9.4 STORMWATER QUANTITY CONTROL

9.4.1 The Department's Design Storms

A problem with developing a design storm distribution is that actual storms have an unlimited combination of durations and intensity patterns. What should the duration of the design storm be? Should the peak rainfall occur near the beginning, in the middle, or near the end of the storm? Should there be multiple peaks?

Most of the current widely used rainfall distributions address this by nesting short-duration, high-intensity storms in the middle of a long duration storm, although very intense peaks do not usually occur in long storms. You usually would place the largest intensity value in the middle of the storm pattern, then place the remaining values alternately before and after this point, in order of decreasing intensity. The various NRCS distributions, the South Florida Water Management District (SFWMD) three-day distributions, and the St. Johns River Water Management District (SJRWMD) four-day distributions are examples of design storm distributions created using this approach. These "nested" distributions are not indicative of actual rainfall patterns and subsequently may produce inaccurate representations of actual runoff characteristics.

You may have used these distributions in the past for the design of conveyance systems because they give conservatively high runoff estimates. But, when you use these distributions to determine the pre-developed discharge, they can overestimate it. In the developed condition, the outlet control structure would be designed to pass the "overestimated pre-developed discharge," thereby discharging more in the post-developed condition.

Another problem with these distributions is that different drainage areas will react differently to the same rainfall pattern. Small basins with short times of concentration and little storage will have higher runoff rates from short, intense storms than from long-duration, low-intensity storms. Long-duration, low-intensity storms usually do not generate peak discharges from small basins. The opposite is true for large basins. Very large basins with large amounts of storage will have less runoff from short, intense storms than from long-duration, low-intensity storms. Large river systems and static water bodies such as lakes reach peak stages when extreme antecedent conditions exist and variations in intensity usually do not affect their stages.

To overcome the concerns of a single design storm distribution, the Suwannee River Water Management District (SRWMD) developed a series of design distributions to better reflect actual rainfall patterns. They developed distributions for 1-, 2-, 4-, and 8-hour storms and for 1-, 3-, 7-, and 10-day storms using National Oceanic and Atmospheric Administration (NOAA) hourly and sub-hourly data. SRWMD requires the use of these distributions for projects within the district.

Chapter 14-86, Florida Administrative Code

In 1986, the Department established Chapter 14-86 of the F.A.C., requiring adjacent developments to maintain discharges at or below pre-developed discharges using a multiple storm approach. In the Department's Drainage Connection Handbook (February 1987), the SRWMD design distributions mentioned above were accepted as appropriate for the entire state. These distributions can be found at the Department's website, listed below:

https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/drainage/files/fdotrainfalldistributions.pdf.

In a July 1988 memorandum, the State Roadway Design Engineer directed the districts to design the Department's stormwater management systems to Chapter 14-86. In October 1992, the *Drainage Manual* was revised to require the design of the Department's stormwater management systems to comply with Chapter 14-86. In 2013, the *Drainage Manual* was amended to require the application of Chapter 14-86 on FDOT stormwater designs only for closed basins and areas where downstream historical flooding is documented.

9.4.1.1 Critical Duration

Since the time the Department developed Chapter 14-86, there have been two interpretations of the critical duration and how to apply the multiple storm concept. The definition of critical duration (shown below), as defined in Chapter 14-86, lends itself to two interpretations.

> "Critical Duration" means the duration of a specific storm event (i.e., 100-year storm) that creates the largest volume or highest rate of net stormwater runoff (post-development runoff less pre-development runoff) for typical durations up through and including the 10-day duration event. The critical duration is determined by comparing various durations of the specified storm and calculating the peak rate and volume of runoff from each. The duration resulting in the highest peak rate or largest total volume is the "critical duration" storm.

(A) Peak Discharge Approach

This interpretation of critical duration and the multiple storm concept allows a post-developed runoff rate, for a given frequency, that is equal to or less than the highest pre-developed runoff rate of any duration. For example, given the pre-developed runoff rates shown in the table below, the allowable runoff rate would be 70, regardless of the duration associated with the peak post-developed runoff rate. The post-developed runoff rates shown are acceptable because none are greater than 70. You need only run enough durations in the post-developed condition to be assured that runoff rates of the other durations do not exceed the allowable.

Duration	Pre-Dev Runoff XX Year Event	Acceptable Post-Dev Runoff XX Year Event
1-hour	65	
2-hour	70	60
4-hour	66	70
8-hour	60	65
24-hour	30	35
3-day	25	
7-day	24	
10-day	21	

This approach is consistent with the last sentence of the definition of critical duration. "*The duration resulting in the highest peak rate . . . is the critical duration.*" With this approach, the pre-developed critical duration can be different from the post-developed critical duration, as shown in the values above. Also, the pre-developed runoff rate could be calculated with the rational method (Q = CIA) for small basins; therefore, it would not be directly associated with any of the eight durations. The examples in the *Drainage Connection Handbook* follow this interpretation.

The above discussion pertains to discharges to open basins only with historical flooding documented. For discharges to closed basins, a similar approach is used with an additional constraint on the runoff volume. For a given frequency, the allowable post-developed runoff volume is the largest pre-developed runoff volume of any duration. When using the NRCS technique for computing runoff, the 10-day duration event will always produce the largest runoff volume and, therefore, be the critical duration. But, for other more-refined approaches to modeling infiltration, the critical duration could be something other than the 10-day duration.

(B) Storm for Storm Approach (Preferred)

This interpretation of critical duration and the multiple storm concept requires, for a given frequency, that the post-developed runoff rate for each duration be less than or equal to the pre-developed runoff rate of corresponding duration. For example, in the table below, the allowable runoff rate for each duration is the pre-developed runoff rate. The post-developed runoff rates shown are acceptable because they are all less than or equal to the pre-developed runoff rate of corresponding duration. The 4-hour duration is critical because it most closely matches the pre-developed runoff rate.

Duration	Pre-Dev Runoff XX Year Event	Acceptable Post-Dev Runoff XX Year Event
1-hour	65	60
2-hour	70	68
4-hour	66	66
8-hour	60	57
24-hour	30	26
3-day	25	23
7-day	24	22
10-day	21	20

This approach is consistent with the first sentence of the definition of critical duration. *"Critical Duration means the duration . . . that creates the . . . highest rate of net stormwater runoff (post-development runoff less pre-development runoff). . .* ." In the example above, when you subtract the pre-development runoff rate from the corresponding post-development runoff rate, all the "net stormwater runoff" values are negative except the 4-hour duration, which has zero "net stormwater runoff." So, the 4-hour duration has the highest rate of net stormwater runoff; therefore, it is the critical duration. This approach is better than the peak discharge approach, where the release timing of the facility is critical. FHWA's Hydraulic Engineering Circular No. 22 (HEC 22) contains a discussion of the concern for release timing.

The above discussion pertains to discharges to open basins only with historical flooding documented. For discharges to closed basins, a similar approach is used with an additional constraint on the runoff volume. For a given frequency, the post-developed runoff volumes for each duration cannot exceed the pre-developed runoff volumes of corresponding duration.

Although both the Peak Discharge Approach and the Storm for Storm Approach have been applied to FDOT projects in the past, the Department prefers that you use the Storm for Storm Approach on its projects. The examples in Section 9.4 are based on the Storm for Storm Approach.

9.4.1.2 Storm Frequencies

The previous sections primarily discuss durations and the multiple storm concept. Chapter 14-86 [14-86.003 (3)(c) 2 & 3] requires that we consider various rainfall event frequencies up to and including the 100-year event. The rule does not say that all frequencies must be evaluated.

The more frequent FDOT design storms (2-year to 50-year) do not usually control the size of the pond because the runoff from these storms is less than the runoff for the 100-year storm. The purpose of evaluating the less frequent storms is to ensure that the pre-developed discharges are not exceeded. And so it becomes a check of the operation of the outlet control structure under various rainfall event frequencies.

Where the discharge is controlled by a simple rectangular weir (one with a constant width), it may be reasonable to run only the 2-year, 25-year, and 100-year events. Where the discharge is controlled by a complex weir (width varies with elevation), an orifice, a pipe, tailwater conditions, or any combination of these, evaluate all frequencies (2-year, 5-year, 10-year, 25-year, 50-year, and 100-year). Some software programs can run all the frequencies at once. If these programs are available to you, run all the frequencies, regardless of the outlet control structure configuration.

9.4.2 Estimating Attenuation Volume

A first step in estimating attenuation volume is identifying outfalls and their associated drainage basins. At this stage, consider if it will be necessary to divert runoff from one basin to another. Although the Department does not encourage diverting runoff, doing so sometimes allows the Department to provide stormwater management (treatment and attenuation) in more economical locations. For example, an economical parcel for a pond site may be available in one drainage basin while the parcels in an adjacent basin are very expensive. Diverting some roadway runoff to the economical parcel basin from the expensive parcel basin may be more economical even when other costs, such as construction and maintenance, are considered. Before you propose diverting runoff, be sure it is acceptable to the regulatory agency.

When diverting runoff, be careful how you calculate the allowable discharge. Base your allowable (pre-developed) discharge calculations on the pre-developed drainage area that discharges to the proposed outfall. If an area does not drain to the proposed outfall in the pre-developed condition, do not include that area in the allowable (pre-developed) discharge calculations. Therefore, in a basin you divert runoff to, the pre-developed drainage area is smaller than the post-developed drainage area. Conversely, in a basin you divert runoff from, the pre-developed drainage area is larger than the post-developed drainage area.

The actual attenuation volume cannot be determined until you "route" the design storms and design the pond. There are several methods for estimating the attenuation volume. The methods more commonly used on the Department's projects are discussed below.

9.4.2.1 Pre Versus Post Runoff Volume

A common technique for estimating attenuation volume is to calculate the difference in runoff volume between the post-developed conditions and the pre-developed conditions using the NRCS equation for runoff.

$$Q_R = \frac{(P - 0.2S)^2}{P + 0.8S}$$

As written, this assumes the initial abstraction (I_a) = 0.2S & S =(1000/CN) – 10

where:

Q_R = Runoff depth (in inches)

P = Rainfall depth (in inches); Use the 100-year, 24-hour depth for evaluating alternate drainage schemes or pond sites

S = Maximum retention or soil storage (in inches)

CN = Watershed curve number

The runoff volume is determined from: VOL = (Q_R) (Drainage Area)

A similar approach can be taken using the Rational Equation Method.

VOL = ($C_{POST} - C_{PRE}$) (P) (Drainage Area)

An advantage of this technique is that it does not involve any design storm distributions. So there is no concern for which storm duration is critical. On the other hand, this technique ignores the timing differences between the pre-developed and post-developed hydrographs. As a result, it may underestimate the attenuation volume.

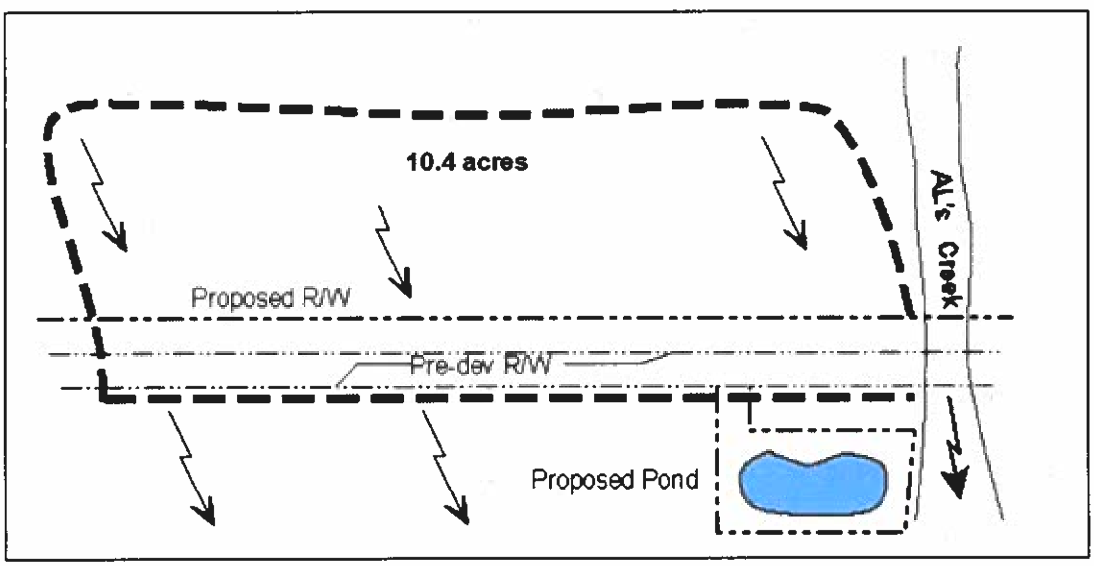
Example 9.4-1: Estimating attenuation volume using differences in runoff volume

Given:

- Pre-developed roadway pavement = 2 10-foot lanes
- Drainage area: includes roadway right of way & off-site drainage to the roadway = 10.4 ac

For preliminary pond sizing, use the information from the old drainage map unless you have reason not to.

- Offsite land use = Residential lots averaging 1/2 ac
- Proposed typical section = 5-lane urban section; Combined roadway, curb, and sidewalk width = 83 ft
- Proposed right-of-way width = 100 ft
- Length of roadway within drainage area = 1,706 ft
- Offsite runoff draining to the project will be taken through the pond, not bypassed around.
- Project located in Somewhere City, Florida, flat terrain <1 percent grade, Hydrologic Soil Group B/D, project drains to open basin.



Example 9.4-1

Find: The estimated attenuation volume.

1. Pre-developed area & curve number:

Roadway pavement:	= 0.79 ac @ CN = 98	(20 ft x 1,706 ft)
Pervious area	= 9.61 ac @ CN = 85	(10.4 ac – 0.79 ac)
Proposed pond area	= 0.77 ac @ CN = 85	
Total	= 11.2 ac @ CN = 85.9	

Assume the pond area is 20 percent of the roadway right of way (0.2 x 1,706 ft x 98 ft = 0.77 ac). For this example, the proposed pond is located outside the area draining to the roadway; thus, the pond must be added to the other areas.

For this example, the roadway right of way to be acquired is within the area draining to the roadway. For your project, the acquired right of way may be outside the area draining to the road, thereby requiring that the additional right of way be added to the other areas.

2. Post-developed area and curve number:

Roadway, curb, and sidewalk:	= 3.24 ac @ CN = 98	(82.7 ft x 1,706 ft)
Pervious area	= 7.17 ac @ CN = 85	(10.4 ac – 3.24 ac)
Pond area	= 0.77 ac @ CN = 98	
Total	= 11.2 ac @ CN = 89.7	

3. Calculate the difference in runoff volume between the pre-developed conditions and post-developed conditions for the 100-year, 24-hour storm using the NRCS equation for runoff.

Refer to the NOAA website link in Section 1.4 of the *Drainage Manual* to obtain location-specific precipitation data for the 100-year, 24-hour volume. For this example, the 100-year, 24-hour volume for Somewhere City, Florida, is 10.7 inches.

$$Q = (P - 0.2S)^2 / (P + 0.8S) \qquad \text{where: } S = (1{,}000 / CN) - 10$$

	Pre	Post
Potential abstraction (S) =	1.64	1.15
Runoff depth (Q) in inches	8.95	9.44
Runoff volume (ac-ft) =	8.36	8.81

Volume difference = 0.45 ac-ft

The estimated attenuation volume is this volume difference of 0.45 ac-ft.

9.4.2.2 Simple Pond Model Procedure

Another technique for estimating attenuation volume is to route a design storm through a simple pond model. It works best with a routing program that allows a rating curve for the stage-discharge relationship and a stage-storage (not area) relationship for the pond configuration. The model should be set up as follows:

- Arbitrarily select pond bottom and top elevations.
- Use two points for the stage-discharge relationship:
  (1) Zero discharge @ pond bottom, and (2) Allowable discharge @ pond top
- Use two points for the stage-storage relationship:
  (1) Zero storage @ pond bottom, and (2) Estimated storage @ pond top

As with any routing, this is an iterative process. During each iteration, the estimated storage volume is changed to bring the routed peak stage close to the top of the pond. The storage volume that causes the peak pond stage to match the top of the pond is the estimated attenuation storage.

This approach is useful when the discharge rate is limited to something other than the pre-developed rate. It is complicated when working with the Department's multiple design storms. Which design storm do you route? The following suggestions will help to simplify working with the multiple design storms:

- Determine the pre-developed discharges for the 100-year, 1-hour design storm through the 100-year, 8-hour design storm. Use the smallest of these calculations as the allowable discharge rate. For the Storm for Storm Approach to critical duration, the post-developed discharge rate will be limited to all of the corresponding pre-developed rates, so using the rate for estimating purposes is reasonable. The basis for running only the 1-hour through the 8-hour design storm is that one of these design storms usually is critical to sizing ponds discharging to open basins.
- Route the post-developed conditions using a "nested" design storm such as the NRCS Type 2 Florida modified or the applicable WMD design storm. These distributions often are as severe as or more severe than the Department's distributions.

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Example 9.4-2: Estimating attenuation volume using a simple pond model

Given:

- The same conditions as in Example 9.4-1
- Pre-developed time of concentration = 29 min.
- Post-developed time of concentration = 21 min.

Find: The estimated attenuation volume

1. Pre-developed runoff:

   Determine the pre-developed discharge rates for the 100-year FDOT 1-hour and 8-hour design storms. Using a typical program based on the NRCS unit hydrograph approach, you should obtain values similar to these when using a peak shape factor of 256. The rainfall volumes for Somewhere City, Florida, are tabulated in Step 1 of Example 9.4-3.

Pre-Developed Peak Runoff Rates (cfs)			
1-hour, 100-yr	2-hour, 100-yr	4-hour, 100-yr	8-hour, 100-yr
33.2	30.1	25.5	27.8

   The discharge associated with the 4-hour, 100-year design storm is the smallest and will be used as the allowable discharge.

2. Develop a simplified pond model as follows.

	Elevation	Discharge (cfs)	Storage
Pond Bottom	0	0	0
Top of Pond	10	25.5	Trial and Error

3. Route a nested design storm through the pond using post-developed conditions. For this example, we will route the 25-year, SFWMD 72-hour storm. Adjust the storage as necessary to have the routed peak stage match the top of pond. After numerous iterations, a storage value of 1.3 ac-ft was found acceptable, so:

   The estimated attenuation volume is 1.3 ac-ft.