Chapter 3 Site Design and Stormwater Management Integration

3.0 Introduction

Chapter 3, Site Design and Stormwater Management Integration, guides the designer in successfully incorporating stormwater management into development site designs, while meeting the Philadelphia Water Department (PWD) Stormwater Regulations (Stormwater Regulations) and stormwater management design criteria for Stormwater Retrofits. The site design procedure is based on Pennsylvania Department of Environmental Protection recommendations, with minor modifications adapted to conditions in Philadelphia.

3.0.1 How to Use This Chapter

Before using this Chapter, the designer should first review the Stormwater Regulations outlined in **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1. Having determined the applicable Stormwater Regulations, the designer should follow the guidance in Chapter 3 from beginning to end. The Chapter 3 Sections are as follows:

This Chapter does not provide detailed design requirements for specific stormwater management practices (SMPs). For detailed SMP design requirements, the designer is referred to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4.

3.0.2 Integrated Site and Stormwater Management Assessment and Design Process Overview

This Chapter outlines a step-by-step process for integrating robust and cost-effective stormwater management into site designs in ways that achieve PWD's key stormwater management goals of minimizing the harmful effects of flooding and maintaining the health of Philadelphia's streams and rivers. Figure 3.0-1 provides an overview of this process and the following Sections represent underlying goals for the designer to keep in mind as they move through the process.

Figure 3.0-1: Chapter 3 Process Flow Chart

Perform Site Assessment in accordance with **Section 3.1** to map critical site features and identify key opportunities and constraints.

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Review Section 3.1 to understand the relationship between Stormwater Management Design Strategies, the Stormwater Regulations outlined in Chapter 1, and the different project Review Paths described in Chapter 2.

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Assess opportunities to use Non-Structural Design strategies outlined in **Section 3.1.4** to protect and use existing site features, minimize impervious cover, and reduce earth disturbance.

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Assess opportunities to use Disconnected Impervious Cover (DIC) outlined in **Section 3.1.5** to reduce the amount of Directly Connected Impervious Area (DCIA) to be managed.

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Develop an approach to managing remaining DCIA, using a systems approach to SMP design per guidance in **Section 3.2** as well as guidance on Infiltration Testing and Soil Assessment for SMP Design in **Section 3.3.** Consider approaches per the SMP Hierarchy outlined in **Table 3.2-2** and consult Chapter 4 for more specific design requirements for individual SMPs.

Making Stormwater a "Before-Thought"

The most important aspect of PWD's process for stormwater design is to start early, before the development plan and site layout are finalized. By considering green stormwater management approaches in the initial stages of the site design planning process, a comprehensive strategy can be integrated more efficiently, effectively, and creatively. Starting early allows designers to find smart ways to incorporate green stormwater management approaches including PWD's highest-preference SMPs (**Section 3.2.2** ☛ p. 42) and other approaches such as disconnected impervious cover (DIC) (**Section 3.1.5** ☛ p. 23) and non-structural design (**Section 3.1.4** ☛ p. 17), into the design process. Waiting until the site layout is finalized before considering stormwater management leaves the designer with options that are less appealing, have limited environmental benefit, and are often more expensive to build and maintain.

Considering the Power of Green

An increasing body of research shows that incorporating green features into an urban environment can have economic benefits for developments, including increased property values, reduced crime, positive changes in consumer behavior, and higher resale values. Sites with green features are often regarded as more welcoming and inviting places. Green stormwater management is becoming a powerful tool in the marketplace as it can provide development sites with a range of benefits not offered by more conventional stormwater management approaches. As discussed in the **Introduction** ☛ water.phila.gov/development/stormwater-plan-review/manual/introduction, the City of Philadelphia is committed to a balanced "land-water-infrastructure" approach in achieving its watershed management goals of fishable, swimmable waters. Every land development project plays a critical role in this city-wide effort to realize a collective future as a vibrant, sustainable, and modern city.

Dedicating space for green stormwater management approaches can be challenging (particularly on small or highly constrained lots), but before excluding "green," the designer should consider all outcomes and base decisions on full life cycle costs. Incorporating green stormwater management is PWD's strongly preferred approach for stormwater management and can help streamline the approval process through Expedited Post-Construction Stormwater Management Plan (PCSMP) Reviews (**Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews). Preserving open space or using SMPs, such as bioinfiltration/bioretention basins or green roofs, to manage stormwater can add value to a development, while meeting the Stormwater Regulations. Green approaches toward stormwater management can also be used to achieve compliance with landscaping requirements within the Philadelphia Zoning Code; contribute towards requirements of third-party project certifications such as the United States Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) certification program; and help achieve other project-specific goals such as improving aesthetics, providing shade, creating habitat, protecting and enhancing viewsheds, and maintaining safety. Furthermore, green stormwater management

> **Quick Tip**
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> PWD acknowledges that infrastructure-based approaches (such as detention facilities) are not the entire solution. Implementing a range of land-based stormwater management techniques and restoration of aquatic habitats achieves a more balanced "land-water-infrastructure" approach that can help restore stream habitats lost to urbanization, as well as comply with the Stormwater Regulations in a cost-effective manner.

approaches have been shown to increase a city's climate resilience through reductions in urban heat impacts and flooding as well as prove local air and water quality benefits. If additional information is desired regarding green stormwater infrastructure's role in climate resiliency, the designer is referred to the Green Infrastructure Leadership Exchange's Climate Resilient Resources Guide.

This Chapter provides guidance on PWD's highest-preference SMPs (**Section 3.2.2** ☛ p. 42) and other environmentally friendly approaches to stormwater management such as non-structural design and DIC. The designer is encouraged to use the guidance in this Chapter to find creative ways of greening a project site while meeting the Stormwater Regulations. The designer is encouraged to contact PWD Stormwater Plan Review for assistance with incorporating green approaches to stormwater management.

Viewing Stormwater as a Resource

Stormwater is not wastewater – it's a resource! Stormwater can be collected, stored, and reused on sites for many purposes, including reclaimed water for toilet flushing and source-water for industrial use. These approaches are good for the environment, but can also make economic sense in reducing the need to purchase potable water, and can be incorporated effectively into an overall strategy for Stormwater Regulation compliance. The designer should consider potential reuse applications early in the design process in a collaborative discussion among the building and site design teams. The designer is referred to **Section 4.5** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-5-cisterns, Cisterns, for more information on rainwater harvesting.

Taking a Site-Wide Approach

In order to help the designer take a site-wide approach to stormwater management, PWD offers enhanced tools such as new guidance on placing SMPs in series and Stormwater Management Banking and Trading. Understanding these options is critical when evaluating where and how much stormwater will need to be managed, addressing applicable Stormwater Regulations across multiple SMPs, and reserving various portions of a site for stormwater management. A designer unfamiliar with placing SMPs in series or Stormwater Management Banking and Trading is referred to Sections **3.2.3** ☛ p. 49 and **3.2.4** ☛ p. 53, respectively, for suggestions on getting started.

3.0.3 Interactions between Design Strategies, Stormwater Regulations, and Review Paths

In using Chapter 3, the designer should understand that some design decisions regarding specific stormwater management strategies can also impact the applicability of the Stormwater Regulations and the appropriate Review Path of a project. As a result, the designer may need to revisit **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1 and **Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2 to make sure these initial determinations remain valid.

There is not a "one-to-one" relationship between the review process outlined in **Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2 and the site assessment and design process outlined in Chapter 3. Guidance throughout Chapter 3 assists the designer with preparing Conceptual Review Phase and PCSMP Review Phase Submission Packages to PWD. The designer preparing a Conceptual Review Submission Package is referred to guidance throughout Chapter 3 in conducting site assessments and developing an initial stormwater management strategy and Conceptual Stormwater Management Plan. The designer preparing PCSMP Review Submission Packages will find **Section 3.2** ☛ p. 41, **Section 3.3** ☛ p. 64, and **Section 3.4** ☛ p. 82 particularly helpful in understanding the technical requirements associated with specific stormwater management strategies.

Applicable Stormwater Regulations and Review Path vary depending on site characteristics, such as site location and amount of earth disturbance. The designer should pay specific attention to changes in the proposed earth disturbance and directly connected impervious area (DCIA) throughout the design process, as well as the potential applicability of Expedited PCSMP Reviews.

Earth Disturbance

The amount of earth disturbance associated with a development project, in part, determines the applicable Stormwater Regulations (**Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1), as well as the appropriate Review Path (**Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2). In this Chapter, the designer will find guidance in using non-structural design techniques that could result in a reduction in earth disturbance. If the level of earth disturbance associated with a project significantly changes as the result of working through the guidance in this Chapter, the designer should revisit Chapters 1 and 2 to assess potential changes in applicability.

Directly Connected Impervious Area

Adjustments in a DCIA associated with a development project can impact the applicable Stormwater Regulations. If a project's DCIA significantly changes as the result of working through the guidance in this Chapter, the designer should revisit **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1 and **Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2 to assess whether the changes in DCIA alter either the applicable Stormwater Regulations or Review Path for the project.

Expedited PCSMP Reviews

A project that proposes a combination of non-structural design, DIC, and/or bioinfiltration/bioretention basins for Stormwater Regulation compliance may be eligible for an Expedited PCSMP Review. As the designer works through Chapter 3, opportunities for modifications in the initial site layout or stormwater management strategy may allow the project to qualify for an Expedited PCSMP Review. The designer is directed to **Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews for more guidance on the types of, and requirements for, Expedited PCSMP Reviews.

3.1 Site Assessment and Stormwater Management Strategies

This Section guides the designer in performing a site assessment – the necessary first step in designing a project that complies with the Philadelphia Water Department (PWD) Stormwater Regulations (Stormwater Regulations) or a grant-funded Stormwater Retrofit project. The designer must know the site location and general development plan before beginning the site assessment process.

The assessment consists of two components: the collection of background site factors, and an analysis into how these factors will shape the development and stormwater management plan for a proposed site. Site assessment must be completed in the early stages of project design, and information gained from the assessment will be requested as part of the Existing Resources and Site Analysis (ERSA) Application Submission Package (**Section 2.1.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-1-existing-resources-and-site-analysis#2.1.1) to PWD. Stormwater Grant-funded Stormwater Retrofits should include site assessment details within the Stormwater Grant Application materials and submitted Conceptual Stormwater Management Plan.

A properly completed site assessment helps the designer understand a site's existing condition and natural systems. The assessment aids the designer in determining the most appropriate site layout and crafting a stormwater management approach and design for a site.

3.1.1 Background Site Factors and Site Factors Inventory

Macro site factors consist of watershed-scale project site characteristics. These factors include a project's watershed and sewershed, and factors that influence flooding.

Micro site factors are smaller, site-scale features including property/land use boundaries and physical features that may affect the site layout or stormwater compliance strategy. Both types of factors play a significant role in determining not only the applicable Stormwater Regulations, but can inform the best strategies for complying.

Project Watershed

A watershed is an area of land that contains a common set of drainage pathways, streams, and rivers that all discharge to a single, larger body of water, such as a large river, lake, or ocean. There are seven major watersheds in Philadelphia. Watershed Maps in **Appendix D** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/d-watershed-maps are available to assist the designer in determining a site's watershed.

While Water Quality requirements are generally consistent across all of Philadelphia's Watersheds, they do differ in terms of rate control requirements; specifically, Flood Control and Channel Protection. This is because the frequency and magnitude of flooding in headwater streams is affected to a far greater degree by unmanaged stormwater than in larger receiving bodies of water such as the Schuylkill or Delaware Rivers. There are some watersheds which are especially impaired in terms of water quality, localized flooding, and stream bank erosion that necessitate the compliance of small earth disturbance projects with some or all aspects of the Stormwater Regulations (**Section 1.2.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations/#1.2.1).

Project Sewershed

A sewershed is a defined area of land, or catchment, which drains via storm drain infrastructure to a common outlet point. As opposed to natural watersheds, the boundaries of which are defined by natural ridges, sewershed boundaries are determined by stormwater infrastructure such as curbs, storm drains, pipes, and stream outfalls. Sewershed boundaries may differ from watershed boundaries because stormwater infrastructure may cross watershed boundaries that predate urbanization.

Runoff may leave a site through a combined sewer system, separate sewer system (PWD-owned or private outfall), or via surface runoff. Some project sites may span multiple sewersheds, and runoff may leave different portions of the site via different methods. Discharge to different sewersheds will not only affect the stormwater management strategy, but also the requirements associated with the Water Quality requirement for the site, as these are different in combined sewer areas than other sewersheds. In addition, projects that discharge to a combined sewer system may be subject to a Public Health and Safety (PHS) Release Rate requirement because of specific capacity limitations in the combined sewer system. Applicants will be informed during the Conceptual Review Phase if a PHS Release Rate applies to their project.

Projects that can discharge stormwater runoff without the use of PWD infrastructure may qualify for exemption from some rate control requirements (**Section 1.2.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations/#1.2.1); however, they may have additional permitting requirements from the Pennsylvania Department of Environmental Protection (PA DEP) (**Section 2.7** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-7-pwd-and-pennsylvania-department-of-environmental-protection) and may require the creation of easements if stormwater runoff will be directed to neighboring property via piped or diffused discharge.

Appendix D ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/d-watershed-maps contains Collection System Maps for use in determining the project sewershed. However, applicants with projects that are located near a sewershed boundary may want to contact PWD to confirm.

Flooding

An evaluation of existing flooding issues on a project site, or on adjacent properties, must be performed. For example, it is important to know whether floodwaters flow via an overland flow path on the site, and whether runoff from off-site properties is a component of these flows. It is also crucial to understand how flooding impacts the conveyance capacity of storm sewer infrastructure if the design proposes overflow connections from stormwater management practices (SMPs). This is especially important for private or semi-private systems. For example, there may be a high tailwater condition at the outfall or connection point during a relatively small rainfall event. The designer must account for these conditions during SMP design.

Although Federal Emergency Management Agency (FEMA) flood maps and related studies show flood-prone areas along the City's streams and rivers, these resources do not adequately address this issue at site scale. Prior property owners, neighbors, and other local sources may be able to indicate anecdotally the extent to which on-site or downstream flooding is already a problem. A review of historic maps may also provide an indication of possible flooding issues, specifically if the site is located in the vicinity of a historic stream or creek that was infilled or bricked up as a combined sewer.

Published FEMA Flood Maps are available at the Philadelphia City Planning Commission, which can be reached by phone at 215-683-4615, or online at **FEMA's Flood Map Service Center** ☛ https://msc.fema.gov/portal/home.

Property/Land Use Boundaries

Property/land use boundaries refer to the parcel's non-physical boundaries, such as zoning classification and/or overlays, setbacks, and any existing easements. Suitable locations for SMPs must be identified by mapping existing property/land use features. These features often leave large spaces of undevelopable land available for non-structural design opportunities and/or structural SMPs. Boundaries must be depicted on the Existing Conditions Plan submitted during the Conceptual Review Phase. The designer is referred to **Section 2.1.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-1-existing-resources-and-site-analysis#2.1.1 and **Appendix E, Table E-2** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/e-plan-and-report-checklists/table-e-2-existing-conditions-plan-requirements for specific Existing Condition Plan requirements.

Physical Features

It is necessary to assess important physical features within the project site to minimize impacts to these features and to identify opportunities to use existing natural areas and drainage patterns for stormwater management. Table 3.1-1 lists critical physical features that are required to be inventoried and understood, methods and data sources for assessing these features, and notes whether each feature is required for an Existing Conditions Plan. Care must be taken to conserve and protect, or avoid, these areas, as appropriate.

Table 3.1-1: Physical Site Features Required in Existing Conditions Plan

Physical Feature	Action	Source
Vegetation	Determine the location and extent of woodlands, riparian areas, or other special habitat areas (e.g., meadows) as defined by the *Pennsylvania Stormwater Best Management Practices (BMP) Manual* (2006 or latest version).	Topographic survey, aerial photography, Geographic Information Systems (GIS) mapping, local and regional natural resources inventories, Pennsylvania Natural Diversity Inventory (PNDI) surveys
Soils and Geology	Determine existing soil conditions, expected permeability, hydrologic soil groups, depths to high seasonal groundwater table/bedrock, and presence of hydric soils or special geologic formations (e.g., carbonate). Document whether the site has native soils or if past development has led to fill conditions.	United States Department of Agriculture (USDA) Soil Surveys, hydrologic soil maps, existing geotechnical reports, existing soil investigation or infiltration reports, United States Geological Survey (USGS) Quadrangle Maps, USGS historic fill maps, historical aerial photography, local or regional groundwater studies or well data (Note: Usefulness of soil survey data for soils in urban settings may be limited)
Wetlands, Waterways, Floodplains, and Drainageways	Note location and type of on-site waterbodies, waterways, and floodplains. Determine existing drainage pathways and patterns, both on-site and for site runoff to off-site receiving waters.	Topographic survey, FEMA Flood Maps, aerial photography, GIS mapping
Existing Structures and Paved Areas	Determine on-site location of buildings, sheds, loading docks, parking lots, driveways, sidewalks, trails, etc.	Topographic survey, aerial photography
Existing Stormwater Infrastructure	Determine on-site locations of stormwater pipes, manholes, inlets, catch basins, outfalls, etc.	Topographic survey, utility records
Existing Utilities, Sewer, and Water Lines (Within 25 Feet of Property Lines)	Determine on-site locations of sewer pipes, manholes, force mains, water lines, water manholes, valve box covers, gas service lines, gas transmission mains, electric lines, and telephone/cable/fiber optic lines.	Topographic survey, utility records, utility locator services (PA One Call, private contractors)
Steep Slopes	Determine location of slopes of 15% or greater. Determine whether site is located in Steep Slope Protection Area, as per **Philadelphia Code §14-704(2)** ☛ https://codelibrary.amlegal.com/codes/philadelphia/.	Topographic survey, GIS topographic data, Philadelphia Code

Hotspot Investigation and Historic Fill Assessment

Understanding the presence, extent, and location of potential soil, groundwater, or surface water contamination and potentially unstable fill is an important component of characterizing existing site conditions. Infiltration of stormwater through contaminated soils has the potential to negatively impact groundwater and downstream surface water bodies. Additionally, concentrated infiltration of stormwater in areas of unstable fill can increase the potential for soil stability issues such as differential settlement and sinkhole formation. Both the presence of contamination and unstable fill can present significant risks to public health and public safety and can damage public and private property.

During this phase of the site assessment, the designer collects important information on both of these factors that may ultimately inform the placement of SMPs as described in **Section 3.2** ☛ p. 41 and whether SMPs can be designed as infiltrating facilities or must instead be designed as slow-release facilities. If a project can comply with the Stormwater Regulations solely through non-structural design techniques and/or disconnected impervious cover (DIC) (Sections **3.1.4** ☛ p. 17 and **3.1.5** ☛ p. 23, respectively), a hotspot and historic fill assessment may not be needed for stormwater management purposes.

The designer should use the following hotspot investigation and historic fill assessment procedure to identify soil contamination and unstable fill risks and to evaluate the potential for implementing infiltration SMPs if these conditions are present.

Step 1

Determine the prior land use at the site where development is proposed, and review all available data on soil and groundwater quality.

This can be done through a formal Phase I site assessment or as informally by conducting a title search; review of aerial photographs, soil surveys, topographic maps, City and State regulatory databases; and a review of local and State records. Historic maps, records of previous construction, local knowledge or test pit data can also be used to determine whether contamination is present on-site if the site has a history of hotspots or the presence of unstable fill.

Step 2

Determine the potential for groundwater or surface water contamination through infiltrating SMPs based on available data and prior land use (determined in Step 1), history of hotspots, and suspected/known presence of unstable fills.

The following land uses are considered to have a potential for contaminated soil, which may adversely affect the quality of groundwater discharging to surface water. These uses may qualify a project site, or portions of a project site, as a hotspot.

- Sites designated as Comprehensive Environmental Response, Compensation, and Liability Act sites, also known as Superfund Sites,
- Sites registered under PA DEP's Land Recycling Program, or Act 2 sites (**Section 2.7.2** ☛ water.phila.gov /development/stormwater-plan-review/manual/chapter-2/2-7-pwd-and-pennsylvania-department-of-environmental -protection#2.7.2),
- Auto recycler facilities and junk yards,
- Commercial laundry and dry cleaning facilities,
- Commercial nurseries,
- Vehicle fueling stations, service and maintenance areas,
- Toxic chemical manufacturing and storage facilities,
- Petroleum storage and refining facilities,
- Public works storage areas,
- Airports and deicing facilities,
- Railroads and rail yards,
- Marinas and ports,
- Heavy manufacturing and power generation facilities,
- Landfills and hazardous waste material disposal facilities, and
- Sites located on subsurface material such as fly ash known to contain mobile heavy metals and toxins.

Infiltration is required on all sites unless the designer can show that it is not feasible. A common factor in the preclusion of infiltration is the potential for contaminant migration (Step 3). Hotspot usage and historic fill sites could contain fill material, such as fly ash, which may contain mobile metals and toxins, as well as being a potentially unstable soil. When concentrated infiltration is present within regions with known hotspot usage or fly ash fill, infiltration can lead to extensive erosion and subsidence of infill containing very fine material. The designer is responsible for investigating the presence of contaminated or unstable soils.

If Steps 1 and 2 reveal that the presence of hotspots or unstable fill is known or anticipated, the designer must proceed to the detailed testing procedures in Step 3. Before starting Step 3, the designer is encouraged to identify initial areas that could be used for stormwater management so that testing can be focused on potential SMP areas.

Step 3 (if necessary)

Conduct field investigations to further evaluate contamination and/or historic fill.

For project sites that qualify as hotspots, due diligence must be performed to determine whether any contamination is present on-site. It is not sufficient to rule out infiltration based on historical site uses alone. Testing must be performed to determine whether the site is contaminated and, if so, in what areas contamination is concentrated. Even if a site is contaminated, there may be some areas where infiltration is still feasible. Contamination must be evaluated per PA DEP guidelines, including, but not limited to, comparing testing results to PA DEP Direct Contact Medium Specific Concentration (MSC) thresholds and Soil-to-Groundwater MSC thresholds, evaluating contaminant solubility, and conducting Synthetic Precipitation Leachate Procedure (SPLP, EPA Method SW-846-1312) testing.

For project sites that anticipate the presence of unstable fill, the designer must work with a geotechnical professional to create a plan of action to identify if unstable fill exists and whether the fill is suitable for infiltration. Field testing may include, but is not limited to, soil sampling, the use of ground penetrating radar (GPR), and electromagnetic induction (EMI) scanning.

Many sites in Philadelphia are constructed on fill; however, the presence of fill alone does not preclude a site from installing infiltrating practices. A waiver from the infiltration requirement can be requested if sufficient proof of soil instability or soil contamination is provided based on soil sampling results (**Section 3.3.6** ☛ p. 78). If a waiver from infiltration is requested due to contamination, environmental reports for any testing completed, as well as a justification letter from the geotechnical engineer or environmental professional clearly stating why infiltration is not recommended, must also be submitted. If appropriate justification and documentation is provided to demonstrate that contamination or soil stability precludes the site from infiltrating, an impervious liner may be necessary for SMPs where stormwater is concentrated.

3.1.2 Site Factors Analysis

The final step in the site assessment is to review the information obtained in the background and site factors inventories and perform a stormwater management opportunities and constraints analysis to identify areas where stormwater management may or may not be appropriate and assists the designer in making preliminary determinations regarding the size and layout of any development features.

Stormwater Management Opportunities

The designer must identify site characteristics that are favorable to stormwater management, such as soils with desirable permeability or locations for proposed discharge points (e.g., connections to existing storm sewers). Likewise, site development should be focused as much as possible in areas that provide poor opportunities for stormwater management, maximizing the areas conducive to stormwater. Certain types of critical natural areas can present both constraints to land development and significant opportunities for stormwater management. For example, riparian areas, which are not prime development areas, can sometimes be used to disconnect impervious cover (**Section 3.1.5** ☛ p. 23). However, the environmental impacts of implementing stormwater management in natural areas must be carefully considered.

Recognizing opportunities to reduce proposed directly connected impervious area (DCIA) to be managed and protecting and using existing site features during the site assessment can lower project costs associated with projects meeting the Stormwater Regulations or Stormwater Retrofit projects. Additionally, proposed site features that are conducive to stormwater management should be identified. For instance, areas such as parking lot islands can be used for surface management of stormwater. The designer is referred to **Section 3.2** ☛ p. 41 for additional guidance on stormwater management design strategies and to **Section 3.5** ☛ p. 103 for examples of integrated stormwater management strategies for different project types.

Stormwater Management Constraints

Stormwater management constraints are areas on the project site where stormwater management may be difficult, infeasible, or inadvisable. These can include constraints such as contamination, existing utilities, wetlands, riparian buffers, steep slopes, and soils with high permeability. The designer is referred to **Section 3.2** ☛ p. 41 for discussion of constraints related to specific design strategies and to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 for constraints related to different SMP types.

For development projects where all the impervious area within the limit of disturbance cannot be disconnected and constraints persist that prohibit stormwater management of the remaining DCIA on-site, the applicant should investigate opportunities to provide off-site management as described in **Section 3.2.4** ☛ p. 53 (Stormwater Management Banking and Trading). If no such opportunities exist, the applicant may consider making a one-time fee in lieu payment for the unmanaged DCIA. All requests for fee in lieu payment must be approved by PWD. More information on the criteria for fee in lieu is provided in **Section 3.4.1** ☛ p. 83.

3.1.3 Integrated Design Approach

PWD has developed an integrated design approach through which developers can meet the Stormwater Regulations for proposed development projects. The intent of the approach is to promote the use of stormwater management solutions that protect receiving waters in a cost-effective manner. The integrated design approach presented here is based on recommendations found within the *PA DEP Pennsylvania Stormwater Best Management Practice (BMP) Manual*, with minor modifications for adaptation to the urban conditions in Philadelphia. For example, non-structural design, one of three major design strategies discussed in this Section, may be challenging to implement in cases where higher densities/intensities are proposed on small sites in densely developed areas. However, non-structural DIC opportunities may be more cost-effective in the highly dense areas of Philadelphia because of energy savings, retail value, and other factors. Additional informational resources on the economic benefits of incorporating green features into an urban environment can be found on the PWD **Stormwater** ☛ water.phila.gov/stormwater/ webpage.

The process of integrating site development and stormwater management design begins with a comprehensive understanding of existing site conditions per a site assessment, as described in **Section 3.1.1** ☛ p. 8 and **Section 3.1.2** ☛ p. 14. The site assessment process allows the designer to identify key site and stormwater management design opportunities and constraints. For example, the designer may desire to locate a proposed building to preserve an existing large and mature tree or an area of existing native vegetation in good condition in order to obtain credits for preserving existing trees under **Philadelphia Code §14-705(g)** ☛ https://codelibrary.amlegal.com/codes/philadelphia/latest/overview. In addition, low-lying areas on a site can be used for SMPs in order to minimize conveyance costs.

With an integrated design approach, the designer uses a combination of three primary strategies to meet the Stormwater Regulations, as applicable: non-structural design, non-structural DIC (rooftop, pavement, and/or tree disconnections), and structural SMPs (e.g. bioinfiltration/bioretention basins, porous pavement, and green roofs). These strategies are implemented initially in sequence, then in an iterative approach leading to formulation of a comprehensive site and stormwater management design as illustrated in Figure 3.1-1.

Figure 3.1-1: PWD's Integrated Design Approach

Non-Structural Design Assess and maximize opportunities to use Non-Structural Design Strategies outlined in **Section 3.1.4** to protect and use existing site features, minimize impervious cover, and reduce earth disturbance.	**Check** compliance with PWD Stormwater Regulations in accordance with **Chapter 1** and evaluate degree of compliance. Confirm Review Path in accordance with **Chapter 2** has not changed.
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Non-Structural Disconnected Impervious Cover (DIC) Assess and maximize opportunities to use Non-Structural DIC approaches, outlined in **Section 3.1.5**, to reduce amount of Directly Connected Impervious Area (DCIA) to be managed.	**Check** compliance with PWD Stormwater Regulations in accordance with **Chapter 1** and evaluate degree of compliance. Confirm Review Path in accordance with **Chapter 2** has not changed.
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SMP Selection, Layout, and Design Develop approach to managing remaining DCIA using a systems approach to SMP design per guidance in **Section 3.2.** In using this Section, consider approaches per the SMP Hierarchy outlined in **Table 3.2-2** and consult **Chapter 4** or SMP-specific design requirements. **Sections 3.2.3 and 3.2.4** include guidance on using SMPs in series and Stormwater Management Banking and Trading to meet the Stormwater Regulations.	**Check** compliance with PWD Stormwater Regulations in accordance with **Chapter 1.**

3.1.4 Non-Structural Design

PWD places a high value on protecting sensitive and special value resources and preserving the natural systems and hydrologic functions that may be present on a site. Non-structural strategies, a primary characteristic of low-impact development, promote the treatment, infiltration, evaporation, and transpiration of precipitation close to where it falls, and are a primary means by which the designer works to preserve and protect high-value natural features. PWD recommends that the designer use non-structural design practices early in the site planning process to reduce the size and cost of stormwater management facilities. Implementing these practices involves the careful consideration of the project site's predevelopment condition, topography, natural drainage systems, and landscaping to arrange site development features in ways that minimize the use of impervious cover and the disruption of existing natural features, and the use of construction staging strategies that limit disturbance and soil compaction.

When used in combination, non-structural strategies can result in a variety of environmental and financial benefits. In the designer's interest, the use of non-structural design practices can reduce land clearing and grading costs, reduce the size and cost of stormwater management facilities, reduce the cost and scope of operations and maintenance, and increase property values. In some cases, these strategies can result in the preservation of open space and working lands, protection of natural systems, and the incorporation of existing site features, such as wetlands and stream corridors, which provide natural hydrologic and water quality functions in addition to fish and wildlife habitat.

Non-Structural Strategies

While most development sites within the City of Philadelphia do not generally possess extensive natural systems, more modest natural systems and features may be of sufficient value to warrant preservation and integration within the development plan. These features may include mature trees or flowering shrubs, natural topography or rock outcroppings, or plant communities that protect slopes from erosion or act as buffers for streams or drainage ways. The designer must complete a site assessment, as described in **Section 3.1.1** ☛ p. 8 and **Section 3.1.2** ☛ p. 14, to better understand the physical features of an existing property before exploring non-structural design strategies.

Following the completion of the site assessment, the first step in the stormwater design process is to thoroughly consider the use of non-structural strategies, finding creative ways of incorporating built features around existing natural areas. Recommended non-structural strategies fall within three categories: protecting sensitive and special value resources, clustering and concentrating, and minimizing disturbance and maintenance.

Protect Sensitive and Special Value Resources

To minimize stormwater impacts, land development activities should avoid encroaching on areas that provide important natural stormwater functions, such as floodplains, wetlands, and riparian areas, and on areas that are especially sensitive to stormwater impacts, such as steep slopes. These features may not be widespread in the urban environment, but where they do exist, they must be identified and protected. By protecting sensitive and special value resources, the designer can make existing natural features an important and integral part of a development site, enhancing the development's role in the landscape and resilience of the community and providing attractive amenities for future tenants or owners. Protecting these features can also reduce the amount of stormwater runoff discharged from the site. For development in the floodplain, in addition to the requirements from the City of Philadelphia **Department of Licenses and Inspections** ☛ www.phila.gov/departments/department-of-licenses-and-inspections/ (L&I), special consideration should be given to SMP placement and design to minimize impacts from current and future floodwater inundation.

Within Philadelphia, most development sites do not have extensive sensitive and special value resources due to the density and history of development in the region. Many of the features that provide hydrologic functions within the landscape have been removed, covered, or buried, and most native soils have been removed, compacted, contaminated, or replaced with low-value fill material and debris. For these reasons, it may be difficult to identify substantial resources or features for protection. This relative scarcity of existing resources, however, prompts PWD to recognize the value and function of less extensive natural areas, even to the extent of valuing an individual tree. PWD urges the designer to consider the preservation and enhancement of natural features present at any scale, as well as enhancements that may help to protect natural features adjacent to the site, such as creating buffer zones or stabilizing steep slopes.

When development sites are adjacent to streams or rivers, riparian buffer systems can protect and enhance streams by limiting erosion, filtering and sequestering pollutants, and providing habitat for wildlife. Riparian buffer systems also aid in the prevention of localized flooding and thereby can protect surrounding property from damage by naturally absorbing flood waters, an important process that will be crucial as extreme storms increase with climate change. Buffers can be especially important along steep banks that are vulnerable to erosion and serve to separate waterbodies from decorative landscape areas where fertilizers are applied, and runoff carries nutrients to the open water. Streambeds, the disturbance of which is regulated by State and Federal regulations, support a variety of life and must be protected from trampling or other abuse. In urban areas where riparian habitat is limited, protecting and enhancing remaining streamside corridors is critical to avoiding further impacts to water quality and ecological health.

Special Value Features

Trees and shrubs are highly effective at retaining precipitation through interception, and all plants further reduce runoff through evapotranspiration. Well-developed root systems help keep soil ecosystems healthy, enhance infiltration, and limit erosion. Naturally-occurring bioretention areas – small, sometimes saturated areas that sustain plant communities such as pocket wetlands and vernal pools – are effective filters that sequester contaminants and support microbes that decompose organic pollutants. These existing vegetated features should be strongly prioritized for preservation. On larger sites, existing drainage pathways, such as natural draws or swales, should be identified and used whenever possible to convey stormwater in the post-development condition. By identifying these features and integrating their preservation within the development plan, sites can benefit from improved quality and reduced volume of off-site stormwater discharges, while simultaneously providing the many benefits of natural vegetation including wildlife habitat, improved air quality, and reductions in the urban heat island effect.

Riparian Areas

When development sites are adjacent to streams or rivers, riparian buffer systems can protect and enhance streams by limiting erosion, filtering and sequestering pollutants, and providing habitat for wildlife. Buffers can be especially important along steep banks that are vulnerable to erosion, and serve to separate waterbodies from decorative landscape areas where fertilizers are applied and runoff carries nutrients to the open water. Streambeds, the disturbance of which is regulated by State and Federal regulations, support a variety of life and must be protected from trampling or other abuse. In urban areas where riparian habitat is limited, protecting and enhancing remaining streamside corridors is critical to avoiding further impacts to water quality and ecological health.

Natural Flow Pathways

Where natural flow pathways or depressions exist, the designer should consider using these systems to help manage site runoff. Planting or protecting existing, deep-rooted plant cover within these existing features can limit erosion. Most larger sites, unless highly disturbed, will possess natural drainage features that, when conditions allow, will sustain and support a diverse plant community while also slowing and filtering runoff before it reaches larger bodies of water. These flow pathways can be attractively integrated within the site's landscaping, reducing irrigation demands, and providing valuable site amenities that require minimal maintenance. Plant choices should be selected from native species that are adapted to the hydrologic conditions expected within the channel. The designer should assess whether existing drainage features are regulated by State or Federal statutes prior to conducting planting within these areas.

Cluster and Concentrate

When assessing the programming needs of the development, the designer should make an effort to cluster and concentrate structures in order to build on the smallest area possible and minimize extensive DCIA, reserving as much area as possible for "green" cover. By limiting the footprints of buildings, parking areas, and other DCIA, either through stacking or clustering structures on the site, the designer can leave larger areas open for green space programming without reducing gross density. This practice not only improves the ability of the site to manage stormwater, but also increases the opportunity for green amenities and enhances long-term property values. Multi-story buildings also have lower energy consumption per square foot of floor space, fetch higher rent compared with low-rise buildings, and retain the urban character of the city.

This practice is not highly applicable to small or single parcel developments, but is more conducive to larger master planning for neighborhoods, campuses for hospitals or educational institutions, or redevelopment of large brownfield sites. In these environments, designation of open spaces can provide enhanced access to shared amenities and promote community cohesion. Concentrating buildings can also reduce per unit construction costs and the cost of providing infrastructure and site circulation.

Minimize Disturbance and Maintenance

Builders and contractors must minimize unnecessary land disturbance in order to limit the movement and compaction of in situ soils and preserve existing vegetation. When planning and staging construction, the designer should work with contractors to avoid trampling or stockpiling where unnecessary, and to stay clear of special value and environmentally sensitive areas. Disturbed or compacted soils are less effective in supporting plant growth and promoting infiltration. Heavy equipment paths must be well marked to avoid unnecessary compaction of in situ soils in areas specified for open spaces, especially areas where infiltration is intended, and tree guards must be erected to prevent damage from construction vehicles. Site planners should also seek to conform to the existing topography to the greatest extent possible, limiting the cost of grading and planting, reducing soil compaction, and assuring that healthy topsoil remains on the surface. These practices will provide for more robust plant growth, speed the recovery of green spaces following construction, and require less maintenance in the long term.

Disturbed areas must be restored with native and recommended adapted non-invasive plants that do not require chemical maintenance and are selected for the appropriate hydrologic regime. In some cases, it will be necessary to protect re-vegetated areas during the establishment period by erecting fences and limiting access.

An example of infiltration area marking to avoid compaction during construction in Philadelphia

Other Considerations Beyond Stormwater Regulations

Beyond the PWD Stormwater Regulations, applicants may want to consider other factors in the stormwater management design to meet immediate development and long term site needs. This may include designing the site such that it complies with both the Stormwater Regulations and
Stormwater quantity and/or quality control requirements for **LEED certification** ☛ https://www.usgbc.org/guide-LEED-certification. Eligible projects may also choose to take advantage of various stormwater management-based Zoning Bonuses to increase a building's height (Philadelphia Code § 14-702(14)) and/or **density** ☛ water.phila.gov/stormwater/incentives/development/. If there are large swaths of existing impervious area that will not be disturbed during construction the applicant may want to consider capturing these areas as well to maximize potential stormwater credits (**Section 6.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-6/6-3-stormwater-credits/).

How to Use Non-Structural Strategies to Help Comply With the Stormwater Regulations

The designer can use non-structural strategies to help comply with the Stormwater Regulations described in **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1 in the following ways:

Water Quality and Channel Protection

Non-structural practices encourage minimizing DCIA, thus reducing the volume of stormwater required to be managed. Additionally, Redevelopment projects that reduce impervious area within the limits of earth disturbance (excluding public right-of-way) by at least 20%, based on a comparison of predevelopment impervious area to post-development DCIA, are exempt from the Channel Protection requirement.

Flood Control

The use of non-structural practices will generally increase on-site stormwater retention and time of concentration, thus reducing the amount and peak flow rate of stormwater required to be managed. Additionally, Redevelopment projects that reduce impervious area within the limits of earth disturbance (excluding public right-of-way) by at least 20%, based on a comparison of predevelopment impervious area to post-development DCIA, are exempt from the Flood Control requirement.

How Non-Structural Design Strategies Influence the PWD Review and Approval Process

As described in **Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2, characteristics of a project will determine the Review Path required for stormwater management compliance. The amount of earth disturbance associated with a proposed project is an important characteristic that can be influenced by non-structural design. By minimizing the amount of earth disturbance, the designer can potentially change Review Paths. For example, a project that is outside of the Darby and Cobbs Creeks or Wissahickon Creek Watersheds and that is able to reduce the amount of earth disturbance to less than 15,000 square feet will be eligible for a Development Exemption Review. After using all possible non-structural strategies to minimize earth disturbance, the designer should refer back to **Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2 to confirm the Review Path for the project.

3.1.5 Disconnected Impervious Cover

This Section includes guidance for discharging stormwater runoff from impervious surface and discusses techniques for reducing DCIA through disconnection. Depending on the configuration, all or a portion of disconnected impervious cover (DIC) may be deducted from the post-development impervious cover on a site, leading to an elimination of, or reduction in, total site DCIA. Further, by incorporating DIC into the design of a Redevelopment project, developers may be eligible for an Expedited Post-Construction Stormwater Management Plan (PCSMP) Review. **Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews details the criteria for Expedited PCSMP Review eligibility. The Online Technical Worksheet (**Section 3.4.3** ☛ p. 101) guides the designer through this stage of the design process and assists in analysis of post-development impervious area, DIC, and ultimate calculation of total site DCIA. All proposed DIC must be documented in the PCSMP Submission Package (**Section 2.3.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1).

Disconnection Strategies

PWD distinguishes between impervious cover from which runoff is directed toward pervious areas for management within the landscape (DIC) and impervious cover from which runoff is directed toward SMPs with discharge/overflow connections to the sewer (DCIA). Disconnection opportunities depend on incorporating sufficient pervious areas into a site layout. Completing a site assessment (**Section 3.1** ☛ p. 7) will help to characterize the nature and extent of existing pervious areas on a site that can be used for impervious area disconnections. Disconnection strategies are described in the following Sections.

Rooftop Disconnection

A reduction in DCIA is permitted when a roof downspout is directed to a vegetated area that allows for infiltration, filtration, and increased time of concentration. PCSMP Approval issued by PWD Stormwater Plan Review may support the designer in their request to obtain relevant and necessary **City of Philadelphia Plumbing Code** ☛ www.phila.gov/departments/department-of-licenses-and-inspections/resources/applicable-codes/ variances for approved rooftop disconnections. The designer is advised to contact **L&I** ☛ www.phila.gov/departments/department-of-licenses-and-inspections/ to confirm the Plumbing Code requirements associated with the disconnection of roof leaders. Under certain circumstances, drainage to an approved point of disposal, SMP, or open space is allowed under the Plumbing Code.

A rooftop is considered to be completely, or partially, disconnected if it meets all of the following requirements:

- The contributing area of rooftop to each disconnected discharge must be 500 square feet or less.
- The soil of the pervious area must not be designated as a hydrologic soil group “D” or equivalent.
- The overland flow path of the pervious area must have a slope of 5% or less.

For designs that meet these requirements, the portion of the roof that may be considered disconnected depends on the length of the overland path as designated in Table 3.2-1.

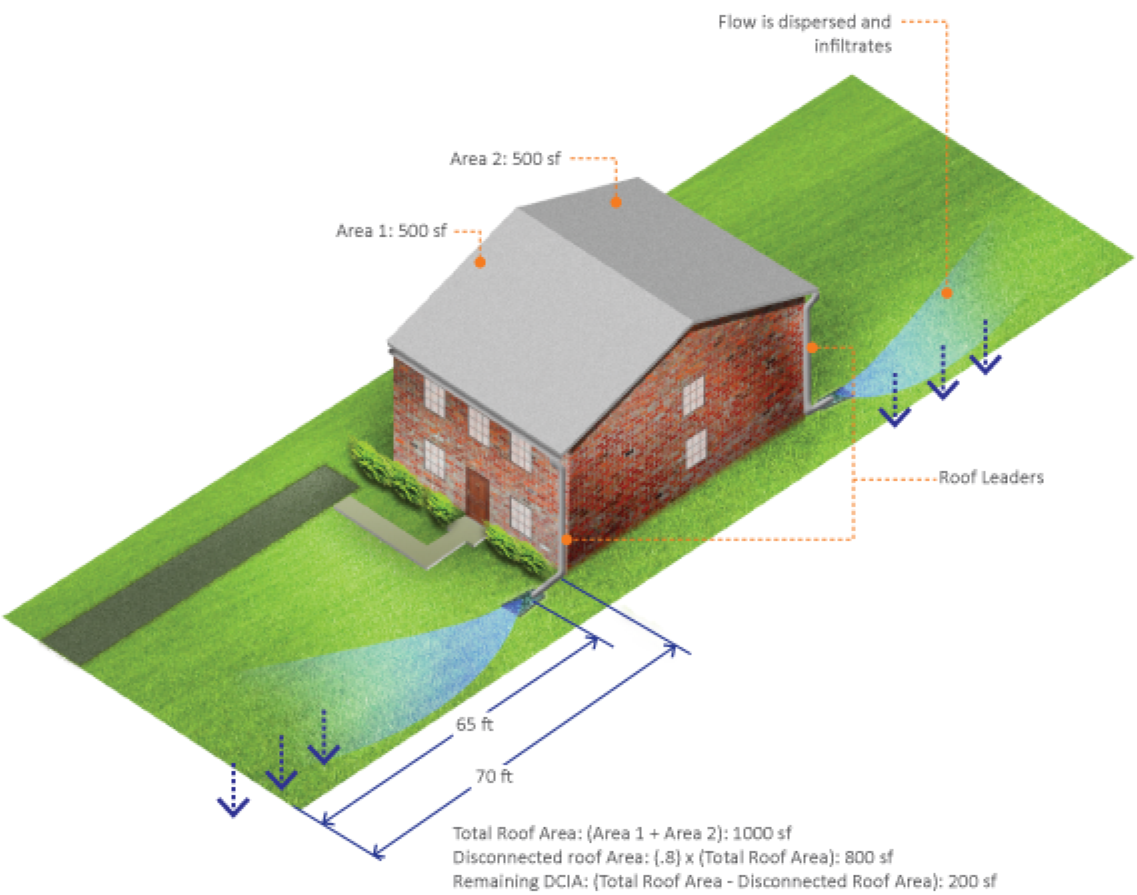
Table 3.1-2: Partial Rooftop Disconnection

Length of Pervious Flow Path* (feet)	Roof Area Treated as Disconnected (% of contributing roof area)
0-14	0
15-29	20
30-44	40
45-59	60
60-74	80
75 or more	100

*Flow path cannot include DCIA, must be at least 15 feet from any ground-level impervious surfaces, and must be continuous starting from the point of roof leader discharge. Two roof leaders cannot discharge to the same flow path for disconnection credit.

For example, consider a 1,000-square foot roof with two roof leaders, each draining an area of 500 square feet (Figure 3.1-2). Both roof leaders discharge to a lawn. The lawn has type B soils and a slope of 3%. The distance from the downspout discharge point to the street is 65 feet. Therefore, based on Table 3.1-2, 80% of the roof area may be considered disconnected and treated as pervious cover when calculating stormwater management requirements. Disconnecting the roof leaders will significantly reduce the size and cost of stormwater management facilities at this site.

Figure 3.1-2: Rooftop Disconnection Example



Roof leader disconnection can be incorporated into Stormwater Retrofit designs and is eligible for stormwater credit. The designer is referred to the ***Stormwater Management Service Charge Credits and Appeals Manual*** ☛ *water.phila.gov/pool/files/stormwater-credits-appeals-manual.pdf* (*Credits and Appeals Manual*) for eligibility requirements.

Pavement Disconnection

A reduction in DCIA is permitted when pavement runoff is directed to a vegetated area that allows for infiltration, filtration, and an increased time of concentration. This method is generally applicable to small or narrow pavement structures such as driveways and narrow pathways through otherwise pervious areas (e.g., a trail through a park).

An example of a pavement disconnection in Philadelphia

Pavement is considered to be completely, or partially, disconnected if it meets all of the following requirements:

- The contributing flow path over impervious pavement must be no more than 75 feet.
- The length and width of overland flow over pervious areas must be greater than, or equal to, the length and width of the contributing flow path over impervious pavement.
- The overland flow must be non-concentrated sheet flow over a vegetated area (flow through a swale is not eligible for pavement disconnection credit).
- The soil of the pervious area must not be designated as a hydrologic soil group “D” or equivalent.
- The contributing impervious area must have a slope of 5% or less.
- The overland flow path of the pervious area must have a slope of 5% or less.

- If discharge is concentrated at one or more discrete points, no more than 1,000 square feet may discharge to any one point. In addition, an erosion control measure, such as a gravel strip, is required for concentrated discharges. Erosion control measures are not required for non-concentrated discharges along the entire edge of pavement; however, there must be provision for the establishment of vegetation along the pavement edge and temporary stabilization of the area until vegetation becomes established.

When choosing pavement disconnections, the designer should consider the impact of directing runoff from adjacent impervious areas on the pervious area. Disconnecting larger areas of pavement along stream banks and other potentially erosive or sensitive areas may necessitate additional measures to be taken beyond meeting the minimum requirements.

Pavement disconnection can be incorporated into Stormwater Retrofit designs and is eligible for stormwater credit. The designer is referred to the ***Credits and Appeals Manual*** ☛ *water.phila.gov/pool/files/stormwater-credits-appeals-manual.pdf* for eligibility requirements.

Tree Disconnection Credit

A reduction in DCIA is permitted when existing or newly proposed tree canopy from an approved species list extends over, or is in close proximity to, impervious area. Trees planted in vegetated practices, such as bioinfiltration/bioretention areas, and that meet the requirements set forth in this Section can be used toward tree disconnection credit.

An example of new tree disconnection credit in Philadelphia

Existing tree disconnection credit may be applied for a reduction in DCIA if it meets the following requirements:

- The existing tree species cannot be an invasive species. The designer is referred to **Appendix I** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/i-plant-lists/ for more information.
- The existing tree must be at least four-inch caliper.
- Existing tree canopies must be field measured, and tree location, size, and species must be indicated on submitted plans. Alternatively, an annotated aerial photo clearly showing the existing tree canopy limits must be submitted.
- Only impervious area located directly under the tree canopy area can be considered disconnected.
- Overlapping existing tree canopy area cannot be counted twice toward disconnection credit.
- Existing trees must be located outside of the public right-of-way.

New tree disconnection credit may be applied for a reduction in DCIA if it meets the following requirements:

- The proposed tree species must be chosen from **Table I-1** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/i-plant-lists/#Table_I.1, the recommended and native non-invasive plant list, in **Appendix I** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/i-plant-lists/.
- New trees must be planted within ten feet of ground-level impervious area, within the limits of earth disturbance, and outside of the public right-of-way.
- New deciduous trees must be at least two-inch caliper.
- New evergreen trees must be at least six feet tall.
- A 100-square foot DCIA reduction is permitted for each new tree. This credit may only be applied to the impervious area adjacent to the tree.
- Overlapping 100-square foot DCIA reduction areas corresponding to adjacent new trees cannot be counted twice toward disconnection credit.

The maximum reduction permitted for both new and existing trees is 25% of ground-level impervious area within the limits of earth disturbance, unless the width of the impervious area is less than ten feet. Up to 100% of narrow impervious areas (e.g., sidewalks and trails) may be disconnected through the application of tree credits.

Tree disconnection credit as listed above is not eligible for stormwater management credit in Stormwater Retrofit projects. Tree canopy cover over unmanaged impervious area is eligible for a separate Tree Canopy Credit as listed in the ***Credits and Appeals Manual*** ☛ *water.phila.gov/pool/files/stormwater-credits-appeals-manual.pdf*.

Green Roof

A reduction in DCIA is permitted when a green roof is installed on a proposed building and when the design, construction, and maintenance plans meet the minimum requirements specified in **Section 4.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-3-green-roofs. To encourage the use of this technology, the entire extent of the green roof area may be considered DIC. However, since a green roof is not a zero discharge system, the remaining site design must safely convey roof runoff from larger storm events to an approved point of discharge. When performing calculations for Flood Control and Public Health and Safety (PHS) Release Rate requirements, green roof discharge (i.e., overflows) must be modeled using appropriate Natural Resources Conservation Service (NRCS) runoff Curve Number (CN) values for green roof areas as described in **Section 3.4.3** ☛ p. 94. The designer is referred to **Section 4.3** ☛ water.phila.gov /development/stormwater-plan-review/manual/chapter-4/4-3-green-roofs for more information on green roofs.

Green roofs may be considered differently for Stormwater Retrofit projects. Designers wishing to incorporate green roofs into Stormwater Retrofit projects should contact **Stormwater Billing and Incentives** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-6/6-3-stormwater-billing-and-incentives/ for additional information.

To encourage the use of green roofs, the Philadelphia Water Department considers the entire extent of the green roof as DIC.

Porous Pavement

PWD recognizes two types of porous pavement systems that can be used to achieve compliance with the Stormwater Regulations: porous pavement DIC areas receiving direct rainfall only; and porous pavement over a structural SMP, which is designed to manage direct rainfall and concentrated runoff from adjacent DCIA.

Porous pavement can be considered DIC when it does not create any areas of concentrated infiltration and does not receive runoff from any adjacent impervious areas.

Porous pavement over structural SMPs is not considered DIC, and therefore must be designed pursuant to the requirements of either a subsurface infiltration (**Section 4.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-4-subsurface-infiltration) or subsurface detention (**Section 4.8** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-8-subsurface-detention) SMP, depending upon the feasibility of infiltration.

For disconnection credit, the design, construction, and maintenance plan must meet the minimum requirements for porous pavement DIC, as specified in **Section 4.2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-2-porous-pavement. When performing calculations for Flood Control and PHS Release Rate requirements, appropriate CN values must be used for porous pavements, as described in **Section 3.4.3** ☛ p. 94.

Porous pavement may be considered differently for Stormwater Retrofit projects. Designers wishing to incorporate porous pavement into Stormwater Retrofit projects should contact **Stormwater Billing and Incentives** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-6/6-3-stormwater-billing-and-incentives/ for additional information.

The Philadelphia Water Department includes certain types of porous pavement systems as DIC.

DIC Applications

There is a broad range of additional applications, including proprietary products, which may be suitable for receipt of disconnection credits. Many of these products will require the use of an appropriate sub-base to allow for storage and infiltration and must generally be installed above non-compacted soil. In most cases, underdrain systems are not required for DIC. The designer must consult with PWD Stormwater Plan Review for specific performance or installation parameters. Potential applications include, but are not limited to, the following:

- Trails (**Section 3.5.4** ☛ p. 112);
- Synthetic turf surfaces for athletic fields (**Section 3.5.5** ☛ p. 114);
- Porous safety surfaces as found in play lots;
- Geogrid systems or other similar soil reinforcements;
- Pervious decking installed over a porous surface; and/or
- Paving tiles with porous grout or gaps.

How to Use Disconnection Strategies to Help Comply With the Stormwater Regulations

The designer can use DIC to help comply with the Stormwater Regulations described in **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1 in the following ways:

Water Quality and Channel Protection

For the strategies described above, impervious area meeting disconnection criteria is considered DIC; these projects are therefore not subject to Stormwater Regulations concerning Water Quality and Channel Protection requirements for treatment of on-site DCIA. Implementing DIC can be an excellent strategy for managing small areas of DCIA for which routing the runoff to the proposed SMP is not feasible, such as porches, steps, concrete pads, walkways, or impervious cover atop utility trenching, etc. Additionally, Redevelopment projects that reduce impervious area within the limits of earth disturbance (excluding public right-of-way) by at least 20%, based on a comparison of predevelopment impervious area to post-development DCIA, are exempt from the Channel Protection requirement.

Flood Control

The use of some disconnection strategies such as green roofs and porous pavements will generally increase on-site stormwater retention, thus reducing the amount and peak flow rate of stormwater required to be managed. Additionally, the use of disconnection strategies reduces DCIA. Redevelopment projects that reduce impervious area within the limits of earth disturbance (excluding public right-of-way) by at least 20%, based on a comparison of predevelopment impervious area to post-development DCIA, are exempt from the Flood Control requirement.

How Disconnection Design Strategies Influence the PWD Review and Approval Process

Reducing DCIA through the implementation of DIC can influence the project Review Path, as described in **Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2. By incorporating DIC into the design of a Redevelopment project, developers may be eligible for an Expedited PCSMP Review (**Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews) to obtain PCSMP Approval faster and meet tighter construction schedules. Disconnection Green Review projects (**Section 2.4.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews#2.4.1) are those that incorporate at least 95% DIC in the stormwater management design in order to meet the Stormwater Regulations, and Surface Green Review projects (**Section 2.4.2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews#2.4.2) use a combination of bioinfiltration/bioretention SMPs and DIC to meet the Stormwater Regulations. Disconnection Green Reviews benefit from a shorter (five-day) PCSMP Review Phase, and exemption from the infiltration testing requirement. Surface Green Review projects benefit from a shorter (five-day) PCSMP Review Phase and the option to delay infiltration testing until construction to provide flexibility and potential cost savings.

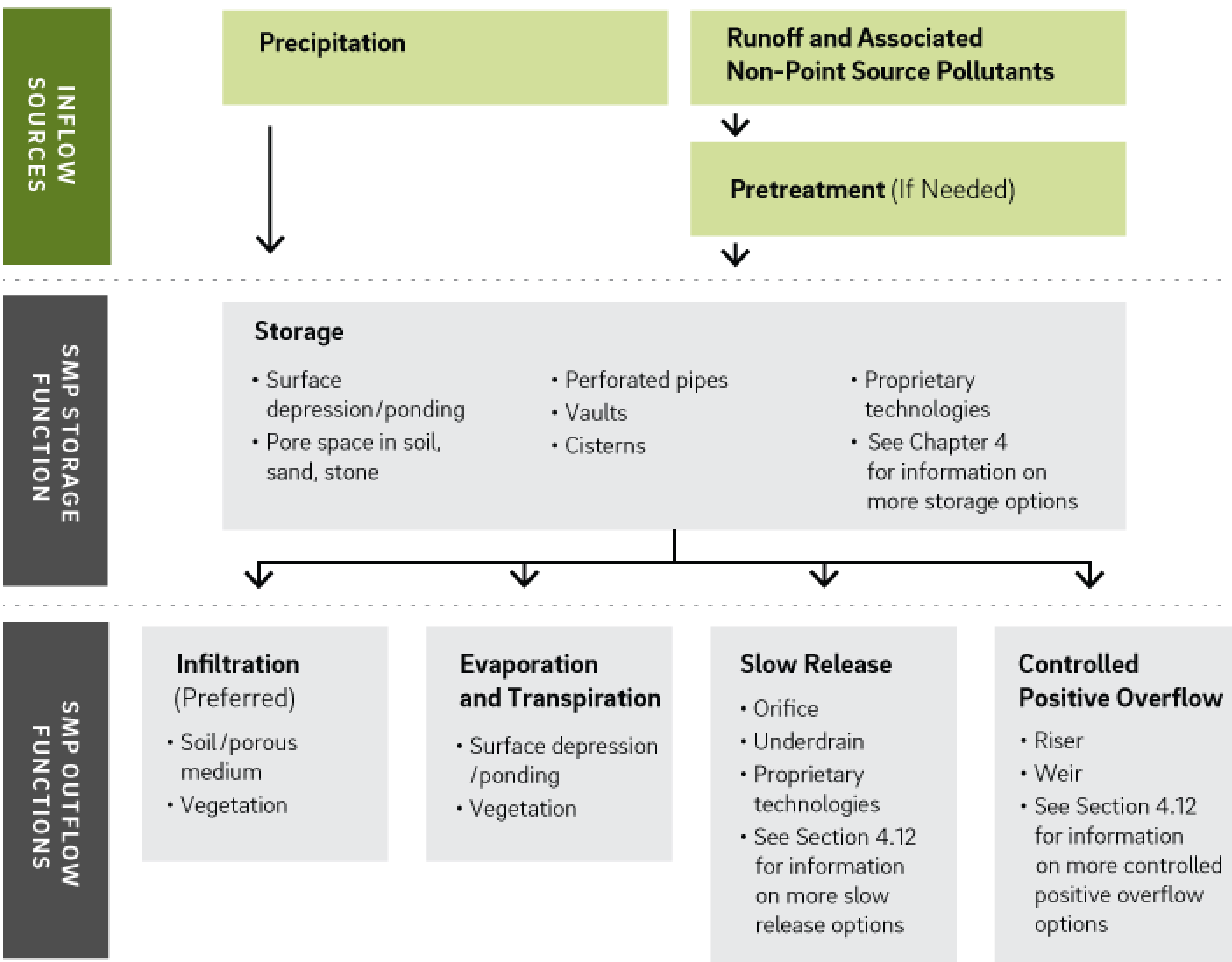
3.1.6 SMP Functions

The designer will often need to use SMPs to meet the Stormwater Regulations. PWD expects that the designer will first consider maximizing the use of non-structural design and DIC strategies outlined earlier in this Chapter, but also recognizes that, for many sites, stormwater management compliance will rely strongly on the use of SMPs.

SMPs are systems that use physical, chemical, and biological processes to provide a certain level of stormwater control and treatment. This level of control typically includes a required storage volume, a volume to be infiltrated, and an acceptable release rate. These requirements are met through five principal hydraulic functions of SMPs, described below.

Figure 3.1-3 illustrates a variety of design elements available to provide these functions. Depending on the configuration, physical, chemical, and biological processes lead to removal of pollutants during these processes. By combining design components in a variety of ways, the designer can identify alternative systems that achieve a given function. The SMP functions are not mutually exclusive and certain SMPs may perform multiple functions.

Figure 3.1-3: Overview of SMP Functions



1. Storage

Storage can be provided through surface ponding, enclosed surface storage, or subsurface storage. Subsurface stone storage beds provide storage in stone pore spaces, or voids. Some SMPs, such as bioinfiltration/bioretention basins, can provide a combination of both surface and subsurface storage.

A rough estimate of *surface storage* can be obtained by averaging the surface area and bottom area of a basin and multiplying by the average depth. For irregular shapes, volume can be estimated by finding the area inside each contour, multiplying each area by the contour interval, and adding the results.

Storage in *stone pores* is equal to the volume of the crushed stone bed times the porosity. A design porosity of 40% can be assumed for the stone if specifications for the crushed stone meet those provided in Chapter 4.

Storage available in *porous media* is equal to the initial moisture deficit, the portion of total porosity that is not already occupied by moisture. This portion varies at the beginning of every storm; acceptable design values are 30% for *sand* and 20% for *growing soil*.

Not all physical space in a given SMP is active. The maximum elevation that is considered active storage is the overflow elevation. In tanks draining by gravity whose bottoms do not infiltrate, any volume below the invert of the orifice or control structure cannot be considered *active storage*.

2. Infiltration

Infiltration of stored water into the underlying soil is desired in order to help restore natural hydrology and reduce the volume of stormwater runoff that enters the City's drainage system. Managing and infiltrating stormwater at its source reduces the risk of localized flooding and combined sewer overflows during heavy rainfall events, which are projected to occur more frequently with climate change. Moreover, the filtration process naturally aids in the removal of pollutants from stormwater runoff and improves the water quality of runoff entering our city's waterways. Surface vegetation helps prolong design life because the growth of plant roots helps to keep the soil pore structure open over time. This effect is greatest with vegetation that has a deeper root structure (e.g., trees, shrubs, and native herbaceous species rather than turf grass). Using such attractive landscaping practices improves the quality of life in the urban landscape.

3. Evaporation and Transpiration

Evaporation and transpiration are minor SMP functions when measured over the course of one storm, but they are significant when measured over time. Surface SMPs will provide the greatest evaporation and transpiration benefit, particularly if they are vegetated. Some water that infiltrates the surface will evaporate. For this reason, vegetated systems provide both water quality treatment and volume reduction.

4. Slow Release

When stored water cannot be infiltrated or evaporated, it must be released at a slow rate to a sewer or receiving water body. This allows the runoff to slowly drain into the City's system, preventing environmental issues stemming from large amounts of water entering the sewer system or receiving water all at once. For volumes in excess of the SMP's infiltrated static storage, and for non-infiltrating SMPs, the SMP may release the volume slowly through an outlet control device. The outlet control structure may require design and maintenance measures to avoid clogging.

5. Controlled Positive Overflow

All designs must have a mechanism for water to overflow, or bypass, the system unimpeded during events larger than the design event. A riser or other overflow structure can be incorporated into the design to achieve this, or the flow capacity of some SMPs themselves can act as a bypass mechanism.

3.1.7 Pollutant-Reducing Practices and Roof Runoff Isolation

Pollutant-Reducing Practices

While infiltration is always preferred, Table 3.1-3 presents a list of acceptable pollutant-reducing practices to be used for projects where infiltration is found to be infeasible. The designer is referred to the **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 Section referenced in the table for detailed design information concerning each type of SMP. Additional information on SMP types is provided later in this Section in the SMP Selection and Conceptual Design Section. If a particular practice is listed as “not acceptable” within separate sewer or direct discharge areas, it does not imply that this practice cannot be used; it simply means that that particular practice does not qualify as pollutant-reducing when used in those areas.

Table 3.1-3: Acceptable Non-Infiltrating Pollutant-Reducing Practices

	Section	Combined Sewer Area	Separate Sewer Area or Direct Discharge
Bioretention	**4.1** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-1-bioinfiltration -bioretention	Yes	Yes
Porous Pavement DIC	**4.2** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-2-porous -pavement	Yes	Yes
Green Roofs	**4.3** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-3-green-roofs	Yes	Yes
Cisterns	**4.5** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-5-cisterns	Yes	Yes
Blue Roofs	**4.6** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-6-blue-roofs	Yes	No
Ponds and Wet Basins	**4.7** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-7-ponds-and -wet-basins	Yes	Yes
Vegetated Media Filters	**4.9** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-9-media-filters	Yes	Yes
Media Filters	**4.9** ☛ water.phila.gov /development/stormwater -plan-review/manual /chapter-4/4-9-media-filters	Yes	Yes
Roof Runoff Isolation*	**3.1.7** ☛ p. 35	Yes	No

**Roof runoff isolation* is the routing of runoff from non-vehicular roof area that is not commingled with untreated runoff.

Roof Runoff Isolation

Recognizing that runoff from some areas is cleaner than others, PWD has identified roof runoff isolation as an acceptable non-infiltrating pollutant-reducing practice for use only on projects that are within combined sewer areas and required to comply with Stormwater Regulations. Roof runoff isolation is the practice of segregating roof runoff from runoff exposed to any vehicular activity (e.g., roof-level parking deck) and from untreated surface ground-level runoff, prior to discharging to the sewer.

This Philadelphia parking garage with rooftop vehicular access does not qualify for roof runoff isolation.

The designer can incorporate roof runoff isolation into site layout and design by providing dedicated stormwater conveyance piping from roof areas to SMPs designed to meet the combined sewer area Water Quality slow release rate requirement. A blue roof (**Section 4.6** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-6-blue-roofs) can also be used as streamlined approach for both achieving roof runoff isolation as well as controlling the roof runoff to meet the Water Quality slow release requirement. Runoff from isolated roofs must not commingle with roof runoff exposed to vehicular activity or other untreated runoff until a point in the system after which such runoff has been treated by another pollutant-reducing practice. An example of an application of roof runoff isolation is illustrated in Figure 3.1-4.

Figure 3.1-4: Roof Runoff Isolation Example

3.1.8 How to Use SMPs to Comply with the Regulations

A well-designed SMP will use combinations of the five principal hydraulic functions described above to achieve compliance with Stormwater Regulations. As noted previously, SMPs are one tool available to the designer to meet the Stormwater Regulations. PWD encourages the designer to first consider non-structural design and DIC to meet the Stormwater Regulations prior to considering SMPs (**Section 3.1.4** ☛ p. 17 and **Section 3.1.5** ☛ p. 23). Specific suggestions for using SMPs for compliance are discussed below. The designer should also consult the guidance on designing SMPs in series and Stormwater Management Banking and Trading in Sections **3.2.3** ☛ p. 49 and **3.2.4** ☛ p. 53, respectively, for additional options in using SMPs to help comply with the Stormwater Regulations.

Water Quality

Where infiltration is feasible, each SMP must provide adequate static storage for its entire Water Quality Volume (WQv) below its lowest outlet. Exceptions to this requirement include SMPs in series (for which the series as a whole must comply with this requirement) and dynamically designed bioinfiltration SMPs (for which static storage of only one inch of the WQv must be provided if the designer demonstrates, through dynamic routing, that the full 1.5-inch WQv is managed throughout the design storm, without overflow). Additionally, the designer must ensure a drain down time of no more than 72 hours. Drain down time compliance is typically achieved by varying the storage area dimensions.

Where infiltration is not feasible in a combined sewer area, the WQv must be treated and released at a controlled release rate and routed through an acceptable pollutant-reducing practice. The designer is referred to **Section 3.4.1** ☛ p. 83 for detailed information on how to comply with the Water Quality requirement.

For gravity systems, the target controlled release rate is a function of head on the outlet structure orifice/weir and the orifice/weir characteristics. Compliance is typically achieved by varying storage area dimensions and outlet structure configuration to meet the target slow release rate.

Channel Protection (if applicable)

Compliance with the Channel Protection requirement is typically achieved by varying storage area dimensions and outlet structure configuration to reduce the peak outflow rate during the one-year storm. Additionally, the designer must ensure a drain down time of no more than 72 hours. Controlled positive overflow must be provided, typically in the form of a riser or other overflow structure, to safely pass events larger than the one-year design storm. The designer is referred to **Section 3.4.1** ☛ p. 83 for detailed information on how to comply with the Channel Protection requirement.

Flood Control (if applicable)

Compliance with the Flood Control requirement is also typically achieved by varying storage area dimensions and outlet structure configuration to reduce the peak outflow rates for the post-development condition. Peak runoff in the proposed condition must be no greater than the peak runoff in the predevelopment condition for design storms specific to a project's given Flood Management District and discharge point. Controlled positive overflow must be provided, typically in the form of a riser or other overflow structure, to safely pass large storms. The designer is referred to **Section 3.4.1** ☛ p. 83 for detailed information on how to comply with the Flood Control requirement.

3.2 Stormwater Management Design

Section 3.2 contains a significant amount of design guidance that the designer should use to integrate robust and cost-effective stormwater management into site designs in ways that achieve the Philadelphia Water Department's (PWD's) key stormwater management goals of minimizing the harmful effects of flooding and maintaining the health of Philadelphia's streams and rivers. Additionally, this section contains general requirements and standards of which the designer must be aware.

3.2.1 Major SMP Types

Infiltrating SMPs

Infiltrating stormwater management practices (SMPs), such as porous pavement, subsurface infiltration, and bioinfiltration practices, manage stormwater by infiltrating it into the ground. The designer is required to use infiltrating practices to meet the Water Quality requirement unless infiltration is found to be infeasible. All infiltrating practices are considered pollutant-reducing.

Slow Release SMPs

Slow release SMPs detain and slowly release stormwater over time. Some slow release practices are inherently pollutant-reducing practices (if stormwater is passed through a soil/vegetation/media complex), while others may need to be designed in series with an additional pollutant-reducing SMP.

Pollutant-Reducing SMPs

On sites where infiltration is not feasible, directly connected impervious area (DCIA) must be routed to an acceptable pollutant-reducing practice. **Table 3.1-3** ☛ p. 36 in **Section 3.1.7** ☛ p. 35 presents the non-infiltrating SMPs that PWD currently accepts as pollutant-reducing practices. For detailed information and design guidelines for individual SMPs, the designer is referred to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4. Alternative pollutant-reducing practices may be proposed and will be reviewed on a case-by-case basis. Pollutant-reducing practices include all infiltrating practices and some slow release practices.

Vegetated SMPs

Vegetated practices include vegetation as a significant or dominant component within the storage area and include bioinfiltration/bioretention basins, ponds and wet basins, green roofs, and vegetated media filters.

Non-Vegetated SMPs

Non-vegetated practices include all subsurface practices, blue roofs, porous pavement, media filters, and cisterns, and do not have significant vegetative components.

3.2.2 SMP Hierarchy and Selection Process

Download a summary of the SMP Hierarchy guidance, with quick reference information for clients and developers:

SMP Hierarchy One-Sheet ☛ water.phila.gov/pool/files/smp-hierarchy-one-sheet.pdf

The process of selecting the right SMPs for a site is complex and can be challenging, particularly for constrained sites. PWD accepts many different SMPs and offers approaches such as SMPs in series and Stormwater Management Banking and Trading that provide the designer flexibility in fitting SMPs into challenging project sites. During the SMP selection and conceptual design process, the designer will select and perform an initial layout of SMPs, incorporating site assessment data; an understanding of remaining stormwater management requirements (after accounting for non-structural design and disconnected impervious cover (DIC) strategies); PWD's SMP preferences; and other factors such as aesthetics, cost, and maintenance requirements. This SMP selection and initial layout process should be performed prior to the finalization of the development site layout, such that the site layout can be revised, if needed, based on SMP requirements. Typically, the designer will perform initial SMP selection and conceptual design prior to the submission of the Conceptual Review Phase Submission Package (**Section 2.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases) or a Stormwater Grant Application for Stormwater Retrofit projects seeking **Stormwater Grant** ☛ water.phila.gov/stormwater/incentives/grants/ funding.

PWD requires that infiltrating SMPs be used to meet the Water Quality requirement unless the designer demonstrates that infiltration is not feasible. Infiltration testing and soil characterization procedures are outlined in **Section 3.3** ☛ p. 64. In many cases, infiltration testing will not be performed until the initial layout of SMPs has been completed. While it is generally prudent to conduct this testing as soon as SMP footprints and depths have been estimated, infiltration testing is not required to be performed during conceptual design. By performing a site assessment and stormwater management opportunities and constraints analysis in accordance with **Section 3.1** ☛ p. 7, the designer can reduce the likelihood that a properly conducted infiltration and soil characterization plan (**Section 3.3.1** ☛ p. 67) will uncover non-infiltrating subsurface conditions at the SMPs' footprints laid out during SMP selection and conceptual design. A site assessment and opportunities/constraints analysis will do so by screening out locations, such as areas with documented high seasonal groundwater, shallow bedrock, clay, or other limiting soil layers that may preclude infiltration, and steering the conceptual SMP layout toward areas more likely to support infiltration.

PWD recommends a three-step process for selecting and advancing SMP design through the conceptual design phase.

Step 1 – Understanding the Options: The SMP Hierarchy

SMPs can differ greatly from each other in terms of cost, function, and applicability to different types of sites. The designer is encouraged to thoroughly review the SMP-specific guidance provided in **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 when selecting SMPs. The SMP One-Sheets at the beginning of each SMP Chapter should help in understanding the potential for using each SMP type to meet the various Stormwater Regulations.

The SMP Hierarchy is a tool developed to help PWD understand and communicate the order of PWD's preference for all SMPs. This tool has allowed PWD to formulate incentive-based policies that promote the use of high-performance and cost-effective stormwater management approaches that more effectively achieve the goals of the *Green City, Clean Waters* program. Similarly, the Hierarchy provides a clear reference point for the private development community to understand which SMPs are most preferred by PWD. Specifically, the Hierarchy seeks to promote practices that do the following:

- Reduce stormwater and pollutants entering and leaving the PWD collection system;
- Are likely to be maintained and have indicated longevity in previous installations; and
- Provide vegetation to create a greener city.

Ranking Criteria

The criteria used to rank the SMPs reflect a wide range of characteristics, such as water quality and quantity performance, space requirements, construction and maintenance costs, likeliness of failure, and triple bottom line performance. As a result, the Hierarchy reflects preferences based on stormwater management performance, constructability, and longevity. Table 3.2-1 outlines the main criteria considered when ranking SMPs in order of their relative weight. The SMP One-Sheet at the beginning of each SMP Section in **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 displays its relative performance level for each attribute.

Table 3.2-1: SMP Hierarchy Ranking Criteria

SMP Hierarchy Ranking Criteria	
Infiltration and Volume Reduction	The SMP's ability to infiltrate or reduce the Water Quality volume (WQv)
Effluent Pollutant Load	The typical annual mass of total suspended solids (TSS) in the SMP's effluent runoff (total annual mass of TSS, accumulated at a point of analysis downstream of the SMP). Annual TSS mass is computed by considering the SMP to be managing one acre of DCIA with effluent event mean concentrations of TSS based on data from the International Stormwater BMP Database.
Likeliness of Failure	The relative likelihood that the SMP will fail to operate and will fail to be repaired so that it functions as designed over a unit period of time based on observations at a program level.
Construction Costs	The marginal redevelopment implementation costs associated with the construction of the SMP per acre of DCIA treated. As defined in the Long-Term Control Plan Update (LTCPU), marginal redevelopment cost is considered the cost beyond traditional measures to implement an SMP approach, assuming that redevelopment is already taking place. SMP costs were derived from the construction cost analysis and reference cost assessment prepared for the LTCPU, with updated unit costs.
Evapotranspiration	The SMP's ability to manage stormwater runoff via evapotranspiration (ET). Each SMP is evaluated based on the characteristics of the surface area available for ET and any enhancement factors (vegetation). These vary by typical vegetation cover type and density, as well as any non-vegetative evaporation pathways (i.e., surface water and void spaces).
Triple Bottom Line	The SMP's ability to provide social, environmental, and economic benefits (land value, energy efficiency, etc.).
Water Quality Rate Control	The ability of an SMP to reduce the release rate of the WQv to not exceed the maximum release rate.
Large Storm Rate Control	The ability of an SMP sized for Water Quality compliance to reduce the discharge rate of large runoff events and to be resized to manage large storm events, which is helpful in complying with the Flood Control and PHS Release Rate requirements.
Operations and Maintenance (O&M) Costs	The annual costs associated with O&M activities for the SMP. They were derived from the maintenance cost analysis prepared for the LTCPU.
Building Footprint Encroachment	Encroachment onto site area that could otherwise be used for building footprint.
Ground-Level Encroachment	Encroachment onto potential usable, open space on the ground-level surface of the site.

The SMP Hierarchy is shown below in Table 3.2-2. All SMPs are classified as one of three preference levels: Highest, Medium, and Lowest.

Highest-Preference SMPs

The highest-ranking SMPs include bioinfiltration, bioretention, permeable pavers, reinforced turf, and green roofs. Bioinfiltration is ranked highest for its ability to infiltrate stormwater and provide triple bottom line benefits while being cost effective and long-lasting. Similarly, bioretention is ranked very high, reflecting its ability to settle suspended solids and cycle nutrients via plant uptake. As bioinfiltration and bioretention basins are both vegetated, they also have the potential for mitigating the urban heat island effect as well as reducing pollutant loads within the City's waterways, which are both important contributions to help limit the predicted impacts on the City due to a warming climate.

The designer is encouraged to incorporate SMPs from this Hierarchy tier into their stormwater management design. As discussed in **Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews, projects that manage stormwater with SMPs only in this category are eligible for a Surface Green Review. Advantages of a Surface Green Review include a shorter (five-day) Post-Construction Stormwater Management Plan (PCSMP) Review Phase and the option to postpone infiltration testing until construction.

Medium-Preference SMPs

SMPs considered to have medium preference (subsurface infiltration, cisterns, blue roofs, porous asphalt, porous concrete, and ponds and wet basins) tend to efficiently manage stormwater via infiltration, volume reduction, or detention. These SMPs often provide fewer triple bottom line benefits and may not last as long as more highly preferred SMPs.

Lowest-Preference SMPs

The least-preferred SMPs in the Hierarchy (subsurface detention with vegetated media filters, subsurface detention with roof runoff isolation, subsurface detention with media filters, vegetated media filters, and media filters) are non-infiltrating and generally provide little, to no, triple bottom line benefits. Additionally, the SMPs in this tier tend to have relatively high operations and maintenance (O&M) costs and may malfunction more frequently than other SMPs.

Table 3.2-2: SMP Hierarchy

SMP / SMPs in Series	Section
HIGHEST PREFERENCE	
Bioinfiltration	4.1
Bioretention	4.1
Permeable Pavers/Reinforced Turf	4.2
Green Roofs	4.3
MEDIUM PREFERENCE	
Subsurface Infiltration	4.4
Cisterns	4.5
Blue Roofs	4.6
Porous Asphalt/Porous Concrete	4.2
Ponds and Wet Basins	4.7
LOWEST PREFERENCE	
Subsurface Detention with Vegetated Media Filters	4.8 / 4.9
Subsurface Detention with Roof Runoff Isolation	4.8 / 3.1.7
Subsurface Detention with Media Filters	4.8 / 4.9
Vegetated Media Filters	4.9
Media Filters	4.9

Step 2 –Determining Residual Management Requirements

The designer may be able to satisfy some or all of the Stormwater Regulations using non-structural design or DIC strategies. Prior to considering the use of SMPs, the designer must develop a quantitative understanding of the remaining stormwater management needs with respect to each of the Post-Construction Stormwater Management Criteria: Water Quality, Channel Protection, Flood Control, and Public Health and Safety Release Rate. Following the evaluation of non-structural and disconnection options, the designer must determine the following prior to proceeding to the SMP design stage:

- Total remaining DCIA to be treated and associated Water Quality volume (WQv)
- Peak flow attenuation required for all site DCIA, for the Channel Protection requirement, if applicable; and
- Total peak flow comparison from predevelopment to post-development conditions for each point of interest, for the Flood Control requirement, if applicable.

Step 3 – SMP Placement and Layout

Some sites will offer numerous options for locating SMPs (on rooftops, on the ground surface, or underground), while other sites, particularly "full build-out" sites (where ground-level open space is not available in the proposed site layout), will have fewer options for SMP placement. PWD encourages the designer to incorporate ground-level vegetated SMPs on sites wherever possible, resorting to subsurface SMPs only when other options have been exhausted. The designer should approach the SMP placement and layout process after becoming thoroughly familiar with the characteristics, advantages, limitations, and appropriate uses of acceptable SMPs. The designer should choose SMPs per the SMP Hierarchy presented above, exhausting opportunities for preferred practices prior to considering lower priority practices.

The following guidelines and suggestions are provided to assist the designer with selecting and arranging SMPs.

- **Assessing Space Constraints** – SMPs rely on storage volume to achieve performance. The availability of space for SMPs will often dictate the location and type of SMPs that can work on a site. Considering SMP placement early in the design process is critical to ensuring that sufficient space for incorporating SMPs, particularly ground-level SMPs, is present. The designer should calculate approximate design requirements (e.g., total required storage volume) to allocate space for stormwater management within the site layout. If sufficient space is unavailable for incorporating surface-vegetated practices, the designer may need to consider alternatives such as porous pavement, or other SMPs, proceeding down the SMP Hierarchy. The use of SMPs in series, Stormwater Management Banking and Trading, and/or adding subsurface storage to a bioretention system can help the designer maximize the use of surface-vegetated SMPs, even on constrained sites.
- **Creating On-Site Amenities** – SMPs such as green roofs and bioinfiltration/bioretention basins can provide on-site greening, as vegetated features can act as an aesthetic amenity, particularly for residential and commercial retail sites. Bioinfiltration/bioretention SMPs should be designed in conjunction with other desired and required landscaping.
- **Choosing Areas with Infiltration Potential** – Although the exact infiltration rate at a particular location within a site is not generally known during the Conceptual Review Phase, the designer should use existing information to locate SMPs in areas that have a strong potential for infiltration. Much of this information, such as United States Department of Agriculture (USDA) Hydrologic Soil Maps, existing geotechnical reports, existing soil investigation reports, drainage feature mapping, topographic mapping, information on existing site drainage issues, and data on high seasonal groundwater, will have been compiled during initial site assessment activities as described in **Section 3.1.1** ☛ p. 8 and **Section 3.1.2** ☛ p. 14, and must be used for this purpose.
- **Prioritizing Low-Lying Areas** – Surface-level SMPs should be located on lower portions of a site, where stormwater can be gravity-fed from DCIA to the SMPs without making the SMPs excessively deep. These low-lying areas should be prioritized for stormwater management early in the site design process.
- **Providing Downstream Points of Relief** – SMPs need to provide gravity drainage for both overflow structures and underdrains. SMP elevations must not be too low to preclude tying in underdrains and overflow structures to a downstream point of relief (e.g., sewer or receiving water)
- **Minimizing Conveyance Requirements** – SMPs are less costly and easier to maintain if the designer reduces the amount of collection and distribution piping. Opportunities to sheet flow stormwater from DCIA to SMPs, or to use surface conveyance systems like swales to bring stormwater into SMPs, should be

sought. In some cases, the designer may be able to use natural drainage features to convey stormwater with little additional cost.

- **Avoiding Utilities** – Careful mapping of surface and subsurface utilities on-site is necessary to reduce conflicts and the potential for relocating of existing utilities. A designer can view PWD utility records by contacting PA One Call and PWD Water Transport Records Unit.
- **Avoiding Sensitive Features** – SMPs should be placed in locations that avoid sensitive features, such as mature tree stands, wetlands, steep slopes, and floodplains, and constraints, such as shallow bedrock and groundwater. These areas will have been mapped during the site assessment process in **Section 3.1.1** ☛ p. 8 and **Section 3.1.2** ☛ p. 14. Many of these areas are regulated by State and Federal agencies and/or City ordinances.
- **Providing Maintenance Access** – Locating SMPs in areas where they can be easily accessed for maintenance is an important design consideration. Vehicular access routes, if needed for sediment removal, should be considered.
- **Avoiding Hotspots and Contamination** – Locating SMPs away from hotspots and areas of known contamination is always a good idea. Location of infiltrating SMPs within contaminated areas is not permitted. The designer is referred to the hotspot investigation procedures in **Section 3.1.1** ☛ p. 8 for more information. During this phase, a preliminary investigation of likely hotspots is suggested. During detailed design, more exhaustive characterization of soil contamination issues may be required for individual SMP sites to determine infiltration feasibility.
- **Avoiding Unstable Fill** – Many areas of Philadelphia are underlain by historic fill, which can be loose or unstable. The designer is advised to identify areas of unstable fill through geophysical methods, exploratory geotechnical testing, or historic mapping to avoid these areas where possible.
- **Maintaining Sight Lines** – Clear lines of sight are critical for pedestrian and vehicular safety. SMPs should be placed so as not to impair lines of sight, and the designer must consider full grow-out condition for vegetation when assessing sight line issues.
- **Ensuring Safety** – Many SMPs contain features such as ponded water that could be unsafe, particularly for vulnerable populations, such as young children. The designer should consider locating SMPs with ponded water away from play-yards, playgrounds, or other areas where children are playing, or installing fencing or other features to limit interaction with the system.
- **Considering Appropriate Conditions for Vegetated SMPs** – Some variables to consider include amount of sunlight received and solar orientation, wind speed and direction, temperature gain, and surface character. For example, sites facing northeast receive morning sun and tend to be cooler and wetter than those facing southwest and runoff from asphalt will be hotter than that from concrete. Combinations of these variables create different micro-climates and should be taken into account when placing the SMP and selecting plants.

3.2.3 Placing SMPs in Series

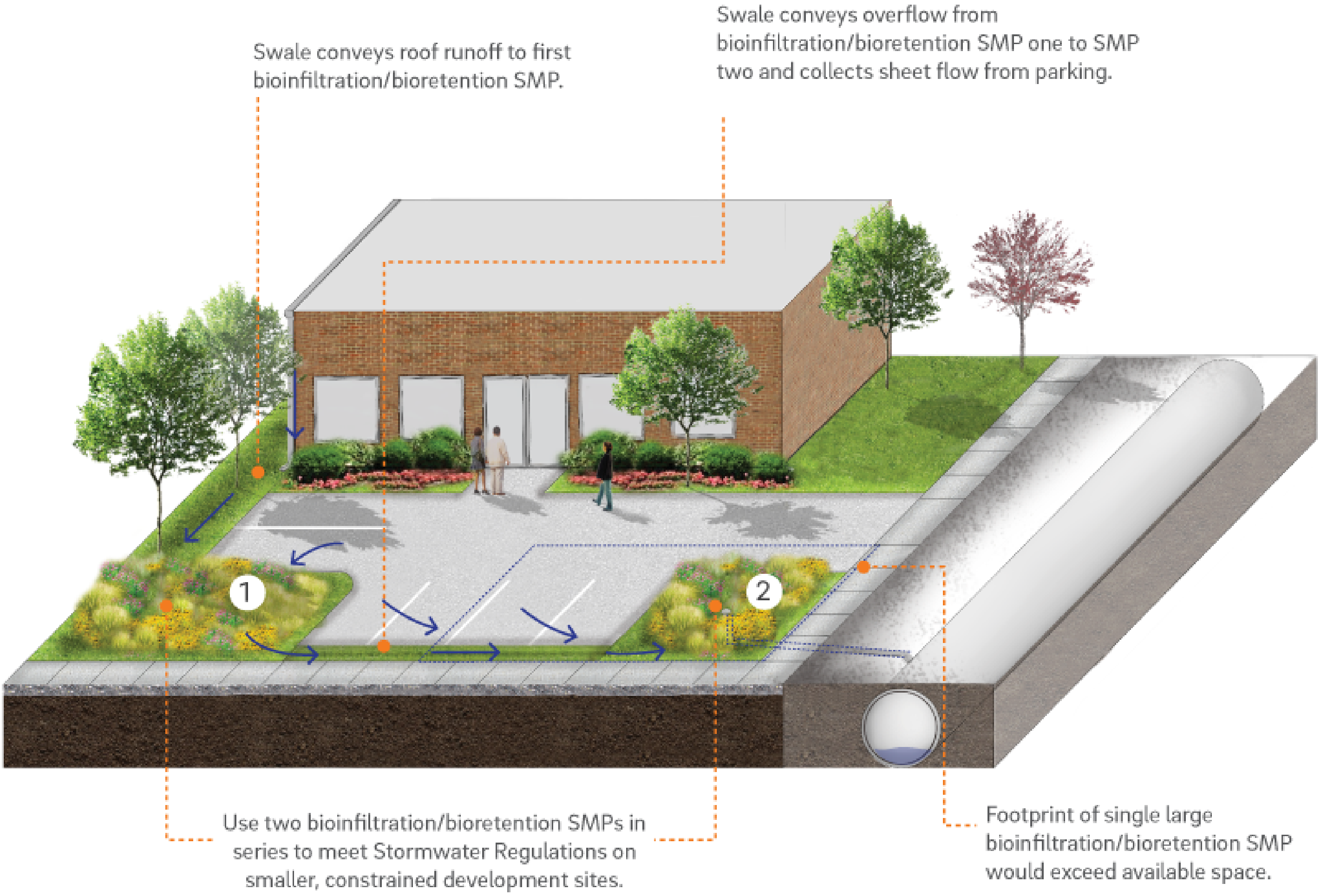
Many of the SMPs discussed in this Manual provide both Water Quality treatment and rate control. Some SMPs provide only rate control. The designer must keep in mind that some SMPs cannot fully meet all applicable Stormwater Regulations on their own, and a network of SMPs can be used to meet the Stormwater Regulations for a given site. For example, peak rate control for Flood Control compliance could be progressively achieved through flow attenuation in a series of smaller, linked SMPs. Many of these SMPs could also be used to meet the Water Quality requirement by providing cumulative static storage equal to the contributing WQv. In addition, non-pollutant-reducing practices, such as subsurface detention systems, can be used to meet the Water Quality slow release rate requirement, Channel Protection, and Flood Control requirements, but they cannot be used to meet the Water Quality pollutant-reduction requirement. In other cases, space constraints may preclude the ability to comply with the Stormwater Regulations using only one SMP.

While it is generally more cost effective, efficient, and easier to meet the Stormwater Regulations using as few SMPs as possible, to provide more flexibility, PWD allows the designer to use approaches that achieve compliance through the use of multiple SMPs connected in series. Placing SMPs in series allows the designer to minimize the disrupted space, limit the construction or maintenance costs of a system, or meet the Stormwater Regulations on a crowded or complex site. Particular approaches will vary by site, and the designer is encouraged to use creativity to combine SMPs in ways that achieve site-wide compliance. Some examples of these approaches are discussed below.

Multiple Small Bioinfiltration/Bioretention SMPs

A series of smaller bioinfiltration/bioretention SMPs can be placed within small landscaped areas in lieu of a single large bioinfiltration/bioretention SMP. This approach can be effective for promoting vegetated surface SMPs within constrained sites. Figure 3.2-1 illustrates this approach.

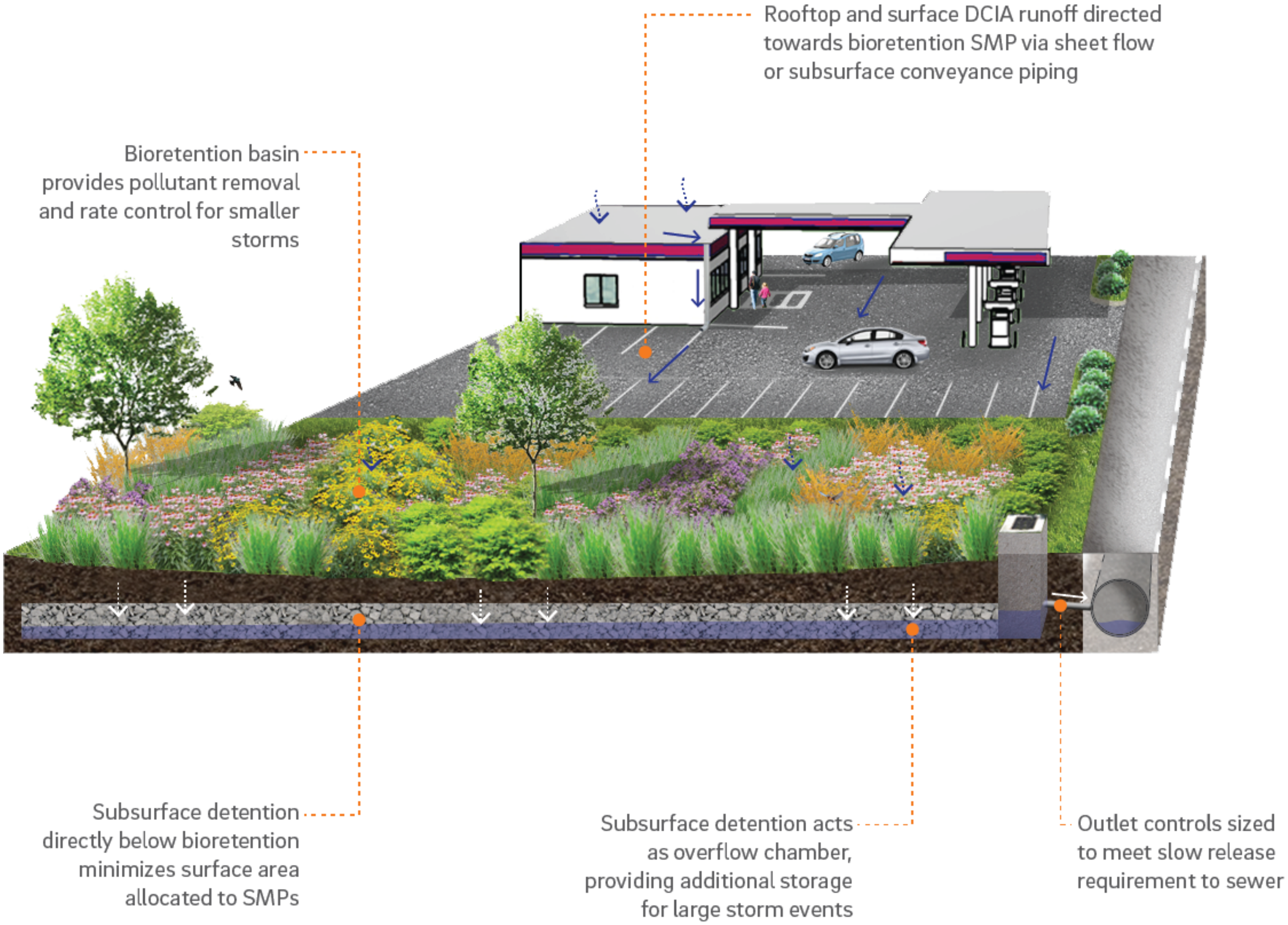
Figure 3.2-1: SMPs in Series Example #1 – Multiple Small Bioinfiltration/Bioretention SMPs



Bioretention with Subsurface Detention

Bioretention systems are particularly effective for managing the WQv. They provide treatment and rate control, but may not provide enough storage to meet the Flood Control or PHS Release Rate requirements, if applicable. A bioretention basin installed directly over a subsurface detention basin provides a number of benefits. The bioretention basin is relatively easy to maintain and is a pollutant-reducing practice. The subsurface detention basin provides effective rate control for small and large storms. This combination allows the subsurface detention basin to act as an overflow chamber for large runoff volumes generated by large storms. The bioretention and subsurface detention basin in series can reduce the amount of usable surface area disrupted while meeting the Stormwater Regulations. Figure 3.2-2 illustrates this approach.

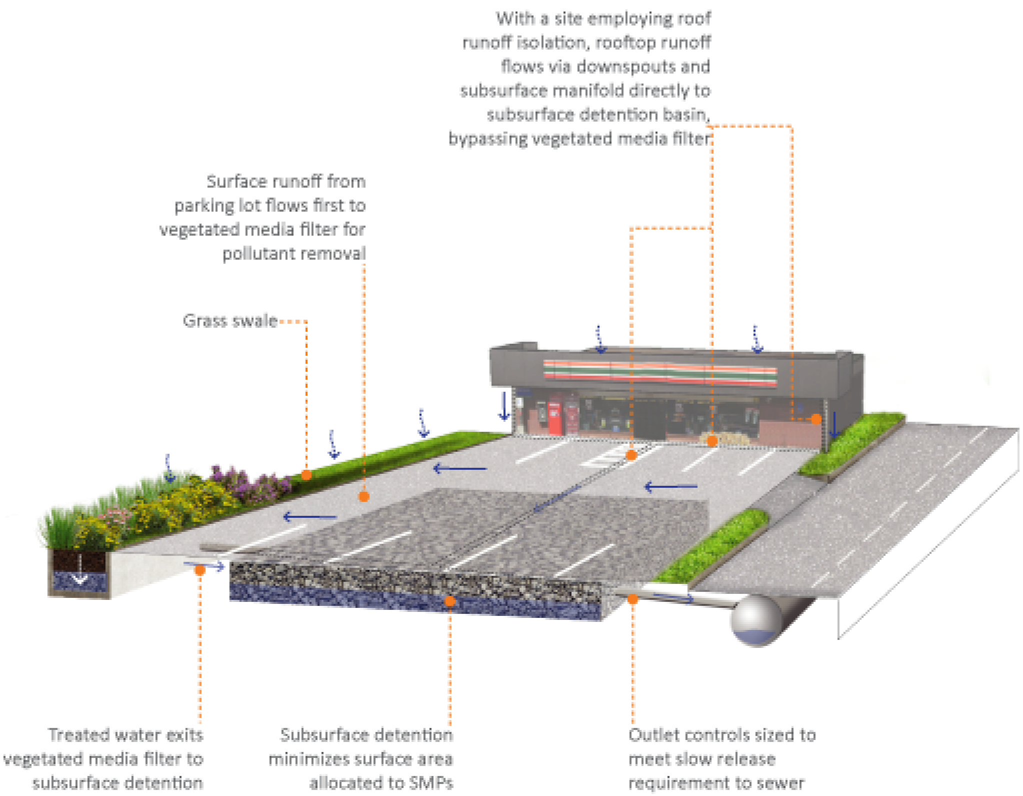
Figure 3.2-2: SMPs in Series Example #2 – Bioretention with Subsurface Detention



Vegetated Media Filter with Subsurface Detention

A subsurface detention basin with an upstream vegetated media filter is a combination of SMPs that can be used to meet the Water Quality slow release and pollutant-reduction requirements on sites that cannot infiltrate in the combined sewer area. The subsurface detention basin is a compact SMP that can be installed below a parking lot to limit the amount of usable surface that is disrupted. With a site employing the pollutant-reducing practice of roof runoff isolation, runoff from rooftop DCIA can be sent directly to the subsurface detention basin without any filtering treatment. A vegetated media filter can then be installed on-site to capture the WQv from surface-level DCIA and treat the runoff before discharging the treated volume to the subsurface detention basin. Figure 3.2-3 illustrates this approach.

Figure 3.2-3: SMPs in Series Example #3 – Vegetated Media Filter with Subsurface Detention



The following requirements apply to SMPs placed in series:

- SMPs can be placed in series to achieve rate control for the Stormwater Regulations. The designer does not have to demonstrate compliance with rate control requirements at the discharge point of each SMP, as long as rate control can be provided at the downstream-most point of the SMP series, prior to discharge to PWD sewer or receiving water.
- When complying with the Water Quality requirement, cumulative static storage volume may be provided within a connected series of SMPs, rather than any single SMP.
- Individual SMPs within a series must be designed in full accordance with design requirements provided in **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4. For example, each bioretention system in a series must individually meet loading ratio and drain down time requirements.
- When using SMP in series, upstream flow splitters may be used to direct larger events around Water Quality SMPs, such as bioretention systems, to larger Flood Control SMPs.

3.2.4 Stormwater Management Banking and Trading

Download summaries of Stormwater Management Banking and Trading guidance, with quick reference information for clients and developers:

Stormwater Management Banking and Trading One-Sheet ☛ water.phila.gov/pool/files/stormwater-management-banking-and-trading.pdf

Stormwater Management Banking and Trading: Same Parcel Trading One-Sheet ☛ water.phila.gov/pool/files/stormwater-management-banking-and-trading-same-parcel-trading.pdf

PWD generally requires full compliance with the Stormwater Regulations for each point at which stormwater leaving the site is discharged to either a receiving water or PWD sewer. SMPs must be provided as appropriate to achieve compliance at each of these locations. If site constraints or existing conditions will prevent a development project from complying fully with the Stormwater Regulations, or if placement of an SMP could result in a potential environmental or safety hazard, the designer may consider Stormwater Management Banking and Trading. Stormwater Management Banking and Trading allow a project to be flexible in the placement of required SMPs. Proposals to use banking and trading methods are considered by PWD on a case-by-case basis, and a pre-application meeting is highly recommended.

Stormwater Management Banking refers to the oversizing of SMPs to be used toward regulatory compliance for future development improvements. To qualify for Stormwater Management Banking, the SMPs must be constructed prior to the associated development project. When Stormwater Management Banking is proposed, each phase of work will be held to the Stormwater Regulations in place at the time of the Existing Resources and Site Analysis (ERSA) Application. Furthermore, the specific performance of the SMP is banked, not the area managed. Future projects must meet the regulations that apply at that time, which may reduce the amount of area for which the banked performance can be traded.

Stormwater Management Trading refers to the siting of SMPs to manage impervious area not associated with the proposed development improvement, whereas the DCIA associated with the development project is traded for an equivalent managed area. The SMPs can be located on the same parcel as the development project but must manage area outside of the development project's limit of disturbance. Area proposed for trade must be unmanaged in the pre-development condition unless the area has been previously identified as part of a Stormwater Management Banking agreement.

Stormwater Management Banking and Trading is only relevant to projects required to comply with Stormwater Regulations. Stormwater Retrofits have differing management strategies, as discussed in **Section 1.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-3-stormwater-retrofits.

Banking and Trading SMP Standards

- SMP(s) must achieve the same regulatory standard (Water Quality and Channel Protection) as if it were directly managing stormwater from the proposed development project.
- Banking and trading methods are not permitted to be used to comply with Flood Control.
- SMP(s) located within the same sewershed are preferred.

- Applicants who wish to engage in large scale Stormwater Management Banking and Trading that involves multiple parcels and/or property owners over a large area must provide a formal agreement that involves all parties and is approved by PWD. The parcel(s) containing the regulated improvement and the SMP(s) will be subject to Post-Construction Stormwater Management (PCSM) Requirements, including an O&M Agreement to be recorded to the property deed(s).
- Applicants must provide sufficient written justification in their PCSMP Report for proposing a banking or trading management solution, including reasons why management of the regulated area(s) is not feasible and why PWD may benefit from the proposal. A short explanation should also be included in the ERSA Application.
- SMP(s) must manage an area equal to or greater than the unmanaged area and produce an equivalent pollutant load. For example, PWD will not approve a trade of unmanaged impervious parking lot with existing roof area because the total pollutant load from the trade surfaces is not equivalent.

Submission Package components for Stormwater Management Banking and Trading are no different from typical submissions. The designer, however, must clearly identify the banking or trading strategy on all plans and reports in the Submission Package. This information can be easily conveyed as a table; an example of which is provided below:

Total LOD	18,000 SF
On-site LOD	17,000 SF
Impervious Area Within On-site LOD	16,500 SF
Managed DCIA (i.e. DCIA routed to SMP) Within On-site LOD	12,400 SF
DIC Area Within On-site LOD	600 SF
Remaining Unmanaged DCIA Within On-site LOD (e.g. parking lot runoff)	3,500 SF
Acceptable Trade Area (i.e. managed impervious area) outside of LOD	**≥ 3,500 SF of surface-level cover**

Additionally, if the designer believes that Stormwater Management Banking or Trading will be necessary to meet the Stormwater Regulations, they are encouraged to discuss this during the Conceptual Review Phase.

Understanding the limit of disturbance is key to proposing a trade approach for regulatory compliance. The existing impervious area to be managed for trade must remain outside the LOD throughout construction. For example, depaving or otherwise converting an existing impervious surface to pervious cover (such as converting a parking lot to porous pavement) cannot be used as trade as this activity increases the LOD, and the LOD boundary is used to determine the area applicable to the Stormwater Regulations. While this approach may help achieve an exemption from the Flood Control requirement (**Section 1.2.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations/#1.2.1), it cannot be used for trade. Instead, the applicant should look at low impact options that will minimize the amount of existing impervious area to be disturbed, thus maximizing potential trade area.

The next section presents examples of how this may be achieved. The most common stormwater trade scenario is Same Parcel Trading, whereby SMPs are sited on a parcel that will manage DCIA not associated with the proposed improvement (outside the project's LOD). The first scenario below presents an example of how Same Parcel Trading can be applied to, and benefit, a Redevelopment project.

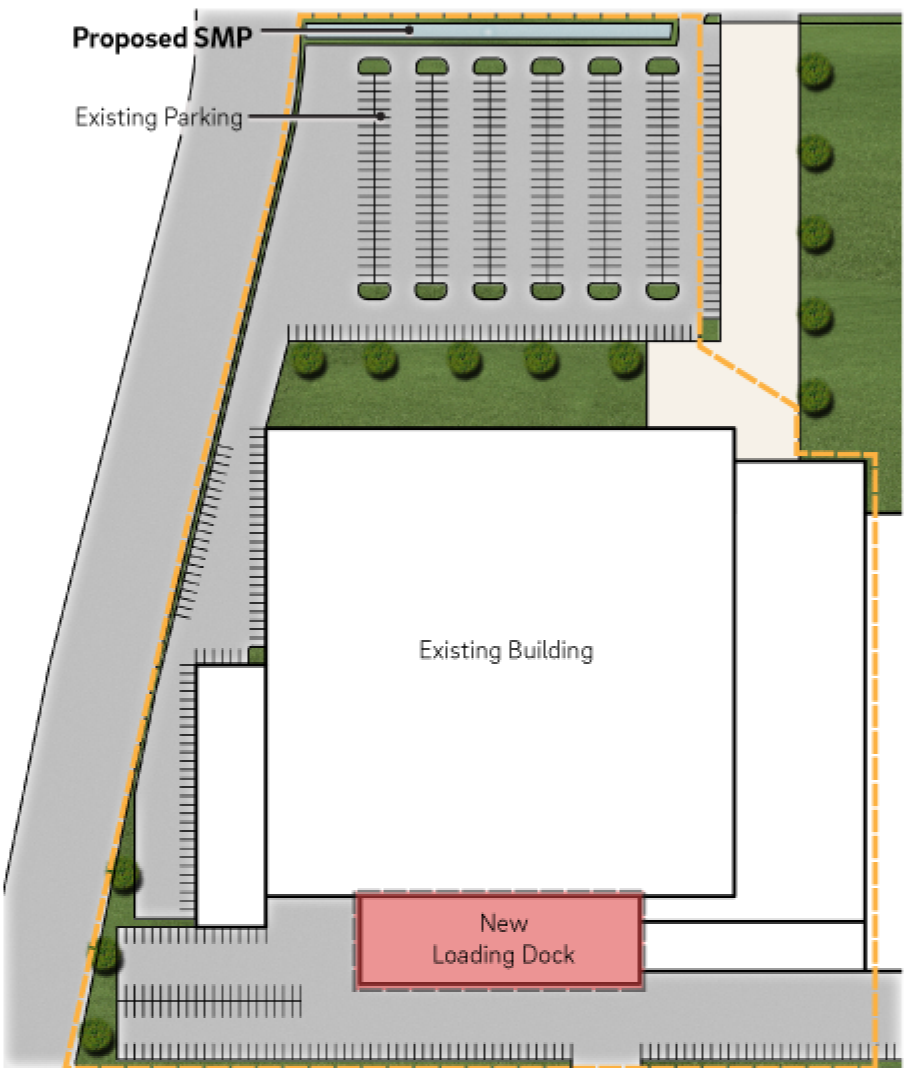
Stormwater Management Trading Examples

Example of Same Parcel Trading – Food Distribution Facility

A property owner sought approval from the City to construct a new loading dock (Figure 3.2-4, in red) at an existing food distribution facility. The only on-site area large enough on which to place an SMP was adjacent to the food warehouse, and the property owner had concerns about food contamination from wildlife attracted to a surface SMP. Therefore, the property owner considered subsurface SMPs that could be installed adjacent to the new loading dock; however, the disadvantages and constraints of subsurface SMPs in this application included the following:

- Relatively high cost to construct and maintain;
- Large space requirements to achieve controlled release standards, since soils near the loading dock were significantly compacted, precluding infiltration; and
- The need for the subsurface SMP design to accommodate heavy truck traffic, balancing SMP access points with heavy load-bearing surfaces.

Figure 3.2-4: Same Parcel Trading Example



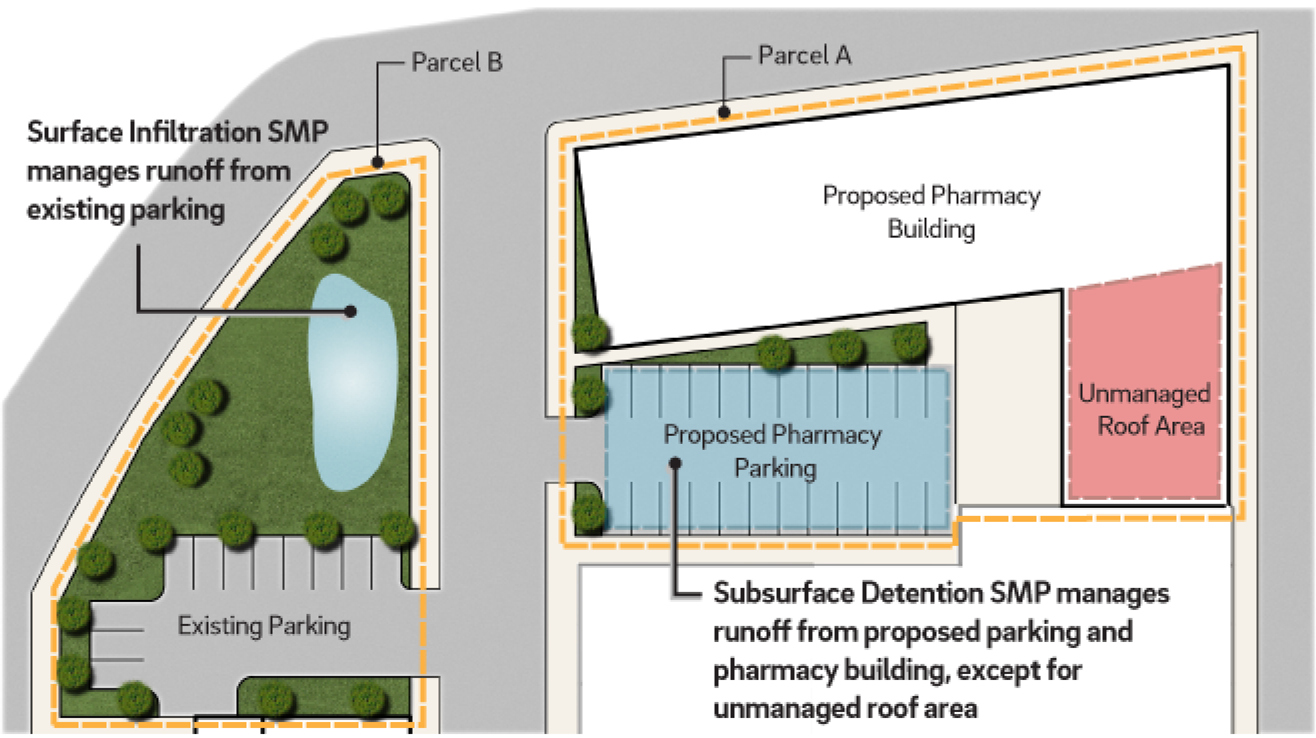
The property owner instead proposed an SMP (shown in blue) elsewhere on-site to manage existing undisturbed impervious area in the same sewershed. The benefits from this trade included the following:

- Less expensive SMP installation cost;
- Less disruption to distribution center's operations during construction;
- Smaller SMP footprint located in better-infiltrating soils; and
- An above-ground SMP that can be more easily inspected and maintained.

Example of Same Owner Trading – Pharmacy and Parking Lot

A single party owned two parcels separated by the public right-of-way (ROW). The developer proposed construction of a pharmacy and a parking lot on one undeveloped parcel. The same developer owns an already developed parking lot across the street (presented post-development in Figure 3.2-5).

Figure 3.2-5: Same Owner Trading Example



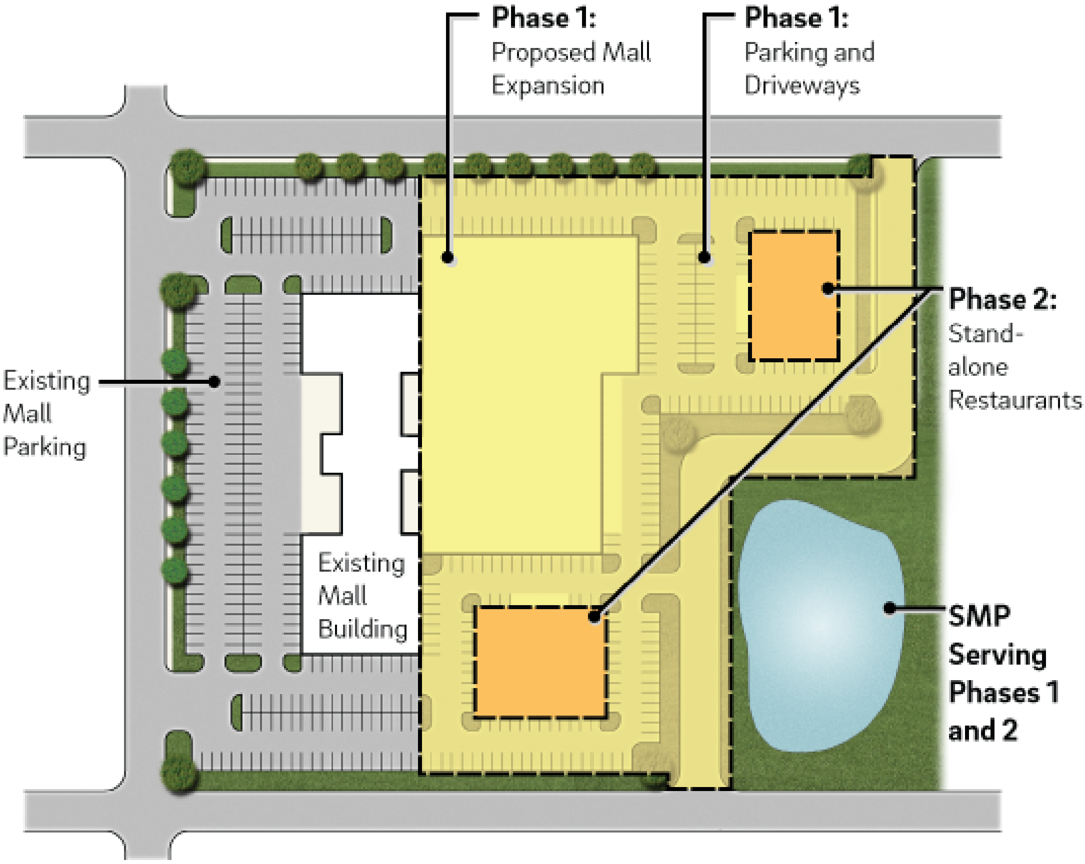
The site designer was able to manage all new impervious area proposed for Parcel A with a subsurface detention facility (shown in blue), except for a portion of the pharmacy roof area (shown in red). To meet Stormwater Regulations on Parcel A, the designer proposed to manage the existing parking lot on Parcel B with a surface infiltration SMP (shown in blue). The unmanaged pharmacy roof area discharges directly to the sewer system. The benefits from this trade included the following:

- Increased ability to fully use Parcel A;
- Less expensive SMP installation cost;
- An above-ground SMP that can be more easily inspected and maintained; and
- Limited reliance on underground SMPs.

Example of Same Owner Banking – Shopping Mall

A shopping mall owner proposed a series of improvements planned in phases. These included expansions to existing mall buildings, new standalone restaurants, and additional parking areas and driveways. Instead of designing and constructing SMPs for each individual improvement, the designer proposed a stormwater management banking scenario to construct a single SMP to serve all improvements.

Figure 3.2-6: Same Owner Banking Example



The designer first proposed an existing building expansion and additional parking areas and driveways under Phase 1 (shown in yellow on Figure 3.2-6). Upon approval of this first phase, as well as a conceptual design of future standalone restaurant buildings under Phase 2 (shown in orange), PWD permitted the owner to install an oversized SMP (shown in blue) to manage these impervious surfaces. The owner then installed the remainder of the proposed improvements in Phase 2. The site designer directed all runoff to the single SMP that was constructed in Phase 1.

A benefit of this scenario was that the owner was able to obtain approvals quickly for the second phase of construction as the SMP was sized to meet the Stormwater Regulations for the entire project.

When Same Owner Banking is proposed, PWD will acknowledge the bank amount in terms of additional cubic feet capacity remaining in the SMP. This type of banking approach works best for projects where phases are planned in rapid succession, as each phase is held to the Stormwater Regulations in place at the time of its ERSA submission. Applicants who are interested in long term site master planning (which may occur over several years or decades, or between multiple parcels and property owners) are encouraged to discuss with PWD prior to implementation.

3.2.5 SMP Design Guidance and General Requirements

Once the initial selection of SMPs is complete, and PWD has approved the conceptual design, detailed design of SMP systems can be performed. Detailed design of SMPs and associated documentation will be submitted as part of the designer's PCSMP Review Phase Submission Package to PWD. The designer is referred to **Chapter 2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2 for details on preparing this Submission Package.

This Section provides guidance to the designer in the design of SMPs, outlining general requirements that apply to all SMPs. The designer is also referred to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4, which provides detailed guidance and requirements for specific SMPs.

Infiltration Testing and Waiver Requirements

A designer using SMPs to comply with the Water Quality requirement must use infiltration unless they can demonstrate that infiltration is infeasible. The designer must exhaust all possibilities for implementing infiltrating practices on proposed sites, including exploring alternative locations for infiltration facilities if initial locations are not found to be suitable for infiltration or over-excavating poorly infiltrating soils. The designer is referred to **Section 3.3** ☛ p. 64 for detailed information on performing infiltration tests, assessing infiltration feasibility, and preparing requests for infiltration waivers. If appropriate justification that contamination will preclude the site from infiltration is provided, an impervious liner must be incorporated into the SMP design.

Pretreatment Requirements

Pretreatment is critical for extending the design life and maximizing the performance of SMPs. The designer must provide adequate pretreatment for all SMPs. Appropriate pretreatment is based on a number of factors including SMP type, loading ratios, and drainage area characteristics. The designer is referred to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 for more information on the design of pretreatment systems for specific SMPs and general pretreatment options.

Conveyance and Inlet and Outlet Control Requirements

Conveyance systems, including piping conveying stormwater to and from an SMP, and inlet and outlet control systems, which regulate the flow into and out of an SMP, are important aspects of SMP design. All storm sewer pipes must be designed to have adequate capacity to safely convey the ten-year storm without surcharging the crown of the pipe. **Section 3.4.2** ☛ p. 92 contains detailed guidance on storm sewer design and pipe capacity calculations, while **Section 4.11** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-11-inlet-controls and **Section 4.12** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-12-outlet-controls provide guidance on the design of inlet and outlet controls, respectively.

Sizing Requirements

Appropriate sizing is critical for SMP performance. The designer must incorporate several factors, including SMP type, function, maximum loading ratio requirements, release rate requirements, ponding depth, static storage requirements, media characteristics, freeboard requirements, and space limitations in determining appropriate SMP sizing. The designer is referred to the loading ratio requirements later in this Section and the SMP-specific sizing requirements in **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 to aid in determining appropriate SMP sizing.

Safe Overflow Requirements

Safe overflow must be provided for all SMPs. Runoff that overflows from an SMP (runoff that is not infiltrated or slow released) must be conveyed to receiving waters or sewers in a controlled manner that does not cause flooding, endanger public safety, or produce erosive conditions. Positive overflow must be provided for large storm events, up to and including the 100-year, 24-hour storm event, or, if the project is exempt from Flood Control, the ten-year, 24-hour storm.

Release Rate Requirements

For non-infiltrating practices in combined sewer areas, the designer must meet slow release rate requirements prior to discharge into PWD sewers or receiving waters. Typically, release rates for slow release systems are met using small orifices or other rate control devices. The designer is referred to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 for specific information on designing outlet control systems.

3.2.6 Loading Ratio Requirements

Download a summary of the loading ratio requirements, with quick reference information for clients and developers:

Loading Ratio Requirements One-Sheet ☛ water.phila.gov/pool/files/loading-ratio-requirements.pdf

Loading ratio is defined as the area of contributing DCIA divided by the bottom surface footprint of vegetated surface SMPs and the bottom footprint of infiltrating subsurface SMPs. The loading ratio is a tool that is used for sizing an SMP with consideration of acceptable sediment loading. It is a balancing point between maintenance requirements, performance requirements, and safety considerations. PWD's loading ratios are used as maximum acceptable SMP sizes for stabilized sites that are appropriately maintained; they are not necessarily the recommended loading ratios. The maximum loading ratio for vegetated surface SMPs is 16:1. The maximum loading ratio for infiltrating subsurface SMPs is 10:1. Runoff that has been filtered through a soil profile should not be counted toward the subsurface loading ratio for SMPs in series.

Loading Ratios	
Maximum Loading Ratios	Surface vegetated SMPs: 16:1 Subsurface infiltrating SMPs: 10:1
Maintenance	Long-term maintenance is a fundamentally important piece of an SMP's design. PWD's loading ratios were selected with the assumption that the final site will be stabilized, and the SMP will be maintained at regular intervals. Surface SMPs with a 16:1 loading ratio will require frequent maintenance, including the removal and replacement of the top layer of soil along the bottom footprint of the SMP.
Safety	The larger the loading ratio, the deeper the SMP must become to store the required volume of water. A surface basin with a 16:1 loading ratio will have a maximum Water Quality storage depth of two feet, which limits the total water depth and the risks to public safety.
Performance	The loading ratio greatly affects the performance of infiltrating SMPs by determining the footprint available for infiltration. PWD requires that all SMPs drain down in no more than 72 hours, however owners may want their SMPs to drain more quickly, thus the loading ratio may need to be reduced to meet the performance goals for the system. For example, an SMP with a loading ratio of 16:1 and an infiltration rate of 0.4 inches/hour drains down in 60 hours; however, the site owner may not want ponded water on-site for 60 hours.
Limitations	The larger the loading ratio, the less redundancy there is in an SMP. The SMP designer should consider the causes of potential failure for their SMP and attempt to minimize their likelihood and their effects. For example, a small SMP with a large impervious drainage area has the potential to receive a significant volume of water and sediment in larger storm events, which could overwhelm and/or clog the small SMP. In this case, a larger basin footprint may be warranted to safely convey the extra volume.Subsurface SMPs are inherently more difficult to maintain because they are buried. If construction sediment or some other sediment source discharges to the subsurface basin it can become clogged. Repairing the basin could require a complete removal and replacement of the system. This is one reason why PWD requires lower loading ratios for subsurface SMPs.When considering SMPs that receive runoff from a likely sediment source, the designer must factor into their design the likelihood of clogging, and therefore the need for increased maintenance frequency; the cost of maintenance/replacement; and the likelihood of this occurring when determining the appropriate sizing of the system.

3.2.7 Planting and Vegetation Guidance

Vegetated SMPs are among the most preferred SMP types, as indicated in the SMP Hierarchy. They can often be integrated within planned landscape areas, with minor modifications to conventional landscape design. It is essential that impervious surfaces be graded toward the vegetated areas that are used as SMPs and that these SMPs are depressed to allow for flow and/or surface ponding.

Landscaping is a critical element to improve both the function and appearance of vegetated SMPs. Integrated stormwater landscapes can provide many benefits, such as construction cost savings, reduced maintenance, aesthetic enhancement, and improved long-term functionality. A well-designed and established landscape will also prevent post-construction soil erosion. Additionally, these approaches can help mitigate urban heat island effects, improve air quality, and reduce atmospheric carbon levels. Since these design approaches are still relatively new to many construction contractors, it is advisable to clearly show planting details in cross-sectional and plan view drawings.

The designer is referred to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 for detailed planting requirements and guidance for specific SMPs and **Section 4.13** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-13-landscaping/, Landscaping, for landscaping guidance.

Vegetated SMPs Advance City Goals

The tree and vegetation components of green stormwater infrastructure (GSI) are integral to advancing multiple City sustainability, climate resilience and community equity goals. By designing stormwater management systems to include vegetated landscapes, designers can directly contribute to these goals. **Greenworks** ☛ www.phila.gov/media/20161101174249/2016-Greenworks-Vision_Office-of-Sustainability.pdf, the City's sustainability plan includes GSI as part of two visions for all Philadelphians: (1) to benefit from parks, trees, stormwater management and healthy waterways, including implementing PWD's **Green City, Clean Waters** ☛ water.phila.gov/green-city/ program, and (2) to be prepared for climate change and reduce carbon pollution. **Philadelphia's Climate Action Playbook** ☛ www.phila.gov/media/20210113125627/Philadelphia-Climate-Action-Playbook.pdf also outlines "utilizing nature as a solution to climate pollution" as one of its three climate action areas, and highlights "increasing and preserving green space" through integrated landscapes that incorporate tree planting, vegetation and stormwater management.

Planting trees as part of vegetated SMPs and site landscaping, as well as protecting mature trees can help meet stormwater regulation requirements while meeting **Philly Tree Plan** ☛ www.phila.gov/media/20230223005617/Philly-Tree-Plan.pdf goals. The Philly Tree Plan identifies long-term strategies for growing and protecting every part of Philadelphia's urban forest, aiming for 30% citywide tree canopy cover through a 10-year strategic plan. It takes partnership across many sectors including the City, non-profit partners, Philadelphia's communities, designers and developers to continue managing stormwater and to protect our waterways through land-based solutions including vegetated SMPs (or green stormwater infrastructure).

Pollution Prevention

Stormwater pollution prevention practices related to landscaping can be categorized into two broad categories: Toxic Substance Use Reduction and Pollutant Source Reduction

- Toxic Substance Use Reduction – Projects should be designed to minimize the need for toxic or potentially polluting materials such as herbicides, pesticides, fertilizers, or petroleum-based fuels within the SMP area before, during, and after construction. Use of these materials creates the risk of spills, misuse, and future draining or leaching of pollutants into facilities or the surrounding area.
- Pollutant Source Reduction – Materials that could leach pollutants or pose a hazard to people and wildlife must not be used as components of a SMP. Some examples of these materials are chemically treated railroad ties and lumber and galvanized metals. Many alternatives to these materials are available.

3.2.8 Operations and Maintenance

An O&M Agreement, discussed in detail in **Section 6.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-6/6-1-property-owner-inspections-and-maintenance/, is a required component of the Stormwater Regulations and Stormwater Grant-funded Stormwater Retrofits. Decisions made in the design phase can affect operations and maintenance and can extend the design life of stormwater facilities. Key factors to consider are ownership, access, maintenance tasks, and frequency.

Designing to Minimize Maintenance

- Use of pretreatment systems should be maximized, particularly for infiltration systems. Reducing velocities and pollutant loads entering SMPs will extend their design lives. The designer is referred to **Section 4.10** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-10-pretreatment for guidance on appropriate pretreatment design.
- For infiltration, surface-vegetated SMPs with deeper-rooted vegetation (e.g., trees, shrubs, and native herbaceous species) should be used whenever possible. Root growth helps to keep the soil's pore structure open and maximizes the life of infiltration SMPs. Routine landscaping tasks are the primary maintenance required.
- On smaller sites, SMPs that do not require slow release control structures should be chosen. These structures can clog and require periodic inspection and maintenance.
- Access
  - Vehicle access from a public right-of-way can help to minimize the difficulty of maintenance.
  - A 15-foot wide vehicle access path leading from a public right-of-way to all stormwater controls is strongly recommended.
- Post-construction ownership
  - The owner of the land where the SMP is located is responsible for performing long-term maintenance.
  - In the case of a single property owner, that owner is responsible for maintenance. In cases of common ownership, a homeowners' or condominium association may assume responsibility for maintenance.
  - Considering the type of ownership and owner preference can help the designer choose between smaller, distributed SMPs and a single, centralized SMP.

3.3 Infiltration Testing and Soil Assessment for SMP Design

After exhausting options for using non-structural design and disconnected impervious cover (DIC), the designer is required to evaluate and document infiltration feasibility when using stormwater management practices (SMPs) as a strategy to comply with the Philadelphia Water Department (PWD) **Stormwater Regulations** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/c-pwd-stormwater-regulations/ (Stormwater Regulations) or applicable stormwater management design standards. If infiltration is deemed feasible, the designer must use infiltration SMPs, such as bioinfiltration basins, to comply with the Water Quality requirement. If infiltration is not feasible, the designer must document justification for this condition (**Section 3.3.6** ☛ p. 78) via the Online Technical Worksheet (**Section 3.4.3** ☛ p. 101) and use acceptable pollutant-reducing SMPs to comply with the Water Quality requirement (**Section 1.2.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations/#1.2.1) if required to comply with Stormwater Regulations. A slow release rate requirement associated with the Water Quality requirement is applicable only to non-infiltrating areas in combined sewersheds for both Development and Stormwater Retrofit project types. Efforts to maximize development potential should not preclude the use of infiltration SMPs.

This Section details the infiltration testing and soil assessment procedures required for the selection and detailed design of SMPs. If conceptual SMP locations and footprint areas have not yet been determined, the designer should return to Sections **3.1** ☛ p. 7 and **3.2** ☛ p. 41 for guidance on conceptual SMP design. PWD recommends that preliminary soil analyses and infiltration testing be completed during the conceptual SMP design phase. This is strongly recommended because the results can be used as a planning tool for identifying areas that are favorable for the construction of infiltration SMPs, and for more thorough investigations. If seeking Stormwater Grant funding for a Stormwater Retrofit project, the designer should review the **Stormwater Grants Application Guide** ☛ water.phila.gov/pool/files/stormwater-grants-application-guide.pdf for guidance on the minimum testing required for a Stormwater Grant Application Conceptual Stormwater Management Plan. The designer should use the guidance below to further inform their Post-Construction Stormwater Management Plan (PCSMP) design.

As a reminder, locating conceptual infiltration SMP footprint areas should be avoided in the following locations identified during the site assessment process (**Section 3.1.1** ☛ p. 8 and **Section 3.1.2** ☛ p. 14). A number of these scenarios will require further investigation before determining infiltration feasibility and SMP layout.

- Areas with previously documented high seasonal groundwater or located in the floodplain;
- Areas with previously documented shallow bedrock, clay, hydrologic soil group "D" soils, or other limiting soil layers;
- Areas within existing rights-of-way and easements;
- Areas that do not achieve the minimum required ten-foot setback from all existing and proposed buildings and neighboring properties; and
- Documented hotspots.

For projects where infiltration is not feasible due to full build-out designs (where ground-level space is not available in the proposed site layout), infiltration testing may not be required. For these scenarios, the applicant must request a waiver from the infiltration requirement (**Section 3.3.6** ☛ p. 78) via the Online Technical Worksheet (**Section 3.4.3** ☛ p. 101). The applicant is encouraged to contact **PWD Stormwater Plan Review** ☛ water.phila.gov/development/stormwater-plan-review/manual/introduction#4 prior to initial plan submission to confirm the full build-out design is eligible for a waiver from infiltration.

After conceptual SMP locations have been determined for the project site, the designer must complete the infiltration testing and soil assessment process illustrated in Figure 3.3-1. Each step of this process is described within the following Sections.

Figure 3.3-1: Infiltration Testing and Soil Assessment Process for SMP Design

Determine conceptual SMP locations (Section 3.2)
IF NECESSARY: Complete hotspot investigation and historic fill assessment procedures (**Section 3.1**)

↓

INFILTRATION TESTING AND SOIL ASSESSMENT

Develop an Infiltration Testing and Soil Characterization Plan (Section 3.3.1)

↓

Perform soil characterization and infiltration testing (Sections 3.3.2, 3.3.3, 3.3.4, and 3.3.5)

↓

Evaluate infiltration testing results (Section 3.3.6)

↓

Proceed with detailed SMP design (Section 3.2 and Chapter 4)

If required, infiltration testing and soil characterization must be completed before the PCSMP Review Phase, unless the project is deemed eligible for an Expedited PCSMP Review. The designer is referred to **Section 2.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases and **Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews for descriptions and requirements related to Review Phases and Expedited PCSMP Reviews, respectively.

3.3.1 Infiltration Testing and Soil Characterization Plan Development

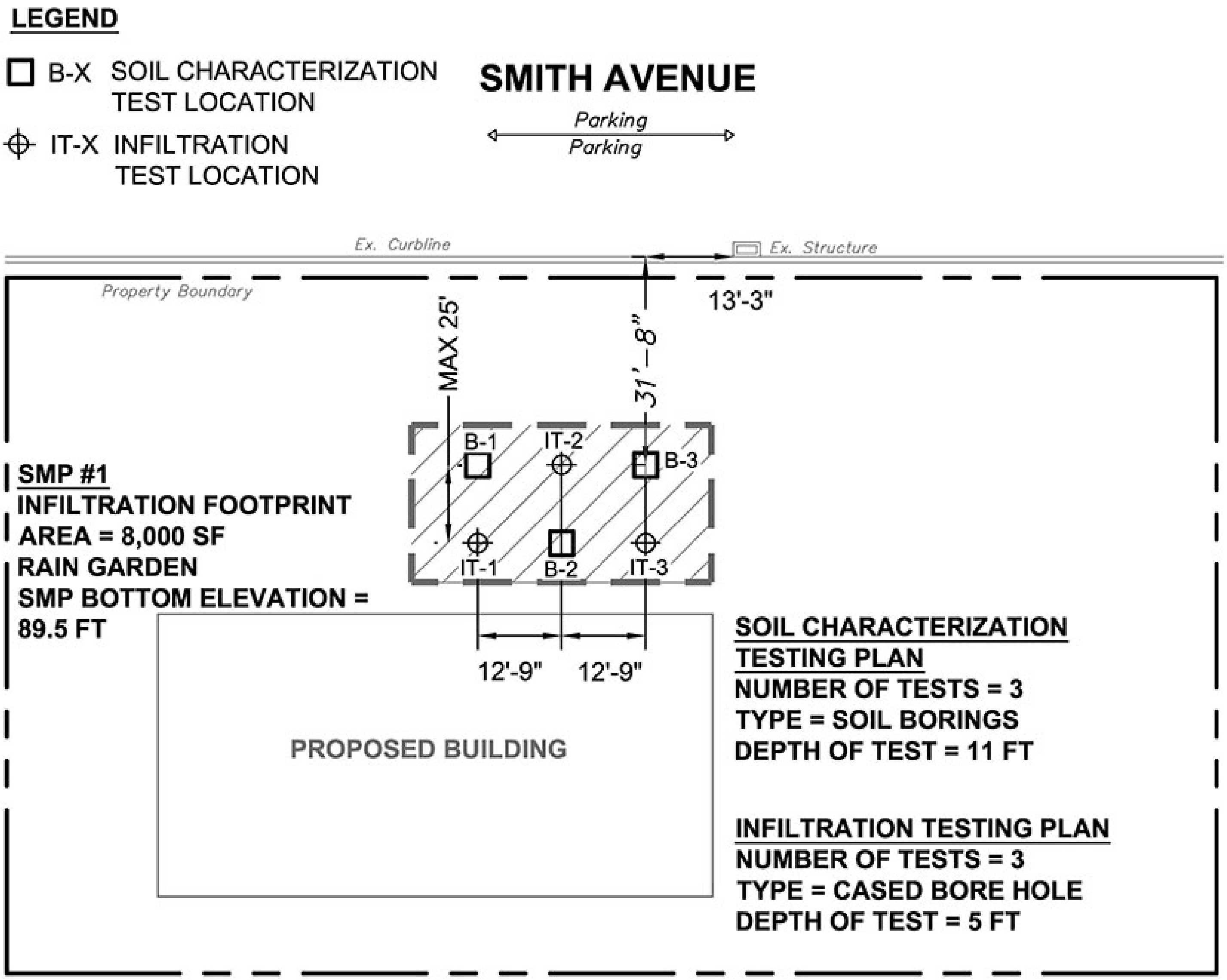
Prior to conducting infiltration testing and soil characterization at the project site, the designer must prepare an Infiltration Testing and Soil Characterization Plan (Testing Plan). This Testing Plan is a required element of the Geotechnical Report (**Section 3.3.6** ☛ p. 78). The Testing Plan must reflect the most up-to-date proposed SMP footprints at the time of testing.

The Testing Plan must be developed to meet the requirements within this Chapter and, at a minimum, must indicate the following information:

- Location and SMP identifier of all proposed SMPs, each labeled with the following information:
  - Proposed infiltration footprint area,
  - Type of SMP proposed, and
  - Proposed infiltration interface (SMP bottom) elevation.
- Location of all proposed test pits, soil borings, and infiltration tests, each labeled with the following information:
  - Number of tests proposed based on the requirements provided within this Section;
  - Type of test(s) proposed (test pit, soil boring, double-ring infiltrometer, cased borehole infiltration test);
  - Depth of testing for each test, relative to existing ground surface elevations, based on the requirements provided within this Section; and
  - Dimensions from parcel boundaries and/or existing structures.

An example Testing Plan is included as Figure 3.3-2. This figure is generic and does not represent the required density or spacing of tests as documented within this Section, but demonstrates how to illustrate the minimum Testing Plan requirements described above. The hatched rectangle delineating the proposed SMP location and proposed test locations are dimensioned from a fixed object (e.g., an existing inlet within the public right-of-way).

Figure 3.3-2: Example Infiltration Testing and Soil Characterization Plan



The designer must adhere to the soil characterization requirements in **Section 3.3.2** ☛ p. 69 and the infiltration testing requirements in **Section 3.3.3** ☛ p. 71 when creating the Testing Plan. Prior to conducting geotechnical testing the appropriate density, type, and spacing for each test must be determined using the requirements provided.

3.3.2 Soil Characterization Requirements

Soil characterization and limiting layer identification provides a visual assessment of the soil profile that is supplemental to infiltration testing results. Understanding the characteristics of soils in which infiltration testing is conducted provides the designer with better insight into the testing results and feasibility of installing an infiltrating SMP at the project site.

The presence of limiting layers such as groundwater, bedrock, or impermeable soils within two vertical feet of the infiltration footprint of an SMP is prohibited. The presence of bedrock or impermeable soils in relatively close proximity to the infiltration interface may result in lateral, as opposed to vertical, infiltration if the rock is not sufficiently jointed and/or fissured to infiltrate. This can result in water migrating to, and emerging within, topographically low areas. The presence of groundwater in close proximity to the infiltration interface could increase the potential for groundwater mounding. Further characterization of subsurface soils can provide information on the underlying site conditions or evidence of limiting layers below the infiltration interface. Therefore, PWD requires that soil excavations be performed beyond the proposed infiltration interface (SMP bottom) elevation. As testing progresses, the testing professional must document the presence of any limiting layers, groundwater presence, and in situ observations of soil characteristics. PWD also requires soil sampling for laboratory soil classification to further supplement infiltration testing results.

Acceptable soil characterization testing methods are as follows:

- Exploratory Test Pits, and
- Hollow-Stem Augered Boreholes (Soil Borings).

These soil characterization methods must be conducted in conjunction with the required soil sampling.

An exploratory test pit allows visual observation of the soil horizons and overall soil conditions both horizontally and vertically in that portion of the site. Test pit observations can be made across a site at a relatively low cost and in a short period of time. When soil borings are performed, the soil horizons cannot be observed in situ, but must be observed from the extracted borings. As a result, visual observation is narrowly limited in a soil boring. As such, test pits are strongly recommended over soil borings unless conditions are present that render the excavation of test pits impractical (e.g., existing structures, utilities, space constraints, depth of test, etc.).

Key requirements for the two acceptable soil characterization methodologies and accompanying soil sampling are summarized below.

Test Pits

- For projects with 15,000 square feet or more of earth disturbance, a minimum of two test pits must be completed for each SMP footprint. For projects with less than 15,000 square feet of earth disturbance, a minimum of one test pit must be completed for each SMP footprint.
- Test pits are required in order to conduct double-ring infiltrometer testing.
- At least one test pit for each SMP must be excavated to a minimum depth of four feet below the proposed infiltration interface of the SMP, which is the lowest elevation where infiltration is proposed (the SMP bottom elevation), or until bedrock or fully saturated conditions are encountered. When conditions

prevent the over-excavation of test pits to the minimum required depth, soil borings, in addition to the under-excavated test pits, should be used in conjunction with double-ring infiltrometer testing to provide soil classification down to the required depths.

- Where test pits are greater than five feet deep, appropriate sloping and benching must be provided for access and infiltration testing, as necessary, in accordance with *Occupational Safety and Health Administration (**OSHA** ☛ https://www.osha.gov/) Regulations (Part 1926, Subpart P – Excavations, Standard Number 1926.652 Requirements for Protective Systems)*.

Soil Borings

- A hollow-stem augered borehole should be used for soil classification when site constraints do not allow for a test pit (e.g., the proposed SMP footprint is located in an area with existing structures or utilities present, or the depth to the infiltration interface does not allow for a benched excavation with site constraints).
- A minimum of one soil boring should be conducted for each cased borehole infiltration test.
- All soil borings must be advanced to a depth of ten feet below the SMP bottom elevation or until auger refusal with continuous split spoon sampling.
- Hollow-stem augered borehole soil characterization studies must not be completed within the same hole as the infiltration testing, but the boreholes must be located no less than five feet, and no more than ten feet, away from the infiltration test locations.
- Drilling and sampling procedures must be in accordance with the Hollow-Stem Auger Method (American Society of Testing and Materials (ASTM) standard D6151-08) with a minimum four-inch inner tube diameter.
- Standard Penetration Tests (SPTs) must be in accordance with ASTM D1586 (Standard Test Method for SPT and Split-Barrel Sampling of Soils). Blow count data must be collected from the soil samples.

Soil Sampling

- PWD requires that three soil samples be taken per acre of SMP footprint area, with a minimum of one soil sample per SMP.
- At least one soil sample must be taken as close to the infiltrating interface (SMP bottom elevation) as possible, within one vertical foot.
- The designer is also required to obtain a soil sample from the location of an infiltration test and conduct a sieve analysis of the sample.
- Soil samples must be obtained during the soil characterization field analysis and classified according to ASTM D2487 (Standard Practice for Classification of Soils for Engineering Purposes [Unified Soil Classification System]) and ASTM D2488 (Standard Practice for Description and Identification of Soils [Visual-Manual Procedure]).
- Soil samples must undergo laboratory particle size analysis according to ASTM D422-63 (Standard Test Method for Particle-Size Analysis of Soils) down to the No. 200 sieve.
- Split spoon sampling must be completed in accordance with ASTM D1586 (Standard Test Method for SPT and Split-Barrel Sampling of Soils). Blow count data must be collected from the soil samples.

3.3.3 Infiltration Testing Requirements

All tests must be performed within 25 horizontal feet of each infiltration area. At least one infiltration test must be conducted as close to the proposed infiltration interface (SMP bottom elevation) as possible within one vertical foot. More tests may be warranted if the results of the first three tests vary significantly. Testing locations should be evenly distributed. Infiltration tests may be used for the design of multiple SMPs as long as the minimum requirements are met for each SMP. Follow-up testing may be required if the location or elevation of any SMPs change in such a way that the infiltration testing previously performed in the area of that SMP no longer meets PWD's proximity, elevation, and density requirements. It is the designer's responsibility to contact **PWD Stormwater Plan Review** ☛ water.phila.gov/development/stormwater-plan-review/manual/introduction#4 or **Stormwater Billing and Incentives** ☛ water.phila.gov/development/stormwater-plan-review/manual/introduction#6 regarding the need for follow-up testing for a project. Each test must be accompanied by either a test pit or soil boring.

Acceptable infiltration testing methodologies consist of:

- Double-Ring Infiltrometer Tests with Test Pits, and
- Cased Borehole Tests with Soil Borings.

The main difference between the two methods is that a double-ring infiltrometer test estimates the vertical movement of water through the bottom of the test area using a larger surface area than a cased borehole infiltration test. The double-ring infiltrometer testing apparatus consists of two concentric metal rings that are driven into the ground and filled with water. The outer ring helps to reduce lateral movement of water in the soil (typically 12 to 24 inches in diameter) while the inner ring is used to calculate an infiltration rate (typically six to 12 inches in diameter). The cased borehole test uses an outer casing (typically four inches in inner diameter) to prevent lateral movement of water through soil. The procedures of these test methods are provided in **Section 3.3.5** ☛ p. 75.

While both testing methods are allowed, PWD strongly prefers the use of double-ring infiltrometer testing where space permits. Because test pits are required to perform double-ring infiltrometer tests, the applicant must first determine whether test pits are feasible (**Section 3.3.2** ☛ p. 69). If test pits are feasible, then the designer should develop the Testing Plan to meet the minimum requirements for double-ring infiltrometer tests and test pits. If conditions render the excavation of test pits impractical, due to existing structures, utilities, space constraints, depth of test, etc., the designer should first document the condition(s), and then develop the Testing Plan to meet the requirements of cased borehole tests and soil borings. Soil borings may be used in lieu of over-excavating test pits where space constraints exist.

Key requirements for the two acceptable infiltration testing methodologies are summarized below.

Double-Ring Infiltrometer Test

- Five infiltration tests must be performed per acre of SMP footprint, or one test per 8,712 square feet, and a minimum of three tests must be performed.
- The diameter of the inner ring must be no less than six inches.
- Test pits are required in order to conduct double-ring infiltrometer tests. A maximum of two double-ring infiltration tests can be conducted within the same test pit.
- Test holes must be presoaked for one hour immediately prior to testing. The presoaking procedure is intended to simulate saturated conditions in the environment and to minimize the influence of unsaturated flow.
- Testing must be conducted for a minimum of eight readings or until a stabilized infiltration rate is measured. A stabilized rate of drop means a difference of 0.25 inch or less of drop between the highest and lowest readings of four consecutive readings.
- The designer is referred to the infiltration testing procedure information provided in **Section 3.3.5** ☛ p. 75 for further double-ring infiltrometer testing guidance.

Cased Borehole Test

- Infiltration tests must not be completed within the same borehole as hollow-stem augered borehole soil characterization studies, but must be completed no less than five feet, and no more than ten feet, away from the soil characterization borehole locations.
- Eight infiltration tests must be performed per acre of SMP footprint, or one test per 5,445 square feet, and a minimum of three tests must be performed.
- The casing installation must be completed using ASTM D6151-08 – Hollow-Stem Auger Method, with the inner diameter of the pipe being no less than four inches.
- Only one infiltration test is acceptable for each borehole, regardless of whether tests are proposed to be completed at different depths.
- Test holes must be presoaked for one hour immediately prior to testing. The presoaking procedure is intended to simulate saturated conditions in the environment and to minimize the influence of unsaturated flow.
- Testing must be conducted for a minimum of eight readings or until a stabilized infiltration rate is measured. A stabilized rate of drop means a difference of 0.25 inch or less of drop between the highest and lowest readings of four consecutive readings.
- The designer is referred to the infiltration testing procedure information provided in **Section 3.3.5** ☛ p. 75 for further cased borehole testing guidance.

3.3.4 Soil Characterization Procedures

Soil characterization and limiting layer identification provides a visual assessment of the soil profile, which can support supplemental infiltration testing results. PWD allows the use of exploratory test pits or soil borings to assess soil for infiltration feasibility; however, PWD strongly prefers the use of test pits where space allows. With both methods, soil sampling and characterization are required. Requirements for each soil characterization and soil sampling method are described in **Section 3.3.2** ☛ p. 69, while procedures are described below.

Exploratory Test Pit Procedure

A test pit consists of a backhoe-excavated trench, of an appropriate width, with the goal of exposing a soil profile. As the excavation progresses, the testing professional must document the presence of any limiting layers, groundwater presence, and in situ observations of soil characteristics. When test pits are the chosen soil characterization methodology, the double-ring infiltrometer method must be used as the infiltration testing methodology. The designer is referred to **Appendix H** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/h-infiltration-testing-log for a blank Infiltration Testing Log, which is required to be completed and submitted as part of the Geotechnical Report and includes guidance for documenting soil characteristics. Soil classifications must be conducted in accordance with ASTM D2488. The designer is referred to **Section 3.3.5** ☛ p. 75 for the double-ring infiltrometer testing procedure.

Hollow-Stem Augered Borehole Procedure

A hollow-stem augered borehole soil characterization can be performed where space constraints prevent the excavation of test pits. The test is completed using a four-inch inner diameter or larger hollow-stem auger. The designer is referred to **Appendix H** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/h-infiltration-testing-log for a blank Infiltration Testing Log, which is required to be completed and submitted as part of the Geotechnical Report and includes guidance for documenting soil characteristics. Soil classifications must be conducted in accordance with ASTM D2488. Blow counts, if the designer and geotechnical professional elect to perform SPTs, must be performed in accordance with ASTM D1586. As the test progresses, the testing professional must document the presence of any limiting layers, groundwater presence, and in situ observations of soil characteristics (Soil Sampling Requirements and Procedure Sections are listed below). The ASTM standard D6151-08, Hollow-Stem Auger Method, should be referenced for specific direction, but the general testing procedure is as follows:

1. Advance a borehole to the proposed testing depth using the Hollow-Stem Auger Method (ASTM D6151-08). The augered hole diameter must be at least two inches larger than the outer diameter of the inner casing. The inner casing will consist of a PVC pipe with a minimum inner diameter of four inches and a smooth, square bottom.
2. Push the inner casing within the auger hollow stem to the infiltration interface and firmly set it into the bottom of the borehole. Use a borehole plane to scarify the soil surface at the bottom of the casing and remove any remaining loose soil. Measure the depth from the top of casing to the bottom of the hole to the nearest 0.01 feet.
3. Collect soil samples per soil sampling requirements and procedure.

4. Remove the augers.
5. Upon completion of the test, remove the hollow-stem auger tubes and backfill the borehole with cuttings. If testing is conducted in vegetated areas, return the surface to its previous state. If testing is completed in paved areas, plug the hole with a bentonite plug and seal the surface with concrete or asphalt.
6. If a cased borehole infiltration test is to be completed, backfill the borehole prior to running the infiltration test. Refer to **Section 3.3.3** ☛ p. 71 and **Section 3.3.5** ☛ p. 75 for guidance on borehole infiltration testing.

Soil Sampling Procedure

- Soil samples must be obtained during the soil characterization field analysis.
- Field soil sample classification must be performed according to ASTM D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).
- Split spoon sampling must be completed in accordance with ASTM D1586 (Standard Test Method for SPT and Split-Barrel Sampling of Soils). Blow count data must be collected from the soil samples.
- Laboratory analysis of collected soil samples must include, at a minimum:
  - ASTM D422-63 – Standard Test Method for Particle-Size Analysis of Soils, down to the No. 200 sieve, and
  - ASTM D2487 – Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).
- Additional laboratory testing can be completed at the geotechnical professional and designer’s discretion.

3.3.5 Infiltration Testing Procedures

PWD allows the use of double-ring infiltrometers or cased boreholes for infiltration testing; however, PWD strongly prefers the use of double-ring infiltrometer testing where space allows. The designer is referred to **Section 3.3.3** ☛ p. 71 for Infiltration Testing Requirements. Each test must be accompanied by a test pit or soil boring and a soil characterization study.

Double-Ring Infiltrometer

A double-ring infiltrometer test estimates the vertical movement of water through the bottom of the test area using a larger surface area than a cased borehole infiltration test. A double-ring infiltrometer test must be completed if a test pit is the chosen methodology for obtaining the soil characterization and soil samples.

The designer is referred to **Appendix H** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/h-infiltration-testing-log for a blank Infiltration Testing Log, which is required to be completed and submitted as part of the Geotechnical Report. The general testing procedure outlined below is based on a slightly modified ASTM standard D3385-09.

1. Determine a location and depth for the test based on the information obtained from the in situ soil classification analysis.
2. Dig a test pit to the desired depth where the infiltration interface is proposed using the benched methodology recommended in the test pit procedure.
3. Establish a level surface for the testing apparatus to be placed.
4. Drive outer ring into the soil to a minimum depth of six inches or at a minimum two inches more than the inner ring. A drive cap is recommended to ensure consistent and uniform installation and to avoid fracturing the soil surface.
5. Center the inner ring within the outer ring and drive to a depth of approximately two to four inches below grade using the same technique as described for the outer ring placement.
6. If soil along the inner ring is excessively disturbed, reset the ring. If the soil along the inside of either ring is slightly disturbed, tamp the soil with minimal force until soil is as firm as prior to disturbance.
7. A constant head must be maintained within the inner ring and annular space between the two rings. Manually controlling the flow of liquid is sufficient; however, the testing professional can consult the ASTM standard for additional methods. If manually controlling the liquid level, depth gauges must be installed such that the reference head is between one and six inches. Place the depth gauges towards the center of the inner ring and midway between the two rings.
8. Install anti-scouring measures such as a one-inch layer of coarse sand or washed, fine gravel and splash guards (pieces of burlap or rubber sheet) to avoid scour when water is applied.
9. Fill both rings with water to the same depth in each ring. Remove splash guards, and do not record this initial volume of liquid.

10. The test area must be presoaked immediately prior to testing. Fill both rings with water to water level indicator mark or rim at 30 minute intervals for one hour. The minimum water depth must be four inches. The drop in the water level during the last 30 minutes of the presoaking period must be applied to the following standard to determine the time interval between readings:
    a. If water level drop is two inches or more, use ten-minute measurement intervals.
    b. If water level drop is less than two inches, use 30-minute measurement intervals.
11. Obtain a reading of the drop in water level in the center ring at appropriate time intervals. After each reading, refill both rings to water level indicator mark or rim. Measurement to the water level in the center ring must be made from a fixed reference point and must continue at the interval determined until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of 0.25 inch or less of drop between the highest and lowest readings of four consecutive readings.
12. The drop that occurs in the center ring during the final period or the average stabilized rate, expressed as inches per hour, represents the infiltration rate for that test location.
13. Backfill the excavation and restore the surface to its original condition once all testing is completed.

Cased Borehole

A cased borehole infiltration test is only recommended when site characteristics do not allow for a test pit and double-ring infiltration test. If a borehole infiltration test is performed, it must not be completed within the same hole as the hollow-stem augered soil characterization study.

The borehole infiltration method is based on a slightly modified ASTM D6391-11 standard. The casing installation method required by PWD is a modified procedure that avoids the use of a bentonite paste at the tip of the casing and a bentonite seal within the annular space between the casing and the surrounding soils. The use of bentonite can absorb moisture from the surrounding soils before swelling and hardening. As a result, the test results may not be accurate.

The designer is referred to **Appendix H** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/h-infiltration-testing-log for a blank Infiltration Testing Log, which is required to be completed and submitted as part of the Geotechnical Report. The modified borehole infiltration testing procedure required is outlined below.

1. Advance a borehole to the depth of the proposed infiltration interface depth using the Hollow-Stem Auger Method (ASTM D6151-08). The augered hole diameter must be at least two inches larger than the outer diameter of the inner casing. The inner casing will consist of a PVC pipe with minimum inner diameter of four inches and a smooth, square bottom.
2. Push the inner casing within the auger hollow stem to the infiltration interface and firmly set into the bottom of the borehole. Use a borehole plane to scarify the soil surface at the bottom of the casing and remove any remaining loose soil. Measure the depth from the top of casing to the bottom of the hole to the nearest 0.01 feet.
3. Remove the augers.

4. Place two inches of washed, fine gravel or clean, coarse sand in the bottom of the borehole to prevent scour during filling of the casing. Be sure to place gravel or sand uniformly to obtain an even depth within the hole. Re-measure the depth from the top of casing to the gravel or sand surface to the nearest 0.01 feet.
5. Presoak test holes immediately prior to testing to simulate saturated conditions. Fill casing with water at a very low rate so as not to disturb the bottom sediments. Place water to a depth of at least six inches above the bottom and readjust every 30 minutes for one hour. A constant head can be applied and maintained at the top of the casing as an alternate method. The drop in the water level during the last 30 minutes of the presoaking period must be applied to the following standard to determine the time interval between readings:
    a. If water level drop is two inches or more, use ten-minute measurement intervals.
    b. If water level drop is less than two inches, use 30-minute measurement intervals.
6. After the presoaking, the water level is measured, using an approved method per the ASTM standard, where the water level remains between 12 and 18 inches above the bottom of the hole. All water added must be recorded as a volume along with the time of addition.
7. Measurements of water level must be made from the top of casing and must continue at the interval determined until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of 0.25 inch or less of drop between the highest and lowest readings of four consecutive readings.
8. Upon completion, remove casing and backfill hole with cuttings. If testing is conducted in vegetated areas, return the surface to its previous state. If testing is completed in paved areas, plug the hole with a bentonite plug, and seal the surface with concrete or asphalt.
9. Use the field-observed stabilized infiltration rate as the test infiltration rate.

3.3.6 Evaluation of Infiltration Testing Results

Upon completion of soil characterization and infiltration testing, the designer must first determine SMP design infiltration rates based on the tested infiltration rates. Once the design infiltration rate is calculated, tentative SMP locations must be assessed for suitable underlying soils that would support an infiltrating practice. The designer must locate SMPs within areas where infiltration is feasible based on the allowable and acceptable infiltration rates. The following steps will assist the designer in determining the final SMP footprint locations.

Step 1: Determine the geometric mean of the tested infiltration rates.

Starting with the *tested infiltration rates*, the geometric mean must be used to determine the average infiltration rate following multiple tests for each SMP. As the rates are log-normally distributed, the geometric mean, not the arithmetic averages, of multiple test results must be reported and used. The field data and/or any statistically derived result of field measurements must pass a rigid quality control procedure. In some situations, a measured rate of zero may be obtained. A measured rate of zero is generally related to inherent flaws in the testing methodology. In these cases, a default value should be used based on one decimal digit less than the smallest detectable reading for that particular test method/equipment. For example, if the smallest detectable reading using an infiltrometer test is a 0.125 inch drop, then 0.124 inches should be substituted for the zero value which represents one decimal digit less than 0.125 inches. This substitution method is necessary to ensure that the test calculations do not yield a zero value for hydraulic conductivity since a zero value cannot be used in the calculation of a geometric mean.

The highest tested infiltration rate from the test results must be discarded when more than three are employed for design purposes. The geometric mean of the remaining readings must be calculated for each SMP.

The geometric mean of a data set is the nth root of the product of “n” numbers:

$$\{a_1, a_2, \ldots, a_n\} = \sqrt[n]{a_1 * a_2 * \ldots a_n}$$

Step 2: Compare the geometric mean to the allowable and acceptable infiltration rates.

Prior to determining whether the SMP footprint and location are suitable for installation of an infiltrating SMP, the designer must check that the geometric mean of the tested infiltration rates falls within the allowable and acceptable range defined by PWD. Soils underlying infiltration practices must have a mean tested infiltration rate between 0.4 and ten inches per hour. Infiltration is to be considered infeasible in soils with tested infiltration rates of less than 0.4 inches per hour. If the designer wishes to design an SMP to infiltrate with a tested infiltration rate of less than 0.4 inches per hour, calculations must be provided demonstrating an SMP drain down of no more than 72 hours with its proposed loading ratio. PWD will review this scenario on a project-by-project basis.

Soils with tested infiltration rates in excess of ten inches per hour will require soil amendments. Upon achieving final subgrade elevations, a two-foot thick layer of amended soil must be placed across the entire cross-section of the infiltrating SMP, below the bottom elevation of the SMP. A conservative infiltration rate must be used in the stormwater routing calculations during the design of the SMP, and a soil amendment sequence of construction must be provided on the plans. A minimum of three infiltration tests must be performed within the amended soil layer during construction to verify rates. The procedure used must be the double-ring infiltrometer test; soil sampling and characterization are also required; and all must be in compliance with the procedures detailed in these Sections. The engineer must provide a signed and sealed Geotechnical Report. All information must be submitted to PWD for review and approval before proceeding with construction. If soil amendments are installed, and the tested infiltration rate is determined to be outside of the PWD allowable range of 0.4 to ten inches per hour or varies significantly from the design infiltration rate, additional soil amendments and/or a system redesign will be required.

Step 3: Evaluate the proposed SMP locations (if necessary).

If infiltration rates are found to be below the minimum allowable rate at proposed SMP locations and there are other areas of the project site where infiltration may be feasible, the designer must consider alternative SMP locations. Alternatively, the designer may explore the possibility of over-excavating poorly infiltrating soils if the removal and replacement of these soils would allow for SMPs to infiltrate into more porous material that may exist below poorly infiltrating soils.

Additionally, SMPs must not be located within two feet of any limiting layers. A two-foot separation between the infiltration interface (SMP bottom elevation) and the regularly occurring seasonally high water table must be maintained. This reduces the likelihood that temporary groundwater mounding will affect the system and allows sufficient distance of water movement through the soil to allow adequate pollutant removal. Also, a minimum separation of two feet must be maintained between bedrock and the SMP bottom elevation in order to ensure adequate pollutant removal.

Step 4: Document infiltration feasibility.

All projects require documentation for infiltration feasibility. If infiltration is determined to be feasible on-site, the designer must provide a Geotechnical Report meeting the requirements provided in **Appendix E** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/e-plan-and-report-checklists and may proceed to detailed design (Step 5). Where infiltration is found to be infeasible, a waiver from the infiltration requirement must be requested.

Infiltration Waiver Request

The two scenarios for which PWD will generally grant a waiver from the infiltration requirement are: (1) full build-out and (2) projects with unacceptable infiltration rates or where contamination is present. If applicable, a request for a waiver from the infiltration requirement must be accompanied by supporting documentation.

1. For projects confirmed to be full build-out (where ground-level open space is not sufficient to accommodate required SMP loading ratios and setbacks), the site layout must be provided to confirm this scenario. Where a full build-out is confirmed, the designer must prepare and submit a Conceptual Stormwater Management Plan and request a waiver from the infiltration requirement via completion and submittal of the Existing Resources and Site Analysis (ERSA) Worksheet (**Section 2.1.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-1-existing-resources-and-site-analysis#2.1.1). A full build-out does not require a Geotechnical Report.
2. Where infiltration has been found to be infeasible due to unacceptable infiltration rates or contamination, a waiver from the infiltration requirement must be requested via the Online Technical Worksheet (**Section 3.4.3** ☛ p. 101). If the waiver from the infiltration requirement is requested due to unacceptable infiltration rates, it must be accompanied by a Geotechnical Report, both of which are required as parts of the PCSMP Review Phase Submission Package. The Geotechnical Report must be signed and sealed by a professional engineer registered in the Commonwealth of Pennsylvania and meet the requirements provided in **Appendix E** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/e-plan-and-report-checklists. If the waiver from the infiltration requirement is requested due to contamination, electronic copies of environmental reports for any testing completed, as well as a justification letter from the geotechnical engineer or environmental professional, must be submitted.

Geotechnical Report

The designer must provide a signed and sealed Geotechnical Report with a testing location plan and summary of results. All information must be submitted to PWD for review and approval before proceeding with construction.

Infiltration testing results are required as part of the PCSMP Review Phase Submission Package (**Section 2.3.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1); however, the designer is encouraged to submit infiltration testing results as early as possible in the review process. If available, infiltration testing results will be accepted and reviewed as part of the Conceptual Review Phase Submission Package or Stormwater Grant Application for Stormwater Grant-funded Stormwater Retrofit projects. PWD may not be able to complete its review of the infiltration testing during the Conceptual Review Phase if all pertinent design information is not provided, such as SMP bottom elevation, and will defer final determination of infiltration feasibility to the PCSMP Review Phase.

Infiltration testing results must be submitted in a signed and sealed (by a professional engineer licensed in the Commonwealth of Pennsylvania) Geotechnical Report containing the engineer's analysis and summary of all results including soil classification (in accordance with ASTM D2488) and site evaluation, along with the engineer's affirmative or negative recommendation on feasibility of infiltration, with justification. The designer is referred to **Appendix E** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/e-plan-and-report-checklists for a complete listing of all required Geotechnical Report components.

Step 5: Proceed with detailed SMP design.

If infiltration has been documented as feasible for the proposed SMP locations, the designer can proceed with detailed design of infiltration SMPs, using guidance provided in **Section 3.2** ☛ p. 41 and **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4. The designer must apply a factor of safety of two to the geometric mean of the tested infiltration rates, as documented in **Section 3.4.1** ☛ p. 83. This rate will be the SMP-specific *design infiltration rate* to be used for all further design and calculations.

For project sites where infiltration is deemed infeasible, and this condition is confirmed by PWD, the designer must use acceptable pollutant-reducing SMPs to comply with the Water Quality requirement. Water Quality release rate requirements also apply to non-infiltrating areas in combined sewersheds. Acceptable pollutant-reducing SMPs are listed in **Section 3.1.7** ☛ p. 35. Additional detailed design guidance for pollutant-reducing SMPs is provided in **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4.

3.4 How To Show Compliance

Section 3.4 provides detail on how to ensure and demonstrate that stormwater management design strategies are implemented in accordance with the Philadelphia Water Department's (PWD's) Stormwater Regulations (Stormwater Regulations). This Section provides resources that can be used in conjunction with the design requirements detailed in **Section 3.2** ☛ p. 41 and **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4.

Section 3.4.1 ☛ p. 83 gives specific guidance and requirements for compliance with the following:

- Water Quality requirement,
- Channel Protection requirement,
- Flood Control requirement, and
- Public Health and Safety Release Rate requirement.

Compliance with some Stormwater Regulations may not be required for all projects; therefore, the applicant is referred to **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1 to assess and/or confirm applicability of specific requirements.

Section 3.4.2 ☛ p. 92 provides guidance and requirements for the design of storm sewer systems.

Section 3.4.3 ☛ p. 94 contains calculation methods and design tools to assist in stormwater management design.

3.4.1 Regulatory Compliance Documentation Requirements

After determining which Stormwater Regulations are applicable to the project site using **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1, the applicant can use this Section as a guide to document regulatory compliance within the Post-Construction Stormwater Management Plan (PCSMP) Review Phase. For each requirement, a step-by-step guide to documenting compliance is provided. While some steps are either identical or similar between requirements, this redundancy is provided for projects where not all requirements are applicable. The applicant is referred to **Section 2.3.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1 for complete PCSMP Review Phase submission requirements.

Quick Tip

As part of an integrated design approach (**Section 3.1.3** ☛ p. 15), the designer may choose to meet multiple Stormwater Regulations with a single SMP or multiple SMPs. Additionally, the designer may choose an approach that uses SMPs in series (**Section 3.2.3** ☛ p. 49)

Water Quality

The designer must use the following steps to document compliance with the Water Quality requirement. This requirement, with key differences noted below and in **Section 1.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-3-stormwater-retrofits, contains the design standards for Stormwater Retrofit projects. No other Post-Construction Stormwater Management Requirement is applicable to voluntary stormwater management.

Step 1:

Delineate all post-development impervious area within the project limit of disturbance (LOD) and differentiate between disconnected impervious cover (DIC) and directly connected impervious area (DCIA). For projects located in combined sewer areas, also differentiate between DCIA that meets roof runoff isolation requirements (**Section 3.1.7** ☛ p. 35) and all other DCIA. For Stormwater Retrofit projects, delineate the impervious area draining to any proposed stormwater management practices (SMPs). The roof runoff isolation pollutant-reducing practice does not apply for Stormwater Retrofit projects.

Step 2:

For all DIC within the project LOD, identify the proposed DIC strategy (i.e., rooftop disconnection, pavement disconnection, tree disconnection credit, green roof, or porous pavement).

DIC strategies must meet applicable requirements in **Section 3.1.5** ☛ p. 23. For Stormwater Retrofit projects, different policies on DIC strategies apply. Refer to **Section 1.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-3-stormwater-retrofits for more information on incorporating DIC into Stormwater Retrofit projects.

Step 3:

Delineate drainage areas and footprints for each proposed SMP or series of SMPs if they share the same drainage area) and all DCIA within each drainage area. Check to ensure maximum loading ratio requirements can be met for each proposed SMP. Loading ratio requirements are discussed in **Section 3.2.6** ☛ p. 60.

Step 4:

Calculate the Water Quality Volume (WQv) for each proposed SMP (or series of SMPs, if applicable) using the following equation:

$$WQv = (DCIA) \times \left(\frac{R}{12}\right)$$

Where:

WQv = Water Quality Volume [cubic feet]
DCIA = Directly Connected Impervious Area [square feet]
R = 1.5 inches runoff depth

Step 5:

Determine the sewershed of the discharge point of each proposed SMP.

Design SMP(s) to provide management of the WQv and to meet all SMP design requirements by SMP-type in **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4. WQv management requirements differ by infiltration feasibility and sewershed, as detailed in **Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1, and based on these factors, proceed to Step 5a, Step 5b, or Step 5c.

Step 5a:

Where infiltration is feasible:

- Design SMP(s) to infiltrate 100% of WQv.
- Size SMP(s) to provide static storage of the WQv below the lowest outlet elevation.
- Bioinfiltration SMPs can be designed for an adjusted WQv= (DCIA) [sf] x (1-inch runoff depth/12) if the designer demonstrates through modeling that the full WQv can be routed dynamically through the system. See **Section 4.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-1-bioinfiltration-bioretention/ for more information.
- Design SMP(s) to ensure drain down time is no more than 72 hours based on the tested infiltration rate with an applied factor of safety of two to the geometric mean of the tested infiltration rates (design infiltration rate) and the SMP horizontal surface area (footprint).

Step 5b:

Where infiltration is not feasible and the project is located in a combined sewer area:

- Design SMP(s) to route 100% of the WQv that is not infiltrated through an acceptable pollutant-reducing practice (**Table 3.1-3** ☛ p. 36). This is not a requirement for Stormwater Retrofit projects.
- Design SMP(s) to ensure a slow release rate on-site that does not exceed 0.05 cubic feet per second (cfs) per acre of DCIA when routing a 1.7-inch PWD Design Storm.
  See **Section 3.4.3** ☛ p. 94 for calculation methods and **Table 3.4-4** ☛ p. 97 for dimensionless rainfall distribution for the PWD Design Storm. A curve number of 98 must be used for all DCIA when performing routing calculations for the Water Quality requirement.
- Design SMP(s) to ensure drain down time is no more than 72 hours after the storm event for a 1.7-inch PWD Design Storm. The drain down time is the time required for evacuation of the instantaneous storage of the WQv in the SMP.

Step 5c:

Where infiltration is not feasible and the project is located in a separate sewer area or is a direct discharge project:

- Design SMP(s) to route 100% of the WQv that is not infiltrated through an acceptable pollutant-reducing practice (**Table 3.1-3** ☛ p. 36).
- Design SMP(s) to ensure drain down time is no more than 72 hours after the 24-hour storm event. The drain down time is the time required for evacuation of the instantaneous storage of the WQv in the SMP.

Step 6:

For Development Projects only, when meeting the Water Quality requirement is not possible for all or a portion of the DCIA within the LOD, the applicant may propose payment of a one-time fee in lieu. The following must be documented for a fee in lieu request to be considered by PWD:

- In the PCSMP Report, outline all stormwater management strategies that have been considered to comply with the Water Quality requirement, including off-site management as discussed in **Section 3.2.4** ☛ p. 53, and why they are not feasible or advisable.
- Investigate and confirm that the Development Project proposal to pay fee in lieu will not adversely affect flooding, stream protection, neighboring properties, or be inconsistent with NPDES Permit requirements or any other applicable local, State, or Federal law.
- On the PCSMP, identify the square footage, type, and location of DCIA that will not be managed in accordance with the the Water Quality requirement. This value will be used to calculate the one-time fee in lieu payment.

All design information developed to document compliance with the Water Quality requirement must be included in the PCSMP Review Phase Submission Package. This includes, but is not limited to:

- PDF printout of completed Online Technical Worksheet;
- Post-development drainage area plans;
- Static storage calculations; and
- Flow routing calculations and model inputs and results for slow release or bioinfiltration dynamic design, if applicable.

Complete PCSMP Review Phase submission requirements are provided in **Section 2.3.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1.

Channel Protection

The applicant must use the following steps to document compliance with the Channel Protection requirement, if applicable. The applicant is referred to **Section 1.2.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations#1.2.1 for details on Channel Protection exemptions.

Step 1:

Determine a point of analysis (POA) for the post-development condition. A POA is a common point of discharge from the project site or drainage area. A POA may serve one or several drainage areas and/or SMPs. PWD recommends using as few POAs as possible for compliance calculations. If there are multiple points of discharge from a property, it may still be possible to use a single POA if all discharge points lead to the same waterbody or outfall. Should a project fall in this category, contact PWD for more information as to how many POAs should be identified.

Step 2

Delineate drainage areas for each POA and all DCIA within each drainage area. All area within the project LOD must be accounted for within a POA, including areas that bypass SMPs.

Step 3

Design stormwater outlet controls (within or external to SMPs) to ensure the release rate at each POA does not exceed 0.24 cfs per acre of DCIA (draining to the POA) when routing a one-year National Resources Conservation Service (NRCS) Type II 24-hour design storm. The design precipitation depth of a one-year, 24-hour storm is 2.83 inches. See **Section 3.4.3** ☛ p. 94 for calculation methods, **Table 3.4-3** ☛ p. 96 for design storm depths, and **Table 3.4-5** ☛ p. 98 for dimensionless rainfall distribution for the NRCS Type II 24-hour design storm. Outlet controls and SMPs must also meet all design requirements of **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4.

Where runoff is routed through an SMP prior to reaching a POA, design SMP(s) to ensure drain down time is no more than 72 hours after the storm event for a one-year NRCS Type II 24-hour design storm. The drain down time is the time required for evacuation of the instantaneous storage of the Channel Protection volume in the SMP.

All design information developed to document compliance with the Channel Protection requirement must be included in the PCSMP Review Phase Submission Package. This includes, but is not limited to:

- PDF printout of completed Online Technical Worksheet;
- Post-development drainage area plans; and
- Flow routing calculations and model inputs and results for the one-year design storm.

Complete PCSMP Review Phase submission requirements are provided in **Section 2.3.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1.

Flood Control

The applicant must use the following steps to document compliance with the Flood Control requirement, if applicable. The applicant is referred to **Section 1.2.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations#1.2.1 for details on Flood Control exemptions.

Step 1:

Determine a POA for comparison of the predevelopment and post-development conditions. A POA is a common point of discharge from the project site or drainage area. A POA may serve one or several drainage areas and/or SMPs. PWD recommends using as few POAs as possible for compliance calculations. If there are multiple points of discharge from a property, it may still be possible to use a single POA if all discharge points lead to the same waterbody or outfall. Should a project fall in this category, contact PWD for more information as to how many POAs should be identified.

Step 2:

Determine the predevelopment and post-development drainage area(s) and drainage area conditions for each POA. The predevelopment condition is determined by the dominant land use for the ten years preceding the date of the project's Existing Resources and Site Analysis (ERSA) Application submission. All area within the project LOD must be accounted for within a POA, including areas that bypass SMPs.

The applicant is referred to **Table 3.4-2** ☛ p. 95 for acceptable curve numbers and must use the following guidance for determining land use designations for Flood Control:

- Pervious area is considered to be area covered by a pervious surface that allows water to drain through it rather than running off of the site.
- All non-forested pervious areas must be considered meadow in good condition for predevelopment runoff calculations.
- Non-forested pervious area consists of the following cover types: meadow, grass/lawn, brush, gravel, dirt, porous pavements, and any combination of these cover types.
- Dirt and gravel are generally considered to be pervious cover, however, if the applicant believes an impervious classification is more suitable, they can submit documentation, such as photographic evidence and testing results, to support this claim.
- DIC should be represented as the appropriate cover type, as this management strategy does not apply to the Flood Control requirement; thus impervious area must be represented as impervious, green roof area as green roof, porous pavement area as porous pavement, and permeable paver area as permeable paver.
- For redevelopment projects, in addition to any other pervious area, 20% of the existing impervious cover, when present, must be considered meadow (good condition) for the predevelopment runoff calculations.

Step 3:

Confirm or determine, if not done previously, the level of flood control required based on the project's Flood Management District (**Appendix D** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/d-watershed-maps) and peak runoff rate requirements by Flood Management District, as per Table 3.4-1 below.

If a project is located near or across a Flood Management District border, the applicant is responsible for contacting PWD to confirm the District requirements that apply to the project. In most cases, a project that is located in multiple Districts will be required to meet the requirements of the District within which each POA is located, resulting in discrete rate reductions for each POA.

Table 3.4-1: Peak Runoff Rates for Management Districts

District	Column A **NRCS Type II 24-hour Design Storm Applied to Proposed Condition**	Column B **NRCS Type II 24-hour Design Storm Applied to Predevelopment Condition**
A	2 – year	1 – year
A	5 – year	5 – year
A	10 – year	10 – year
A	25 – year	25 – year
A	50 – year	50 – year
A	100 – year	100 – year
B	2 – year	1 – year
B	5 – year	2 – year
B	10 – year	5 – year
B	25 – year	10 – year
B	50 – year	25 – year
B	100 – year	50 – year
B-1	2 – year	1 – year
B-1	5 – year	2 – year
B-1	10 – year	5 – year
B-1	25 – year	10 – year
B-1	50 – year	25 – year
B-1	100 – year	100 – year
B-2	2 – year	1 – year
B-2	5 – year	2 – year
B-2	25 – year	5 – year
B-2	50 – year	10 – year
B-2	100 – year	100 – year
C*	Conditional Direct Discharge District	
C-1**	Conditional Direct Discharge District	

SMPs shall be designed such that peak rates from Column A are less than or equal to Peak Rates from Column B.

** In District C, a Development Site that can discharge directly without use of City infrastructure may do so without control of proposed conditions peak rate of runoff.*

*** In District C-1, a Development site that can discharge directly to the Tookany/Tacony-Frankford main channel or major tributaries without the use of City infrastructure may do so without the control of proposed conditions peak rate of runoff greater than the 5-year storm.*

Redevelopment located in the Delaware Direct Watershed or that discharges to the Lower Schuylkill River, Manayunk Canal, or Mingo Creek, but situated outside of District C, that can discharge directly to the Delaware Direct or Lower Schuylkill main channels without the use of City infrastructure, may do so without the control of proposed conditions peak rate of runoff according to the procedures found in the Manual.

For Conditional Direct Discharge Districts, the proposed conditions peak rate of runoff for a Development site that discharges to City infrastructure must be controlled to the Predevelopment Conditions peak rate as required in District A provisions or the specified Design Storms. The Predevelopment Condition shall be defined according to the procedures found in the Manual.

Step 4:

Design stormwater outlet controls (within, or external to, SMPs) to ensure the peak runoff rate in the proposed condition (left column of Table 3.4-1) does not exceed the peak runoff rate in the predevelopment condition (right column of Table 3.4-1) at each POA for the stated design storms. For a given Flood Management District, all storms' rate reductions must be met concurrently. Peak rate reduction provided by SMPs that meet the Water Quality and Channel Protection requirements may be considered in sizing calculations for peak rate controls. See **Section 3.4.3** ☛ p. 94 for calculation methods, **Table 3.4-3** ☛ p. 96 for design storm depths, and **Table 3.4-5** ☛ p. 98 for dimensionless rainfall distribution for the NRCS Type II 24-hour design storm. Outlet controls and SMPs must also meet all design requirements of **Chapter 4** ☛ water.phila.gov/development /stormwater-plan-review/manual/chapter-4.

All design information developed to document compliance with the Flood Control requirement must be included in the PCSMP Review Phase Submission Package. This includes but is not limited to:

- PDF printout of completed Online Technical Worksheet;
- Predevelopment and post-development drainage area plans;
- Predevelopment time of concentration (Tc) calculations;
- Post-development Tc calculations (if demonstration of a Tc greater than an assumed six minutes is desired); and
- Flow routing calculations and model inputs and results for predevelopment and post-development conditions during all design storms applicable to the Flood Management District's required rate reductions.

Complete PCSMP Review Phase submission requirements are provided in **Section 2.3.1** ☛ water.phila.gov /development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1.

Public Health and Safety Release Rate

The applicant must use the following steps to document compliance with a Public Health and Safety (PHS) Release Rate requirement, if applicable. The designer is referred to **Section 1.2.1** ☛ water.phila.gov /development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations/#1.2.1 for more information on the PHS Release Rate requirement.

Step 1:

Confirm the project-specific PHS Release Rate requirement with PWD Stormwater Plan Review. A PHS Release Rate requirement is stated as a peak runoff release rate in cfs per acre of earth disturbance, pervious and impervious, alike. This information will be noted by PWD during the Conceptual Review Phase (**Section 2.3** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases).

Step 2:

Determine a POA for the post-development condition. A POA is a common point of discharge from the project site or drainage area. A POA may serve one or several drainage areas and/or SMPs. Multiple POAs must be identified for project sites with multiple points of discharge.

Step 3:

Delineate drainage areas for each POA, the extent of earth disturbance within each drainage area, and the post-development condition within the LOD. All area within the project LOD must be accounted for within a POA, including areas that bypass SMPs.

Step 4:

Design stormwater outlet controls (within, or external to, SMPs) to ensure the peak runoff release rate at each POA does not exceed the project-specific PHS Release Rate requirement (cfs per acre LOD within the POA) when routing the one-year through ten-year NRCS Type II 24-hour design storms. See **Section 3.4.3** ☛ p. 94 for calculation methods, **Table 3.4-3** ☛ p. 96 for design storm depths, and **Table 3.4-5** ☛ p. 98 for dimensionless rainfall distribution for the NRCS Type II 24-hour design storm. Outlet controls and SMPs must also meet all design requirements of **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4.

All design information developed to document compliance with the PHS Release Rate requirement must be included in the PCSMP Review Phase Submission Package. This includes but is not limited to:

- PDF printout of completed Online Technical Worksheet;
- Post-development drainage area plans;
- Post-development Tc calculations (if demonstration of a Tc greater than an assumed six minutes is desired); and
- Flow routing calculations and model inputs and results for the one-year through ten-year design storms.

Complete PCSMP Review Phase submission requirements are provided in **Section 2.3.1** ☛ water.phila.gov /development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1.

3.4.2 Storm Sewer Design Requirements

All storm sewer pipes must be designed to have adequate capacity to safely convey the ten-year storm without surcharging the crown of the pipe. Pipe capacity calculations are required for all stormwater conveyance that is not connected to the roof drainage system. The designer is referred to the **City of Philadelphia Plumbing Code** ☛ www.phila.gov/departments/department-of-licenses-and-inspections/resources/applicable-codes/ (Plumbing Code) for guidance on sizing roof drainage systems.

If Flood Control is required, runoff from larger storms must be safely conveyed off the site, either through overland flow or a storm sewer. Runoff may not be conveyed to a neighboring property.

The Rational Method may be used when designing storm sewers. The Rational Method is a simple method for determining peak runoff discharge from both pervious and impervious cover. This method uses Rational Method runoff coefficients (C-values) based on land use, soil type, and watershed slope, to estimate peak runoff rates during different rainfall conditions. The Rational Method is primarily used to estimate runoff rates and not runoff volume.

The Rational Method may not be used for SMP design, outlet control design, or detention routing. It may be used for storm sewer capacity design, including open channel collection and conveyance systems analyses.

Required assumptions to obtain conservative results using the Rational Method include the following:

- A runoff coefficient value of 0.35 must be used for pervious areas.
- A runoff coefficient value of 0.95 must be used for impervious areas.
- A precipitation intensity of 6.96 inches per hour must be used, which is the five-minute inlet concentration time in the ten-year storm event. The designer is referred to the *Pennsylvania Department of Transportation (PennDOT) Drainage Manual*, Chapter 7, Appendix A, Field Manual For Pennsylvania Design Rainfall Intensity Charts From the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Version 3 Data (2010 or latest) for the Intensity Duration Frequency (IDF) for Region 5 for more information.
- For use with Manning's Equation for calculating full channel flow, a Manning's n value of 0.013 must be used for RCP, VCP, and CIP, and a value of 0.011 must be used for PVC and HDPE.

When designing a site's storm sewer system, the designer must be mindful of the following requirements:

- Length, material, size, and slope of all piping associated with stormwater conveyance and roof drainage systems must be clearly labeled on the submitted PCSMP and should be consistent with associated profiles, if provided.
- Piping conflicts must be avoided.
- Inlets may not be connected in series. Similarly, roof drainage systems may not tie directly into an inlet. Wye connections, or similar, may be used to ensure that inlets are offline.
- A minimum of 12 inches of vertical clearance is required when a sanitary sewer line crosses above a storm sewer line. The sanitary sewer must be encased in concrete if the clearance is less than 12 inches.
- Any manholes between outlet structures and sewer connections in combined sewer areas must have sanitary (non-vented) covers.

- A cleanout must be provided, at minimum, every 75 feet, at the end of all pipes, and for all 90-degree bends.
- If curb cuts or non-standard inlets are used to capture runoff, especially from driveways or roadways where the inlets are not in a sump condition, verification that the one-year storm will be captured by the inlet must be provided.
- The invert elevation(s) for the proposed connection(s) to the existing City sewer and a pipe connection detail must both be provided on the submitted PSCMP.
- The outlet culvert(s) must be right-sized to minimize impacts on PWD infrastructure.
- All stormwater conveyance pipe material must be in compliance with the **Plumbing Code** ☛ www.phila.gov/departments/department-of-licenses-and-inspections/resources/applicable-codes/.
- A minimum cover of 36 inches must be provided over all private storm sewer pipes, in accordance with the **Plumbing Code** ☛ www.phila.gov/departments/department-of-licenses-and-inspections/resources/applicable-codes/.
- Stormwater conveyance pipes must be designed with a minimum velocity of two feet per second. Designs should attempt to maintain velocity without sacrificing SMP depth.
- All proposed connections to the City sewer must be right-sized to convey the necessary flow while minimizing the pipe diameter.
- All proposed connections to the City sewer must be inspected by PWD Water Transport Records. More information on this process can be found in the **Sewer Connection and Repair Manual** ☛ water.phila.gov/pool/files/sewer-connection-manual.pdf.
- As City sewers are regularly at full capacity, two feet of clearance between the bottom of the SMP and the crown of the City sewer pipe and/or a backflow prevention device must be provided to alleviate potential flooding. If a backflow prevention device is proposed, please take into consideration the on-site point of relief during larger storms.
- Stormwater conveyance piping and SMPs cannot receive runoff from fueling station pads for gas stations. The drainage area under a pad’s canopy must be treated by an oil/water separator then discharge directly to the sanitary sewer system.
- Stormwater conveyance piping and SMPs that encroach onto an adjacent property require a drainage easement.

3.4.3 Calculation Methods and Design Tools

The designer will need to use various calculation methods and design tools in order to prepare an integrated stormwater management design and to demonstrate compliance with the Stormwater Regulations. The calculation methods and design tools described in this Section are used for a variety of purposes relating to integrated design including computing the amount of runoff from DCIA and other surfaces, modeling peak flow rates and drain down times, determining SMP sizing, and developing inlet/outlet control and conveyance system designs. Calculations, model inputs/outputs, and completed Online Technical Worksheet are used in the preparation of PCSMP Review Phase Submission Package, which is detailed in **Section 2.3.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-3-review-phases#2.3.1.

Calculation Methods

Runoff Estimation

The NRCS Curve Number Method is used to estimate site stormwater runoff from a given storm. While it is PWD's preferred runoff estimation method, additional methods may be used at the designer's discretion with approval from PWD.

The NRCS Curve Number Method is widely used to produce estimates of runoff volume for both pervious and impervious cover. It empirically accounts for the initial abstraction and infiltration of rainfall events on based on ground cover type characteristics. For a detailed description of the Curve Number Method, the designer is referred to Urban Hydrology for Small Watersheds (NRCS Technical Release 55).

Care must be taken to select appropriate curve number values since this calculation method is very sensitive to changes in these values. In order to obtain conservative results, separate calculations for pervious and impervious area runoff must be used. Weighted curve number values between pervious and impervious areas are not acceptable. The resulting flows can be routed, if necessary, and then summed.

Table 3.4-2 below provides acceptable curve number values for each Hydrologic Soil Group.

Table 3.4-2: Acceptable Curve Number Values

Cover Description		Curve Number for Hydrologic Soil Group				
COVER TYPE	HYDROLOGIC CONDITION	A	B	C	D	Ub*
Lawns, parks, golf courses, etc.						
	Poor (grass cover <50%	68	79	86	89	79
	Fair (grass cover 50–75%)	49	69	79	84	69
	Good (grass cover > 75%)	39	61	74	80	61
Brush (brush-weed-grass mixture with brush the major element)						
	Poor	57	73	82	86	73
	Fair	43	65	76	82	65
	Good	32	58	72	79	58
Wood-grass combination (orchard or tree farm)						
	Poor	57	73	82	86	73
	Fair	43	65	76	82	65
	Good	32	58	72	79	58
Woods						
	Poor	45	66	77	83	66
	Fair	36	60	73	79	60
	Good	30	55	70	77	55
Paved parking lots, roofs, driveways, streets, etc.		98	98	98	98	98
Gravel/Crushed Stone		76	85	89	91	89
Dirt Streets and Roads		72	82	87	89	87
Green Roof**		86	86	86	86	86
Athletic Field		68	79	86	89	79
Porous Pavement		70	70	74	80	70
Permeable Pavers		70	70	79	84	70
Pour-in-Place Rubber		70	70	74	80	70
Porous Turf		70	70	79	84	69
Meadow		30	58	71	78	58

* Ub refers to “Urban Land” and generally conforms to a hydrological soil group classification of B. A Ub curve number must be used on Redevelopment projects unless the engineer provides soil mapping indicative of another, more appropriate soil classification.

** Existing rainfall runoff models are limited in their ability to predict runoff from green roofs since this process is dominated by percolations through a thin veneer of soil and is not surface runoff. Green roof research studies have back-calculated a range of curve number values for various storms and roof media types/thicknesses. Alternative curve number values may be applied when supported by submitted analysis and relevant references, which will be reviewed on a case-by-case basis.

Design Storms

Sizing requirements for compliance with the Stormwater Regulations have been developed using long-term computer simulations. These requirements have been translated to single event design conditions that yield roughly equivalent results.

The rainfall depths of design storms shown in Table 3.4-3 are taken from the *PennDOT Drainage Manual*, Chapter 7, Appendix A, Field Manual For Pennsylvania Design Rainfall Intensity Charts From NOAA Atlas 14 Version 3 Data (2010 or latest). These totals indicate the largest depth that can be expected over the specified interval in the specified return period. These design precipitation depths are similar to those found in other standard references such as **NOAA Technical Paper No. 40** ☛ https://www.weather.gov/gyx/TP40s.htm or the **NOAA Atlas 14** ☛ http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=pa; however, the designer must use the values provided in Table 3.4-3 for their design calculations.

Table 3.4-3: Design Precipitation Depths (in)

	Return Period						
DURATION	1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5 min	0.37	0.45	0.52	0.58	0.59	0.65	0.71
10 min	0.58	0.69	0.81	0.90	1.04	1.15	1.26
15 min	0.71	0.85	1.00	1.11	1.29	1.42	1.56
30 min	0.94	1.14	1.37	1.56	1.82	2.04	2.27
1 hr	1.17	1.42	1.76	2.03	2.39	2.69	3.04
2 hrs	1.39	1.69	2.12	2.46	2.93	3.34	3.90
3 hrs	1.53	1.86	2.33	2.71	3.25	3.75	4.34
6 hrs	1.91	2.31	2.91	3.40	4.12	4.70	5.34
12 hrs	2.37	2.86	3.56	4.20	5.15	5.96	6.86
24 hrs	**2.83**	**3.40**	**4.22**	**4.95**	**6.10**	**7.16**	**8.43**

PWD Design Storm Rainfall Distribution

The Water Quality requirement is required to be demonstrated with the new PWD Design Storm rainfall distribution, found in Table 3.4-4 below.

This distribution is only to be used for complying with the Water Quality requirement. It is not intended to replace any assessments of Flood Control requirement compliance, Channel Protection requirement compliance, pipe sizing, or conveyance capacity for large events that are necessary for other design requirements. The NRCS Type II 24-hour storm should still be used for those purposes.

Table 3.4-4: PWD Design Storm Rainfall Distribution

Time elapsed, minutes	Cumulative % of total event volume	Time elapsed, minutes	Cumulative % of total event volume
15	0.000	285	0.389
30	0.002	300	0.413
45	0.012	315	0.437
60	0.037	330	0.464
75	0.058	345	0.492
90	0.079	360	0.518
105	0.102	375	0.543
120	0.121	390	0.677
135	0.141	405	0.808
150	0.166	420	0.828
165	0.186	435	0.853
180	0.207	450	0.877
195	0.234	465	0.892
210	0.258	480	0.912
225	0.283	495	0.933
240	0.310	510	0.953
255	0.338	525	0.980
270	0.364	540	1.000

NRCS Type II 24-Hour Design Storm Rainfall Distribution

The Channel Protection, Flood Control, and PHS Release Rate requirements all require calculations using design rainfall depths distributed in a NRCS Type II 24-hour dimensionless rainfall distribution. The Type II distribution was selected not because it represents a typical event, but because it includes periods of low-intensity and high-intensity rainfall; design that uses this distribution results in SMPs that can manage a variety of event types, particularly high intensity storms.

Table 3.4-5: Tabulated NRCS Type II 24-Hour Rainfall Distribution

Time (hr)	Dimensionless Rainfall CUMULATIVE	INCREMENTAL
0.00	0.000	0.000
2.00	0.022	0.022
4.00	0.048	0.026
6.00	0.080	0.032
7.00	0.098	0.018
8.00	0.120	0.022
8.50	0.133	0.013
9.00	0.147	0.014
9.50	0.163	0.016
9.75	0.172	0.009
10.00	0.181	0.009
10.50	0.204	0.023
11.00	0.235	0.031
11.50	0.283	0.048
11.75	0.357	0.074
12.00	0.663	0.306
12.50	0.735	0.072
13.00	0.772	0.037
13.50	0.799	0.027
14.00	0.820	0.021
16.00	0.880	0.060
20.00	0.952	0.072
24.00	1.000	0.048

Storm Return Periods for Large Events and Flow Bypass

At a minimum, safe conveyance of the ten-year, 24-hour design storm must be provided to and from all SMPs. Additionally, the flow that is leaving the system must meet the requirements of the Stormwater Regulations. For SMPs designed to manage smaller storms, the designer may choose to allow runoff from larger storms to bypass or quickly pass through a storage element. This is permitted as long as all applicable Stormwater Regulations, along with all SMP design requirements (**Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4), are met.

Flow Routing

Sheet Flow and Shallow Concentrated Flow

Sheet flow consists of shallow flow spread out over a plane. Eventually, this flow will generally concentrate into a deeper, narrower stream. While the prevalence of sheet flow in the natural environment is debated among design professionals, it does provide a reasonable mathematical basis for predicting travel time over short distances.

Urban Hydrology for Small Watersheds (TR-55) provides a sheet flow equation based on Manning's kinematic solution. Tables of roughness values for sheet flow are available in Urban Hydrology for Small Watersheds and in Table 3.4-6 shown below.

PWD will only accept sheet flow for the first 100 feet. After sheet flow, overland flow is considered shallow concentrated flow. Shallow concentrated flow will be considered as flowing over paved or unpaved surface for the purpose of estimating velocity.

Another method for routing overland flow is the kinematic wave solution, which can be obtained by coupling the momentum and continuity equations with simplifying assumptions and it may be solved in a computer program using numerical methods.

Table 3.4-6: Roughness Coefficients (Manning's n) for Sheet Flow

Surface Descrption	n[1]
Roof Tops	0.011
Concrete	0.013
Asphalt	0.015
Bare Soil	0.018
Sparse Vegetation[2]	0.100
Grass: Short grass prairie, Lawn	0.150
Grass: Dense Grasses[3]**, Meadow** (good condition)	0.240
Range (natural)	0.130
Woods[4]**: Light underbrush**	0.400
Woods[4]**: Dense underbrush**	0.800

- [1] The n values are a composite of information compiled by Engman (1986) and Akan (1985)
- [2] Areas where vegetation is spotty and consists of less than 50% vegetative cover.
- [3] Species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
- [4] Consider cover to a height of 0.1 ft. This is part of the plant cover that will obstruct sheet flow.

Channel Flow

Channel flow equations may be used to estimate flows in free-flowing gutters and swales. Manning's equation is sufficient for these estimates on many sites. Tables of roughness values are available in *Civil Engineering Reference Manual (CERM) Appendix 19.A*. For channels with significant backwater, culverts which may flow under pressure, or other complex features, the St. Venant equations may be needed. These equations represent the complete solution of the momentum and continuity equations in one dimension. These may require a computer program to solve.

Time of concentration paths must be shown from the hydraulically most distant point of each drainage area to a point of interest within the drainage area, and the path must be perpendicular to each area's contours. For reference, the post-development Tc will be less than or equal to the predevelopment Tc values, unless the site is specifically altered to increase this path. Total post-development Tc for any path must be no less than six minutes.

Storage Routing

For small storage elements where travel time within the element is insignificant, simple mass balance routing may be performed in a spreadsheet. At each time step, the change in storage volume is the difference between inflows and outflows. Inflows and outflows are a function of design and soil properties.

For larger or more complex structures, where the shape and size of the element have a significant effect on outflows, the Modified Puls (also called storage-indication) method provides more accurate routing.

Table 3.4-7: Summary of Recommended Methods for Flow Routing

Type	Mathematical Mode	Appropriate For...	Hand/Spreadsheet Calculations	Example Computer Programs
Overland Flow	Simplified Manning kinematic solution	Sheet flow path up to 100 feet	Yes	TR-55, TR-20
	Shallow concentrated/ NRCS empirical curve	Overland flow longer than 100 feet	Yes	TR-55, TR-20
	Kinematic wave	Larger or more complex sites	No	EPA SWMM, HEC-HMS
Channel Flow	Manning equation	Uniform flow without backwater	Yes	TR-55, TR-20, EPA SWMM, HEC-HMS
	St. Venant equations	Channels with storage, backwater	No	EPA SWMM, HEC-RAS
Storage Routing	Simple mass balance	Small storage elements	Yes	USACE STORM
	Modified Puls/storage-indication	Large or irregularly shaped elements	Yes	TR-55, TR-20, HEC-HMS

Design Tools

Hydrologic Computer Software Applications

The empirical methods discussed above are most commonly applied using hydraulic and hydrologic software applications. Both public domain and proprietary programs are available. The designer is strongly encouraged to consider the assumptions and mathematical models underlying each computer program when choosing an appropriate tool to aid in design. PWD requires any stormwater model to use the minimum time step allowable by the implemented hydrologic software or a maximum of 0.01 hours.

Examples of computer programs available in the public domain are listed in Table 3.4-8**.**

Table 3.4-8: Acceptable Calculation Methods for Runoff Estimation

Type	Mathematical Method	Impervious Cover	Experience Modeling Soil Properties	Hand/Spreadsheet Calculations	Example Computer Programs
Empirical Methods	NRCS Curve Number Method	Any	Moderate to High	Yes (smaller sites)	NRCS, TR-55, TR-20, HEC-HMS
Infiltration Loss Models	Constant Loss	Any	Moderate to High	Yes (smaller sites)	HEC-HMS
	Green-Ampt	Any	High	No	EPA SWMM, HEC-HMS
	Horton	Any	High	No	EPA SWMM

PWD Stormwater Plan Review Online Technical Worksheet

The PWD Stormwater Plan Review Online Technical Worksheet is designed to standardize and summarize the results of design calculations. The worksheet is generated via, and can then be accessed at any time through, the **PWD Stormwater Plan Review** ☛ www.pwdplanreview.org website's Project Dashboard. The Project Dashboard is accessed by logging into (clicking "Login Here to Apply" in the upper righthand corner of) the website.

The completed worksheet is a required part of each PCSMP Review Phase Submission Package. In addition to the worksheet, the designer must also submit relevant data, field testing results, assumptions, hand calculations, and computer program results.

The **Stormwater Plan Review** ☛ www.pwdplanreview.org website also contains many other resources for the designer to use as the design and Submission Packages are prepared.

PWD Stormwater Plan Review Design Guidance Checklists

The PWD Stormwater Plan Review Design Guidance Checklists are a supplemental list of guidelines for regulatory compliance, plan creation, hydrologic modeling and calculations, and the design of specific SMPs. They are provided to assist in the formation of both sound, compliant stormwater management designs and complete PCSMP submissions.

The designer should use the checklists as guidance during the design and calculation stages or as useful quality assurance/quality control checks prior to PCSMP Review Phase submission. They can be found in **Appendix F** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/f-design-guidance-checklist.

Standard Details

Typical construction details for several SMPs, including all of PWD's highest-preference SMPs, such as bioinfiltration/bioretention basins, porous pavement, and green roof, and for SMP-related structures, such as cleanouts, observations wells, and outlet control structures, are available for download in AutoCAD (*.dwg) format in **Appendix L** ☛ water.phila.gov/development/stormwater-plan-review/manual/appendices/l-standard-details of this Manual. These Standard Details incorporate design specifications pursuant to each SMP's respective design and material requirements. The designer is encouraged, not required, to use them for PCSMP creation when possible.

For bioinfiltration/bioretention basins, the minimum requirements set forth in the Standard Detail must be used, along with the Bioinfiltration/Bioretention Basin Sizing Table, to ensure that bioinfiltration/bioretention SMPs can be fully designed and approved for Water Quality compliance without knowledge of infiltration feasibility under a Surface Green Review. This allows for postponement of infiltration testing until construction of the development project. The designer is referred to **Section 4.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-1-bioinfiltration-bioretention for more information on bioinfiltration/bioretention SMPs and to **Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews for more information on Expedited PCSMP Reviews. Additional PWD resources can be found in the PWD Development Services **Resource Directory** ☛ water.phila.gov/development/resources/.

3.5 Integrated Stormwater Management Examples

The following hypothetical examples illustrate various components of an integrated site design and stormwater management planning process and how this process can be implemented for different types of land development projects:

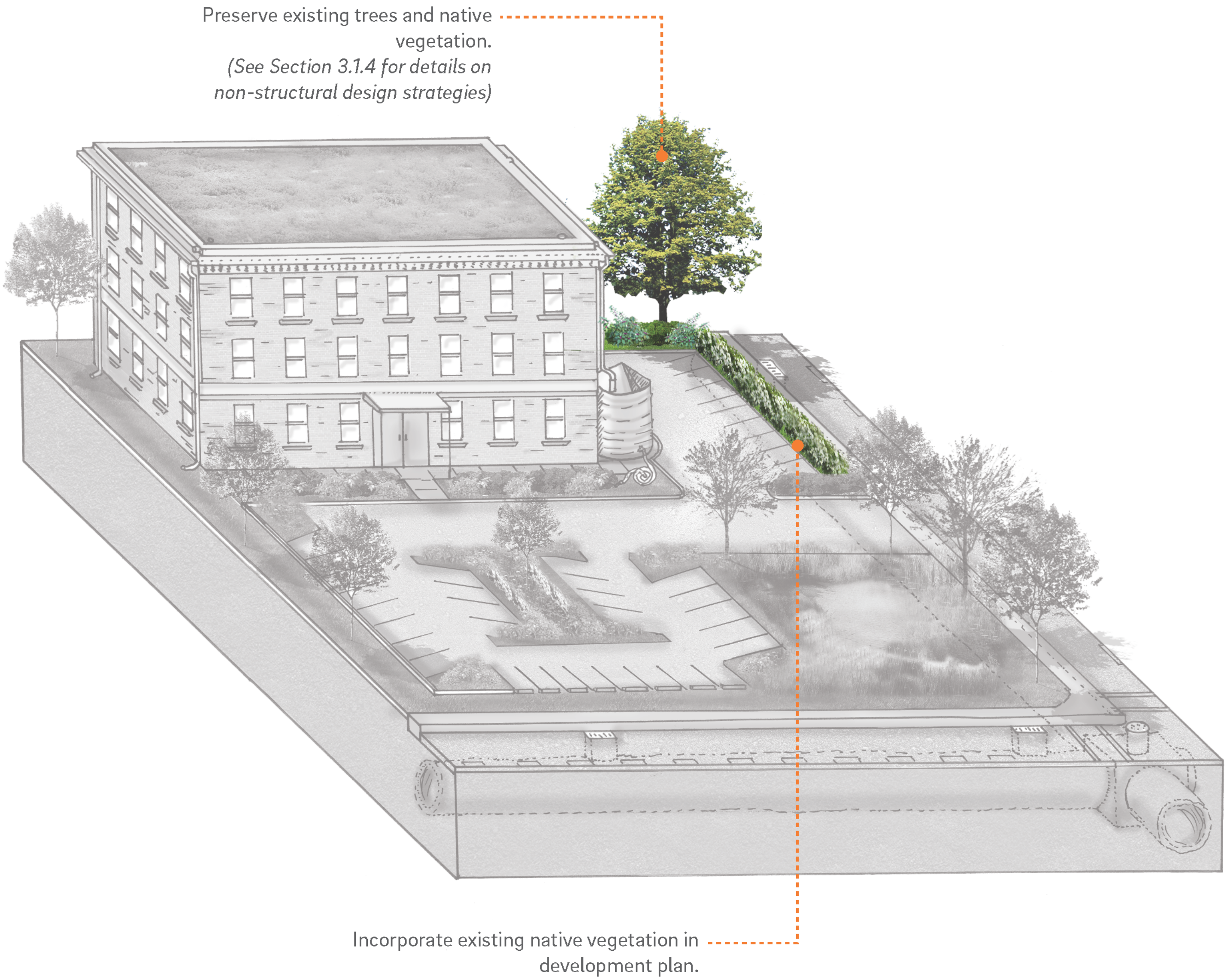
3.5.1 Commercial Office Building Development

This example includes the following three-step process:

Step 1

Preserve existing mature trees and native vegetation as illustrated in Figure 3.5-1. Incorporate existing trees and native vegetation into the development plan.

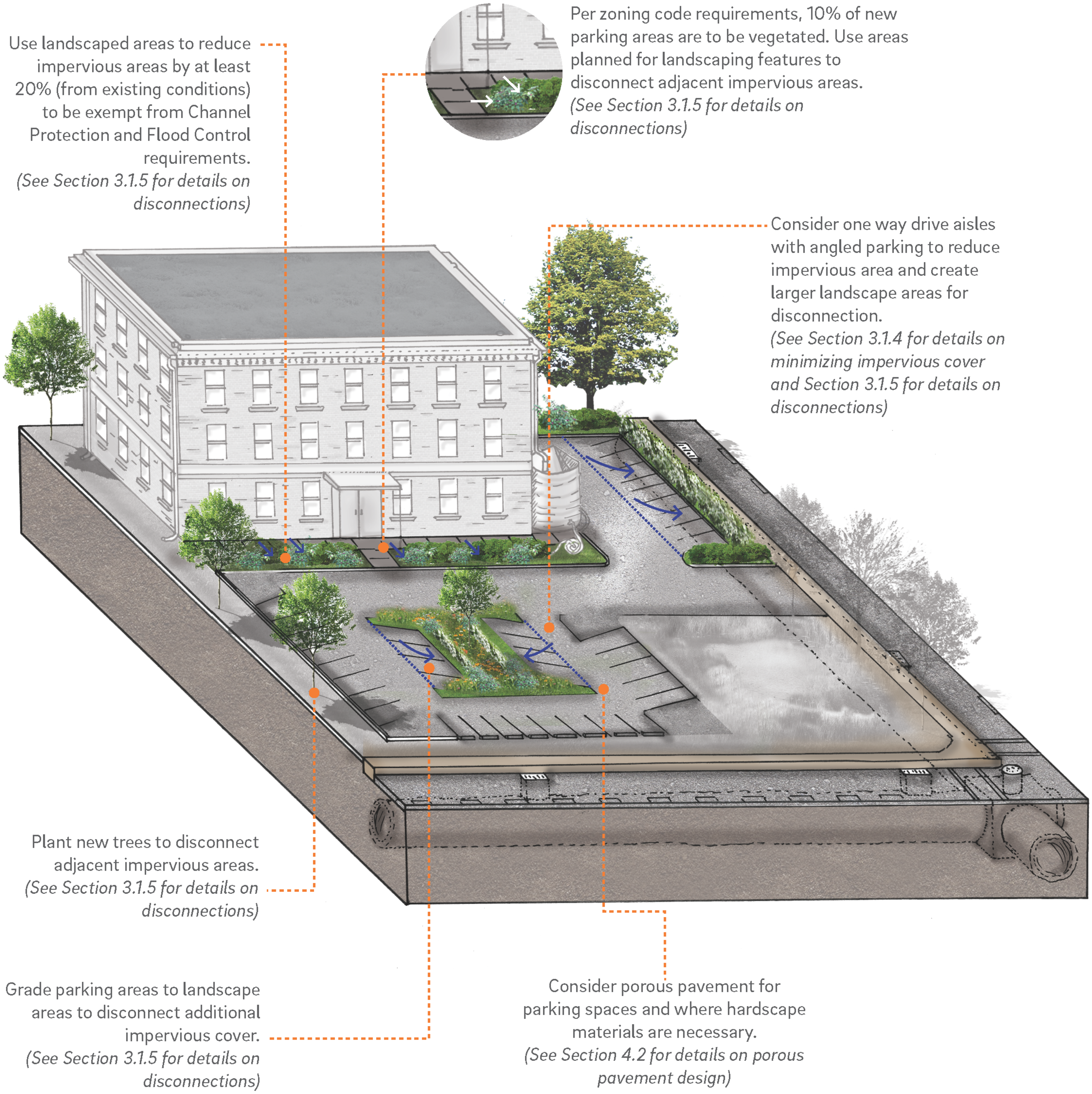
Figure 3.5-1: Commercial Office Building Development Example, Step 1



Step 2

Minimize impervious area and look for opportunities to disconnect impervious areas as illustrated in Figure 3.5-2.

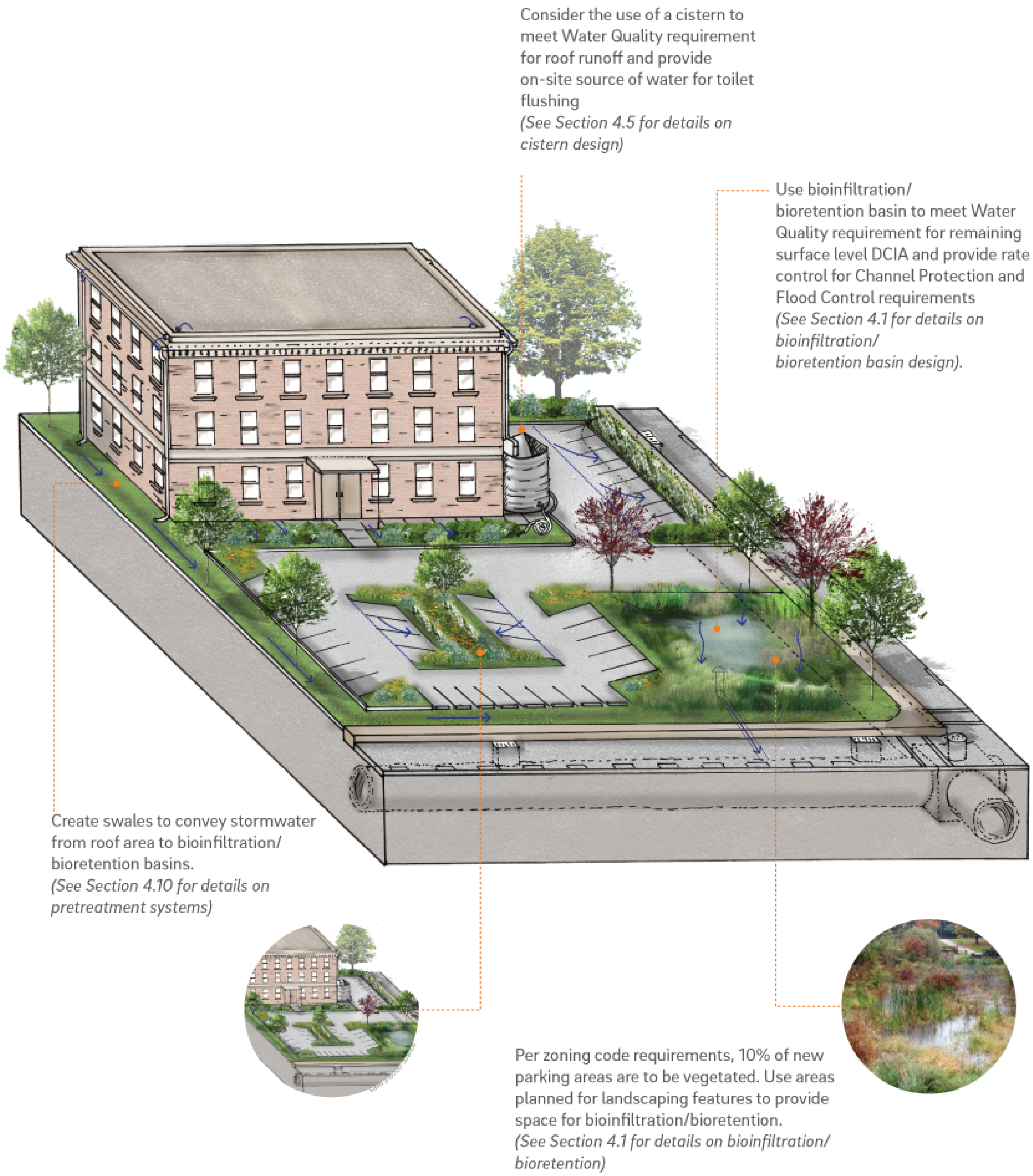
Figure 3.5-2: Commercial Office Building Development Example, Step 2



Step 3

Use surface-vegetated stormwater management practices (SMPs) to manage runoff from a directly connected impervious area (DCIA) in order to meet the Philadelphia Water Department (PWD) Stormwater Regulations (**Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1) as illustrated in Figure 3.5-3.

Figure 3.5-3: Commercial Office Building Development Example, Step 3



3.5.2 Residential Multi-Family Development

This example includes the same three-step process as described in the commercial office building development example and is illustrated in Figures 3.5-4, 3.5-5, and 3.5-6.

Step 1

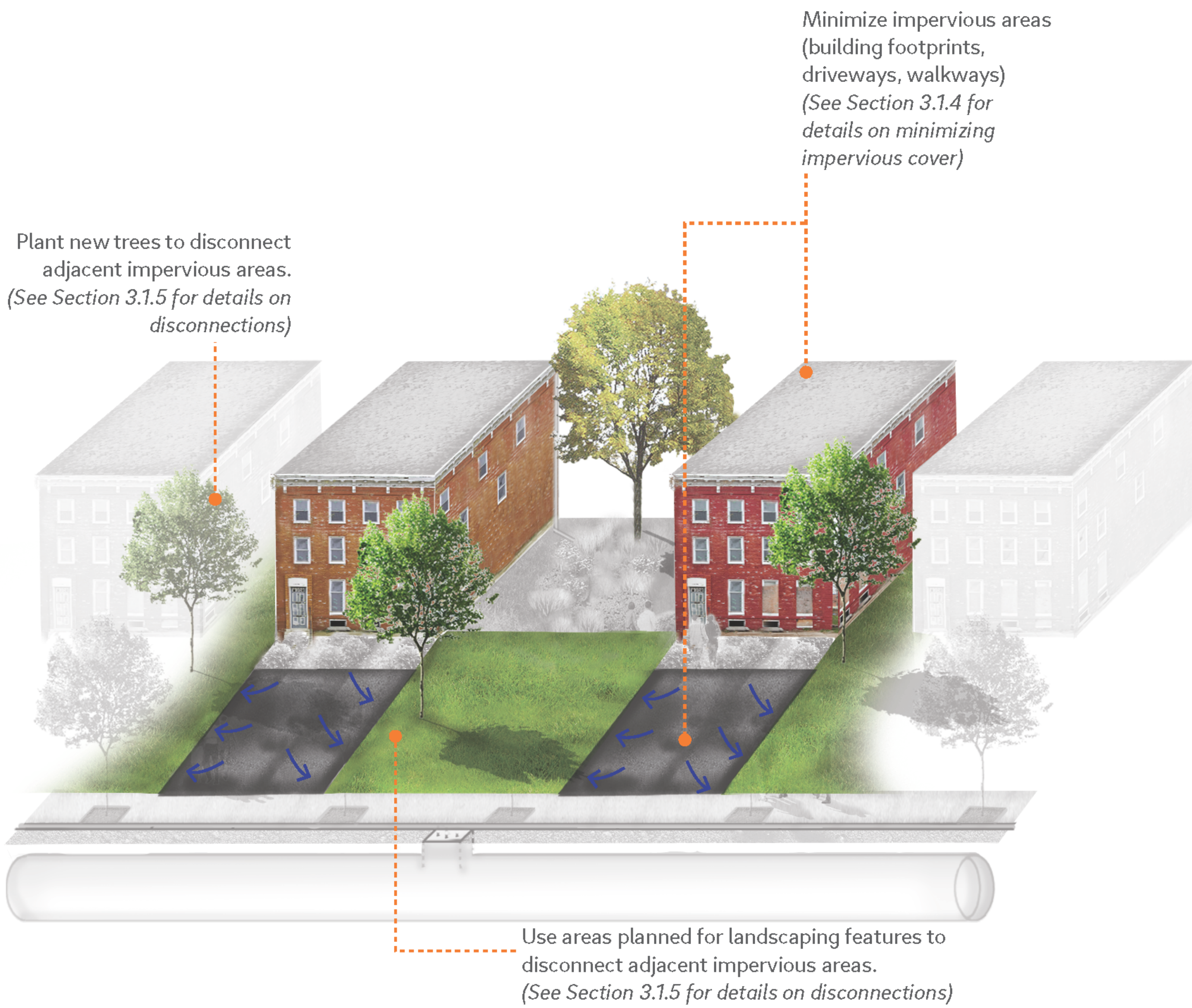
Preserve existing mature trees and native vegetation as illustrated in Figure 3.5-4. Incorporate existing trees and native vegetation into the development plan.

Figure 3.5-4: Residential Multi-Family Development Example, Step 1

Step 2

Minimize impervious area and look for opportunities to disconnect impervious areas as illustrated in Figure 3.5-5.

Figure 3.5-5: Residential Multi-Family Development Example, Step 2



Step 3

Use surface-vegetated SMPs to manage runoff from impervious areas in order to meet the Stormwater Regulations (**Chapter 1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1) as illustrated in Figure 3.5-6.

Figure 3.5-6: Residential Multi-Family Development Example, Step 3

3.5.3 Full Build-Out

Non-structural options are limited for a full build-out scenario as the building footprint will cover the entire lot. For a full build-out project, the designer is encouraged to select green roof and cistern SMPs, as illustrated in Figure 3.5-7, before considering subsurface practices or to select a green roof/blue roof combination as illustrated in Figure 3.5-8. If the project is a redevelopment project, by making a percentage of the roof area a green roof, the applicant may be able to demonstrate a 20% reduction in impervious area and be eligible for an exemption from Flood Control and Channel Protection requirements. A blue roof on the remainder of the same roof can be used to meet the Water Quality requirement peak release rate.

Figure 3.5-7: Full Build-Out Example, Green Roof

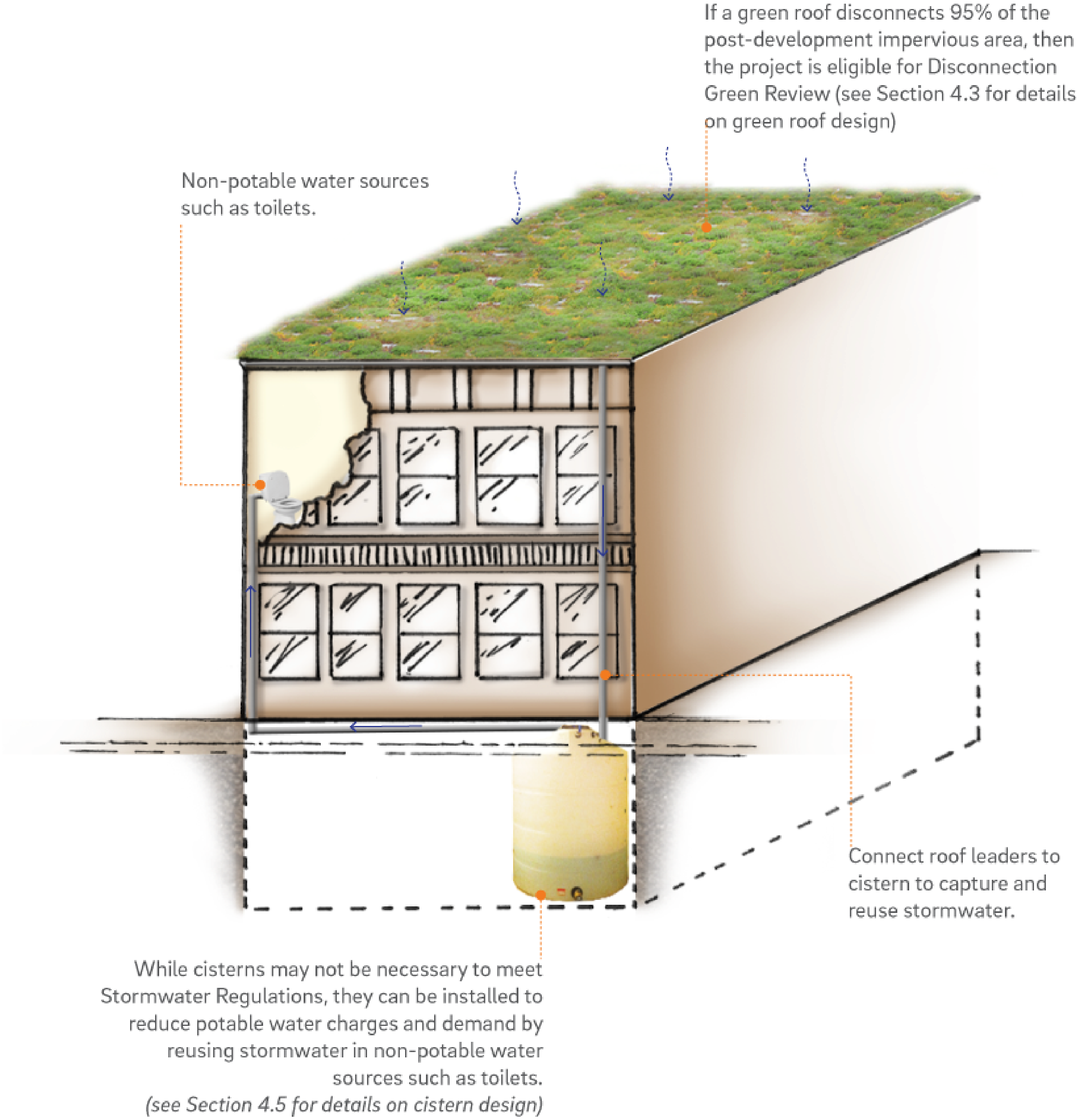
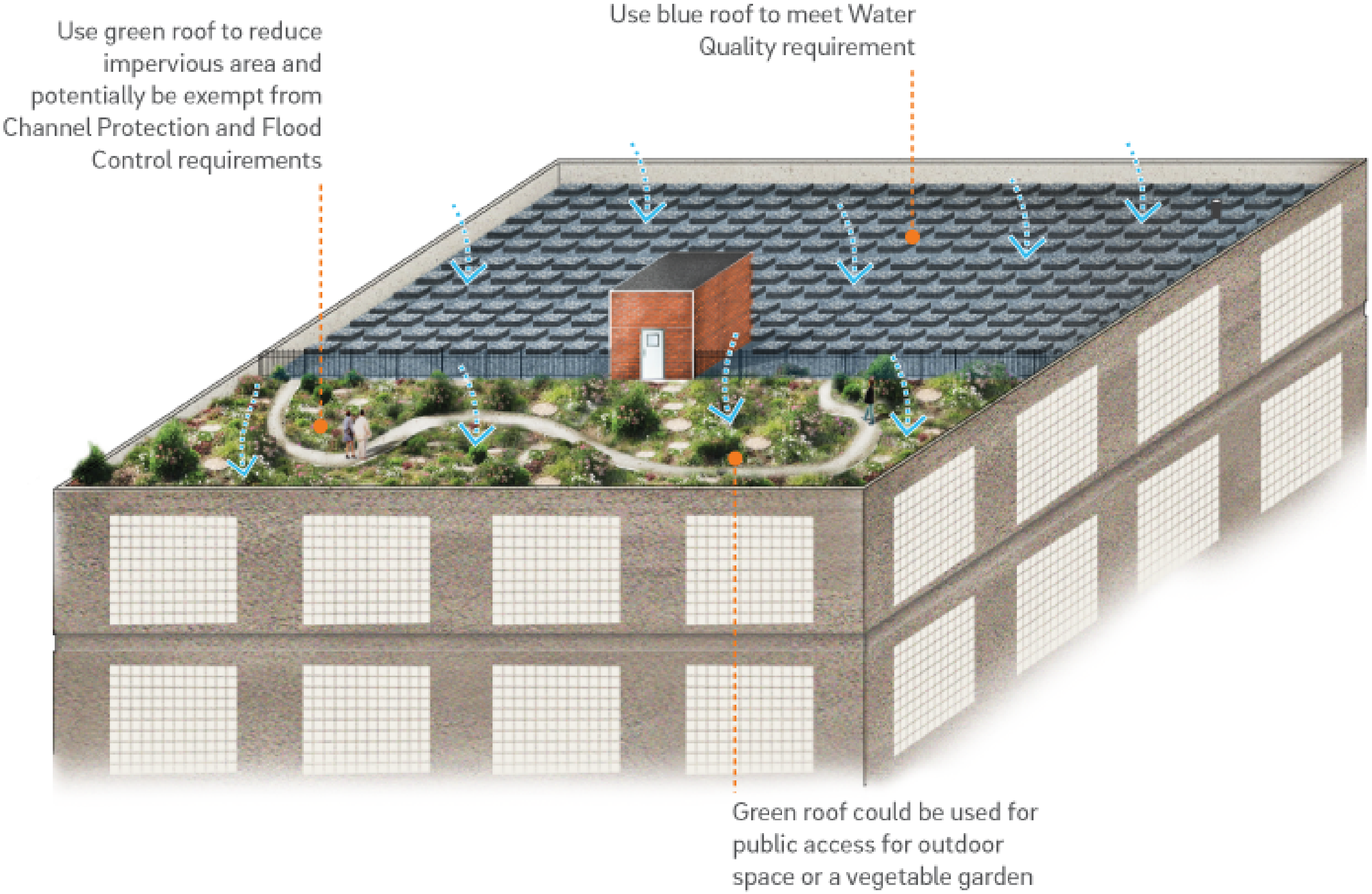


Figure 3.5-8: Full Build-Out Example, Green Roof/Blue Roof



3.5.4 Trails

A trail is defined as a relatively narrow pathway (not a road) used for pedestrian, bicycle, or small vehicle travel on public or private property. For the purposes of complying with the Stormwater Regulations, PWD will determine whether a proposed project may be considered a trail.

Figure 3.5-9: Trail Example

Trails may be paved or unpaved, as illustrated in Figure 3.5-9. Pavements used to construct trails may be pervious or impervious. Examples of paved trails include off-road paths, greenway bike trails, and sidewalks. The trail designer is encouraged to first consider specifying pervious materials such as porous pavement, gravel, or mulch for proposed trail projects. If pervious materials are not feasible or desired, the designer should consider a disconnected impervious cover (DIC) design approach, using porous pavement, pavement disconnections, or tree disconnections. The designer is referred to **Section 3.1.5** ☛ p. 23 for more information on DIC options. As a last resort, the designer should consider using SMPs to manage stormwater runoff from proposed trail projects in order to meet the Stormwater Regulations.

By their nature, it may be difficult for trail projects to meet applicable Channel Protection and Flood Control requirements, so use of DIC should be sought before considering any SMP implementation.

3.5.5 Athletic Fields

Athletic fields are typically made of porous surface types (e.g., natural or synthetic turf) but may or may not include run-on from adjacent DCIA. The replacement of existing athletic fields with natural turf often does not require an SMP for management of stormwater. For fields that include impervious surfaces, such as new bleacher areas or team dugouts, the designer should first explore ways to disconnect these surfaces rather than proposing an SMP. Redevelopment projects that propose natural turf athletic fields are often eligible for an Expedited Post-Construction Stormwater Management Plan (PCSMP) Review (**Section 2.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-4-expedited-pcsmp-reviews). The designer should select natural turf options for field design when appropriate, as synthetic turf fields will typically require structural and maintenance-intensive management strategies.

When synthetic turf fields require maintenance, the turf surface or drainage components may need to be replaced. Replacement of the synthetic turf surface or repairs to the drainage system that do not expose the subbase will not be considered earth disturbance. Modifications to the drainage system may affect the turf system's ability to qualify as DIC.

An example of a natural turf athletic field DIC is illustrated in Figure 3.5-10. For this example, the designer should grade adjacent DCIA so that it can be disconnected to the vegetated areas. If this is not feasible, the designer should consider designing the athletic field to include a subsurface storage component to demonstrate compliance with the Stormwater Regulations, which is illustrated in Figure 3.5-11.

Figure 3.5-10: Athletic Field Example, DIC

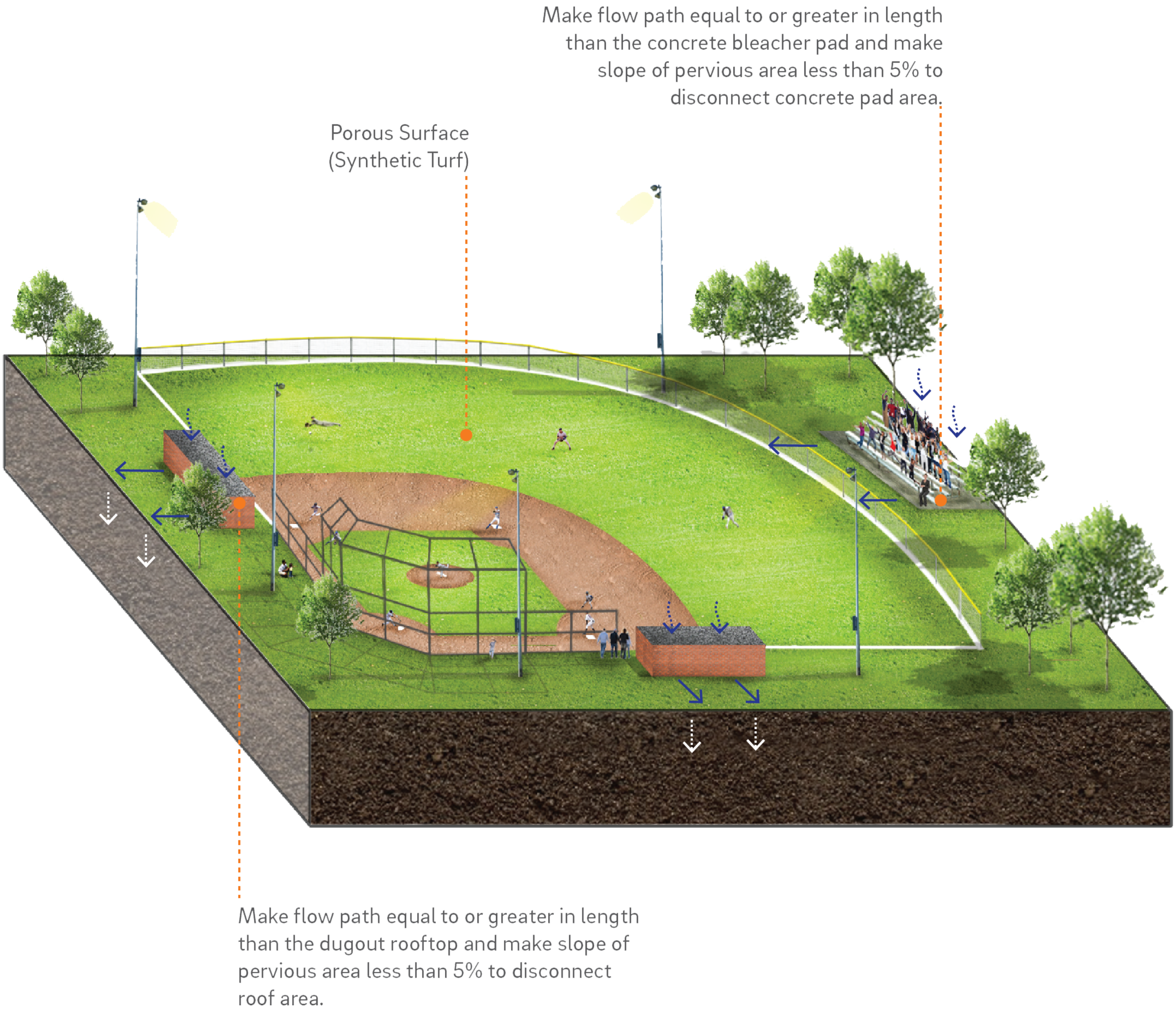
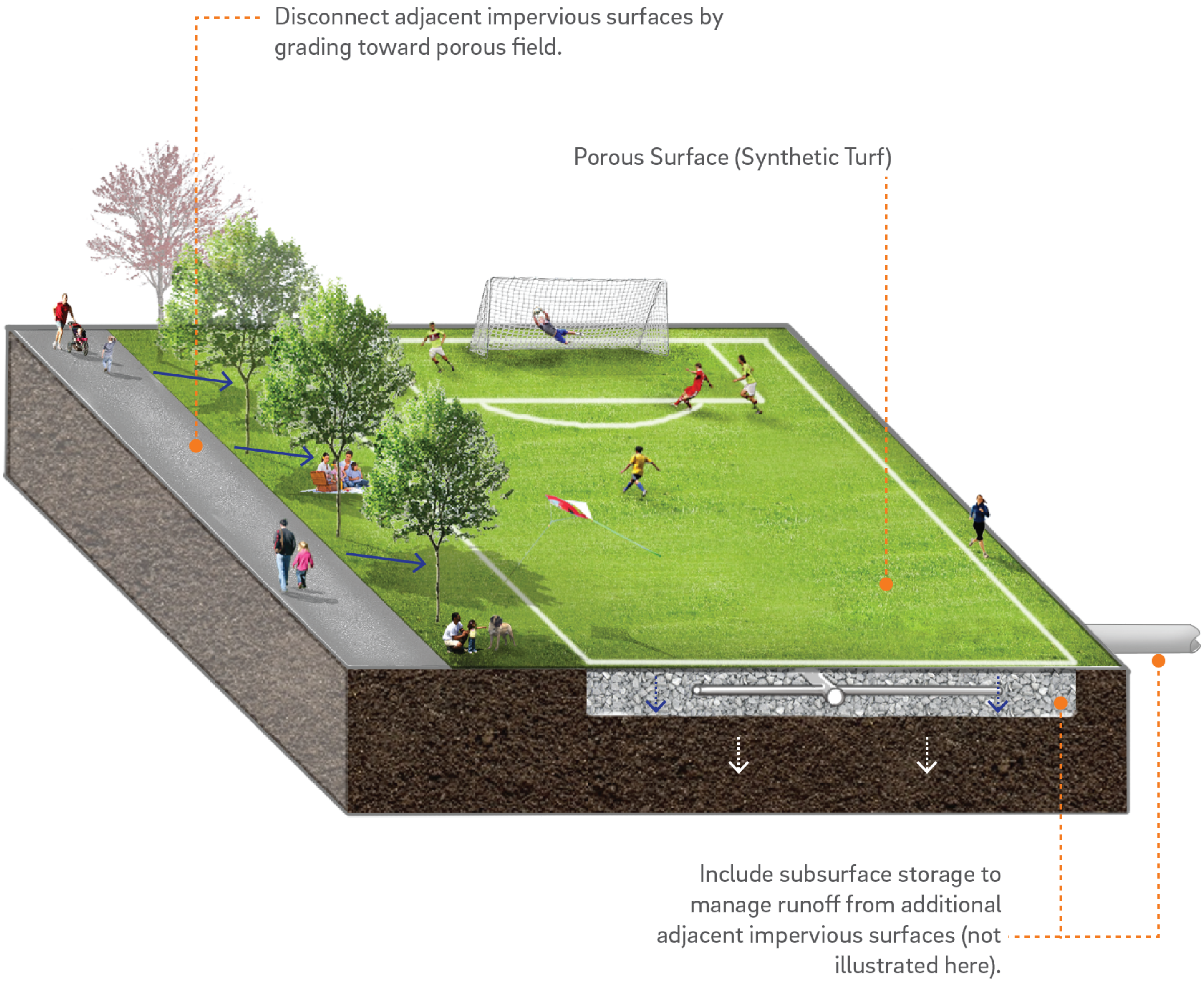


Figure 3.5-11: Athletic Field Example, Subsurface SMP to Manage DCIA



There are three main approaches for designing synthetic turf fields to meet the Stormwater Regulations: (1) designing the field to function as DIC; (2) designing the field, or a portion of the field, to function as an SMP; or (3) designing the field to convey stormwater to a separate SMP for treatment. The guidance below focuses on options (1) and (2), the two methods that are aimed at managing stormwater within the field itself, and describe PWD's design requirements that apply to each of these approaches. Although there are fundamental differences between the primary use, design, and construction of synthetic turf fields and porous pavement systems, due to similarities in stormwater management function, PWD considers synthetic turf fields to be similar to porous pavement. As such, PWD's requirements for synthetic turf fields as stormwater management systems are similar to the requirements for porous pavement systems.

1. PWD will allow synthetic turf fields to be considered DIC if design of the field is in accordance with the design requirements of porous pavement DIC, as described in **Section 4.2** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-2-porous-pavement. If compaction of the subgrade is preferred for structural design purposes, infiltration testing must be performed during construction, after compaction of the subgrade, in accordance with **Section 3.3** ☛ p. 64. If infiltration is determined to not be feasible, the field area must be considered DCIA, treated as such when determining compliance with the Water Quality requirement, and modeled with a curve number of 98 in all required stormwater routing calculations. If an underdrain is proposed, the synthetic turf field will only be considered DIC if the first 1.5 inches of runoff can be stored below the lowest invert of the underdrain.

2. Any portion of a synthetic turf field that receives stormwater runoff from impervious areas, or is determined to not be feasible for infiltration, must be considered DCIA rather than DIC. In such a case, if any portion of the field system is designed to function as an SMP (as opposed to a conveyance system), that portion of the field must meet PWD's requirements for subsurface basins. Infiltration testing is required, and, based on the feasibility of infiltration; the designer must adhere to the design requirements of either a subsurface infiltration system or subsurface detention system, which are detailed in **Section 4.4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-4-subsurface-infiltration and **Section 4.8** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-8-subsurface-detention, respectively.

3. Stormwater runoff from the field may be directed to a separate SMP for management. The designer is referred to **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4 for guidance on, and requirements for, the design and implementation of a suite of acceptable SMPs.

3.5.6 Streets

When new Streets are proposed as part of a development project, whether public or private in designation, the impervious area must be managed to meet the Water Quality requirement. To meet Water Quality, the runoff from the Street must be directed to an on-site SMP. It is acceptable for the on-site SMP to manage both Street runoff and runoff from the development site. On-site SMPs will be owned and maintained by the property owner (**Chapter 6** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-6).

Private Streets

New private streets can be managed in a similar manner to other private developments. Inlets, manholes, and conveyance piping will be owned and maintained by the property owner or their designee. In addition to the Water Quality requirement, the Channel Protection, Flood Control, and Public Health and Safety Release Rate requirements may also apply to the private street (**Section 1.2.1** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-1/1-2-stormwater-regulations/#1.2.1). The designer should refer to **Section 3.4.2** ☛ p. 92 and **Section 4.11** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4/4-11-inlet-controls of this Manual for guidance on designing conveyance infrastructure.

Public Streets

New public streets must be managed by the private SMP on the development site. As such, new public streets are typically designed with two different stormwater conveyance systems. A green system is used to manage the Water Quality storm from all the impervious surfaces, and a traditional grey sewer system serves as an overflow for larger storm events. A green stormwater system typically consists of Green Inlets, which are placed in the street to convey runoff to a junction box or manhole located at the property line that is connected to the private SMP on the development site. A grey sewer system may be a single combined sewer or a separate stormwater-only sewer depending on the connecting sewer network.

The on-site SMP should be sized to account for 1.5 inches of runoff over the proposed Street drainage area, while any street conveyance systems should be sized to covey a 2.5 inches per hour precipitation intensity (the average peak 15-minute intensity from the 24-hour rain gauge network in Philadelphia). This intensity translates to a 2.04-inch 24-hour storm event.

For conveyance of public street runoff, it is recommended that Green Inlets are located five feet upstream of an existing PWD inlet. For additional guidance on Green Inlet design, the designer is referred to Section 3.3.6, Inlets, of the **PWD Green Stormwater Infrastructure Planning and Design Manual** ☛ water.phila.gov/pool/files/gsi-planning-and-design-manual.pdf.

In most cases, the Green Inlet, inlet lateral, junction box, and the grey sewer system will be designed to PWD standards, located in a right-of-way, and PWD will own and maintain these systems.

PWD's Design Branch (**Section 2.5** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-2/2-5-pwds-development-review-process) will be responsible for the review and approval of all infrastructure to be owned by PWD, facilitated concurrently with the PCSMP Review. PWD's Construction Unit will inspect the proposed PWD infrastructure during construction to ensure installation to PWD standards. The designer should contact PWD for the standard details and plan requirements for these conveyance features.