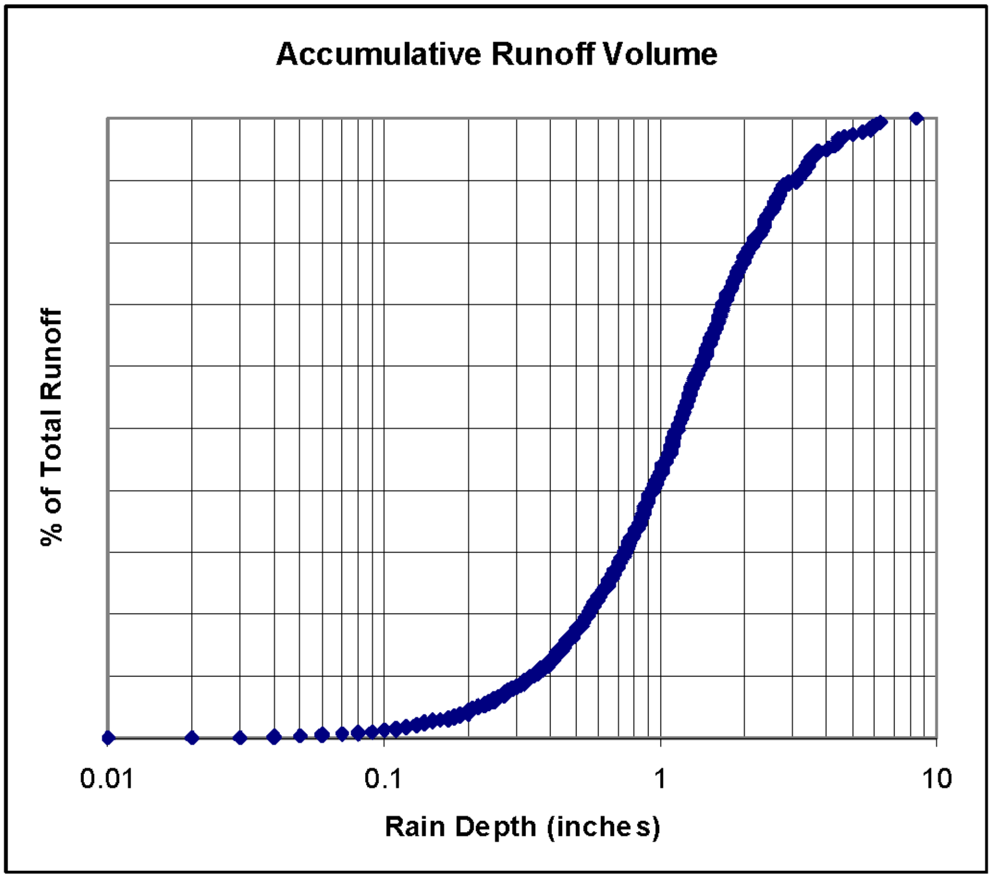
Introduction

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.

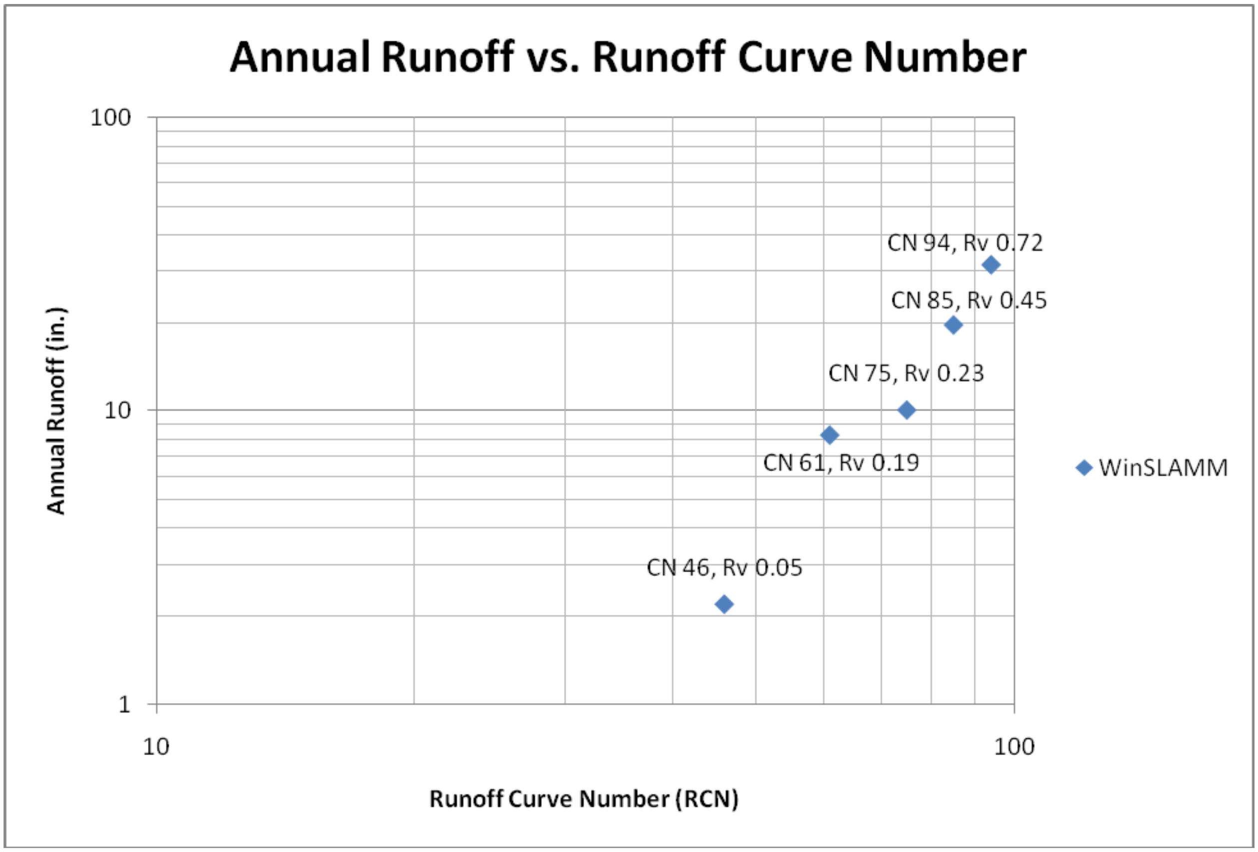


Fig. 4 Log-Log Plot of Conjugate RCN/Rv Pairs vs. Annual Runoff

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.

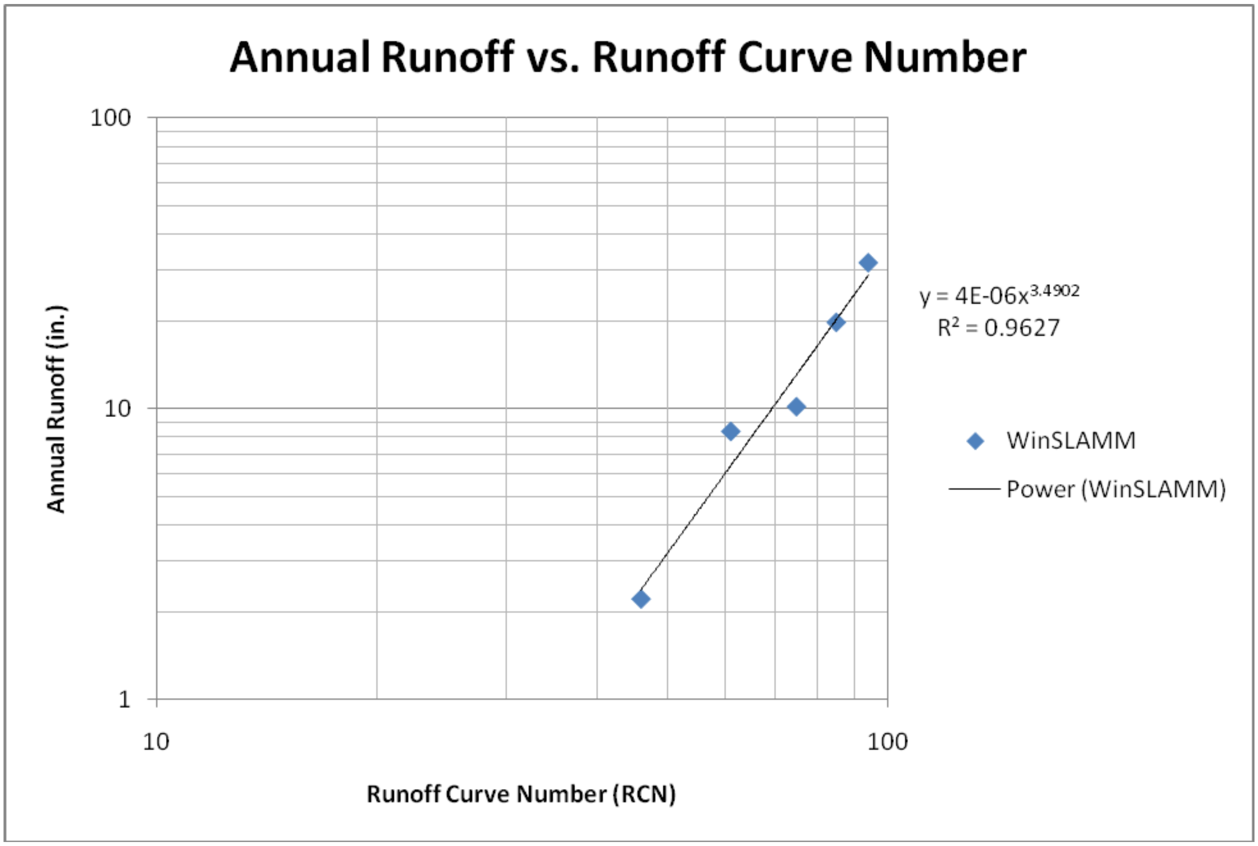


Fig. 5 Regresssion Analysis of RCN vs. Annual Runoff

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:

$$RCN = (\text{Reduced Annual Runoff}/0.000004) \wedge (1/3.5) \qquad (\textit{Equation 2})$$

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:

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

Alternative Methodology for Computing the RPv Volume and Runoff Reduction

Lucas (2005) observed that an adjusted initial abstraction (Ia) value of 0.05S in place of the standard value of 0.20S in the NRCS runoff equation yields reasonably similar results compared to the WinSLAMM equations for computing runoff volumes from small storm events more frequent than the 2-YR storm. This is further supported in an internal USDA/ARS white paper (Hawkins, et al, 2002) which noted that using an initial abstraction value of 0.05S in the NRCS runoff equation yielded more accurate results for predicting the runoff from small, more frequent storm events. As the result of this finding, the NRCS has convened a working group in partnership with the American Society of Civil Engineers (ASCE) to update their National Engineering Handbook 16 – Hydrology to include an adjusted Ia value of 0.05S for modeling small storm events.

To date, the official NRCS TR-55 and WinTR-20 hydrologic modeling programs do not allow a user to modify the initial abstraction value. However, both the commercially available HydroCAD and the USACE HecHMS public domain software packages allow such modifications. The NRCS runoff equation can therefore be used to compute the runoff volume for the RPv using these software programs if the Ia/S value is adjusted to 0.05.

In addition to computing the RPv runoff volume, these software packages can also be used to model the runoff reduction from the various best management practices (BMPs) contained in Article 3.06.2 Post Construction Stormwater BMP Standards & Specifications. Storage practices, such as infiltration basins and bioretention facilities, can be modeled using the same adjusted Ia/S value as used for computing the RPv runoff volume. Figure 7 illustrates how the alternative methodology for computing runoff and modeling storage practices can be done using the HydroCAD software package. Surface recharge practices, such as filter strips and vegetated channels, can be modeled using the methodology outlined in Article 3.06.2 Post Construction Stormwater BMP Standards & Specifications, Appendix A- 7 Alternative Methods for RPv Compliance.

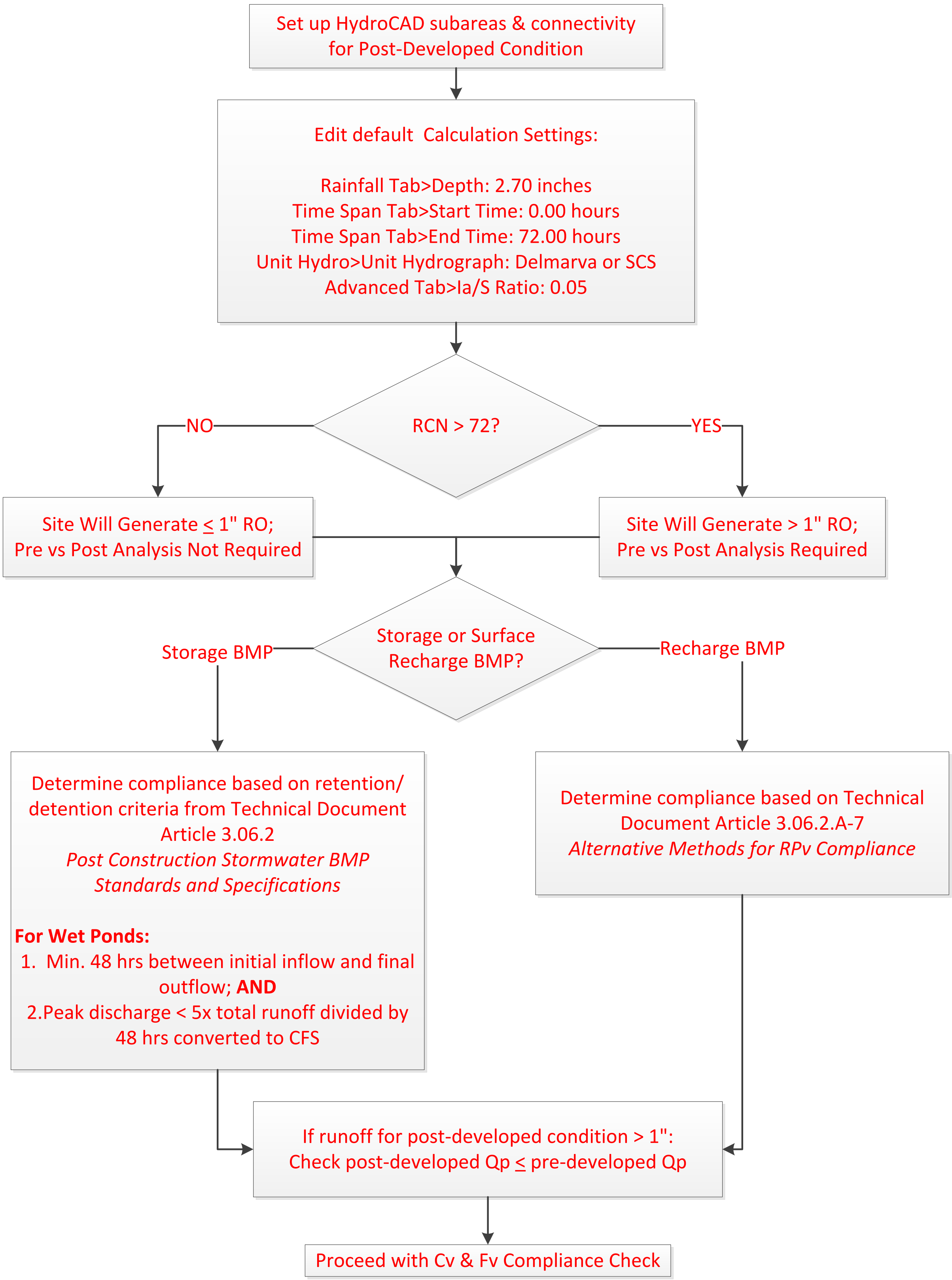


Fig. 7: Alternative Methodology for RPv Compliance using HydroCAD

References

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