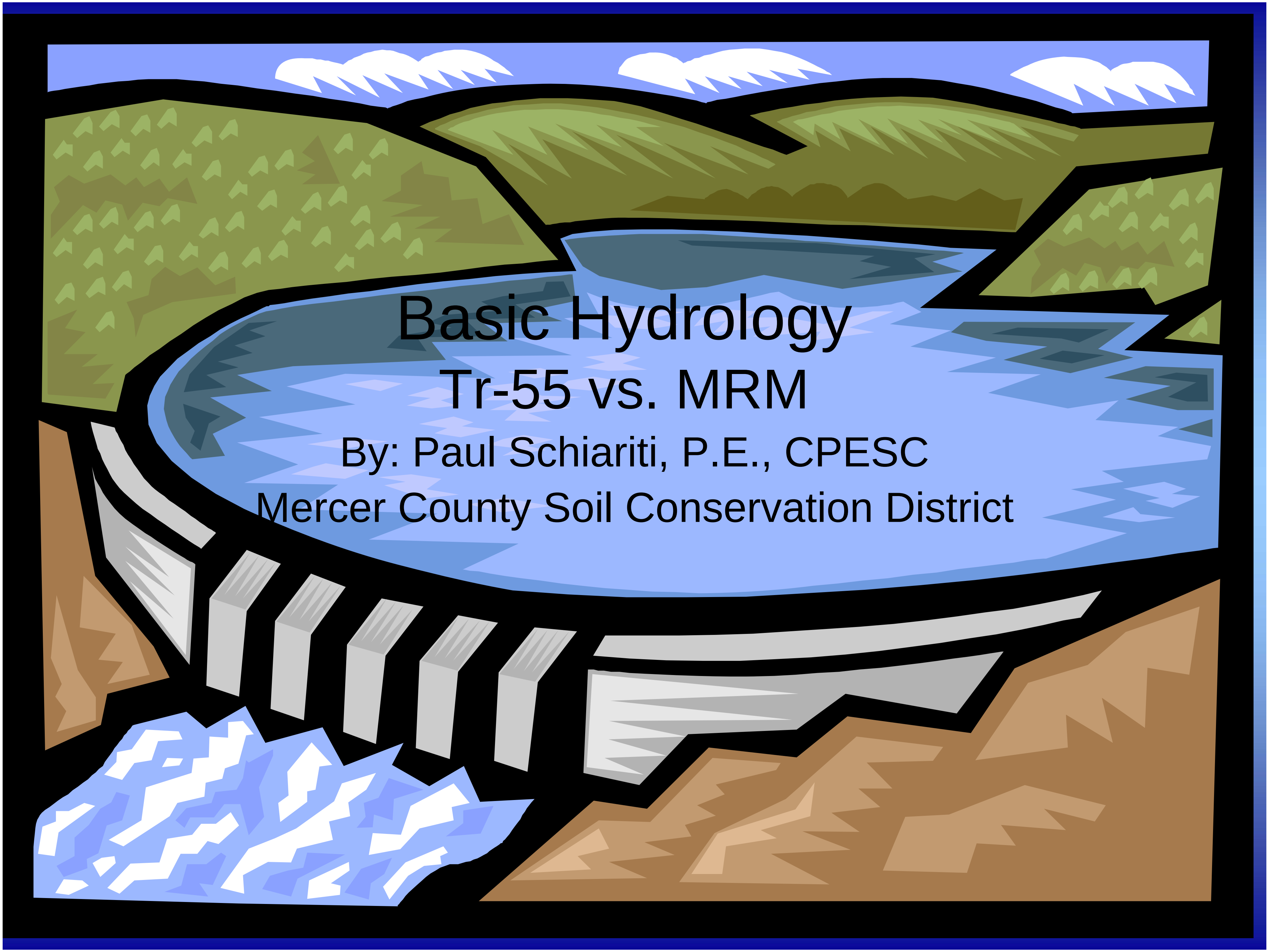


Basic Hydrology

Tr-55 vs. MRM

By: Paul Schiariti, P.E., CPESC

Mercer County Soil Conservation District

Rational Method Equation:

Based upon the Rational Method Equation:

$$Q = C \times I \times A \times APF$$

Where:

Q = The **Q**uantity Flow Rate in CFS

C = Dimensionless Runoff Coefficient

I = The Rainfall **I**ntensity in In / Hr

A = The Drainage **A**rea in Acres

APF = Antecedent Precipitation Factor

How do you get Q in CFS, when you are multiplying In / Hr x Ac? It would seem that the math would equal In-Ac / Hr.

Lets convert In-Ac/Hr to CFS:

[(1ft / 12 In) x (43,560 ft^2 / Ac)] / 3600 Sec / Hr = 1.008 CFS / In-Ac / Hr

The degree of accuracy does not warrant a units conversion factor (constant) of 1.008!!

Rational Method Runoff Coefficients

TABLE 7.1 TYPICAL RUNOFF COEFFICIENTS (C VALUES) FOR 100-YEAR FREQUENCY STORM

LAND-USE DESCRIPTION	HYDROLOGIC SOIL GROUP A	B	C	D
Cultivated land:				
without conservation treatment	0.49	0.67	0.81	0.88
with conservation treatment	0.27	0.43	0.61	0.67
Pasture or range land:				
poor condition	0.38	0.63	0.78	0.84
good condition	NA	0.25	0.51	0.65
Meadow: good condition	NA	NA	0.44	0.61
Wood or forest land:				
thin stand, poor cover, no mulch	NA	NA	0.59	0.79
good cover	NA	NA	0.45	0.59
Open spaces, lawns, parks, golf courses, cemeteries:				
good condition, grass cover on 75% or more of area	NA	0.25	0.51	0.65
fair condition, grass cover on 50-75% of area	NA	0.45	0.63	0.74
Commercial and business areas (85% impervious)	0.84	0.90	0.93	0.96
Industrial districts (72% impervious)	0.67	0.81	0.88	0.92
Residential: Average lot size / Average impervious				
1/8 acre — 65%	0.59	0.76	0.86	0.90
1/4 acre — 38%	0.25	0.55	0.70	0.80
1/3 acre — 30%	NA	0.49	0.67	0.78
1/2 acre — 25%	NA	0.45	0.65	0.76
1 acre — 20%	NA	0.41	0.63	0.74
Paved parking lots, roofs, driveways, etc.	0.99	0.99	0.99	0.99
Streets and roads:				
paved with curbs and storm sewers	0.99	0.99	0.99	0.99
gravel	0.57	0.76	0.84	0.88
dirt	0.49	0.69	0.80	0.84

NOTE: NA denotes information is not available; design engineers should rely on another authoritative source.

SOURCE: *Technical Manual for Land Use Regulation Program*, Department of Environmental Protection, Bureaus of Inland and Coastal Regulations, Stream Encroachment Permits (Trenton, New Jersey, revised September 1995), p. 12.

Rational Method Runoff Coefficients

Type of Development		Runoff Coefficients
Business		
Downtown		0.70 to 0.95
Neighborhood		0.50 to 0.70
Residential		
Single family		0.30 to 0.50
Multi-units (detached)		0.40 to 0.60
Multi-units (attached)		0.60 to 0.75
Residential (suburban)		0.25 to 0.40
Apartment		0.50 to 0.70
Industrial		
Light		0.50 to 0.80
Heavy		0.60 to 0.90
Park, Cemeteries		0.10 to 0.25
Playgrounds		0.20 to 0.35
Railroad Yard		0.20 to 0.35
Unimproved		0.10 to 0.30
Character of Surface		
Pavement		
Asphalt and Concrete		0.70 to 0.95
Brick		0.70 to 0.85
Roofs		0.75 to 0.95
Lawns, Sandy Soil		
Flat	2%	0.05 to 0.10
Average	2% to 7%	0.10 to 0.15
Steep	7%	0.15 to 0.20
Lawns, Heavy Soil		
Flat	2%	0.13 to 0.17
Average	2% to 7%	0.18 to 0.22
Steep	7%	0.25 to 0.35

Source: Design and Construction of Sanitary and Storm Sewers, American Society of Civil Engineers and the Water Pollution Control Federation, 1969.

Rational Method Runoff Coefficients

Residential: Average lot size	Average impervious				
1/8 acre	65%	0.59	0.76	0.86	0.90
1/4 acre	38%	0.25	0.55	0.70	0.80
1/3 acre	30%	NA	0.49	0.67	0.78
1/2 acre	25%	NA	0.45	0.65	0.76
1 acre	20%	NA	0.41	0.63	0.74

¼ Acre Single Family Dwelling with 38% Impervious Surface Coverage in HSG "D" would have a Runoff Coefficient of 0.80 from the above table, and a maximum of 0.50 from the table below.

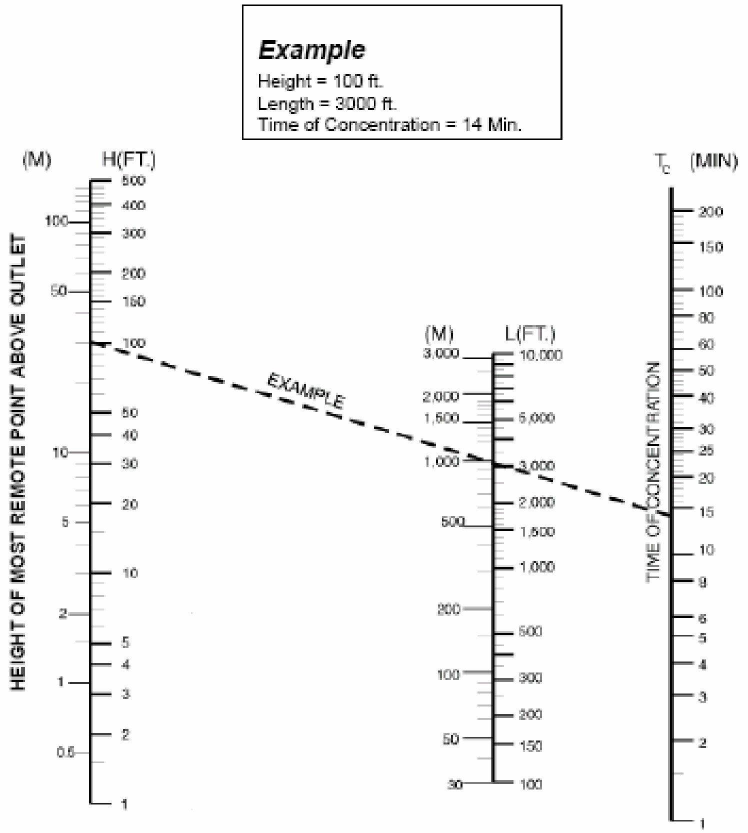
Residential	
Single family	0.30 to 0.50
Multi-units (detached)	0.40 to 0.60
Multi-units (attached)	0.60 to 0.75
Residential (suburban)	0.25 to 0.40
Apartment	0.50 to 0.70

Depending upon the source of the Coefficients, there can be a significant amount of variability!

Time of Concentration Nomographs

Figure 7.1

TIME OF CONCENTRATION



Notes:

Use Nomograph T_c for natural basins with well-defined channels, for overland or bare earth, and for mowed grass roadside channels.

For overland flow, grassed surfaces, multiply T_c by 2.

For overland flow, concrete or asphalt surfaces, multiply T_c by 0.4.

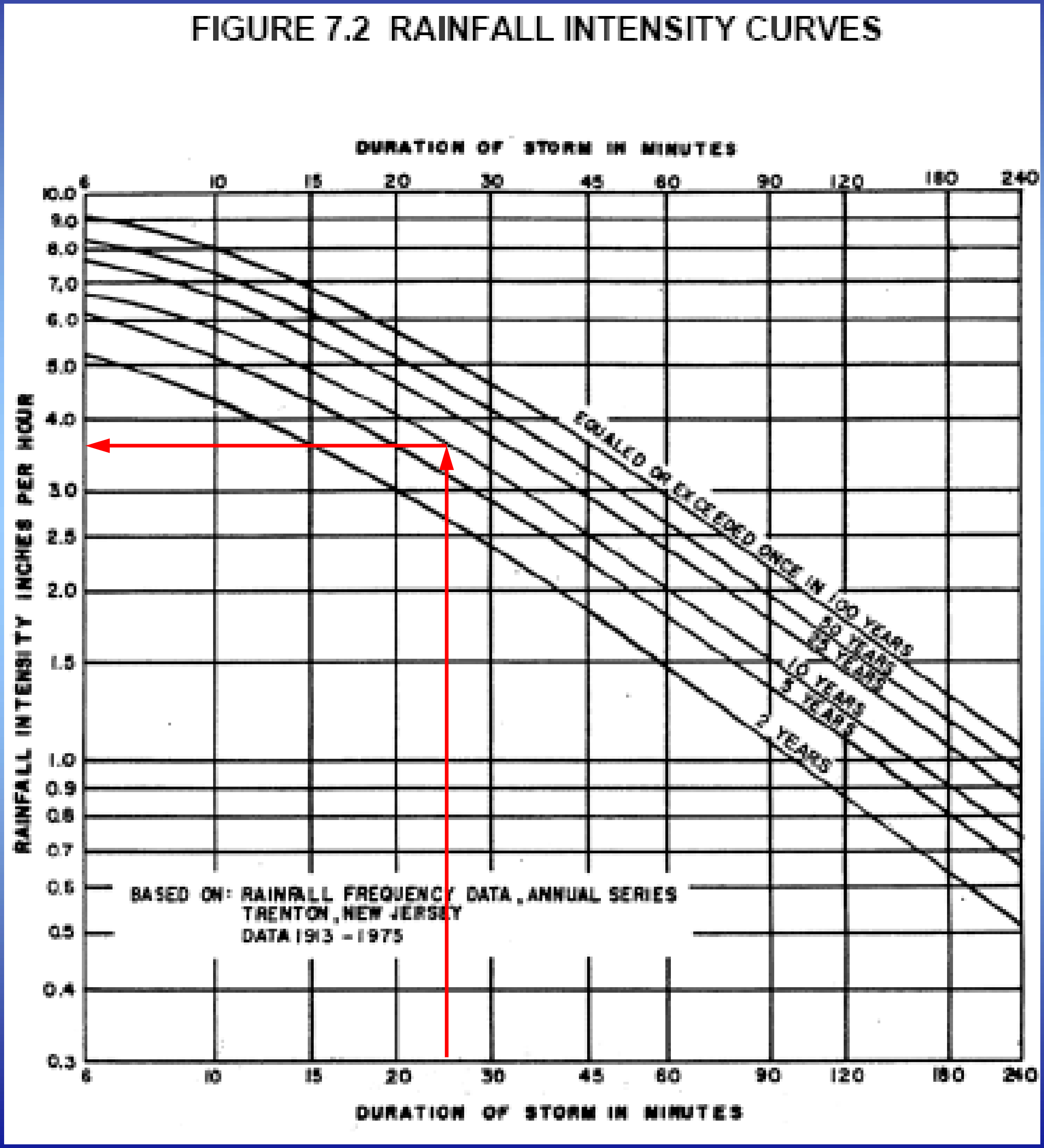
For concrete channels, multiply T_c by 0.2 overland flow.

Based on a study by P.Z. Kirpich, *Civil Engineering*, Vol.10, No.6, June 1940, p. 362.

Compare the results from nomographs with the segmental T_C method contained within TR-55.

If the difference adversely effects the analysis, request a segmental analysis.

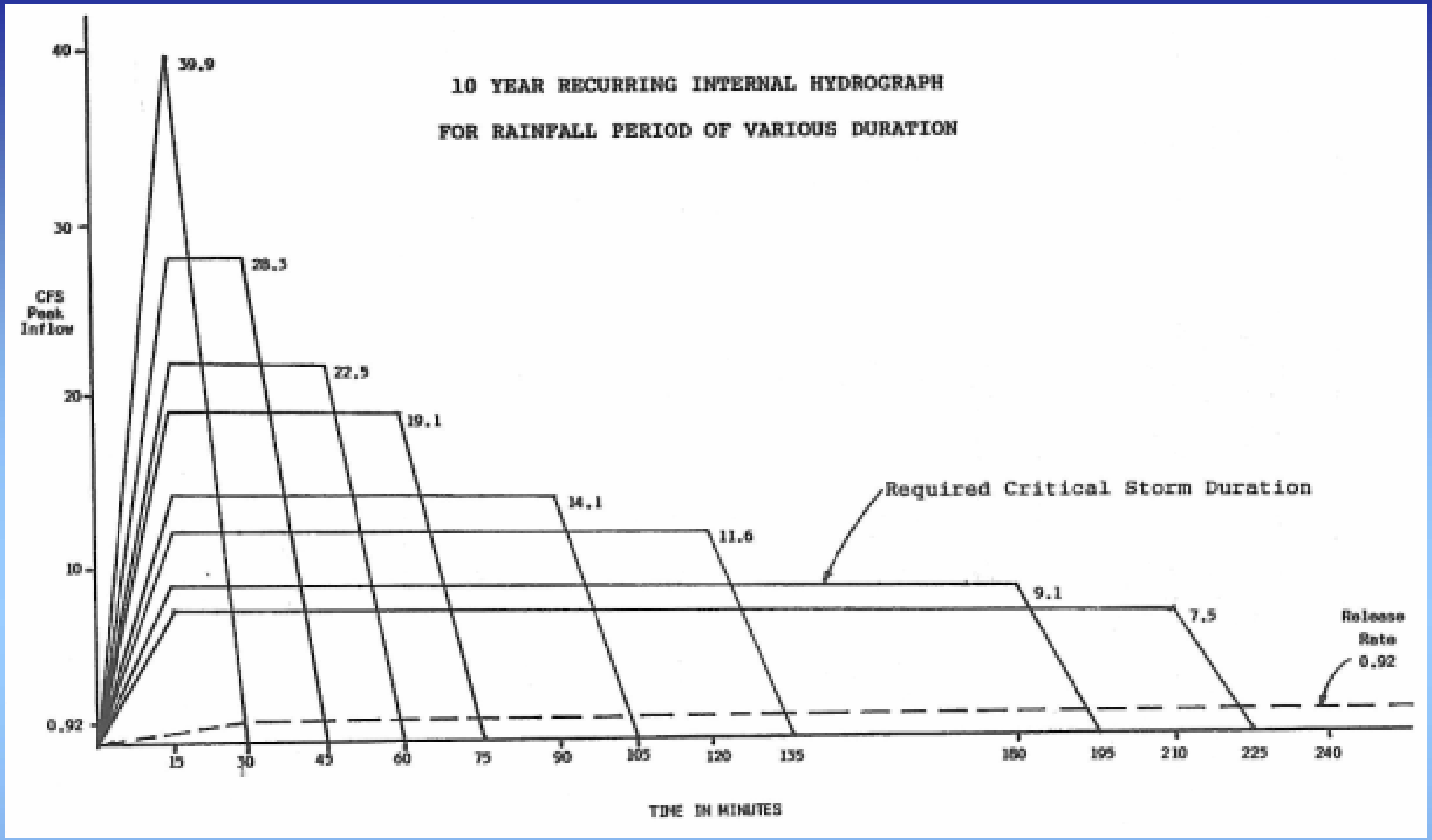
Rainfall Intensities Based upon I-D-F Curves



Rainfall Intensities are obtained by entering the Log- Log nomograph with the Time of Concentration along the abscissa, intersecting the Storm Return Period Curve, and proceeding horizontally to the Rainfall Intensity.

As the T_C goes up, the “I” goes down.

But what is the Modified Rational Method (MRM) ?



A series of "Trapezoidal" shaped hydrographs are created for different Storm Durations. The "I" in the Rational equation is based upon the duration and not the Time of Concentration, However the hydrographs initially peak at the original Time of Concentration. The runoff volume from the pre-development hydrograph is subtracted from each of the runoff volumes (areas under the Trapezoid), for each storm duration. **The greatest difference in volume between the pre and post hydrographs becomes your critical hydrograph with respective critical storm duration.**

MRM Maximum Storage Volume Calculations

Third step. Construct a series of hydrographs for each selected duration of the storm as shown in figure A9.1, Modified Rational Method Hydrographs. The estimated critical storage for this site is 88,858 cubic feet. Since the inflow volume must equal the outflow volume of 98,794 cubic feet, the time to the end of the release rate is 30.3. To reach zero outflow approximately 0.5 hours must be added so the total dewatering time will be about 30.3 hours. The outflow hydrograph reaches maximum flow at the intersection with the falling limb of the hydrograph resulting from a storm with a duration equal to the time of concentration.

<u>Table A9.2</u>

<u>Storage-Duration Values</u>

Duration of Storm (hr) (1)	Intensity I (in/hr) (2)	Peak Flow Q (cfs) (3)	Volume of Runoff (cuft) (4)	Release Flow Volume (cuft) (5)	Required Storage Volume (cuft) (6)
0.25	4.8	39.9	35,925	828	35,097
0.50	3.4	28.3	50,894	1,656	49,238
0.75	2.7	22.5	60,624	2,484	58,140
1.00	2.3	19.1	68,856	3,312	65,544
1.50	1.7	14.1	76,341	4,968	71,373
2.00	1.4	11.6	83,825	6,624	77,201
3.00	1.1	9.1	98,794	9,936	88,858 << Maximum Storage Volume Required
3.50	0.9	7.5	94,303	11,592	82,711

Column (3) Peak Flow = Q = c i a
example : 0.7 X 4.8 X 11.88 = 39.9 cfs

Column (4) Runoff Volume = Q (col 3) X Duration of Storm (col. 1) X 3600
example : 39.9 cfs X 0.25 hrs X 3600 = 35,925 cuft

Column (5) Release Volume = 0.92 cfs X Duration of Storm (col. 1) X 3600
example : 0.92 X 0.25 X 3600 = 828 cuft

Column (6) Required Storage = Runoff Volume (col. 4) - Release Volume (col 5)
example : 35,925 - 828 = 35,097

Compare Rational Method Hydrograph to a TR-55 Hydrograph (Pre-Dev.)

Drainage Area = 10.0 Acres

T_C = 0.50 hours

Land Use = Meadow in Good Condition, HSG – C

Runoff Curve Number = 71 *(TR-55)*

Runoff Coefficient = 0.44 *(MRM)*

10 Year Storm

What is the difference between Runoff Volumes, Peak Flow Rates and Hydrograph Shape?

Comparison between TR-55 and Rational Method Hydrographs – TR-55 (Pre-Dev.):

WinTR-55 Small Watershed Hydrology

Project Identification Data

User: PS State: New Jersey

Project: Exa,ple County: Mercer

Subtitle: Execution Date: 11/29/2008

Sub-areas are expressed in: (•) Acres ( ) Square Miles

Dimensionless Unit Hydrograph: <standard>

Storm Data Source: User-provided custom storm data

Rainfall Distribution Identifier: Type III

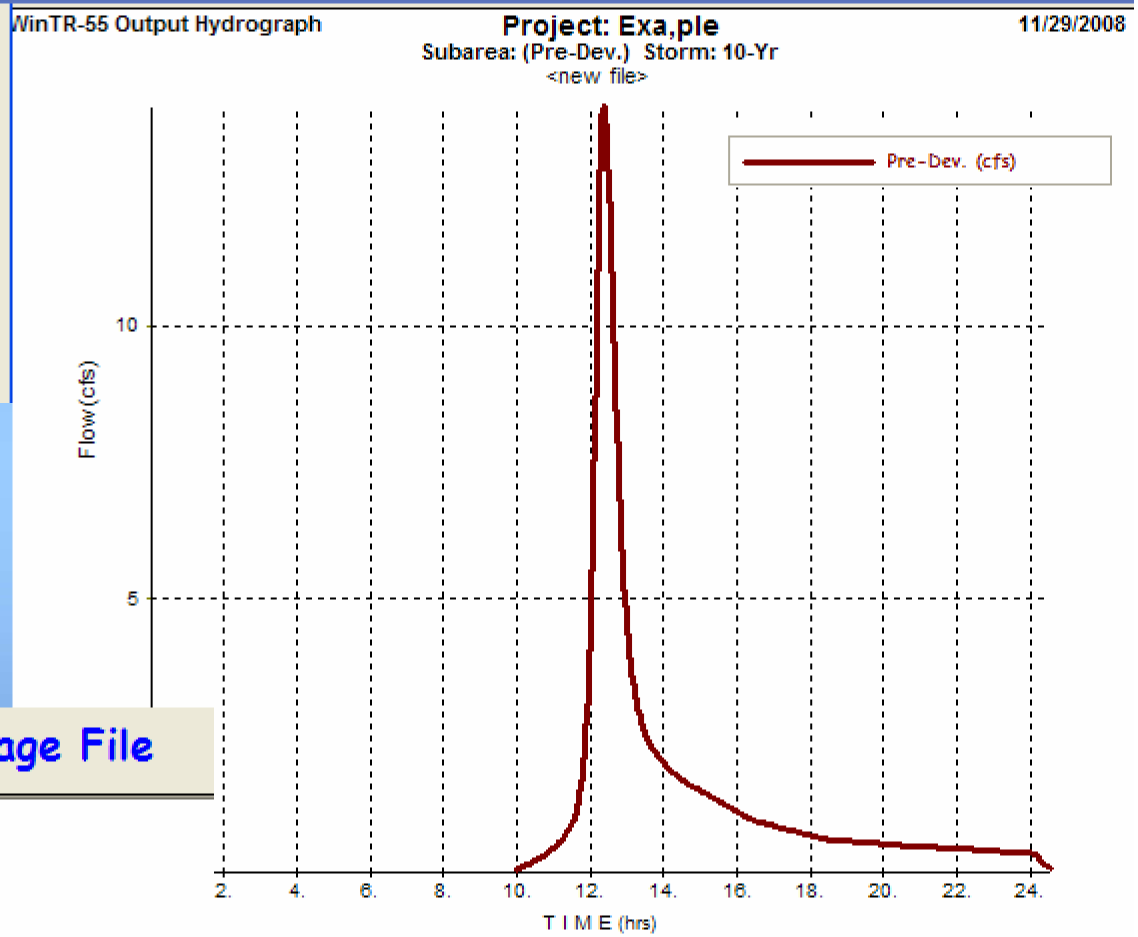
Sub-area Entry and Summary

Sub-area Name	Sub-area Description	Sub-area Flows to Reach/Outlet	Area (ac)	Weighted CN	Tc (hr)
Pre-Dev.		Outlet	10.00	71	0.500

Q_{PEAK} = 14.03 cfs

T_{PEAK} = 12.38 Hours

Volume = 76,775 cf



WinTR-20 Printed Page File

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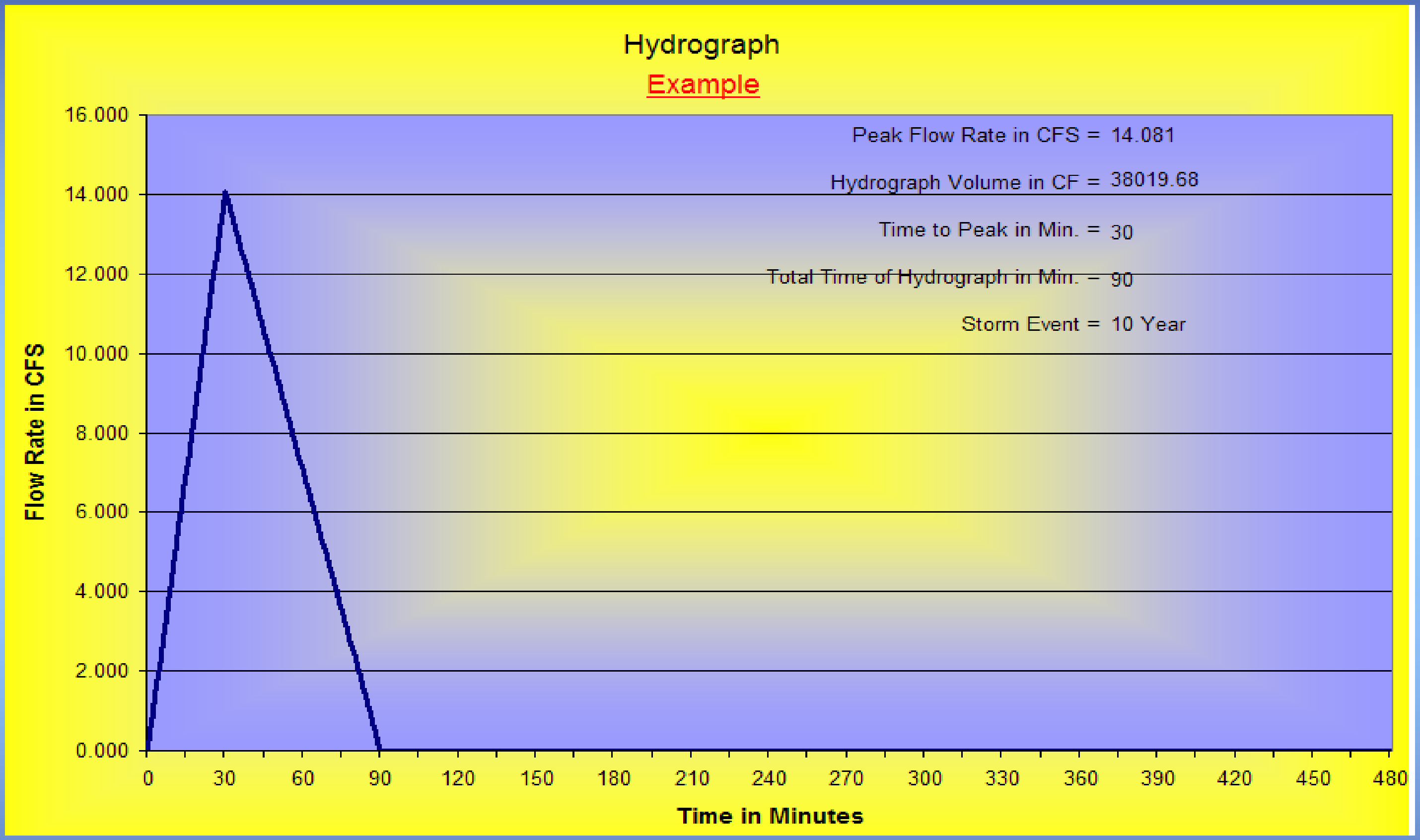
                           TR20.out

                                        STORM 10-Yr

Area or     Drainage   Rain Gage     Runoff    ------------ Peak Flow ----
 Reach        Area      ID or        Amount    Elevation    Time      Rate
Identifier  (sq mi)    Location       (in)       (ft)       (hr)     (cfs)

Pre-Dev.      0.016                  2.115                  12.38     14.03
```

Comparison between TR-55 and Rational Method Hydrographs – Rational Method (Pre-Dev.):



Q_{PEAK} = 14.08 cfs

T_{PEAK} = 30 Min.

Volume = 38,020 cf

Comparison between TR-55 and Rational Method Hydrographs (Pre-Dev.)

	Tr-55	Rational	Difference
Q_{PEAK}	14.03 cfs	14.08 cfs	Negligible
T_{PEAK}	12.38 Hrs.	0.50 Hrs.	Significant
Vol.	76,775 cf	38,020 cf	Significant

Compare Modified Rational Method (MRM) Hydrograph to a TR-55 Hydrograph (Post-Dev.)

Drainage Area = 10.0 Acres

T_C = 0.20 hours

Land Use = Industrial, HSG – C

Runoff Curve Number = 91 *(TR-55)*

Runoff Coefficient = 0.88 *(MRM)*

10 Year Storm

Pre-Development $Q_{PEAK\ 10\ YEAR}$ *= 14.03 cfs*

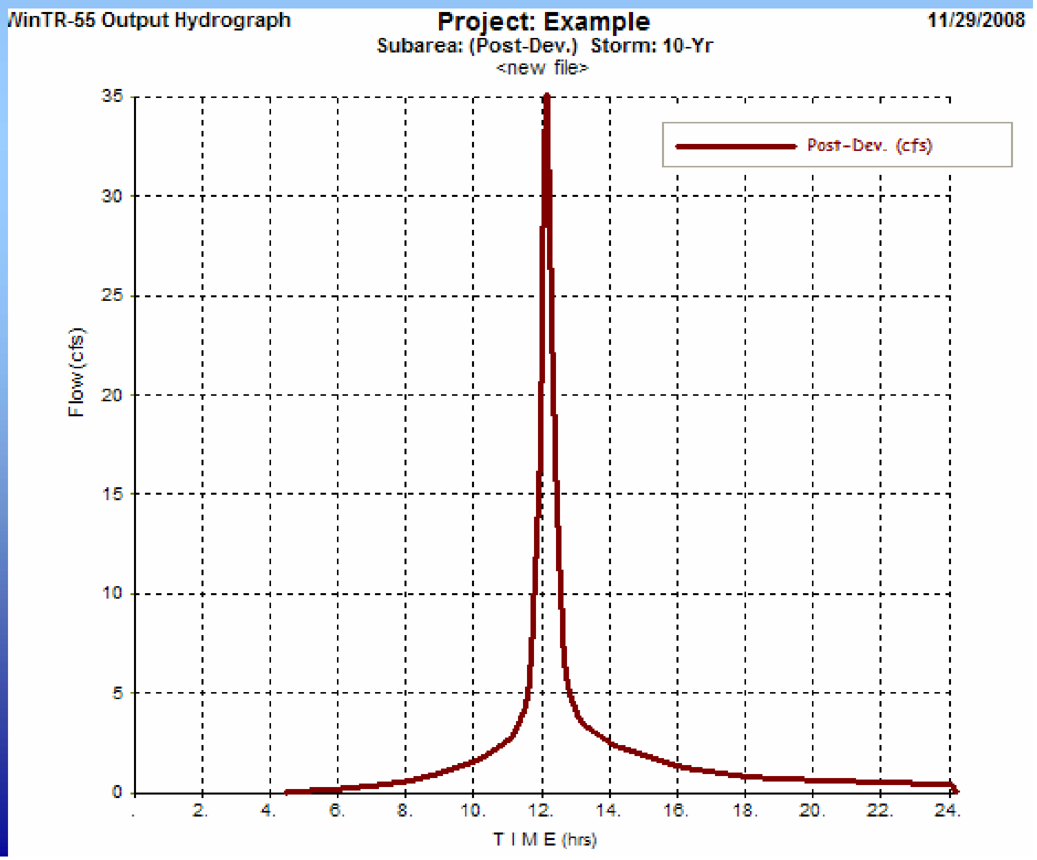
What is the difference between Runoff Volumes, Peak Flow Rates and Hydrograph Shape?

Comparison between TR-55 and Rational Method Hydrographs – TR-55 (Post-Dev.):

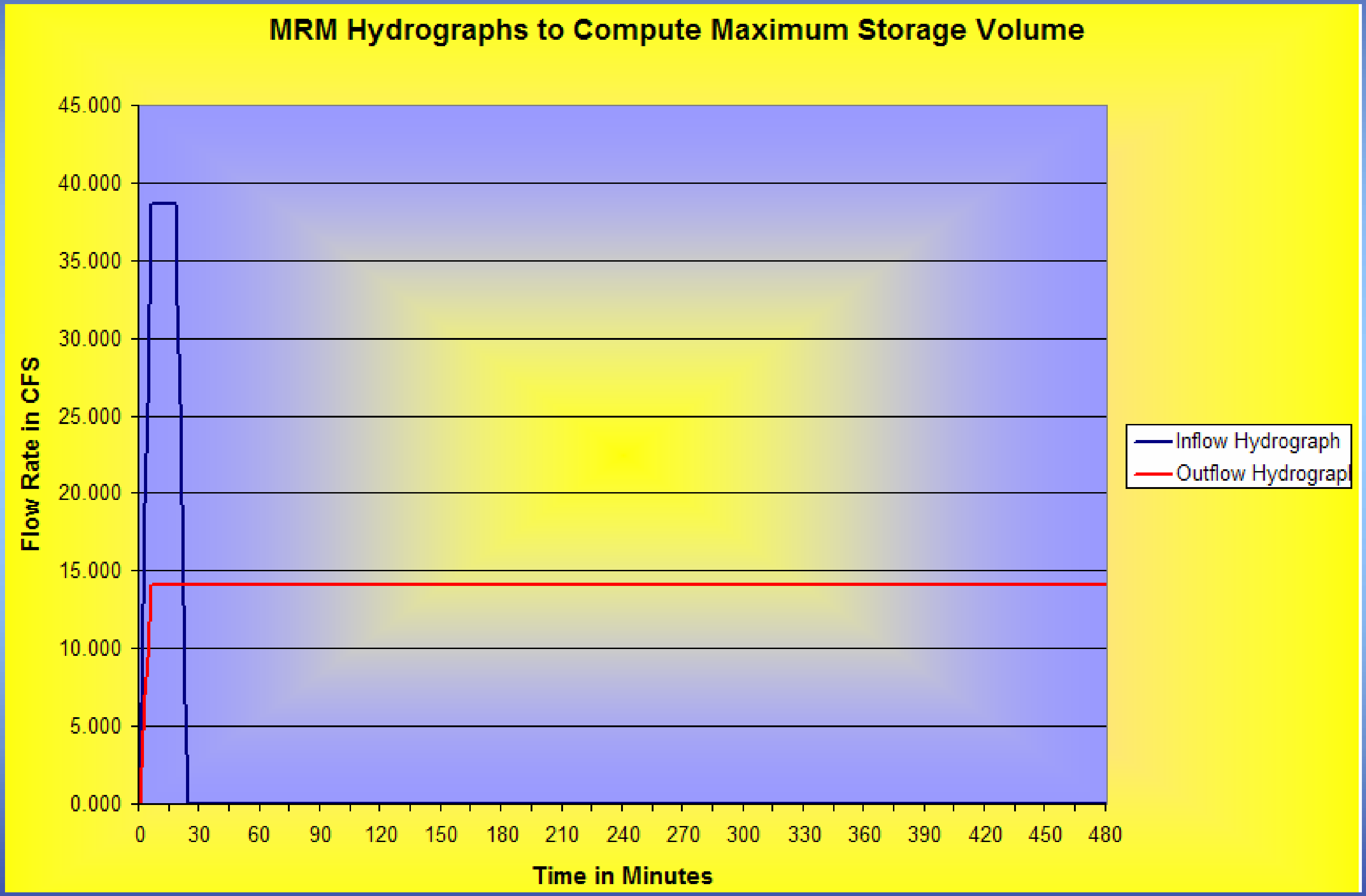
WinTR-20 Printed Page File

Area or Reach Identifier	Drainage Area (sq mi)	Rain Gage ID or Location	Runoff Amount (in)	------------ Peak Flow ------------ Elevation (ft)	Time (hr)	Rate (cfs)	Rate (csm)
Post-Dev.	0.016		3.980		12.11	38.46	2460.78

Q_{PEAK} = 38.46 cfs
T_{PEAK} = 12.11 Hours
Volume = 144,474 cf



Comparison between TR-55 and Rational Method Hydrographs – Rational Method (Post-Dev.):



Comparison between TR-55 and Rational Method Hydrographs – Rational Method (Post-Dev.):

MRM Maximum Required Storage Volume Computations

Pre-Development Inflow Hydrograph to Establish Allowable Release Rate:	Example
Post-Development Hydrograph to Compute MRM Values:	Post Sub-Area 1
Storm Event Analyzed:	**10 Year Storm**
Maximum Required Storage Volume in CF:	**26534.78**
Pre - Development Values:	
Pre-Development Peak Flow Rate (Allowable Release Rate) in CFS:	14.08
Pre-Development Release Volume in CF:	15207.87
Post - Development Values:	
Post-Development Peak Flow Rate for the Maximum Storage Volume in CFS:	38.65
Post-Development Runoff Volume for this Peak Flow Rate in CF:	41742.65
Storm Duration for this Volume in Minutes:	18
Storm Intensity for the Maximum Duration in Inches per Hour:	4.392
Total Time of MRM Hydrograph in Minutes:	24
Time of Concentration in Minutes:	6

Q_{PEAK} = 38.65 cfs

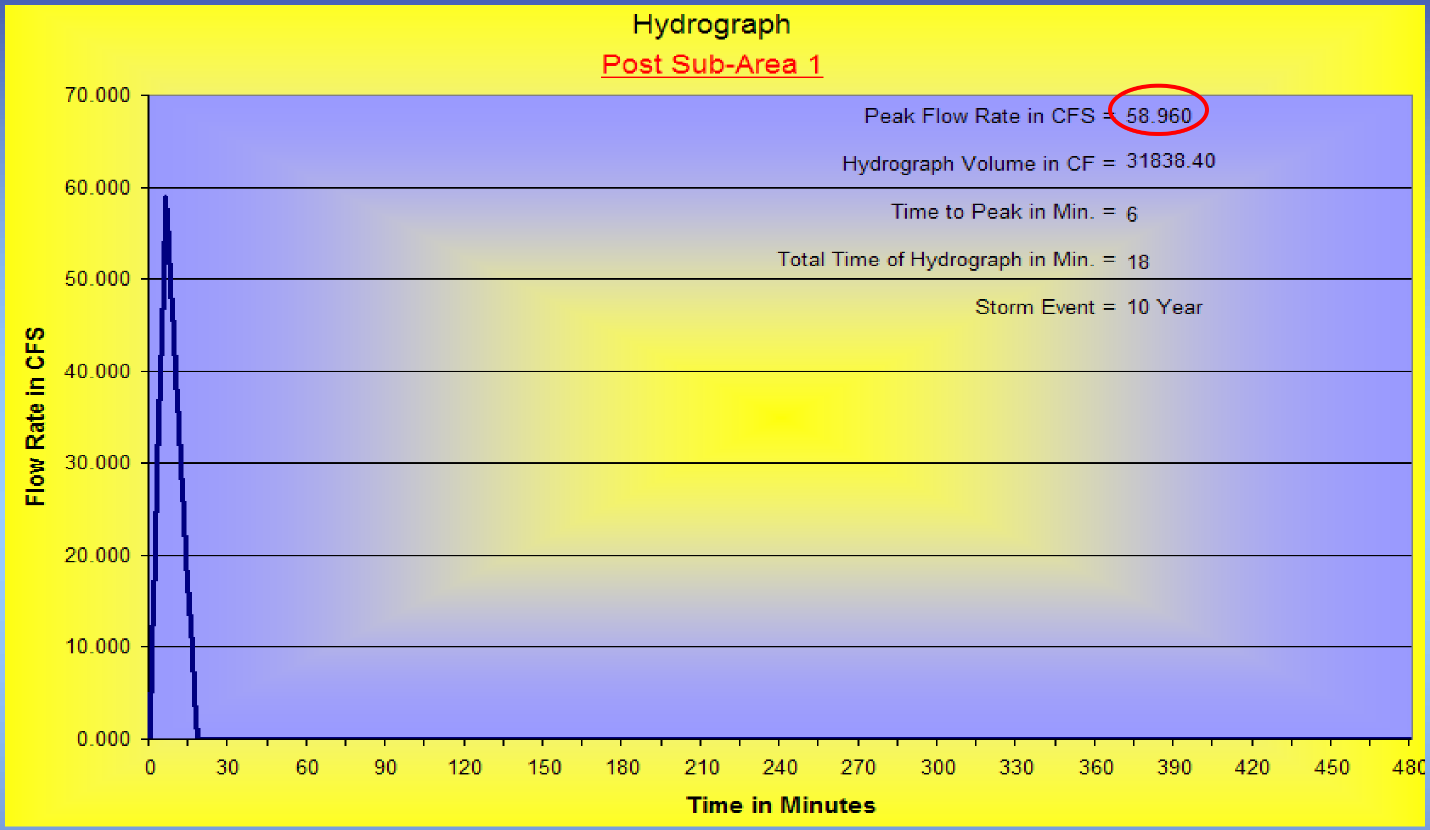
T_{PEAK} = 0.10 Hours

Volume = 41,743 cf

Comparison between TR-55 and Rational Method Hydrographs (Post-Dev.)

	Tr-55	MRM	Difference
Q_{PEAK}	38.46 cfs	38.65 cfs	Negligible
T_{PEAK}	12.11 Hrs.	0.10 Hrs.	Significant
Vol.	144,474 cf	41,743 cf	Significant

Comparison between TR-55 and Rational Method Hydrographs – Rational Method (Post-Dev.):



Remember, the actual Q_{PEAK} will be based upon the Standard Rational Method Equation, not the MRM Equation.

Therefore, if this were an inflow point into the detention basin, the storm drain and the Conduit Outlet Protection would need to be sized for this Q_{PEAK}.

How do the two (2) methods compare when the drainage area is smaller?

Pre-Development:

Drainage Area = 2.0 Acres

T_C = 0.40 hours

Land Use = Pasture in Good Condition,

HSG – B

Runoff Curve Number = 61 *(TR-55)*

Runoff Coefficient = 0.25 *(MRM)*

100 Year Storm

What is the difference between Runoff Volumes, Peak Flow Rates and Hydrograph Shape?

Comparison between TR-55 and Rational Method Hydrographs – TR-55 (Pre-Dev.):

Example
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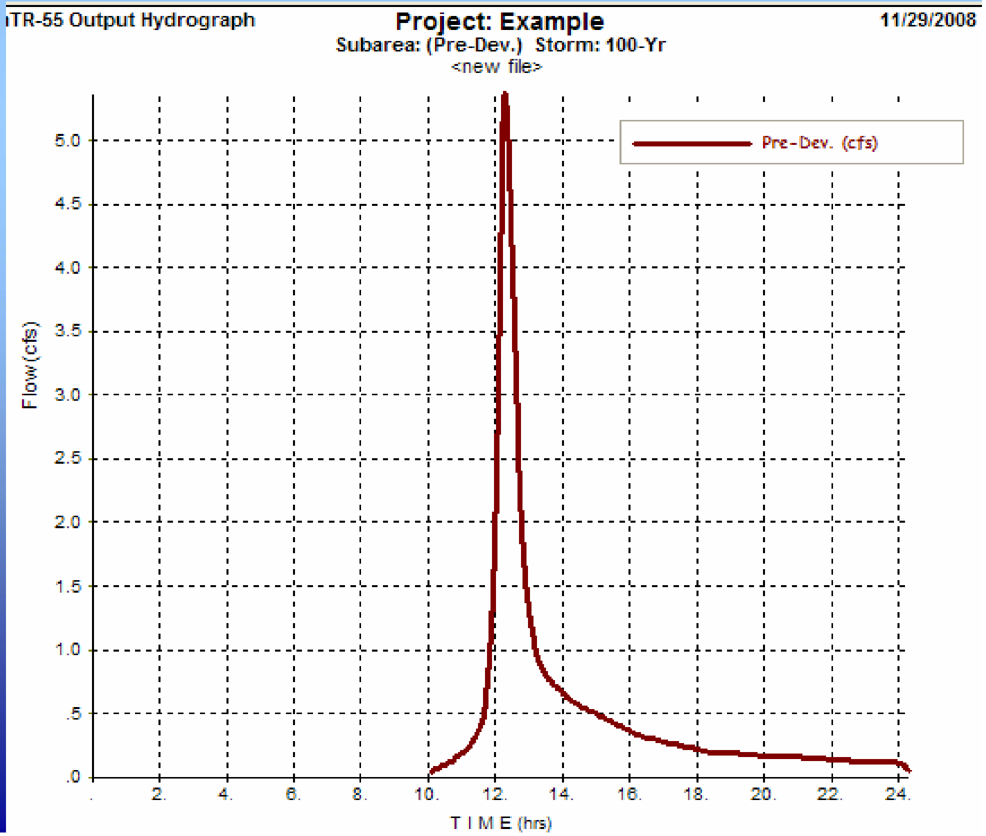
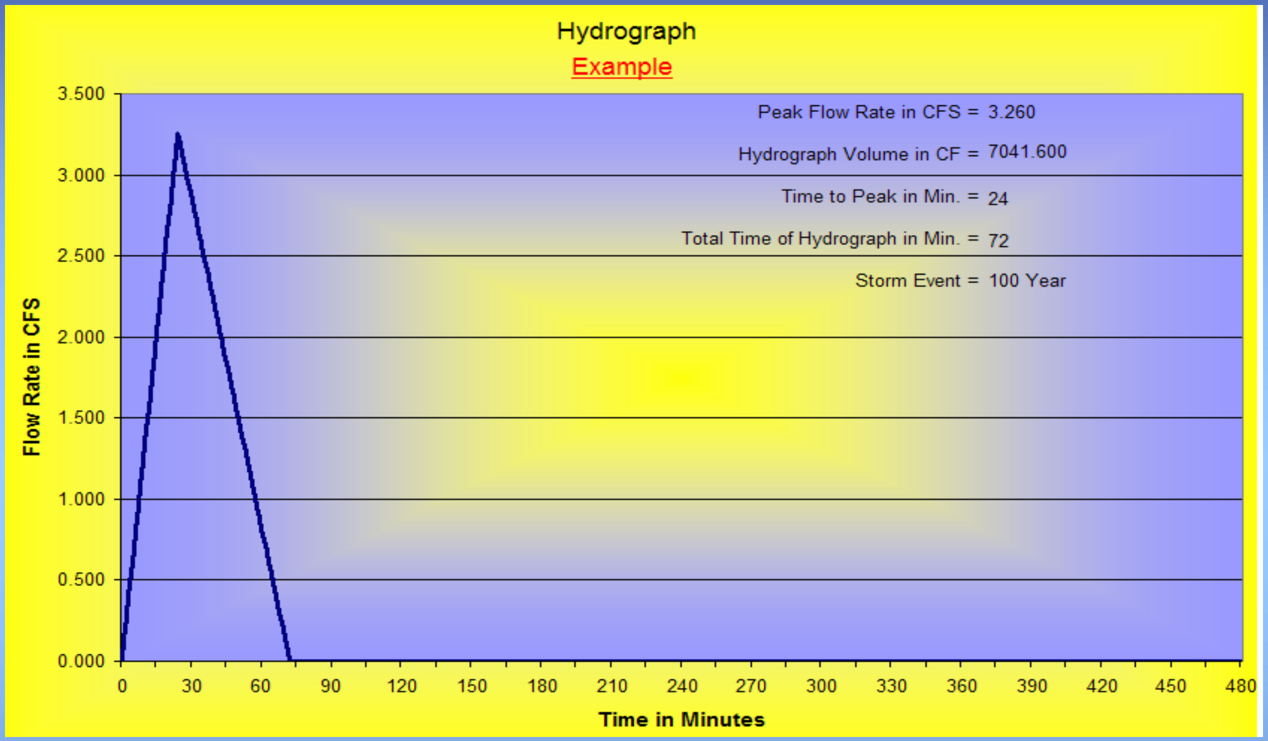
STORM 100-Yr

Area or Reach Identifier	Drainage Area (sq mi)	Rain Gage ID or Location	Runoff Amount (in)	------------ Peak Flow ------------ Elevation (ft)	Time (hr)	Rate (cfs)	Rate (csm)
Pre-Dev.	0.003		3.665		12.30	5.37	1716.36

Q_{PEAK} = 5.37 cfs
T_{PEAK} = 12.30 Hours
Volume = 26,608 cf



Comparison between TR-55 and Rational Method Hydrographs – Rational Method (Pre-Dev.):



Q_{PEAK} = 3.26 cfs

T_{PEAK} = 24 Min.

Volume = 7,042 cf

Comparison between TR-55 and Rational Method Hydrographs (Pre-Dev.)

	Tr-55	MRM	Difference
Q_{PEAK}	5.37 cfs	3.26 cfs	Significant
T_{PEAK}	12.30 Hrs.	0.40 Hrs.	Significant
Vol.	26,608 cf	7,042 cf	Significant

How do the two (2) methods compare when the drainage area is smaller?

Post-Development:

Drainage Area = 2.0 Acres

T_C = 0.10 hours

Land Use = Commercial & Business,

HSG – B

Runoff Curve Number = 92 *(TR-55)*

Runoff Coefficient = 0.90 *(MRM)*

100 Year Storm

What is the difference between Runoff Volumes, Peak Flow Rates and Hydrograph Shape?

Comparison between TR-55 and Rational Method Hydrographs – TR-55 (Post-Dev.):

Example
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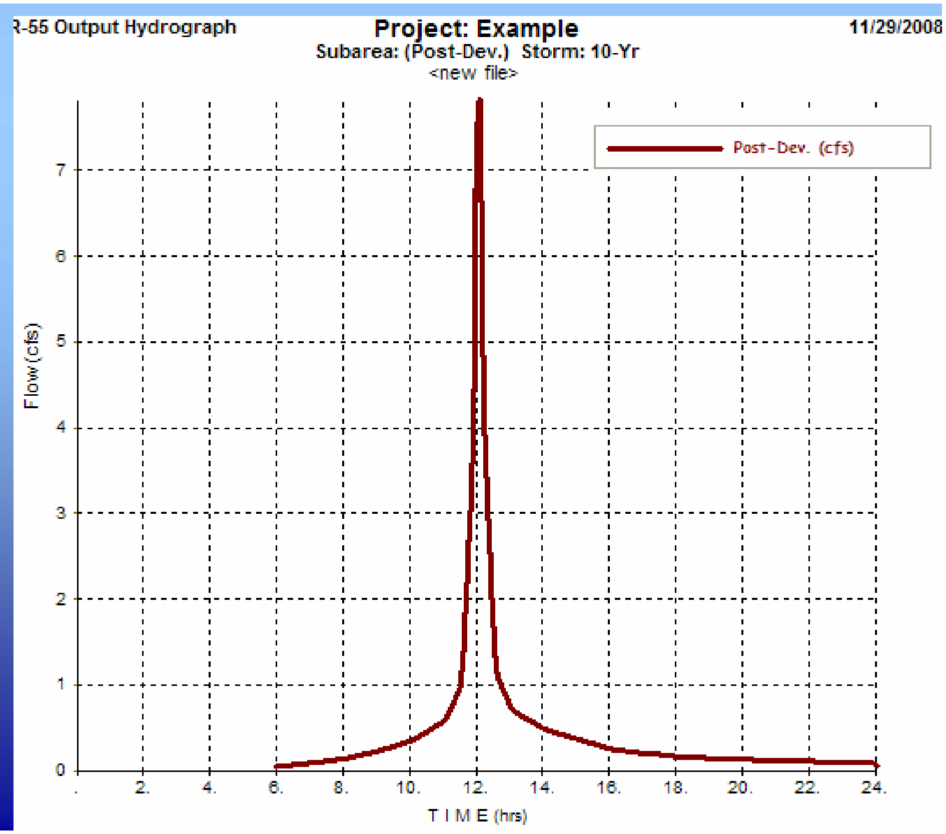
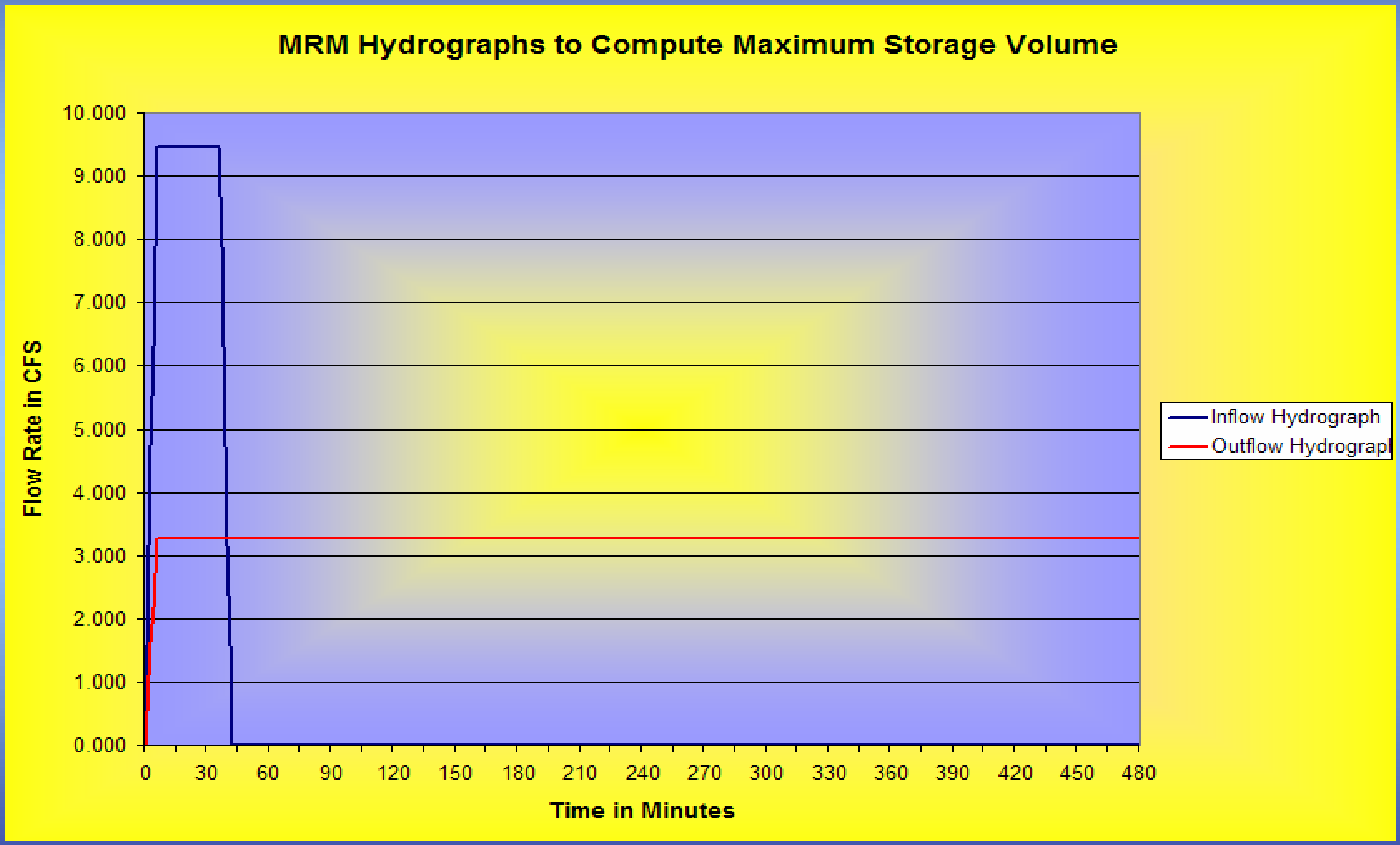
STORM 100-Yr

Area or Reach Identifier	Drainage Area (sq mi)	Rain Gage ID or Location	Runoff Amount (in)	Peak Flow Elevation (ft)	Peak Flow Time (hr)	Peak Flow Rate (cfs)	Peak Flow Rate (csm)
Post Dev.	0.003		7.323		12.10	13.55	4328.69

Q_{PEAK} = 13.55 cfs
T_{PEAK} = 12.10 Hrs.
Volume = 53,165 cf



Comparison between TR-55 and Rational Method Hydrographs – Rational Method (Post-Dev.):



Comparison between TR-55 and Rational Method Hydrographs – Rational Method (Post-Dev.):

MRM Maximum Required Storage Volume Computations

Pre-Development Inflow Hydrograph to Establish Allowable Release Rate:	Example
Post-Development Hydrograph to Compute MRM Values:	Post Sub-Area 1
Storm Event Analyzed:	**100 Year Storm**
Maximum Required Storage Volume in CF:	**13399.62**

Pre - Development Values:

Pre-Development Peak Flow Rate (Allowable Release Rate) in CFS:	3.26
Pre-Development Release Volume in CF:	7041.60

Post - Development Values:

Post-Development Peak Flow Rate for the Maximum Storage Volume in CFS:	9.46
Post-Development Runoff Volume for this Peak Flow Rate in CF:	20441.22
Storm Duration for this Volume in Minutes:	36
Storm Intensity for the Maximum Duration in Inches per Hour:	4.206
Total Time of MRM Hydrograph in Minutes:	42
Time of Concentration in Minutes:	6

Q_{PEAK} = 9.46 cfs

T_{PEAK} = 0.10 Hours

Volume = 20,441 cf

Comparison between TR-55 and Rational Method Hydrographs (Post-Dev.)

	Tr-55	MRM	Difference
Q_{PEAK}	13.55 cfs	9.46 cfs	Noticeable / Significant
T_{PEAK}	12.10 Hrs.	0.10 Hrs.	Significant
Vol.	53,164 cf	20,441 cf	Significant

Summary:

1. Rational / MRM Peak Flow Rates are reasonably close to TR-55 for larger drainage areas.
2. Runoff Volumes are significantly different for the two methods, (Rational / MRM volumes can be 3 to 4 times less then TR-55 volumes).
3. The Time to Peak is significantly different for both methods.
4. Rational / MRM Peak Flow Rates can be significantly different from TR-55 for smaller drainage areas.
5. A detention basin will be significantly smaller when Flood Routing an MRM hydrograph for a larger drainage area. Basins are more sensitive volume then peak!