
- Shallow detention ponds
- Vegetated Roof

Increased infiltration

- Runoff spreaders
- Porous pavement
- Improved sinkholes / Class V injection well (See Crawford, 1989, Chapter 3)
- Perforated pipes
- Bioretention cells / rain gardens

Decreased velocity

- Increased vegetation density / vegetated swales
- Terraced slopes
- Rip rap (preferably using carbonate rock)

Pollution control/water quality

- Filter berms
- Gravel or sand filtration systems
- Peat moss or activated carbon filtration
- Constructed wetlands (lined)
- Increased vegetation density / rain gardens
- Rip rap
- Compost

7.5 Mined Lands

Disturbed lands that have been strip or surface mined, or are underlain by deep mine excavations, are one of the most difficult areas on which to apply stormwater BMPs. The drainage of rainfall that has percolated through residual mine wastes on the land surface, or infiltrated the existing land surface and drained into deep mines and subsequently found its way to the surface from mine tunnels, has produced one of the most severe water quality conditions in Pennsylvania. Thousands of miles of streams within the state are devoid of aquatic life because of the extreme acidity of surface waters that are polluted by abandoned mine discharges. This condition is considered by most experts to be the single greatest pollution issue in the state, simply because it has no obvious or easy solution.

Since this acid drainage from abandoned mines begins as rainfall on the surface, the obvious solution would seem to be to redirect any rainfall away from any surface materials containing mine wastes, and assure that as little infiltration as possible took place above deep mine layers.

The exclusion of all infiltration BMPs in these areas would negate many of the BMPs described in Chapter 6, other than the vegetated roof systems and the capture/reuse measures. One important consideration is that the use of vegetation to remove or change the chemical form of pollutants in acid mine drainage could also include the pollutant load from new impervious surfaces where suitable. A great deal of research has been directed toward the use of wetland systems as passive AMD treatment technologies (PADEP, 2005). These systems form part of a larger strategy for abandoned mine reclamation (PADEP, 1998) in those watersheds where the problem is widespread.

All of this very important water quality research does not address the specific problem created by new development or redevelopment on mined lands. Where the potential exists for runoff from new development to come into contact with mine wastes, then surface drainage design should convey runoff to surface swales and channels free of any mine waste residual. If detention basins are used for rate mitigation, they should be lined if situated on surface mined lands or over deep mines. Water quality measures will need to rely on intensive maintenance programs for new development, and control of pollutant application, especially fertilizers, herbicides and pesticides. If porous pavements are designed, the sub-surface beds must be lined, so that the primary function will be detention rather than volume reduction by infiltration. Finally, the land development plan should place special emphasis on protection of existing vegetation and restoration of new woodlands, because they offer the best method of healing and restoring these damaged lands.

7.6 Stormwater Management Near Water Supply Wells

Pennsylvania ranks third in the nation for the total number of public water supply wells, and nearly half of Pennsylvania's 12 million residents get drinking water directly from ground water sources. It is critical that stormwater BMPs be designed to remove pollutants from stormwater that is to be infiltrated in close proximity to public or private water supply wells, and be sufficiently isolated from ground water supply sources.

Water supply wells in Pennsylvania generally pump water from two types of aquifers, unconsolidated aquifers and consolidated rock or fractured-bedrock aquifers. Unconsolidated aquifers are composed of sands, silts and gravel. They are generally unconfined and close to the surface, have high porosity and a high measure of permeability. Water moves into and through unconsolidated aquifers readily. These aquifers are generally limited to major stream valleys, the Atlantic Coastal Plain and the glaciated northeast and northwest regions of the state. Fractured-bedrock aquifers are the most widespread and commonly exploited aquifers in the state. They may be bedrock layers composed of sandstone, shale, or carbonate rocks such as limestone and dolomite but they can also be layered or irregular bodies of crystalline rocks such as gneiss, schist, granite and diabase. Ground water in bedrock aquifers can occur in either unconfined or confined conditions. Fractured-bedrock aquifers have low primary porosity and ground water is mainly stored in openings between rock layers and in fractures throughout the rock. Water moves into and through these aquifers much more slowly than in unconsolidated aquifers. Exceptions occur in limestone and dolomite where dissolution of the rock increases the size and frequency of the fractures and therefore increases secondary porosity and permeability. Some Pennsylvania public water supply wells in limestone and dolomite aquifers produce larger volumes of water than do wells in unconsolidated aquifers.

Stormwater infiltration BMPs near water supply wells

Pennsylvania's Safe Drinking Water Regulations (25 Pa. Code § 109) establish a three-tiered approach to wellhead protection of public ground water supplies. Zone I is the innermost protective zone surrounding a well, spring or infiltration gallery that may range from a radius of 100 to 400 feet depending on site-specific source and aquifer characteristics. The water supplier must own this area or substantially control activities within the zone that could potentially harm quality or quantity of the source. Zone II is the capture zone that encompasses the portion of the aquifer through which water is diverted to a well or flows to a spring or infiltration gallery. Zone II is defined as a one-half mile radius around the source unless a more rigorous hydrogeologic delineation is performed. Zone III is the area beyond the capture zone that contributes significant recharge to the aquifer within the capture zone. For more detailed information about protecting underground drinking water supplies, please refer to the Department's Source Water Protection Program.

Infiltration BMPs should not be located within Zone I wellhead protection areas. In addition, extreme caution must be exercised when planning stormwater infiltration BMPs for use in delineated Zone II areas or for use in areas within one half mile of public water supply wells. This is especially important where the water supply wells are in unconsolidated aquifers or bedrock aquifers of fractured limestone of dolomite. These easily recharged aquifers can become contaminated through stormwater infiltration BMPs unless adequate stormwater pre-treatment occurs first. It is also essential that local government officials be contacted early when planning infiltration BMPs within Zone II wellhead protection areas. Some municipalities have specific ordinances that address land use within rigorously delineated Zone II areas.

To ensure that privately owned wells and ground water sources serving non-community water supply systems are adequately protected, a minimum isolation distance of 50 feet must be observed between the ground water source and all infiltration BMPs.

As always, the basic tenets of stormwater management should be applied:

- All efforts should be taken to minimize the amount of impervious area on the site; and
- Stormwater management should be designed to disperse runoff to a number of BMPs scattered around the site rather than conveying and concentrating runoff to just a few locations.

One of the most effective ways to pre-treat stormwater for infiltration is to pass the stormwater through a layer of compost or a compost/soil mixture before allowing it to infiltrate into the ground. (Compost is meant to be decomposed or composted organic material, not mulch.) EPA and others report that organic materials in the compost and compost/soil mixtures have demonstrated pollutant removal rates of over 90 percent for sediments, metals, bacteria and petroleum hydrocarbons, and as high as 75 percent for total phosphorous. Pollutant removal effectiveness increases with the amount of compost/soil mixture the stormwater has to pass through. Compost or soil/compost mixtures are not effective in removing chlorides such those found in deicing salt. The post-construction stormwater operation and maintenance plan should include limited use of deicing salts in areas draining to infiltration BMPs. Sand or other inert antiskid materials should be used in parking lots or roadways if stormwater infiltration is being used near water wells to minimize water quality impacts from stormwater/melt water runoff.

Use compost or compost/soil mixtures in vegetated swales, bio-retention areas, and infiltration trenches and basins so that stormwater must first pass through 18 to 36 inches of compost or a compost/soil mixture before percolating into the ground. The type of vegetation planted in the compost or compost/soil layer should be selected, in part, for its ability to replenish organic matter through seasonal leaf fall, root die back etc. It is important to maintain a high percentage of organic material in the soil because it is the organic material (compost) that has the cation exchange capacity necessary to capture pollutants in stormwater.

Porous pavement and other sub-surface stormwater infiltration BMPs are not recommended for use in areas close to water supply wells. These BMPs generally cannot be designed to allow stormwater to percolate through 18 to 36 inches of compost or soil/compost mixture.

Non-infiltration BMPs near water supply wells

Non-infiltration type stormwater BMPs can be used in areas close to water supply wells. As with all stormwater BMPs, they should be planned so that the stormwater runoff is spread throughout a number of locations rather than conveyed and concentrated in just a few places. Stormwater conveyance systems for loading docks, gas stations and other areas that have an increased likelihood of hazardous spills should be designed with an emergency shutoff to contain spills if there is an accident or release.

Appropriate BMPs

Some appropriate BMPs to consider for stormwater management in areas within one half mile of a water supply well are discussed below. These BMPs are detailed more thoroughly in Chapters 5 and 6.

Reduce Parking Imperviousness: Parking areas should be kept to the minimum allowed by the municipality. Excess parking area increases the volume of runoff that must be managed.

Rooftop Disconnection: Roof leaders (gutters) in residential and urban areas can be re-configured to drain into Rain Barrels, or flow onto lawn areas. 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, vertical storage or infiltration BMPs. Roof runoff can often be routed directly to an infiltration BMP. Roof runoff is generally cleaner than street and parking lot runoff and may not require as much pre-treatment before infiltrating into the soil.

Vegetated Roof: A vegetated roof is one of the most effective (both cost and stormwater – wise) methods to manage stormwater in an urban environment. Many buildings in urban areas have large flat roofs that can be converted into vegetated roofs.

Rain Garden/Bioretention: Rain Gardens are excellent applications for use around water supply wells and can be designed to fit 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 graded surfaces. Curb cuts can be utilized in parking areas and along roads to convey stormwater to these systems. Rain gardens and bio-retention areas should contain 18 to 36 inches of compost or compost/soil mixture. The pollutant removal capability of the BMP increases with the depth of the compost or compost/soil mixture used.

Infiltration Trench: Infiltration trenches can pick up runoff from parking areas and roads. A variation of this theme is the planting of trees and other vegetation in the trench along sides of roads, between the road and the sidewalk. This system promotes tree growth and facilitates the evapotranspiration of stormwater through tree and plant uptake. Infiltration trenches must be constructed with a layer of 18 to 36 inches of compost or compost/soil mixture for pollutant removal. The efficiency of the BMP improves with the depth of the compost or compost/soil mixture used.

Capture & Reuse of Rooftop Runoff: Rain barrels can be used to capture runoff originally coming from roof leaders. They are small enough to fit in yards and can easily be employed 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 well suited for use in urban areas where space is at a premium; the shape and location of this BMP requires very little horizontal land area.

Wet ponds: Monitored performance of well constructed and maintained wet ponds has documented efficiencies of greater than 90 percent removal for suspended solids, and ranges of 60 – 70 percent removal for nutrients and 60 – 95 percent removal for heavy metals. Wet ponds can also be used to pre-treat stormwater before it is conveyed to infiltration and bio-retention BMPs.

Vegetated swales: Vegetated swales are excellent applications to attenuate stormwater volume and provide effective pollutant removal while conveying and dispersing stormwater runoff. The swales should contain 18 to 36 inches of compost or compost/soil mixture to remove pollutants from any stormwater infiltrating through the swale.

De-icing alternatives: Sand or other inert antiskid materials should be used in parking lots or roadways in areas near water supply wells or upstream of surface-water intakes to minimize water quality degradation from stormwater or melt water runoff.

7.7 Surface Water Supplies and Special Protection Waters

Antidegradation requirements for special protection waters (High Quality and Exceptional Value) and for surface water supply (Potable Water Supply) will be met if the post-construction stormwater infiltration volume equals or exceeds the pre-construction stormwater infiltration volume, and that any post-construction stormwater discharge is pre-treated and managed so that it will not degrade the physical, chemical or biological characteristics of the receiving stream. Please refer to the Department's *Water Quality Antidegradation Implementation Guidance* (document number 391-0300-002) for more information.

The project should be designed to minimize the amount of impervious area. Any resultant stormwater should be infiltrated to the maximum extent possible. Water quality treatment BMPs should be employed for all stormwater that is discharged. Stormwater BMPs should be planned so that the stormwater is spread out to a number of locations rather than conveyed and concentrated in just a few places. Finally, the volume and rate of any stormwater discharge must be managed to prevent the physical degradation of the receiving water, such as scour, and stream bank destabilization.

Stormwater infiltration near surface water supplies and Special Protection waters

Care must be taken when planning stormwater infiltration BMPs for use in areas within two miles * on either side of special protection waters or surface waters used for public water supply. Infiltration BMPs in these areas must be designed to encourage maximum pollutant removal before the stormwater is infiltrated into the ground or discharged to a receiving stream.

[Pennsylvania also employs a three-tiered approach - for surface water source protection.* ***Zone A* *is a 1/4 mile buffer on either side of the river or stream extending from the area 1/4 mile downstream of the intake upstream to the five hour time-of-travel (TOT).* ***Zone B*** *is a two-mile buffer on either side of the water body extending from the area 1/4 mile downstream of the intake upstream to the 25 hour TOT.* ***Zone C*** *constitutes the remainder of the basin. Please refer to the Department's Source Water Protection Program for more information.]*

One of the most effective ways to pre-treat stormwater for infiltration is to pass the stormwater through a layer of compost or a compost/soil mixture before allowing it to infiltrate into the ground. The organic materials in the compost and compost/soil mixtures have repeatedly demonstrated pollutant removal rates of over 90 percent for sediments, metals, bacteria and petroleum hydrocarbons, and as high as 75 percent for total phosphorous. Pollutant removal effectiveness increases with the amount of compost or compost/soil mixture the stormwater has to pass through. Compost or soil/compost mixtures are not effective in removing chlorides such those found in deicing salt. The operation and maintenance plan for these BMPs should include judicious or limited use of deicing salts in areas draining to the BMP.

Vegetated swales, bio-retention areas, infiltration trenches and basins should be constructed so that stormwater must first pass through 18 to 36 inches of compost or a compost/soil mixture before percolating into the ground. The type of vegetation planted in the compost or compost/soil layer should be selected, in part, for its ability to replenish organic matter through seasonal leaf fall or root die back. Maintaining a high percentage of organic material in the soil is of utmost importance. It is the organic material (compost) that has the cation exchange capacity necessary to capture pollutants in stormwater.

What if the stormwater cannot be infiltrated?

Infiltration is not the only way to reduce stormwater runoff volumes. Vegetated roofs can be used effectively on brownfield sites to retain much of the rainwater that falls on the roof. Stormwater can also be retained in basins or landscaped ponds and allowed to evaporate. 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 to urban areas where space is at a premium. The shape and location of this BMP requires very little land area. Water collected this way can be re-used for things such as fire suppression, drip irrigation, lawn sprinkling, cooling buildings, toilet flushing and recreational water. Chapter 6 of this manual provides more detailed information on stormwater capture and reuse.

7.8 Urban Areas

7.8.1 Highly Impervious Urban Land

This land area of special consideration includes the most densely populated regions of the state. The intensity of land development in most urban centers has resulted in a land use pattern that could be considered fully developed, with an almost continuous impervious surface comprised of multi-story structures surrounded by pavement. Beneath these paved areas lay a complex web of; water, wastewater, stormwater, gas, electric, stream and communications infrastructure. In the most densely developed urban communities, people also move beneath the surface in trains and subways. Auto parking is largely provided in concrete boxes or below buildings. The few “green areas” remaining are isolated parks and public spaces, many of which are also underlain with auto parking levels extending 60 feet or more into the ground. Narrow planting strips along many urban corridors support “street trees” that wage a constant battle to survive in a hostile environment.

Beneath these urban landscapes lie the residue of prior development, which in older cities such as Philadelphia can form a rubble layer many feet thick, comprised of bricks, blocks, concrete, wood, and other building materials. All of these conditions severely limit the use of any BMPs that are dependent on infiltration into the soil mantle for volume reduction, and so the use of other BMPs is necessary.

One of the few “downtown” locations suitable for volume reduction is the roof of building structures. European engineers and architects learned the importance of going “up on the roof” for stormwater management several decades ago, and it has become the primary method in most cities. In Germany local ordinances require the construction of vegetated roof systems on flat or up to 20% sloping roofs. Failure to comply with these rules result in a “stormwater tax” being levied that is sufficiently onerous to virtually assure compliance. This action was precipitated by an increased awareness of the impacts of stormwater on “combined” sewers that convey both runoff and raw sewage to the nearest stream, river or lake. Many of the German cities were reduced to rubble during World War II, and in the rebuilding process it was recognized that vegetated rooftops on all new buildings provided a solution to anticipated urban stormwater problems.
Mandatory application of this BMP in existing urban centers, such as Philadelphia and Pittsburgh, will require specific ordinances that guide both new and existing building efforts, a significant capital program for any municipality. Without the opportunity for infiltration measures, however, the available alternatives to vegetated roof systems are quite limited, and focus on various capture and reuse efforts, most of which would require a significant re-plumbing effort for existing structures.

In terms of appropriate Control Guidance for the urban center, the solution may have to be tailored to fit the hydraulic capacity of the existing conveyance system. Where combined sewers are the only drainage pipes available, the overflow and discharge from CSO outfalls is usually triggered by frequent rainfall events of an inch or less. If the volume of runoff from a 1-inch storm event can be reduced in these areas, many combined sewer overflows can be avoided and much water quality benefits can be gained. Detailed computer modeling can develop the appropriate volume control guidance for highly urban watersheds with single pipe sewers.

As development has extended out from urban centers 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 environment. 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, equal to or greater than some older communities, even though it exists on an isolated parcel. 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 land that has been altered and then re-vegetated. The construction process has compacted the soils in these grassed and landscaped areas such that runoff volume has increased significantly. Thus a low-density suburban residential lot could degrade water quality as severely as the row home in center city Philadelphia.

7.8.2 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 on a watershed can be measured when the level of impervious cover reaches 5 percent. Water quality in the watershed is severely degraded by the time the level of impervious cover reaches 20 percent. This reduction of water quality and stream habitat occurs from the increased runoff volumes eroding stream banks, pollutants conveyed with this runoff, and diminished stream base flow. The pattern of degradation for urban streams shows a dramatic increase in magnitude and intensity of runoff with a corresponding reduction in stream flow during much of the year, and 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 function as combined sewers beneath the city streets.

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. Such street runoff is affected by hydrocarbon emissions 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. 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 a significant water quality issue in urban areas that can quickly pollute receiving waters. Although interception or 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 low dissolved oxygen levels in receiving streams are related to the extreme temperature variability of runoff from impervious areas (as temperature increases, dissolved oxygen levels decline with lethal consequences to aquatic life). For fish and aquatic insects, temperature ultimately can be one of the most critical pollutants, presenting especially difficult challenges in urban areas.

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 19^{th} century. These buried streams still serve as storm runoff conduits with the natural movement of groundwater along and into the stream channel. In some areas, the fill material above the original channel may eventually wash away, creating subsidence problems and “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.

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 uncovered and restored 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.

High levels of trash and debris, including concentrated areas of pet waste, characterize 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 a significant source of pollutants that 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 purchase 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.

Stormwater "hot spots" such as gas stations, industrial areas, vehicle service areas, and public works storage areas are commonly 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 the runoff should be 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.

7.8.3 Other Urban Stormwater Management Considerations

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.

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.

Most of the BMPs described in Chapter 6 can find some application in the urban environment, but a number of seemingly small measures, not described in separate BMP sections, can have a cumulative effect if applied to hundreds or thousands of individual residences or small buildings. These types of measures include:

Reduce Parking Imperviousness - New parking lots in urban areas can follow the guidelines set out in Chapter 5 relating to reducing imperviousness, 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 Downspout Disconnection - Roof leaders (gutters) in residential, urban areas can be re-configured to drain into rain barrels or 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.

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.

Vegetated Roof: A vegetated roof is one of the most effective (both cost and stormwater – wise) methods to manage stormwater in an urban environment. Many buildings in urban areas have large flat roofs that can be converted into vegetated roofs

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. They’re appropriate where stormwater is discharged without other treatment and where removing pollutants before they enter the conveyance system is crucial. They are not appropriate for areas with combined sewers

Use of Parking lots and rooftops, as special detention areas - Detaining runoff on impervious surfaces does not have any volume benefit, but does reduce CSO impacts by temporarily holding the runoff and slowly releasing it so that the treatment plant can properly treat it. 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.

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