



Application of the Natural Resources Conservation Service Technical Release 55 Method in Stormwater Management for Land Development Projects: A Practitioner Case Study

Anna Kyrystsia

Civil Engineer, Independent Researcher, Pennsylvania, USA.

Abstract

The Natural Resources Conservation Service Technical Release 55 (TR-55) method remains one of the most widely used tools for estimating runoff on small land development sites in the United States, and in many Pennsylvania municipalities it is effectively the default method required for stormwater submissions. Most published work on the method concerns its theoretical basis, particularly the curve number and the initial abstraction ratio, while comparatively little describes how practicing engineers actually apply it and defend it in review. This paper documents that practice from the perspective of a civil engineer preparing site design and stormwater management plans for land development projects in Bucks County, Pennsylvania. It describes when the runoff calculation takes place in a typical project, how the principal inputs are selected (curve number from mapped hydrologic soil groups, time of concentration from segmented flow paths with a 100-foot sheet-flow limit, and rainfall depths from NOAA Atlas 14 checked against municipal ordinances), and how pre-development conditions are established on previously disturbed sites. These choices are then illustrated through one example from current practice: a townhouse development of approximately 3.5 acres, where the calculations led to two infiltration basins and a vegetated swale. The example shows how the hydrologic result meets the ordinance requirement, while site geometry, groundwater, infiltration rates, easements, utilities, and cost determine the final facility design. Review experience shows that stormwater submissions typically require two to three cycles, and that the most frequent comments concern time of concentration, curve number documentation, and the correspondence of drainage areas with the grading plan. Illustrative computations show why these inputs attract scrutiny: on small sites, modest changes in sheet-flow length, slope, or curve number shift peak discharge noticeably. The paper argues that many avoidable review cycles stem from inconsistent interpretation rather than from the method itself, and proposes a documentation standard for the assumptions reviewers most often question.

Keywords: Land Development, Municipal Review, Runoff Calculation, Stormwater Facilities, Stormwater Management.

INTRODUCTION

Every land development plan in Pennsylvania eventually has to answer a simple question: if this site is built as drawn, how much more water will leave it, and what peak flow will discharge from it? The answer decides the size of infiltration beds and detention basins, the diameter of pipes, the shape of swales, and often how much of a parcel a developer can actually build on. For most small sites, the tool used to answer this question is the method published by the U.S. Department of Agriculture's Soil Conservation Service, now the Natural Resources Conservation Service (NRCS), as Technical Release 55, Urban Hydrology for Small Watersheds (Soil Conservation Service, 1986). First issued in 1975 and

revised in 1986, TR-55 combines the curve number (CN) runoff equation with a time of concentration (T_c) procedure and standard rainfall distributions to estimate runoff volume and peak discharge from small watersheds.

The method has a long academic literature, much of it critical. Researchers have questioned whether the curve number is a physical parameter or a fitted coefficient (Ponce & Hawkins, 1996; Hawkins, 1993), whether the standard initial abstraction ratio of 0.2 should be closer to 0.05 (Woodward et al., 2003), and how the method is misused outside its intended range (Garen & Moore, 2005). A comprehensive review by an American Society of Civil Engineers task committee summarized decades of this debate (Hawkins et

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al., 2009). What the literature says much less about is what happens between the manual and the approved plan: how engineers in consulting practice choose inputs, where their judgment enters, and what reviewers push back on.

That gap between the manual and the approved plan matters in Pennsylvania because of how stormwater is regulated. Under Chapter 102 of the Pennsylvania Code, earth disturbance of one acre or more requires a post-construction stormwater management plan that addresses runoff volume and peak rate (Commonwealth of Pennsylvania, 2010). Municipal stormwater ordinances, many of them derived from county watershed plans prepared under the Storm Water Management Act of 1978 (Pennsylvania General Assembly, 1978), add their own criteria, and the Pennsylvania Stormwater Best Management Practices Manual guides facility design (Pennsylvania Department of Environmental Protection, 2006). In the Bucks County townships where I work, TR-55 is generally the method reviewers expect to see. The quality of a submission therefore depends not only on the method but on how its assumptions are documented and read.

This paper describes that practice from the inside. Its objectives are to document how the TR-55 method is applied in routine land development work, to show where input selection involves engineering judgment, to illustrate with a current project how the calculated result relates to the final design of the facility, to identify the recurring points of disagreement in municipal review, and to discuss the method's practical limitations as they appear on real sites.

MATERIALS AND METHODS

Study Setting and Approach

This is a practical case study based on my professional work as a civil engineer preparing site design, grading, and stormwater management plans for land development projects in Bucks County, Pennsylvania, and coordinating their review with township engineers. The projects are mostly small, typically ten acres or less, and include residential and commercial development. The findings draw on three sources: the standard workflow I follow on these projects, a current townhouse development used as a worked example, and my record of review comments and resubmissions across several townships. Because the evidence comes from one engineer's practice in one county, the paper describes practice rather than measuring it statistically.

Hydrologic Method

Runoff depth is computed with the NRCS runoff equation (Natural Resources Conservation Service, 2004; Soil Conservation Service, 1986):

$$Q = (P - I_a)^2 / (P - I_a + S) \quad (1)$$

$$S = 1000 / CN - 10, I_a = 0.2S \quad (2)$$

where Q is runoff depth (in), P is rainfall depth (in), S is potential maximum retention (in), and I_a is initial abstraction (in). T_c is the sum of travel times along the longest hydraulic flow path, divided into sheet flow, shallow concentrated flow, and channel or pipe flow. Sheet-flow travel time follows the kinematic solution to Manning's equation used in TR-55:

$$T_t = 0.007 (nL)^{0.8} / (P_2^{0.5} s^{0.4}) \quad (3)$$

where T_t is travel time (h), n is Manning's roughness coefficient for sheet flow, L is flow length (ft), P_2 is the 2-year, 24-hour rainfall (in), and s is land slope (ft/ft).

Software and Data Sources

Calculations are performed in Autodesk Civil 3D using the Hydraflow Hydrographs extension and its SCS runoff hydrograph tool (Autodesk, n.d.). T_c is computed within the program using the TR-55 segment method, and the tool generates the runoff hydrograph and peak discharge for the selected design storms, typically the 2-, 5-, 10-, 25-, 50-, and 100-year events. Hydrologic soil groups are taken from the NRCS Web Soil Survey (Soil Survey Staff, n.d.), rainfall depths from NOAA Atlas 14 (Bonnin et al., 2006), and site conditions from the project survey, aerial imagery, and prior plans or permits. A separate spreadsheet is used to check the weighted CN calculated by the software.

Illustrative Computations

To show why certain inputs attract scrutiny in review, Equations (1) to (3) were evaluated over typical ranges of CN, rainfall, sheet-flow length, and slope. These computations are illustrative. They use an assumed 2-year, 24-hour rainfall of 3.3 in, which is representative of southeastern Pennsylvania, and a sheet-flow roughness of 0.24 for dense grass (Soil Conservation Service, 1986). They are not results from any specific project.

RESULTS AND DISCUSSION

When the Runoff Calculation Takes Place in a Project

On a typical land development project, the runoff calculation is performed during preliminary design, once there is a working understanding of existing and proposed conditions, drainage areas, grading, and proposed impervious coverage (Figure 1). It is not an isolated task at the end of design. Almost everything in the stormwater design waits on it: the calculated peak discharges and runoff volumes are what I use to size detention facilities, infiltration systems, pipes, swales, and other best management practices (BMPs), and the grading and drainage design depends on the same results. When grading changes, the calculation has to change with it, which is the main reason I keep the hydrology inside Civil 3D rather than in a standalone program. Drainage areas, flow paths, and impervious areas can be updated quickly when the site design is revised, which is a common occurrence in land development.

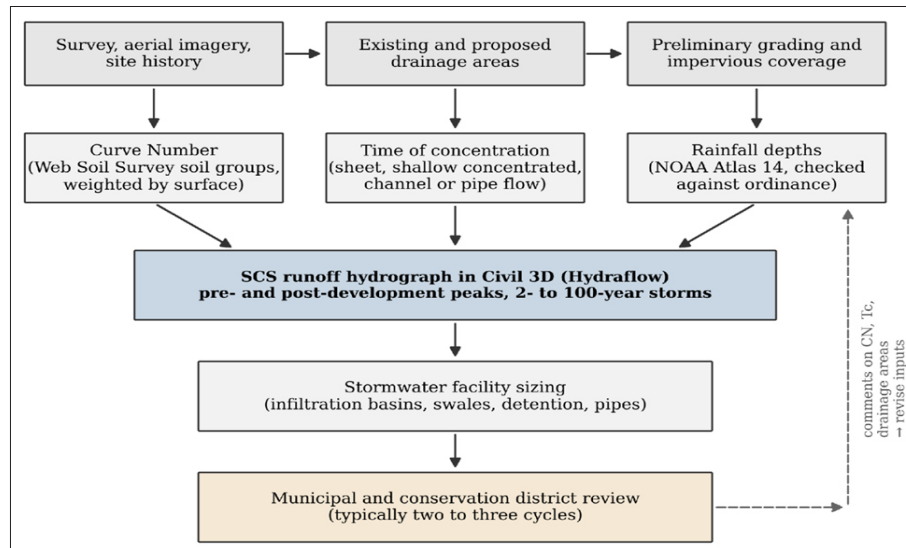


Figure 1. Position of the TR-55 runoff calculation in a typical land development workflow, including the review loop that sends comments back to the hydrologic inputs.

There is a practical trade-off in this choice. Integrated software makes the calculation simple to repeat, but it also makes it easy to accept outputs without looking at them. The software can calculate the weighted CN automatically, for example. I intentionally confirm that value in a spreadsheet, outside of the program, to ensure its accuracy. I make a point of doing this because the software is not designed to recognize incorrect data at this stage in the calculation, and the wrong CN would undoubtedly lead to an erroneous facility size.

Selecting the Curve Number

The CN is where two engineers can most easily reach different answers from the same site, so the inputs need to be traceable. Survey data for land development rarely include hydrologic soil groups, so I take them from the NRCS Web Soil Survey. In Civil 3D, I enter the area of each combination of soil group and surface type, and the program computes the area-weighted CN for each drainage area. The documentation that accompanies the submission shows the soil map, the land-use classification for each surface, and the weighting, so that a reviewer can follow the number back to its sources (Table 1).

Disagreement over CN is theoretically possible when field soil investigations and mapped soil groups do not match. In my projects to date, that conflict has not arisen. If it did, the decision on which data to use would rest with the project's licensed Professional Engineer, and the basis for the choice would need to be documented.

Table 1. Principal TR-55 inputs, their sources in practice, and the documentation provided with submissions.

Input	Source and method in practice	Documentation provided
Curve Number	Hydrologic soil groups from NRCS Web Soil Survey; area-weighted by soil group and surface type in Civil 3D; checked by spreadsheet	Soil map, land-use classification by surface, weighted CN table
Time of concentration	Longest hydraulic path split into sheet flow (≤ 100 ft), shallow concentrated flow, and channel or pipe flow	Flow path drawn on plan; length, slope, surface, and roughness per segment
Rainfall	NOAA Atlas 14 depths for the site, compared with municipal or watershed ordinance values	Return periods and durations used; ordinance values where they govern
Pre-development condition	Baseline required by Pennsylvania rules and the municipality; for disturbed sites, aerial imagery, survey, prior plans, permits, and site history	Basis for land-use classification, CN, drainage areas, and flow paths

Determining the Time of Concentration

For T_c , I divide the longest hydraulic flow path into its segments and compute the travel time of each (Figure 2). The most relevant segment is sheet flow. The 1986 edition of TR-55 allowed sheet flow up to 300 ft, but later NRCS guidance recommends a maximum of 100 ft (Natural Resources Conservation Service, 2010), which is the limit I follow in my work in Pennsylvania. The Pennsylvania Department of Transportation's hydrology review criteria also require the 100-ft maximum (Pennsylvania Department of Transportation, 2015). When the physical flow path is longer, the excess is treated as shallow concentrated flow rather than an extended sheet-flow segment.

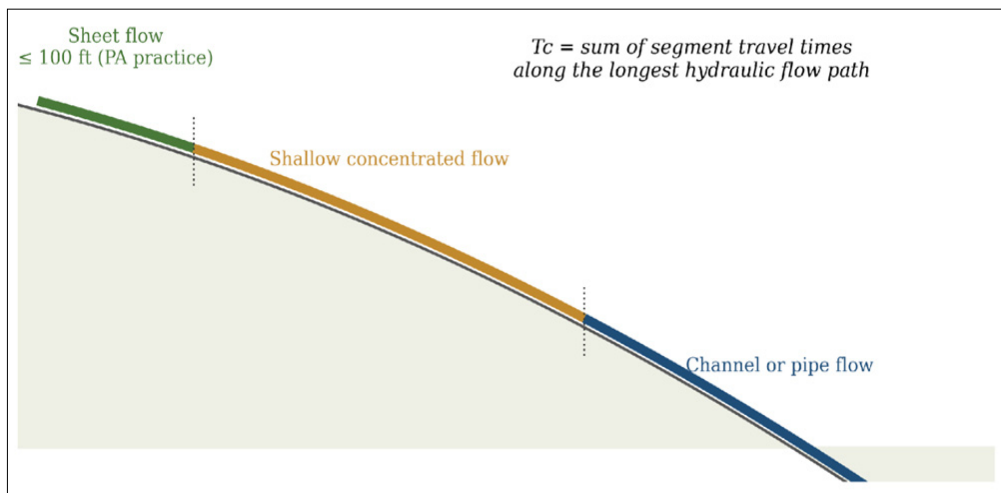


Figure 2. Division of the hydraulic flow path into sheet flow, shallow concentrated flow, and channel or pipe flow for the time of concentration calculation.

The reason this limit is enforced becomes obvious from Equation (3). Figure 3 shows sheet-flow travel time for dense grass at three slopes. At a 2% slope, 100 ft of sheet flow takes about 14 minutes, while 300 ft takes about 34 minutes. Because T_c controls how quickly runoff reaches the outlet, a longer assumed sheet-flow segment lengthens T_c and lowers the computed peak. An overly long sheet-flow length therefore tends to make a site look better than it is, and reviewers are right to question it.

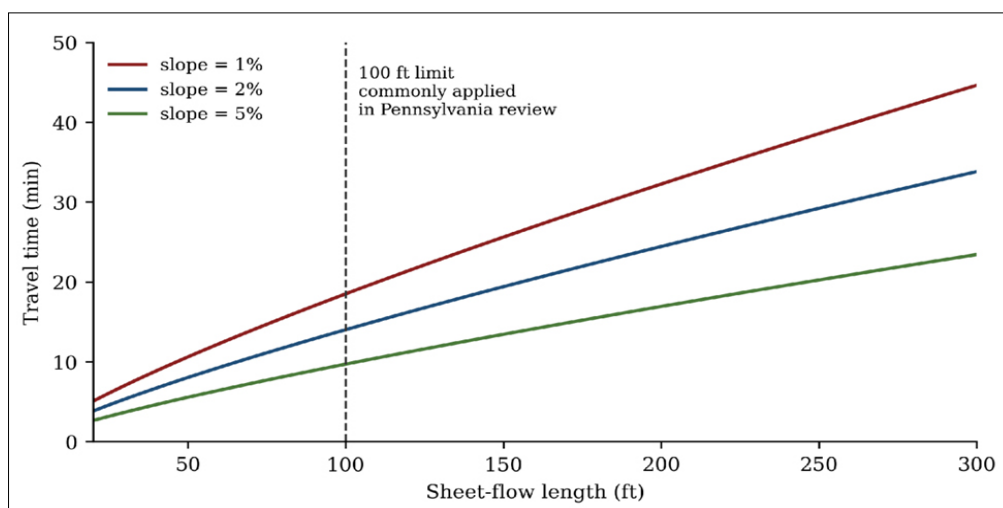


Figure 3. Illustrative sheet-flow travel time for dense grass ($n = 0.24$) and a 2-year, 24-hour rainfall of 3.3 in, from Equation (3).

I have had T_c assumptions questioned during review. The process is the same each time: return to the drainage area and the flow path, verify the surface condition, slope, length, and flow regime of each segment, and document the reason for each choice. If the reviewer's interpretation is more appropriate, or is what the reviewing agency requires, I revise the calculation. The aim is a T_c that represents a realistic flow path consistent with the design criteria, not a value chosen because it produces a convenient peak discharge.

Rainfall Data

Rainfall depths come from NOAA Atlas 14 for the project location (Bonnin et al., 2006), which I compare against any values specified in the municipal or watershed ordinance so that the submission uses the numbers that the reviewing municipality requires. The move from older rainfall sources to Atlas 14 did change design results in places where depths increased. Higher depths produce higher runoff and peak discharge, and can lead to larger detention or infiltration basins. Updated rainfall is not, however, a reason to upsize a facility automatically. I recalculate the hydrology with the currently required data, compare pre- and post-development conditions, and size the BMPs from those results and the applicable stormwater requirements.

Establishing the Pre-Development Condition

The pre-development condition is the baseline against which post-development runoff is compared, so its classification has direct consequences for facility size. On undisturbed land, the choice is usually straightforward. It becomes harder on sites that have already been altered, such as a gravel lot, a fallow field, or a partially cleared parcel. In those cases, I

review aerial imagery, the survey, previous plans or permits, and the site history to determine the baseline required by Pennsylvania regulations and the reviewing municipality. The land-use classification, CN, drainage areas, and flow paths are then documented so that the assumption can be defended if a reviewer challenges it. Of all the inputs, this is the one where a documented basis most clearly saves a review cycle.

Sensitivity of Results on Small Sites

Small land development sites are where the method's simplifications are most visible. Figure 4 shows runoff depth from Equations (1) and (2) across the range of CN for three rainfall depths. For a 3.3-in storm, raising CN from 70 to 75 increases runoff depth from about 0.89 in to 1.16 in, roughly 30%. At lower CN values, the relative change is larger still. On a site of a few acres, a change of that size in weighted CN can come from a modest change in impervious area, which is why small adjustments to a site plan can move the calculated peak noticeably.

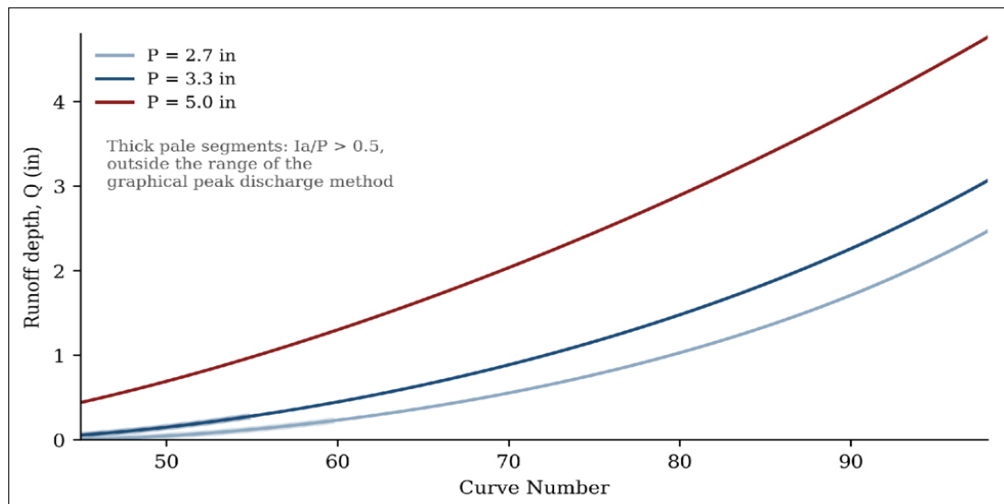


Figure 4. Illustrative runoff depth as a function of curve number for three rainfall depths, from Equations (1) and (2). Pale thick segments mark conditions where I_a/P exceeds 0.5.

The figure also shows the lower edge of the method's range. TR-55's graphical peak discharge procedure applies for CN of 40 or more, T_c between 0.1 and 10 hours, and ratios of initial abstraction to rainfall (I_a/P) between 0.1 and 0.5 (Soil Conservation Service, 1986). At CN near 55 and a 3.3-in storm, I_a/P reaches 0.5, and computed runoff becomes very small and very sensitive to CN. This is also where the research on the initial abstraction ratio suggests the standard 0.2 assumption performs worst (Woodward et al., 2003). In practice, I treat low-CN drainage areas and small urban catchments with extra care, and check whether the result makes physical sense for the site rather than accepting the model output as given.

Table 2. Illustrative runoff depths for a 3.3 in rainfall, from Equations (1) and (2).

CN	S (in)	I _a (in)	I _a /P	Q (in)
55	8.18	1.64	0.50	0.28
61	6.39	1.28	0.39	0.49
70	4.29	0.86	0.26	0.89
75	3.33	0.67	0.20	1.16
80	2.50	0.50	0.15	1.48
85	1.76	0.35	0.11	1.84
98	0.20	0.04	0.01	3.07

Values are computed for illustration and do not represent a specific project.

Project Example: Townhouse Development

A current project I am working on illustrates how the calculation translates into a design. The site is a townhouse development of approximately 3.5 acres in Bucks County. The TR-55 and SCS hydrologic calculations established the storage and infiltration capacity needed to meet the stormwater requirements, and the resulting system consists of two infiltration basins and one vegetated swale. The calculations determined how much water had to be managed. They did not, on their own, decide where or in what form.

That second question is answered by factors TR-55 never sees. Available site area, grading and drainage patterns, seasonal high groundwater, soil infiltration rates, setbacks and easements, utility conflicts, and constructability all shape a facility, and cost often decides which of several technically valid BMPs is practical. The runoff calculation is therefore the starting point that establishes the hydrologic requirement. The final design combines that requirement with site constraints and with Pennsylvania and municipal criteria (Pennsylvania Department of Environmental Protection, 2006).

Clients have not rejected a project design that the calculations required. Their concern is more often the amount of land given over to stormwater management. When that happens, the task is to find a layout that meets the requirements, while using the site as efficiently as possible, for example by rearranging or combining BMPs, rather than revisiting the hydrology to produce a smaller number.

Municipal Review

A stormwater submission in my practice typically takes two to three review cycles, depending on the municipality and the complexity of the project. The comments that drive additional rounds fall into a small number of recurring categories (Table 3). Other municipal departments sometimes contribute comments that also require changes to the stormwater design. To limit the number of cycles, I address every comment in a single revision and coordinate the hydrology, grading, and stormwater plans together, since a change to one usually affects the others.

Table 3. Most frequent review comments on TR-55 submissions and the typical response.

Topic	Typical reviewer concern	Response
Time of concentration	Flow path location, sheet-flow length, assumptions for shallow concentrated and channel flow	Re-verify path, slope, surface, and flow regime; document each segment; revise if the alternative is more appropriate or required
Curve Number	Documentation of soil groups, land-use classification, and weighted CN	Provide soil map, classification basis, and weighting table
Drainage areas and flow paths	Whether drainage areas match the grading plan and flow paths reflect actual site conditions	Reconcile drainage area boundaries with proposed grading; update calculations

Across the Bucks County townships where I have worked, the overall approach is consistent: TR-55 is generally the required method. What varies is interpretation and documentation. Townships differ in how they want T_c , CN, and pre-development conditions to be presented, and occasionally in what they will accept. Checking the specific township ordinance and stormwater requirements at the start of each project is therefore part of the method, not an administrative afterthought.

Limitations

TR-55 is a useful design method, but it is a simplified model. It represents a watershed with a single CN and T_c per drainage area, assumes a standard rainfall distribution, and was developed for small watersheds where those simplifications are tolerable (Soil Conservation Service, 1986; McCuen, 2005). I pay extra attention when working with small urban drainage areas, low CN values, and assumptions about drainage areas and flow paths, which are also the areas identified in the research literature (Garen & Moore, 2005; Hawkins et al., 2009). I verify that drainage areas and hydraulic flow paths represent the proposed grading rather than relying on the model output alone.

This study also has limitations of its own. It reflects one engineer's practice in one county, and the review experience it reports may not transfer to jurisdictions with different ordinances or review cultures. My work has been with TR-55 and the SCS runoff hydrograph tools in Civil 3D; I have not worked directly with TR-20, HEC-HMS, or continuous simulation models, so the paper does not compare TR-55 with those methods. The computations in the Sensitivity of Results on Small Sites section are illustrative and do not substitute for project data.

Toward Consistent Documentation

If one thing about the use of TR-55 in review could be changed, it would be consistency in how its assumptions are applied and read. The method itself is standardized. The interpretation of T_c , CN, and pre-development conditions is not, and it varies between engineers and between municipalities. Review works best when the engineer documents each assumption clearly and the reviewer evaluates it against the same established criteria. That would remove revision cycles caused by differences of interpretation and let review focus on stormwater performance and compliance. Table 4 summarizes a minimum documentation set, drawn from the comments in Table 3, that would allow a reviewer to check each assumption without a further request.

Table 4. Suggested minimum documentation for TR-55 stormwater submissions.

Item	Documentation
Soils	Web Soil Survey map with hydrologic soil groups overlaid on drainage areas
Curve Number	Table of area by soil group and surface type, CN values used, and weighted result for each drainage area
Time of concentration	Flow path drawn on the plan; sheet-flow length (≤ 100 ft), roughness, slope, and travel time for each segment
Rainfall	Source, return periods, durations, and depths; ordinance values where they govern
Pre-development condition	Classification with supporting imagery, survey, prior plans, or permits
Drainage areas	Pre- and post-development drainage area maps consistent with the grading plan

CONCLUSION

This case study described how the TR-55 method is applied in routine stormwater management for land development projects in Bucks County, Pennsylvania. The runoff calculation is performed during preliminary design and drives facility sizing, grading, and drainage design. Its inputs, particularly CN, Tc, rainfall, and the pre-development condition, involve engineering judgment that must be documented to survive review. The townhouse example showed that the calculation establishes the hydrologic requirement, while the final facility is shaped by site constraints, groundwater, infiltration capacity, easements, utilities, and cost. Submissions typically require two to three review cycles, and the recurring comments concern Tc, CN documentation, and the fit between drainage areas and the grading plan. Illustrative computations showed why those inputs matter so much on small sites.

For practitioners, the lesson is that a defensible TR-55 calculation is as much a matter of documentation as of computation. For municipalities and reviewers, the evidence points to consistent interpretation criteria as the most direct way to reduce avoidable resubmissions. Further work comparing documented assumptions and review outcomes across several firms and counties would help establish whether the patterns described here hold more widely.

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