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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-2-stormwater-management-design and **Chapter 4** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-4.

Section 3.4.1 ☛ p. 2 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. 11 provides guidance and requirements for the design of storm sewer systems.

Section 3.4.3 ☛ p. 13 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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-1-site-assessment#3.1.3), 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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-2-stormwater-management-design#3.2.3)

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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-1-site-assessment#3.1.7) 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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-1-site-assessment#3.1.5. 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** ☛ water.phila.gov /development/stormwater-plan-review/manual/chapter-3/3-2-stormwater-management-design#3.2.6.

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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-1-site-assessment#Table_3.1-3). 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. 13 for calculation methods and **Table 3.4-4** ☛ p. 16 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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-1-site-assessment#Table_3.1-3).
- 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** ☛ water.phila.gov/development/stormwater-plan-review/manual/chapter-3/3-2-stormwater-management-design#3.2.4, 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. 13 for calculation methods, **Table 3.4-3** ☛ p. 15 for design storm depths, and **Table 3.4-5** ☛ p. 17 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. 14 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. 13 for calculation methods, **Table 3.4-3** ☛ p. 15 for design storm depths, and **Table 3.4-5** ☛ p. 17 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. 13 for calculation methods, **Table 3.4-3** ☛ p. 15 for design storm depths, and **Table 3.4-5** ☛ p. 17 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	Dimensionless Rainfall	
(hr)	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/.