3.04
Post Construction Stormwater Management

Background

Introducing impervious surfaces to a landscape can substantially impact receiving streams and water bodies by increasing both stormwater runoff and its associated pollutants. It has been estimated that a site with 35-50% imperviousness has three times the runoff compared to a more natural groundcover. By limiting the ability of the soil to infiltrate, an increase in impervious surfaces leads to reduced groundwater recharge as well as increased stormwater runoff volume, peak rate and duration of flow, all of which tends to increase the potential for flooding. In addition, data indicates a direct relationship between the amount of imperviousness in a given watershed and the degree of degradation. A recent report to Congress by the National Academies of Science places additional emphasis on the habitat impacts from urban stormwater runoff. Highly impervious watersheds tend to be flashier and exhibit lower base flows. The frequency of out-of-bank occurrences also increases, leading to increased bank erosion and sediment deposition. All these factors stress aquatic organisms, potentially shifting the aquatic ecosystem to favor less desirable species.

Sediment has been determined to be the most significant pollutant of concern associated with stormwater runoff. Suspended sediment particles cause turbidity problems in the water treatment process and act as an environmental stressor on aquatic life. In addition, as soil particles wash off the land through the erosion process, their chemically active nature makes them particularly conducive to transporting adsorbed nutrients, metals, toxics, and other contaminants into the receiving waters. Typical loadings for total suspended solids from urban land uses range from less than 100 lb/ac/yr for low density residential development to over 500 lb/ac/yr for urban highways. In addition to these land-based sources, urban stream channel erosion can lead to sediment loads that are an order of magnitude greater in the receiving waters themselves depending on the effective imperviousness of the watershed.

Nitrogen is a nutrient associated with the soluble component of stormwater runoff. Although necessary for plant growth, excess nitrogen in water becomes a pollutant by stimulating the growth of algae and other less desirable plants. Nitrogen enrichment is typically more problematic in estuarine ecosystems. Major sources associated with urban stormwater runoff include fertilizers and atmospheric deposition. Typical loadings for total nitrogen from urban land uses range from 10 to 15 lbs/ac/yr. Phosphorus is a nutrient more associated with the particulate component of stormwater runoff, since it readily adsorbs to sediment. Also necessary for plant growth, excess phosphorous becomes a pollutant typically more problematic in freshwater ecosystems. The major source of phosphorus associated with urban runoff is fertilizer. Some soluble phosphorus can be traced to septic systems; however, the use of low phosphorus detergents has significantly reduced this source. Typical loadings for total phosphorus from urban land uses range from 0.75 to 1.25 lbs/ac/yr. Other pollutants in urban stormwater runoff include bacteria, trace metals and hydrocarbon derivatives.

The traditional approach to stormwater management was one of quantity control to prevent flooding. Later, greater emphasis was placed on managing stormwater runoff from a water quality perspective. A wide selection of best management practices (BMPs), including manmade ponds, filtration systems, and infiltration structures have been successfully used to manage stormwater runoff. Until recently, however, such BMPs have largely sought to control the particulate pollutants found in surface runoff, such as sediment and those pollutants which tend to adsorb to sediment, such as phosphorus. Soluble pollutants, such as nitrogen, can be found in both surface runoff and subsurface flow. BMPs that have a vegetative component designed for nutrient uptake and/or an anaerobic component to induce denitrification, such as constructed wetlands, biofiltration systems, and bioretention structures, can reduce these pollutants. Current urban BMP designs remove 10 to 50 percent of total nitrogen, and 45 to 75 percent of total phosphorous. With the recent recognition of the habitat impacts associated with urban stormwater runoff, stream stability issues must also be addressed. The traditional approach of "collect and convey" using a single BMP is no longer seen as adequate to manage the complex problems associated with urban stormwater runoff. Contemporary designs aim to reduce runoff volume utilizing distributed techniques and "treatment trains" tailored to the problems associated with a specific site. The post-construction stormwater management component adheres to this philosophy.

General Requirements

All post construction stormwater management BMPs shall be designed and constructed in accordance with the standards and specifications developed or endorsed by the Department. These include, but are not limited to:

A. Natural Resource Conservation Service (NRCS) National Engineering Handbook

B. Water Environment Federation (WEF) Manual of Practice FD-20, "Design and Construction of Urban Stormwater Management Systems"

C. Federal Highway Administration (FHWA) Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts"

D. Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 22, "Urban Drainage Design Manual"

E. U.S. Army Corps of Engineers (USACE) Engineer Manual 1110-2-2300, "Earth and Rock-Fill Dams – General Design and Construction Considerations"

F. Delaware Dept. of Transportation (DelDOT) Road Design Manual

G. Delaware DNREC Standards & Specifications for Post Construction Stormwater Management BMPs

H. Delaware DNREC Erosion & Sediment Control Handbook

I. NRCS Small Pond Code 378 for Delaware

All hydrologic computations shall be in accordance with Natural Resource Conservation Service (NRCS) methodologies. In addition, the Delmarva Unit Hydrograph shall be used for all projects south of the Chesapeake and Delaware (C&D) canal. Computations for estimating annual runoff shall be based on the methodologies from the Source Loading and Management Model (WinSLAMM). Hydrologic references include, but are not limited to:

A. Natural Resource Conservation Service (NRCS) National Engineering Handbook, Part 630, "Hydrology"

B. Natural Resource Conservation Service (NRCS) Technical Release 55 (TR-55)

C. Delaware DNREC Runoff Reduction Guidance Document (see 3.04.2)

D. WinSLAMM User's Guide

All water surface profile computations shall be in accordance with U.S. Army Corps of Engineers (USACE) methodologies. References include, but are not limited to:

A. U.S. Army Corps of Engineers (USACE) Engineer Manual 1110-2-1416, "River Hydraulics"

B. U.S. Army Corps of Engineers (USACE) HEC-RAS, River Analysis System Hydraulic Reference Manual

Any hydrologic or hydraulic software program proposed for performing computations to comply with the Delaware Sediment & Stormwater Regulations must be endorsed by the Department. The USACE HEC-HMS and HEC-RAS software programs shall be used as the standards to resolve conflicting computational results between different software programs.

Pre-engineered and/or proprietary devices proposed for compliance with the Delaware Sediment & Stormwater Regulations must meet the Standards & Specifications for Post Construction Stormwater Management BMPs contained in 3.06.2.15.

A soils investigation report shall be provided for any post construction stormwater management BMP that relies on full or partial infiltration. Procedures for conducting the infiltration testing shall be in accordance with Department guidance (see 3.06.2.A-1).

Compliance Criteria for Regulatory Storm Events
(see Stormwater Management Compliance Flowchart, 3.04.1)

Resource Protection Event

A. The design parameter for the Resource Protection Event shall be the annualized runoff volume produced by a storm having a 99% probability of occurring annually (i.e., the 1-YR event) based on post-developed conditions.

B. The Resource Protection Event volume (RPv) shall be determined in accordance with Department guidance (see Runoff Reduction Guidance 3.04.2).

C. Compliance with the Resource Protection Event may be accomplished by:

   i. Reducing the RPv in accordance with Department guidance (see Runoff Reduction Guidance 3.04.2). For new development, the RPv shall be reduced to an equivalent 0% effective imperviousness. For redevelopment, the RPv shall be reduced to an equivalent 70% of the existing effective imperviousness. The RPv shall be further reduced to an equivalent wooded condition for any existing meadow or wooded areas within the limit of disturbance based on the 2007 Delaware Land Use/Land Cover data; or

   ii. In cases in which only partial reduction can be achieved, releasing the residual RPv at a rate not to exceed the equivalent 24-hr extended detention of the full RPv and providing an offset in accordance with Department guidance (see Article 2.04); or

   iii. Limiting the reconstruction of existing paved areas, re-grading and replacement of existing turfgrass areas, rebuilding or repairing of structures damaged by fire, flood, wind, or other natural disaster and where the disturbed area will return to the original hydrologic condition and land cover at the conclusion of the project.

D. If compliance cannot be achieved in accordance with Section C above after employing all runoff reduction practices to the Maximum Extent Practicable

(MEP), an offset shall be provided in accordance with the guidelines included in Article 2.04.

Conveyance Event

A. The primary design parameter for the Conveyance Event shall be the additional runoff volume (above the RPv) produced by a storm having a 10% probability of occurring annually (i.e., the 10-YR event) based on post-developed conditions. The peak discharge may be considered a secondary design parameter under certain circumstances.

B. The Conveyance Event volume (Cv) shall be determined using the NRCS runoff equation. Peak discharge for the Conveyance Event shall be based on the NRCS Type II, 24-HR design storm.

C. Compliance with the Conveyance Event may be accomplished by:

i. Discharging into either a closed drainage system or open channel having adequate capacity for the Conveyance Event to tidal waters under non-erosive conditions; or

ii. Reducing the entire Cv in accordance with Department guidance (see Runoff Reduction Guidance 3.04.2).; or

iii. For projects that qualify by receiving all “Minor” ratings on the Stormwater Assessment Report (SAR) and opt for the Unit Discharge approach, releasing the Cv at a rate not to exceed the weighted average based on the following pre-developed land use as determined from the 2007 Delaware Land Use/Land Cover data:

a. Non-woodland/Non-meadow: 0.75 cfs/ac

b. Woodland/meadow: 0.375 cfs/ac

c. Woodland (Hydrologic Soil Group A): 0 cfs/ac; or

iv. For projects that are required or opt for the performance-based approach, complying with Department guidance (see 3.02.2.3); or

v. A “de minimis” discharge rate determined on a case-by-case basis.

Flooding Event

A. The primary design parameter for the Flooding Event shall be the additional runoff volume (above the Cv) produced by a storm having a 1% probability of occurring annually (i.e., the 100-YR event) based on post-developed conditions. The peak discharge may be considered a secondary design parameter under certain circumstances.

B. The Flooding Event volume (Fv) shall be determined using the NRCS runoff equation. Peak discharge for the Flooding Event shall be based on the NRCS Type II, 24-HR design storm.

C. Compliance with the Flooding Event may be accomplished by:

i. Discharging into either a closed drainage system or open channel having adequate capacity for the Conveyance Event to tidal waters under non-erosive conditions; or

ii. For projects that qualify and opt for the Unit Discharge approach, releasing the Cv at a rate not to exceed the weighted average based on the following pre-developed land use as determined from the 2007 Delaware Land Use/Land Cover data:

a. Non-woodland/Non-meadow: 2.25 cfs/ac

b. Woodland/meadow: 1.25 cfs/ac

c. Woodland (Hydrologic Soil Group A): 0.25 cfs/ac; or

iii. For projects that are required or opt for the performance-based approach, complying with Department guidance (see 3.02.2.3.)

Alternative Criteria

A. In cases where a watershed master plan has been developed and endorsed by the Department, the management criteria defined by that master plan shall take precedence over the criteria in Compliance Criteria for Regulatory Storm Events above.

B. In cases where a receiving waterbody has been identified as impaired, or designated with a specific pollutant reduction target necessary to meet State or Federal water quality regulations, additional stormwater treatment practices or alternative criteria may be required in accordance with Department guidance. Examples include, but are not limited to, a Total Maximum Daily Load (TMDL)

requirement for nutrients and/or sediment which would require specific pollutant reductions for compliance.

C. In cases where a specific pollutant source or “hot spot” has been identified, additional stormwater treatment practices or alternative criteria may be required in accordance with Department guidance. An example of this would be specific permits required under the National Pollutant Discharge Elimination System when discharges are a combination of stormwater and industrial or domestic wastewater or which must comply with Parts 122, 123, and 124 of Title 40 of the Code of Federal Regulations.

   i. When a land disturbing activity that falls under the applicability of these Regulations occurs on a site with an existing NPDES stormwater discharge permit, the Department shall determine if:

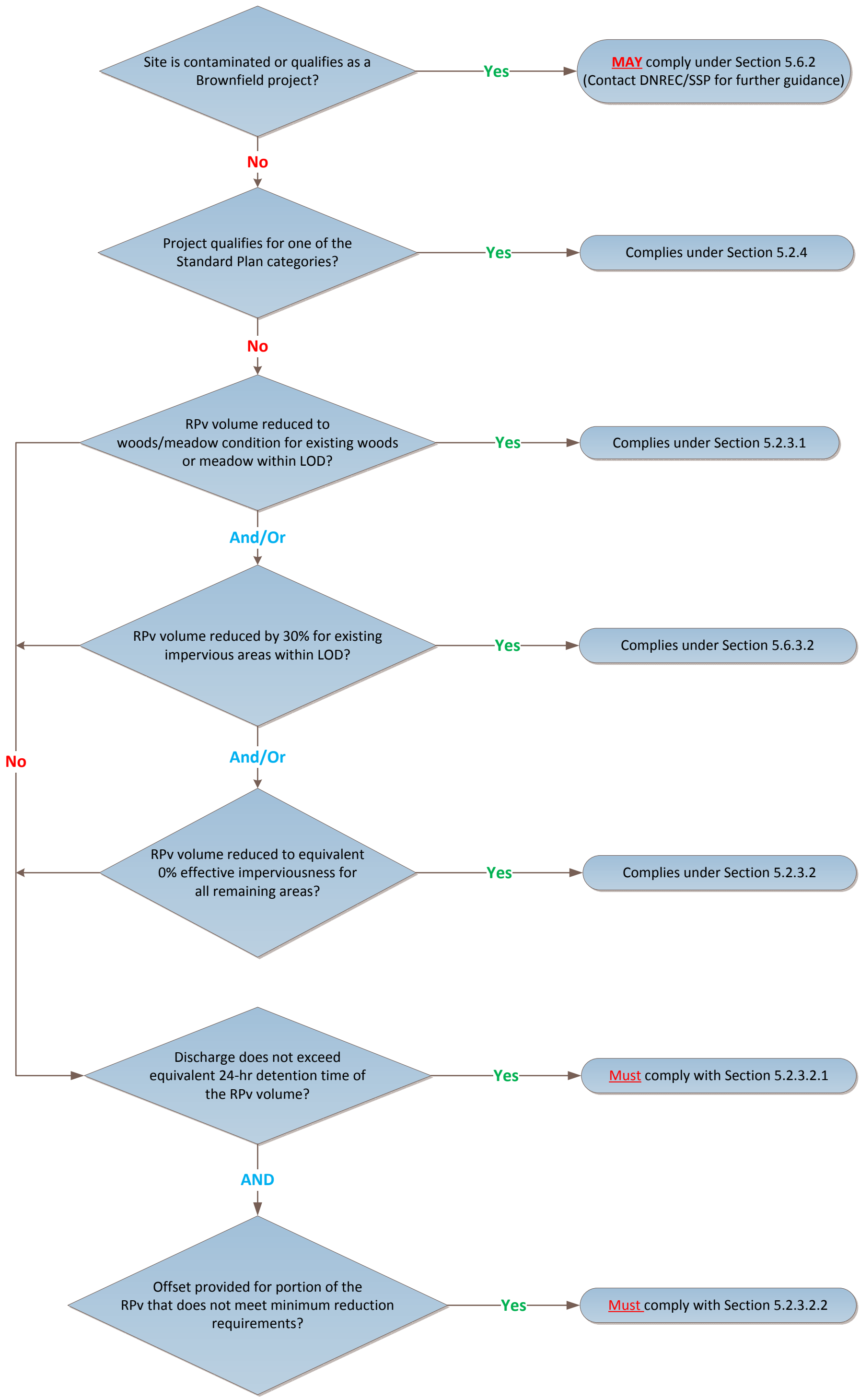
      a. The post-construction discharge is covered under the existing Federal NPDES permit; or

      b. The post-construction discharge will be covered under a revision to the existing Federal NPDES permit; or

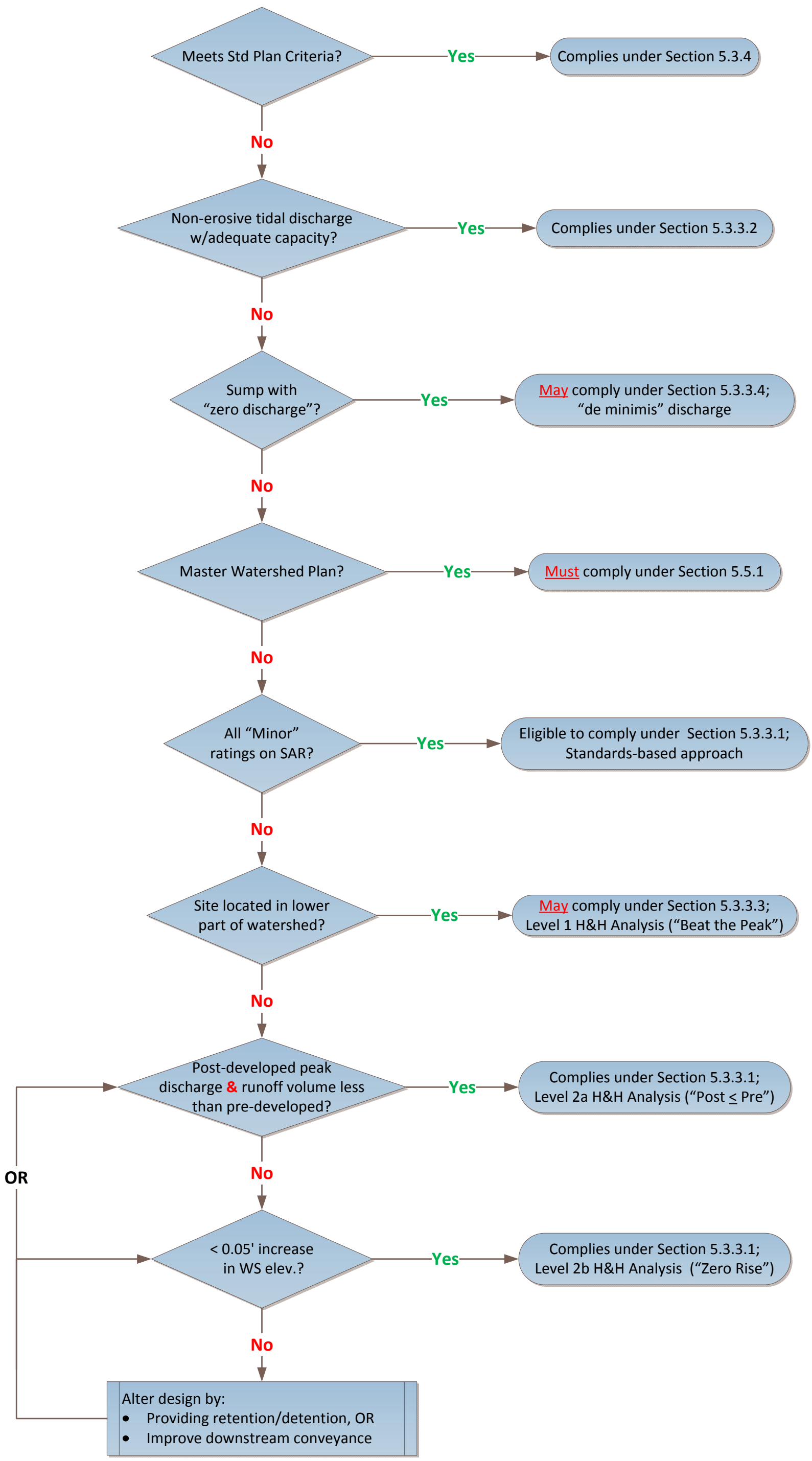
      c. The post-construction discharge must comply with the requirements for the Resource Protection Event (RPv) in accordance with the Compliance Criteria for Regulatory Storm Events above.

   ii. Projects that must meet the requirements of this section for water quality purposes must nonetheless meet the quantity management requirements for the Conveyance Event (Cv) and Flooding Event (Fv) in accordance with the Compliance Criteria for Regulatory Storm Events above.

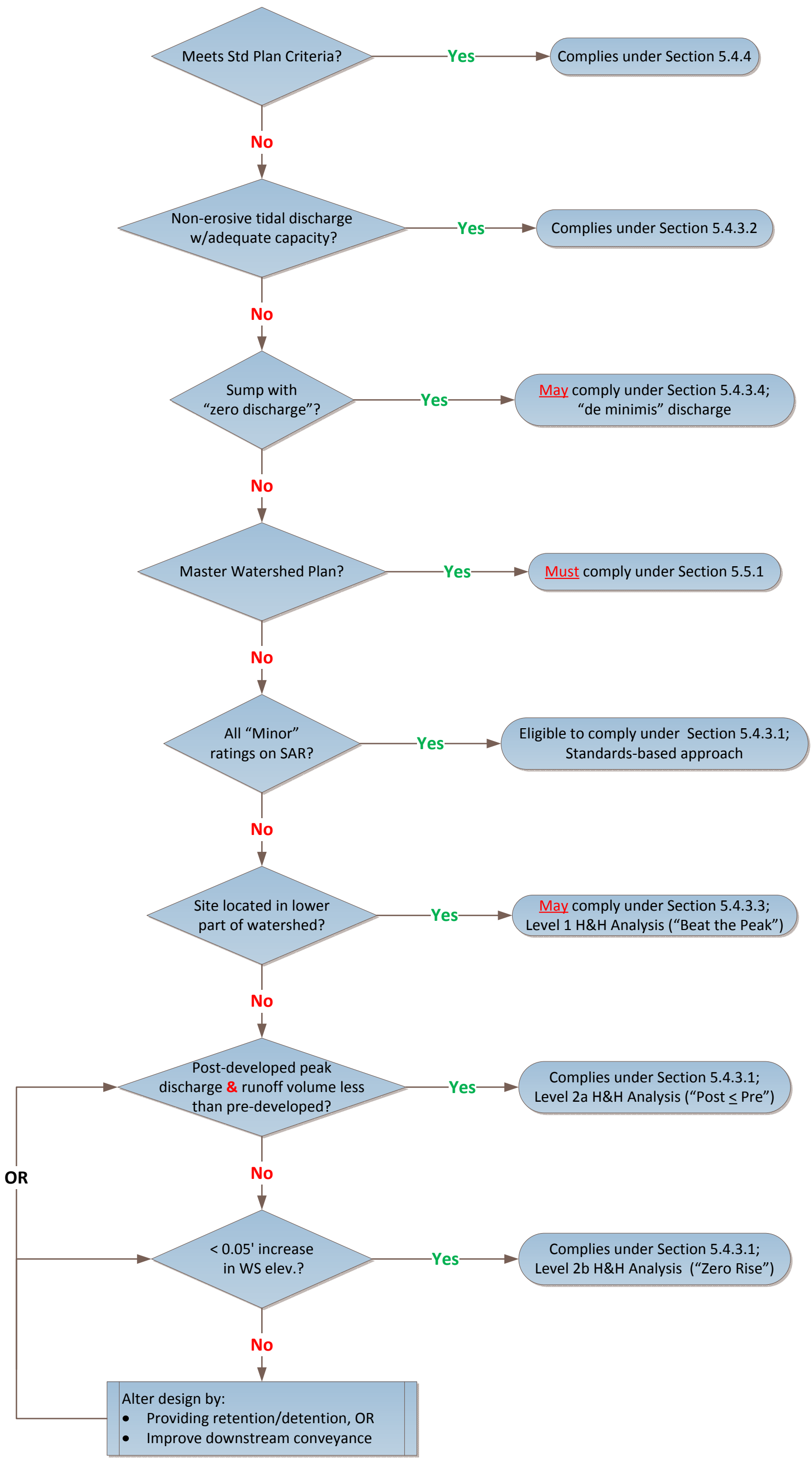
RPv Compliance Check Flowchart



Cv Compliance Check Flowchart



Fv Compliance Check Flowchart

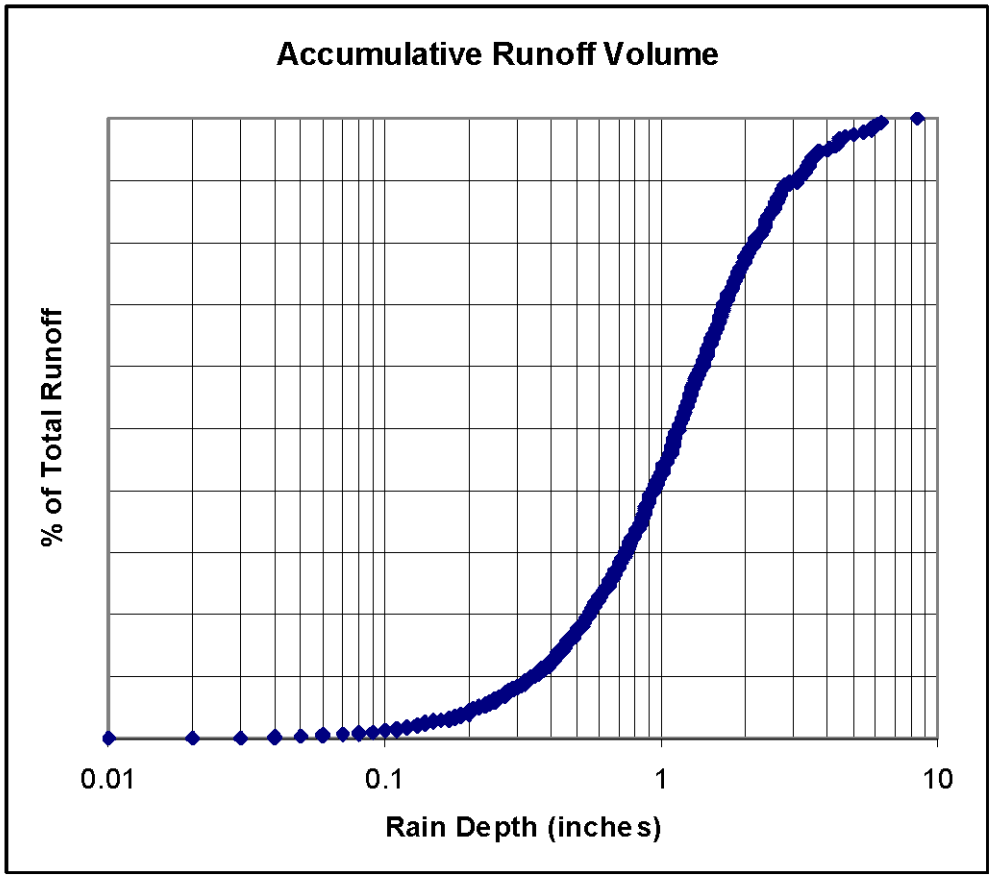


Introduction

The benefits of controlling stormwater runoff volume that results from land development activities have been well documented and are generally accepted by contemporary stormwater management practitioners. Although infiltration practices have been used for many years to mitigate the impacts associated with increased stormwater runoff, the benefits of more passive and non-structural approaches have only recently been recognized. Unfortunately, methods to quantify and assess those benefits have been limited, ranging from relatively simple empirical methods based on percentage of impervious cover to highly complex deterministic models which are beyond the needs of site-level analysis. In addition, the benefits from these so-called "green infrastructure" practices are generally associated with reductions in the annual runoff volume. Traditional stormwater management has relied on event-based methods to evaluate stormwater impacts and verify regulatory compliance. The Delaware Sediment & Stormwater Program has developed a methodology based on the Natural Resource Conservation Service's Runoff Curve Number (RCN) methodology to estimate the annual runoff from developing lands and runoff reduction benefits associated with Green Technology Best Management Practices (GTBMPs). This guidance document presents the scientific background behind, derivation of, and application of the methodology for compliance with the Delaware Sediment & Stormwater Regulations.

Background

It has been shown that the majority of the annual stormwater runoff is generated by small storm events accumulating over time. Dr. Robert Pitt of the University of Alabama is recognized in the scientific community as a national leader on the subject of small storm hydrology. Figure 1 illustrates his findings that rain events between 0.35" and 3" are responsible for about 80% of the total annual runoff volume based on data collected from BWI airport and modeled in his WinSLAMM model. Although rainfall events less than 0.1" can account for up to 20% of the annual precipitation, as Figure 1 shows, they produce little if any runoff, which tends to skew the annual rainfall-runoff relationship. Based on Pitt's data, it was determined that the median runoff event was about 1.25 inches, which is approximately the 90th percentile rainfall event for the Delmarva region. That is, the 90th percentile rainfall event only accounts for about 50% of the annual runoff. This has important implications for stormwater management, particularly from a water quality and resource protection perspective. In order to manage the 90th percentile annual runoff volume, one would need to capture the runoff generated by the 99th percentile rainfall event.



Plot showing accumulative runoff (100% full scale) against rain depth (Baltimore rains and typical medium density residential areas with silty soils).

Fig. 1 (from Pitt & Vorhees, 2004)

Derivation of the Methodology

The research cited earlier by Pitt (2004) also included tabulated annual flow-weighted Rv values for various land uses and soils as calculated by his WinSLAMM model. Analysis of this data indicated that one could reasonably derive conjugate RCN values for the Rv values in the table. Several values were selected as representative of the typical RCN values used in Delaware for land development activities, ranging from ultra-low density residential site with sandy soils to commercial shopping center with clay soils. Figure 2 shows the Rv values selected for the analysis. Figure 3 shows the respective conjugate RCN values from the NRCS Technical Release 55.

		% Pervious	% Impervious (directly connected)	% Impervious (disconnected)	Clay RV	Silt RV	Sand RV
Residential	Ultra low density	90.4	5.6	4.0	0.11	0.09	0.05
	Low density						
	typical	79.6	14.9	5.5	0.16	0.14	0.11
	connected	79.6	20.4	0	0.22	0.20	0.17
	disconnected	79.6	7.0	13.4	0.12	0.10	0.07
	Medium density						
	typical	62.3	24.2	13.5	0.26	0.23	0.19
	connected	62.3	37.7	0	0.35	0.34	0.32
	disconnected	62.3	12.8	24.9	0.19	0.14	0.11
	High density						
	typical	47.0	39.9	13.1	0.37	0.34	0.32
	connected	47.0	53.0	0	0.46	0.45	0.43
	disconnected	47.0	13.5	39.5	0.29	0.24	0.21
Commercial (shopping center)		8.28	91.72	0	0.72	0.72	0.72
Industrial		16.7	62.8	20.5	0.52	0.52	0.52

Fig. 2 (from Pitt & Vorhees, 2004)

Table 2-2a Runoff curve numbers for urban areas [1]

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82

Fig. 3 (from Table 2-2a, USDA-NRCS TR-55)

Based on rainfall data from Wilmington, Dover and Georgetown, it was determined that the grand mean annual rainfall for Delaware was 43.85". Using this annual rainfall amount, the selected WinSLAMM Rv values from Figure 2 were used to calculate the annual runoff for those land use/soil conditions. The Rv values were then paired with their conjugate RCN values, which were in turn plotted against the calculated annual runoff on log-log axes. Figure 4 is a graphic of this plot.

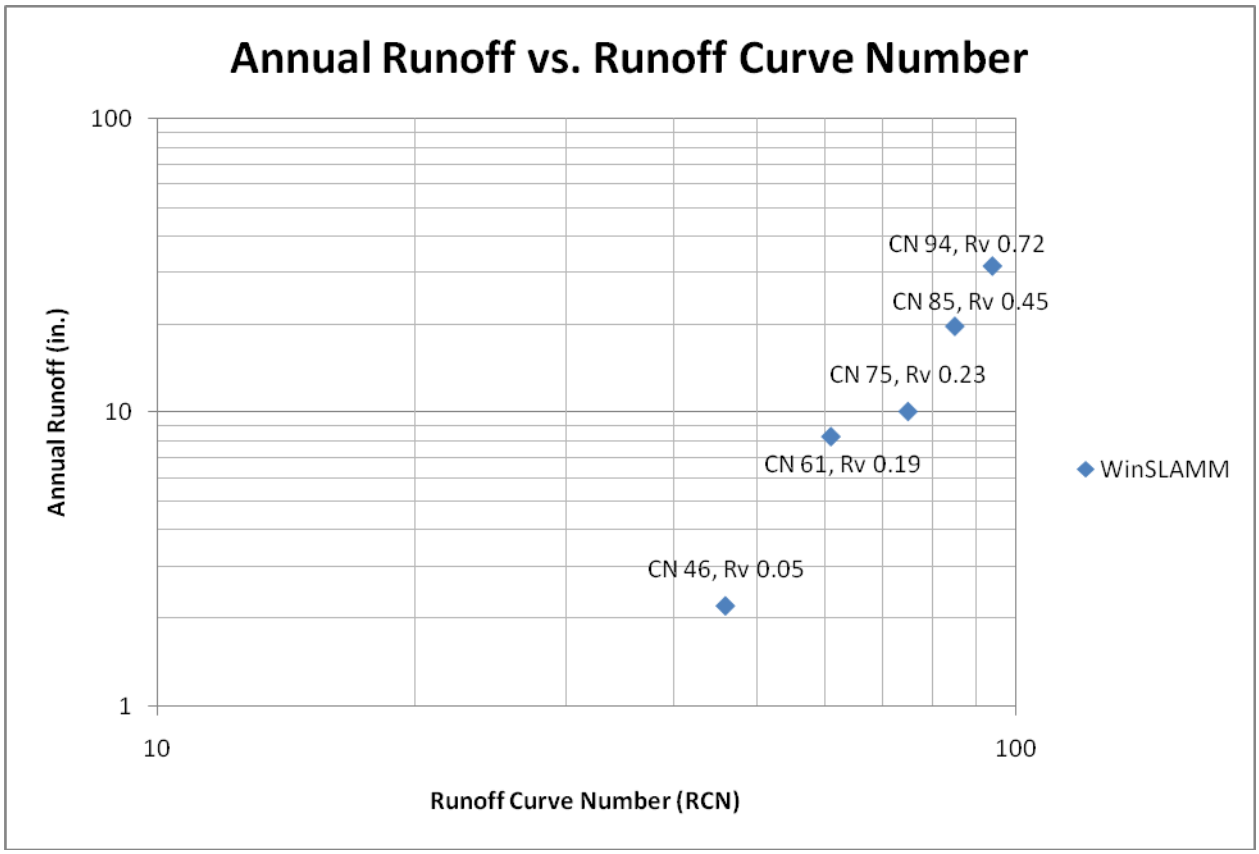


Fig. 4 Log-Log Plot of Conjugate RCN/Rv Pairs vs. Annual Runoff

A regression analysis of Runoff Curve Number vs. annual runoff was then performed using the tools contained in Microsoft Excel™. Results from this analysis are shown in Figure 5.

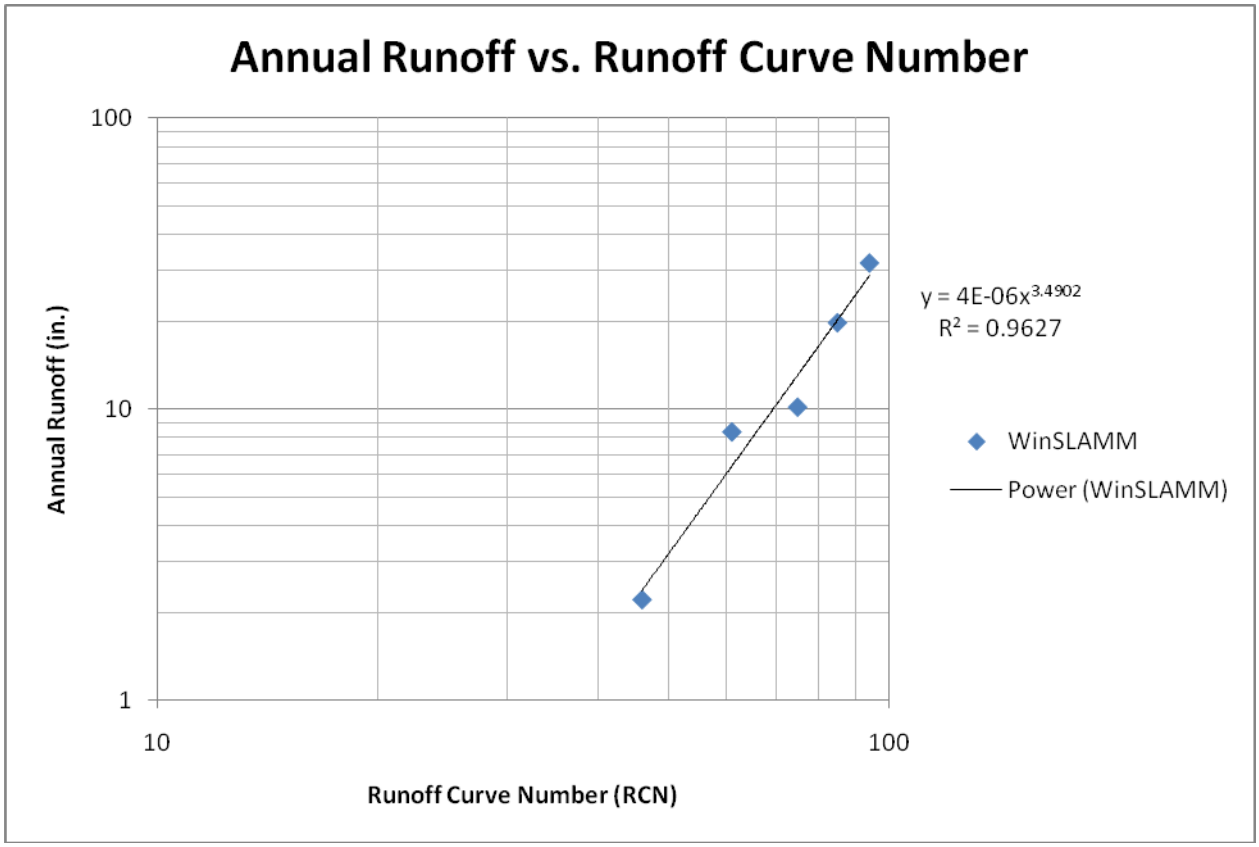


Fig. 5 Regresssion Analysis of RCN vs. Annual Runoff

It was determined that the best fit for the data was a power function of the form $y = aX^b$, where a = 4.00034E-6 and b = 3.4902. The R^2 value for the regression was 0.9627. For regulatory purposes, it was decided that using a = 4.0E-6 and b = 3.5 would yield acceptable results that were within the uncertainty of the data, while simplifying the equations. Thus the equation to be used for compliance purposes under this methodology is:

$$\text{Annual Runoff (in.)} = 0.000004(\text{RCN})^{3.5} \qquad (\textit{Equation 1})$$

Application of the Methodology

If the NRCS Runoff Curve Number is known for a given drainage subarea, Equation 1 can be used to determine the annual runoff in watershed inches. This information is of limited use, however, without the benefits of runoff reduction practices being factored in. Although there is relatively little long-term data available on the ability of these practices to reduce runoff volume, the data that are available are typically based on the percentage of annual runoff reduction. The best source for this information currently available is the Chesapeake Stormwater Network's Technical Bulletin No. 4. While this document also contains a methodology for determining the appropriate "treatment volume" for these practices based on the 90th percentile annual rainfall, it was determined that a larger percentage of the annual runoff should be targeted for management under the Delaware Sediment & Stormwater Regulations. However, the information in this document related to runoff reduction is still deemed to be appropriate, albeit at some reduced level. Figure 6 is a table which summarizes the runoff reduction capabilities of various stormwater management practices as proposed to meet the requirements of the Delaware Sediment & Stormwater Regulations. The runoff reduction allowance for retention practices is based on their storage capacity and is independent of the soil type. Practices that rely on passive infiltration and recharge have variable runoff reduction allowances based on the soil Hydrologic Soil Group (HSG).

The annual runoff reduction values from this table are used to determine the change in the annual runoff from a given drainage subarea. The adjusted Runoff Curve Number for that subarea can then be determined by rearranging Equation 1 and solving for RCN:

RCN = (Reduced Annual Runoff/0.000004) ^ (1/3.5) (*Equation 2*)

The steps required to perform the runoff reduction analysis can be summarized as follows:

Step 1: Determine annual runoff for subarea using Equation 1.

Step 2: Apply runoff reduction for selected practice based on values from Fig. 6.

Step 3: Adjust the Runoff Curve Number for the subarea using Equation 2.

This process can be repeated for other practices in a "treatment train" within the subarea. The final adjusted Runoff Curve Number can then be used in traditional hydrologic programs to route more complex sites with multiple subareas.

DURMM v.2 BMP Suite	RR, A/B Soil	RR, C/D Soil
Runoff Reduction Practices		
Urban Infiltration Practices with Sand/Vegetation (including Bioretention w/o Underdrain)	100% of Storage	100% of Storage
Urban Infiltration Practices without Sand/Vegetation	100% of Storage	100% of Storage
Bioretention with Underdrain (including planter boxes, etc.)	50% of Storage	50% of Storage
Permeable Pavement with Sand/Vegetation	100% of Storage	100% of Storage
Permeable Pavement without Sand/Vegetation	100% of Storage	100% of Storage
Vegetated Roofs	100% of Storage	100% of Storage
Rainwater Harvesting	75% of Storage	75% of Storage
Impervious Disconnection	20%	10%
Bioswale	50%	25%
Vegetated Open Channels	20%	10%
Filter Strip	20%	15%
Urban Riparian Forest Buffers	25%	15%
Urban Tree Planting	0%	0%
Soil Amendments	0%	0%
Sheetflow to Turf Open Space	40%	40%
Sheetflow to Forested Open Space	65%	40%
Wet Swales and Ephemeral Wetlands	0%	10%
Stormwater Treatment Practices		
Dry Extended Detention Basins	10%	10%
Dry Detention Ponds	0%	0%
Hydrodynamic Structures	0%	0%
Urban Filtering Practices	0%	0%
Wetlands and Wet Ponds	0%	0%
Source Control Practices		
Urban Nutrient Management	0%	0%
Street Sweeping	0%	0%
Other Practices		
Urban Stream Restoration	0%	0%

Fig. 6: Runoff Reduction Allowances for Select Stormwater Management Practices

Delaware Urban Runoff Management Model (DURMM)

The runoff reduction methodology lends itself well to the use of an automated spreadsheet solution. The DNREC Sediment & Stormwater Program has modified the DURMM spreadsheet program to include the runoff reduction procedures outlined in this guidance document. It is expected this updated version will become available upon adoption of the revised Regulations.

Runoff Reduction Methodology Caveats

- The methodology is proposed as an empirical compliance tool, not a physically-based solution of the rainfall-runoff relationship for developed sites.
- Under actual rainfall conditions, low magnitude events would be expected to be fully captured by the runoff reduction practices. However, as magnitude increases, the percentage of runoff volume captured decreases. Therefore, the runoff reduction calculated using this methodology for the Resource Protection Event should be viewed as an average value based on the annual rainfall distribution, not the reduction for a 1-YR storm event.
- The adjusted curve number (CN*) for infiltration and other retention practices having a storage component may be used for the Conveyance Event and the Flooding Event with modifications to the equations. The ability of runoff reduction practices to manage the runoff from these higher magnitude events is limited, though some nominal reduction allowance is warranted.

General Form of the Equation for Estimating Annual Runoff

The equations used in the methodology were developed specifically for use in Delaware. However, the DNREC Sediment & Stormwater Program has developed a general form of the equations that could be used in other locations assuming results can be verified under local conditions.

I. General equation for estimating annual runoff:

$$Annual\,Runoff\ (in.) = C_{Ra}(RCN)^{Exp}$$

Where:

C_{Ra} = annual runoff coefficient

RCN = NRCS runoff curve number

Exp = 3.5

II. Derivation of the annual runoff coefficient (C_{Ra}):

$$C_{Ra} = \frac{(P)(R_v)}{RCN_{R_v}{}^{3.5}}$$

Where:

P = annual precipitation (in.)

R_v = percent annual precipitation converted to runoff

RCN_{Rv} = conjugate NRCS runoff curve number at R_v

III. The analysis based on Pitt's results using WinSLAMM found that R_v = 0.85 at RCN = 98.

Substituting:

$$C_{Ra} = \frac{(P)(0.85)}{98^{3.5}}$$

References

CSN. 2009. Technical Support for the Bay-Wide Runoff Reduction Method, Version 2.0. Chesapeake Stormwater Network, CSN Technical Bulletin No. 4.

Lucas, William, 2005. "Green Technology: The Delaware Urban Runoff Management Approach. A Technical Manual for Designing Nonstructural BMPs to Minimize Stormwater Impacts from Land Development", Delaware DNREC, Dover, DE.

Pitt, R., 1998. "Small storm hydrology and why it is important for the design of stormwater control practices". In: *Advances in Modeling the Management of Stormwater Impacts, Volume 7* (W. James, ed.), Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press.

Pitt, R. and J. Voorhees. 2004. "The use of WinSLAMM to evaluate the benefits of low impact development." *Low Impact Development Conference: Putting the LID on SWM*. College Park, MD. Sept. 21-23, 2004.

USDA-NRCS, 1986. Technical Release 55, "Urban Hydrology for Small Watersheds".

APPENDIX 3.04.3

McCUEN'S CHANGE IN CURVE NUMBER METHOD

Ref: Queen Anne's County, MD; Environmental Site Design Manual (2007)

McCUEN'S CHANGE IN CURVE NUMBER METHOD*

(* Adapted from MDE 1983)

There are three different methods that can be used with the TR-20 program for modeling infiltration systems. The TR-20 methods include: 1) the change in curve number method, 2) the truncated hydrograph method, or 3) the hydrograph routing method. Method 1, the change in curve number method is described below.

Background

The method described below describes a volume based approach to control increases in discharge rates by storing the increased runoff depth due to changes in land use. This method was developed by Dr. Richard McCuen as part of the development of the Maryland Standards and Specifications for Stormwater Management Infiltration Practices (MDE 1984) and described by MDE in the publication titled, "Modelling Infiltration Practices Using TR-20) (MDE, 1983). The materials presented below have been adapted from these two publications.

Most stormwater management policies require the peak discharge for a selected return period(s). The before development peak discharge (qb) can be determined using the SCS graphical method:

$$q_b = (q_{ub})(A)(Q_b) \qquad \text{Equation 1}$$

In which q_{ub} is the unit peak discharge, in cubic feet per second per square mile per inch of runoff (csm/in.), from Exhibit 4-II, page 4-5 of the NRCS TR-55 (NRCS, 1986) based on the before development time of concentration (t_{cb}) in hours, and Q_b is the before development depth of runoff in inches, and A is the drainage area in square miles. Using a subscript "a" to indicate "after development", the after development peak discharge (q_a) is given by:

$$q_a = (q_{ua})(A)(Q_a) \qquad \text{Equation 2}$$

While the total drainage area (A) will remain constant, both the unit peak discharge (q_u) and the runoff depth (Q) will typically be greater for the after development conditions. If the development causes a decrease in the time of concentration, then the unit peak discharge will increase. Similarly, an increase in the percent of imperviousness will cause an increase in the volume of runoff. If the stormwater management policy requires qa to be equal to q_b, then the policy could be met if a difference in depths of runoff ΔQ was controlled; this is determined as follows:

$$Q_{ua}(A)(Q_a-Q_b) = q_{ub}(A)Q_b \qquad \text{Equation 3}$$

Therefore solving for ΔQ yields:

$$\Delta Q = Q_a - (q_{ub} / q_{ua})(Q_b) \qquad \text{Equation 4}$$

If there is no significant change in t_c, then (q_{ub} / q_{ua}) equals 1.0, and $\Delta Q = q_a - q_b$.
If the development increases the t_c significantly, q_{ub} will usually be less than q_{ua} and ΔQ will be greater than the difference in the runoff depth (Q_a-Q_b).

Method 1 - Change in Curve Number Method

The change in curve number method is used by reducing the after development curve number to reflect the runoff volume stored by the infiltration practices. The runoff volume stored by the infiltration practices will be the total increased runoff volume as defined by Equation 4 above, or a volume based on the size of the infiltration practices. The revised after development curve number (CN*) is determined by the following equation:

$$CN^* = 200 / [(P+2Q+2) - \sqrt{(5PQ+4Q^2)}]$$

where P is the design rainfall depth in inches, and Q is the after development runoff depth minus the runoff depth stored by the infiltration practices *(ΔQ)* in inches. The after-development hydrograph computed by the TR-20 program with the revised curve number is the downstream Q hydrograph that accounts for infiltration storage.

The revised curve number method is most applicable for cases where several Infiltration practices are distribute evenly over the drainage area. For example, the method is best applied for residential land uses where each lot may have an infiltration practice. The level of peak discharge reduction is achieved by distributing the runoff storage volume over the entire watershed area and is reflected by adjusting the curve number.

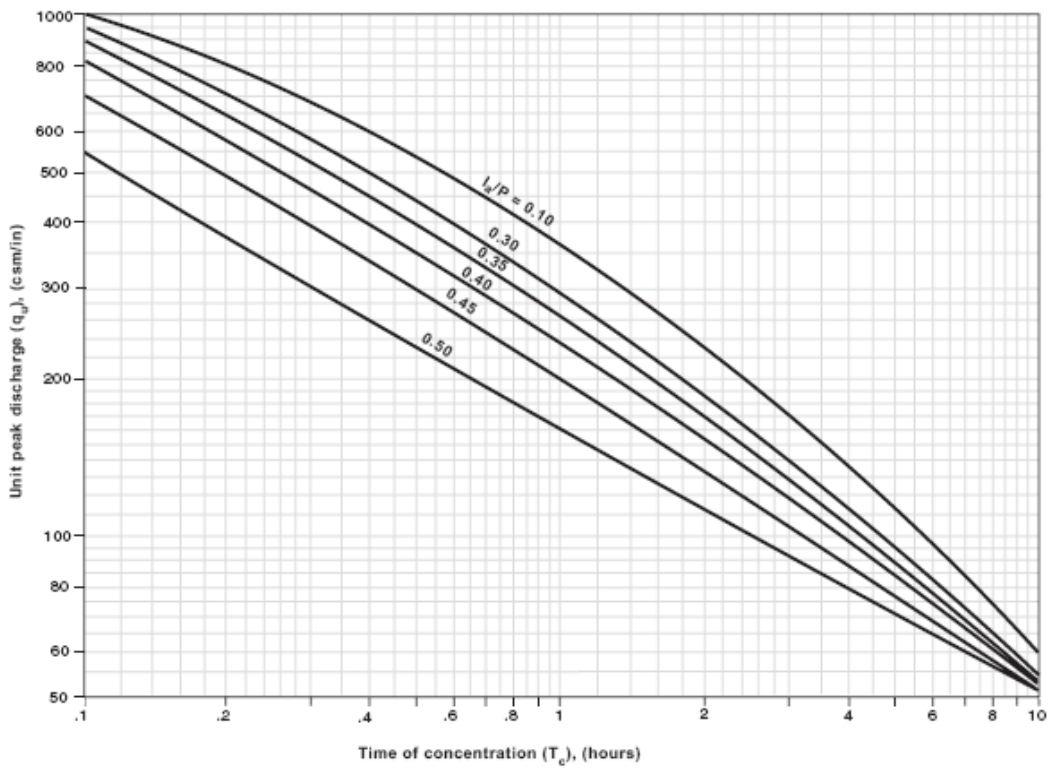
Case Study

A 25 acre wooded area is to be converted to 1/4 acre residential lots. The change in curve number method will be used to determine the volume of storage required to release the 2-year pre-development discharge rate, and develop the outflow hydrograph below an infiltration basin.

Hydrologic Data
D.A. = 25 acres = 0.0390 square miles
P (2-year storm) = 3.3 inches)
CN_b = 66 t_b = 0.75 hrs
CN_a = 75 t_a = 0.37 hrs
q_{ub} = 375 csm/in (from Exhibit 4-II, page 4-5 of the NRCS TR-55 (NRCS, 1986)
q_{ua} = 590 csm/in (From Exhibit 4-II, page 4-5 of the NRCS TR-55 (NRCS, 1986)

2-Year Peak Discharges (TR-20 Program)
q_a = 23.0 cf s
q_b = 8.0 cfs (the predevelopment discharge is our goal)

Exhibit 4-II Unit peal discharge (q_u) for NRCS (SCS) type II rainfall distribution



Method 1 - Change in Curve Number Method

Step 1: Compute the increased upland runoff depth for the 2-year storm.

$Q = Q_a - (q_{ub} / q_{ua})Q_b$

$Q = 1.16 - (375 / 590)\ (0.69) = 0.72$ inches

The infiltration basin is sized to store 0.72 inches (65,340 ft3)of runoff.

Step 2 : Compute the adjusted curve number (CN*) associated with the revised after development runoff depth (Q).

$Q = 1.16 - 0.72 = 0.44$ inches

$CN^* = 200 / [(P+2Q+2) - \sqrt{(5PQ + 4Q^2)}$

$CN^* = 200 / [(3.3+2(.44)+2) - \sqrt{(5(3.3)(.44) + 4(.44)^2)}$

$CN^* = 59.78$

Step 3 - Compute the revised peak discharge and outflow hydrograph from the TR-20 Program.

Input: D.A. = 0.0390 square miles

CN* = 59. 78

t_c = 0.37 hrs

P = 3.3 inches

Output: q_a (with infiltration basin) = 6.1 cfs

See Figure 1 for the resultant outflow hydrograph.

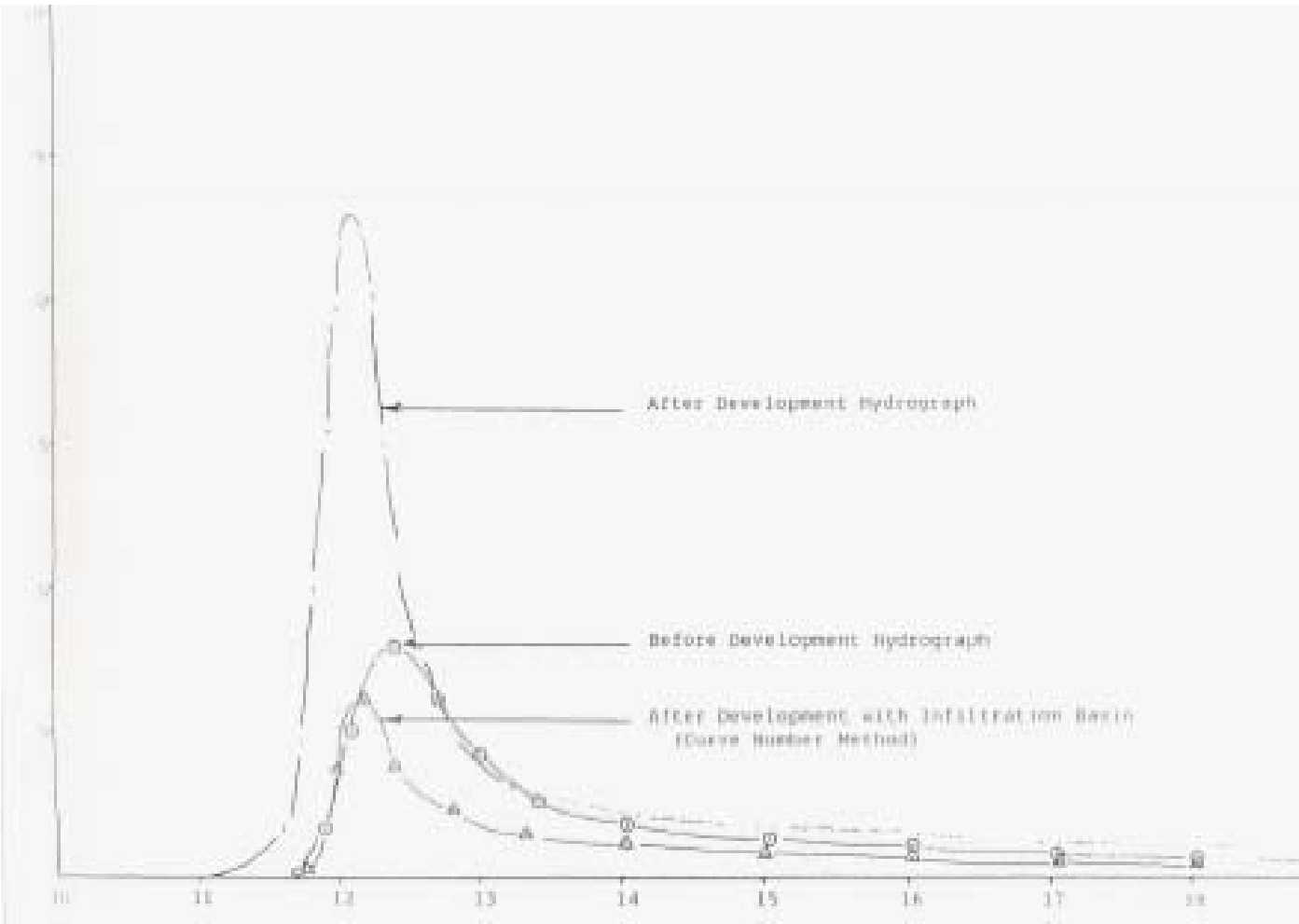


Figure 1 Change in Curve Number Method