

Hybrid Nonlinear Reservoir Routing Algorithm (HNRA)

**A Time of Concentration-agnostic approach
for the Rational Method Framework**

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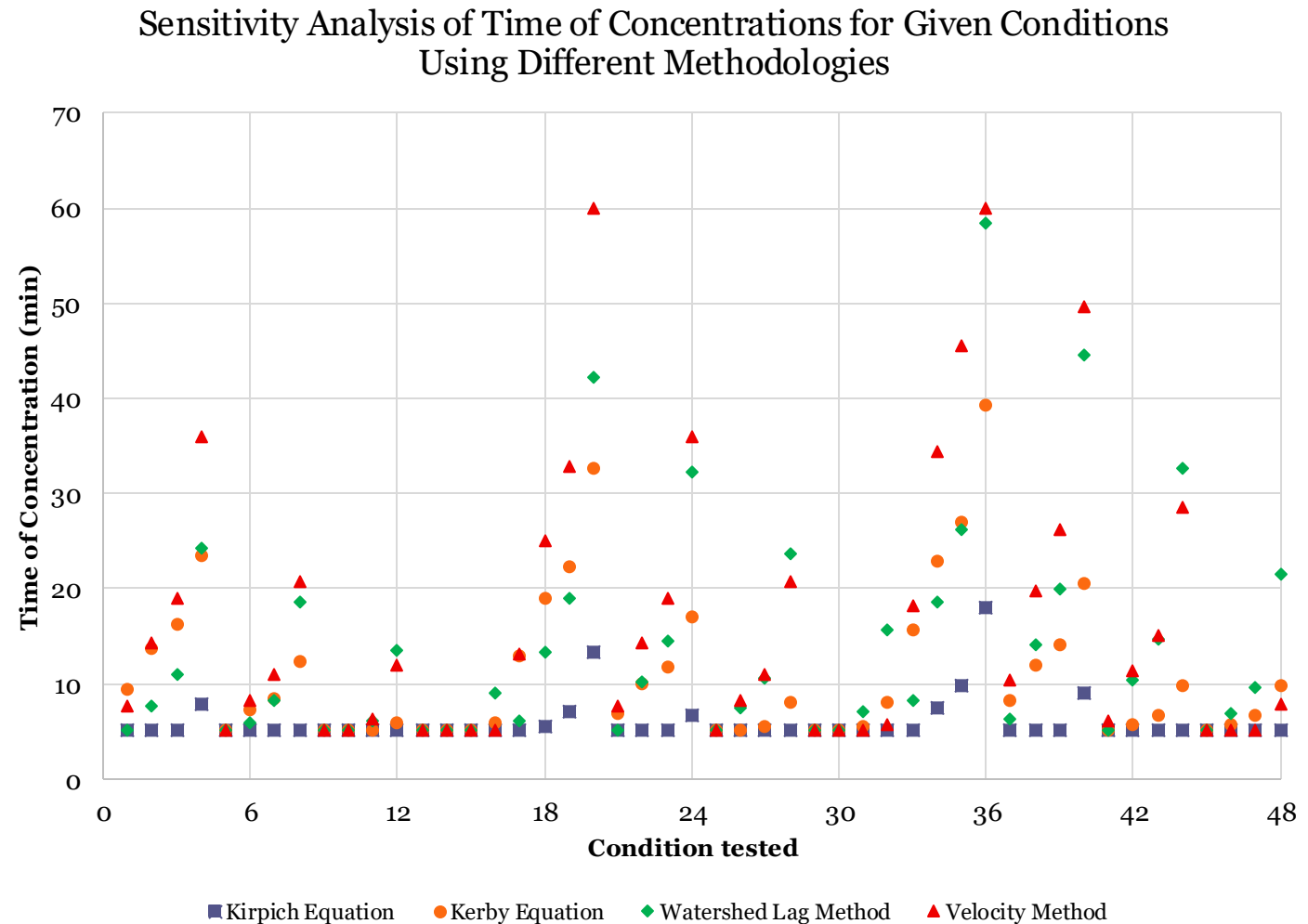
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Rational Method

- One of the oldest approaches for hydrological studies to determine peak flows from a drainage area for a given recurrence interval
- While many improved hydrological approaches have appeared over time, it is still widely applied
- Rational Method use many limiting assumptions, including:
 - Spatiotemporal uniformity of abstractions through a C coefficient
 - Spatiotemporal uniformity of rainfall intensities derived from an IDF
 - Critical rainfall duration matches the time of concentration of the whole drainage area
- Applicable to smaller areas (<80 Ha or 200 acres)
- Difficulties in determining the time of concentration T_c

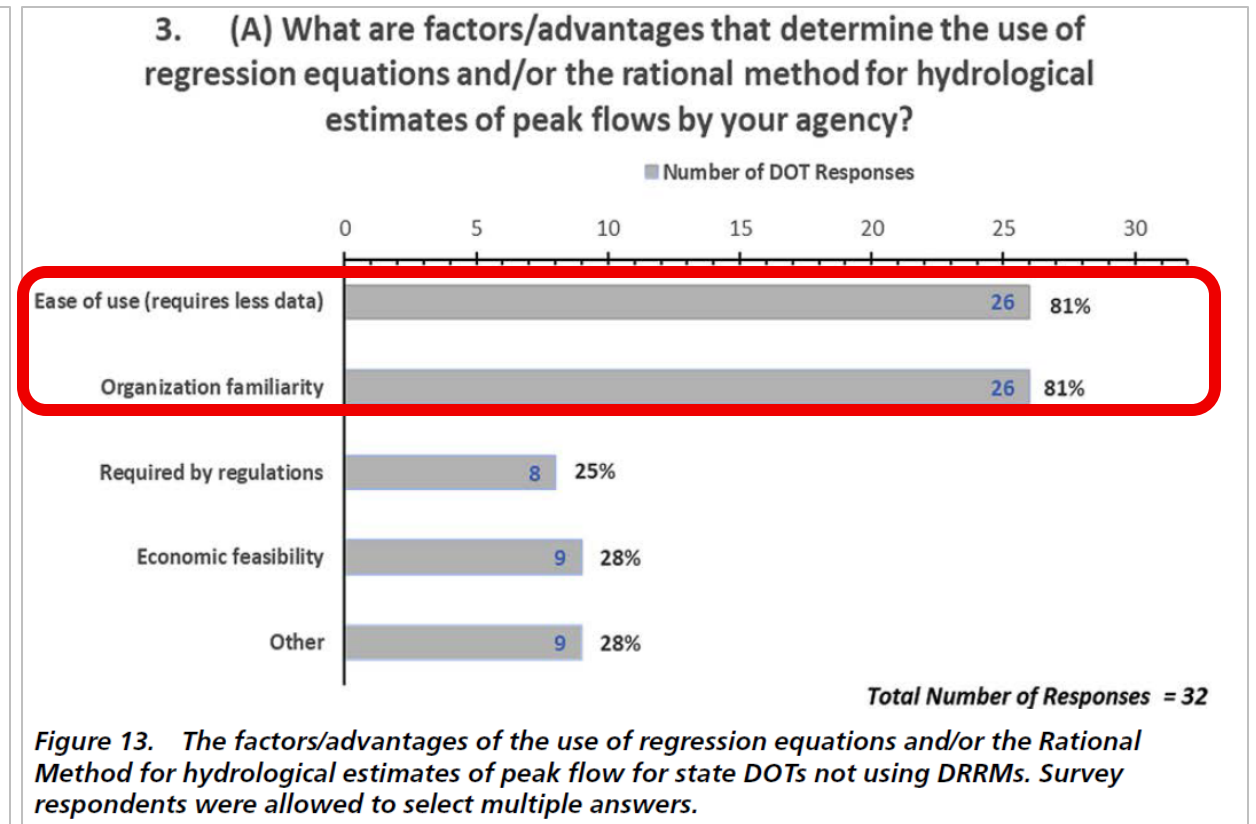
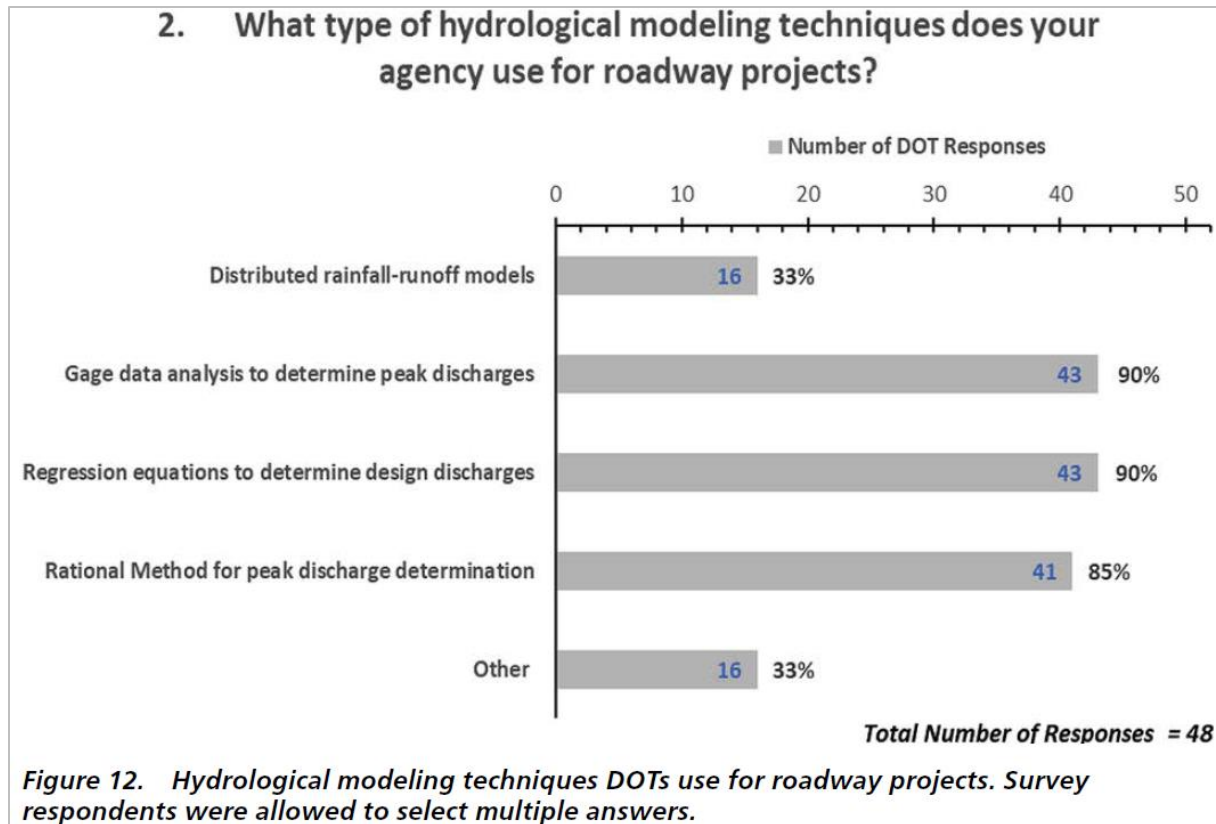
Results of Time of Concentration Sensitivity Analysis

- Different Tc formulas yield very different predictions the same set of slopes, flow path lengths, and types of ground cover/roughness.
 - Test conditions created by varying Curve Number, Slope, Roughness, Ground Cover, and Flow Length



Despite limiting assumptions, the Rational Method is still widely used across DOTs and municipalities in the US

- NCHRP Synthesis 602, Questions 2 and 3 (NAE 2023)

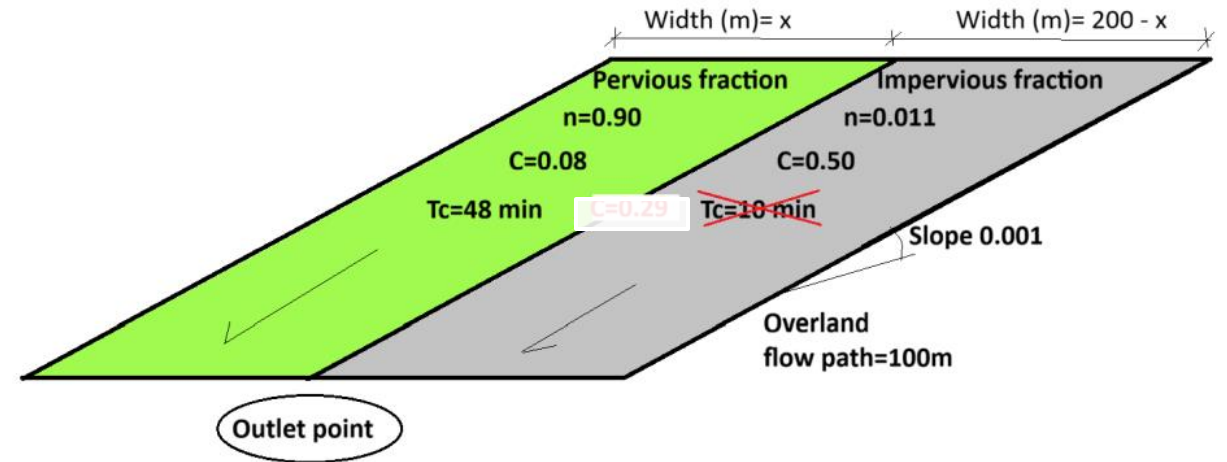


Improving the Rational Method

- Under the general goal of keeping using the Rational Method for smaller subcatchments, can the method yield more representative predictions while retaining its low data requirements?
- Which problems and limitations with the method can be addressed?
 1. Avoid combining/lumping subcatchments of very different characteristics (e.g., averaging C)
 2. While still using IDF curve/data, do not assume largest T_c correspond to the critical rainfall duration
 3. Could the calculations be performed without T_c uncertainties?
- Items 1 and 2 have been studied before. A recent paper proposing the PFSA method (Vasconcelos et al. 2025) outline proposed changes
- Yet, the approach still uses T_c , which introduces uncertainties in peak flow determination

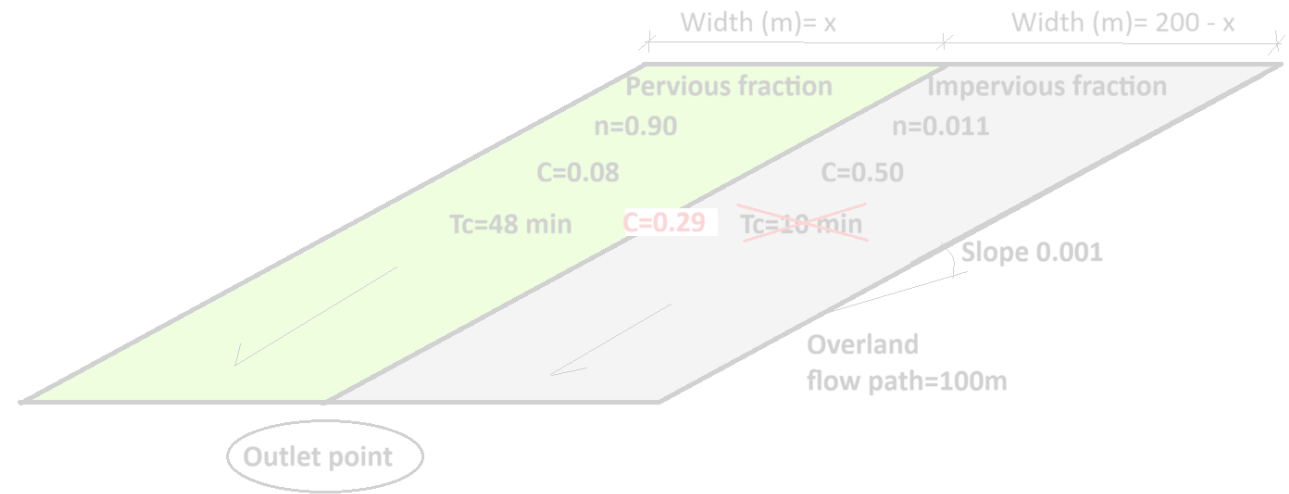
Peak Flow Search Approach

$$Q_p = CiA$$



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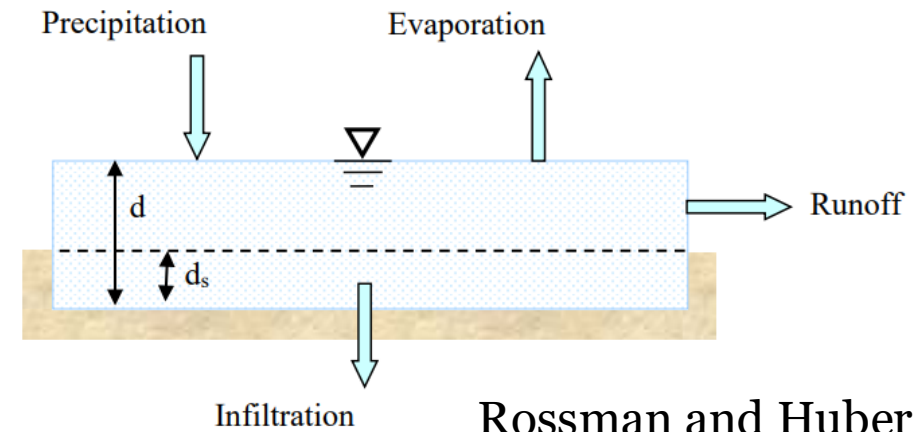
Still dependent on T_c calculations and its uncertainties!

Objectives

- We propose the **Hybrid Nonlinear Reservoir Routing Algorithm (HNRA)**, combining characteristics of SWMM overland routing algorithm with the simplicity of RM data
 - Use **SWMM ideas for overland flow routing to avoid T_c computation**
- By using intensities from the IDF curve, and unique C values from varying lang uses, HNRA performs a heuristic approach to find the critical time when the maximum peak discharge occurs
- This approach is amenable for implementation in easy-to-use tools such as Microsoft Excel

Non-linear Reservoir Routing - SWMM Implementation

- Nonlinear subcatchment discharge evaluated at each time step based on current depth d
- Runoff hydrograph generated directly from computed $Q(d)$
- Outflow is dependent on parameters
 - Subcatchment width W
 - Manning roughness n
 - Subcatchment slope S_o
 - Depression storage d_s
- More realistic fast-rise/slow-recession hydrographs when compared to the Modified Rational Method



Rossman and Huber 2016

$$\frac{\partial d}{\partial t} = i - e - f - \alpha(d - d_s)^{5/3}$$

where α is defined as:

$$\alpha = \frac{1.49WS^{1/2}}{An}$$

Adapting HNRA to Available Rational Method Data

- No time-varying abstractions. The runoff coefficient C and IDF intensity i are used for each subcatchment (no lumping!)
 - Abstraction: $A_b = i \cdot (1 - C)$
- Simpler ODE tracking depth change in a subcatchment over time
 - For $t \leq t_{\text{duration}} \rightarrow \frac{\partial d}{\partial t} = i - A_b - \alpha \cdot d^{5/3} = C \cdot i - \alpha \cdot d^{5/3}$
 - For $t > t_{\text{duration}} \rightarrow \frac{\partial d}{\partial t} = -\alpha \cdot d^{5/3}$
- No assumption is made regarding the critical rainfall duration
 - Rainfall duration and intensity systematically varied from 5 to 60 minutes.
 - Depth and outflow from each subcatchment updated every second
 - Goal is to determine which duration leads to largest peak flow

Test 1 - HNRA vs SWMM Sensitivity Analysis

Comparison for isolated subcatchments

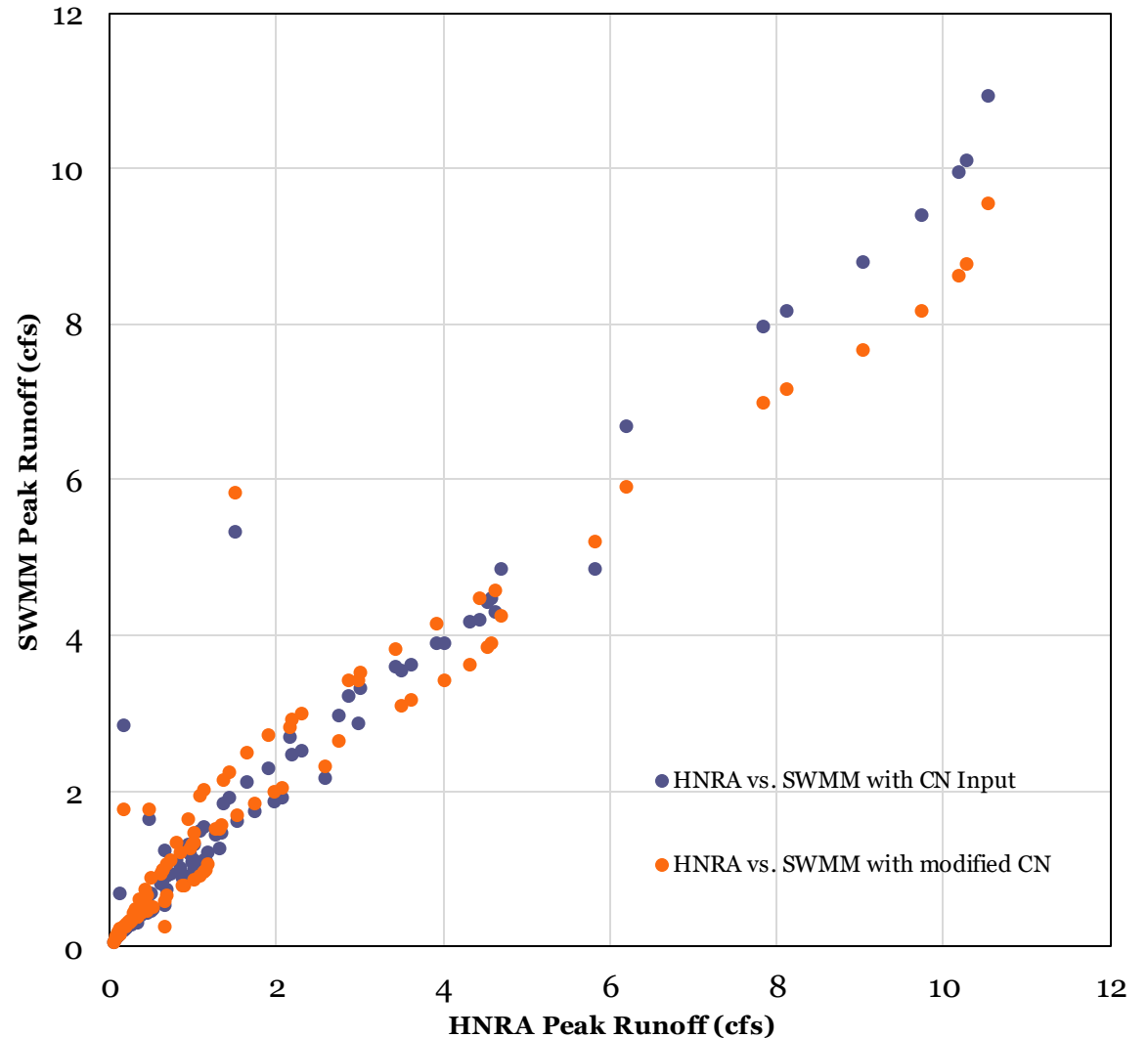
- Tested 144 cases, where C, slope, flow length, and area were varied
- The critical rainfall for HNRA (fixed intensity, duration) was also used as rain time series in SWMM
- Two different methods tested for converting C to Curve Number

Parameter	Range of variation			
Runoff Coefficient	0.25	0.35	0.4	0.7
Manning's Roughness Coefficient	0.2	0.1	0.05	0.01
Curve Number	65	75	85	95
Slope	0.05	0.01	0.005	0.001
Flow path length (ft)	100	200	300	
Subcatchment area (ft ²)	10000	40000	90000	

Results for Test 1 - HNRA vs SWMM Sensitivity Analysis Comparison for isolated subcatchments

Orange Points – CN to C conversion based on Pitt (1999). “Small Storm Hydrology”

Blue Points – CN to C conversion by matching C values from TxDOT Hydraulic Design manual Table 4-10 to NRCS TR-55 CN values



Test 2: HNRA and SWMM Setup for catchments with varying land use characteristics

- Soccer field in Birmingham, AL studied by Yang (2024) using PFSA
- Five sub-areas routed to the outlet with differing characteristics

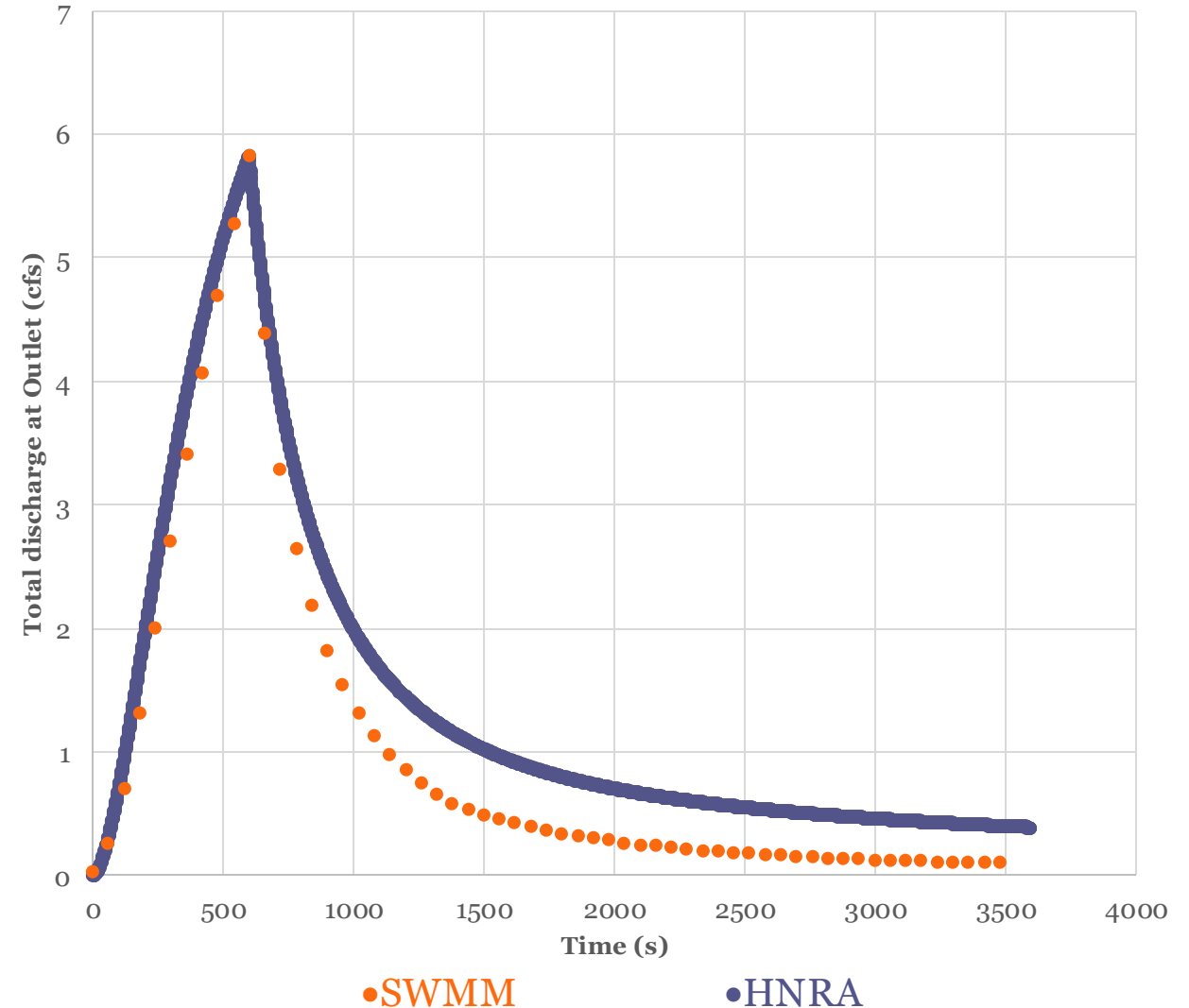
Table 10: Football field Sub-areas parameters

Sub-Area	Area (Acres)	Runoff Coefficient	Slope	CN	% Impervious	Highest Manning n	Relevant flow length (ft)
1	5.23	0.18	0.198	69	10	0.4	598.22
2	4.41	0.1	0.01	61	0	0.15	552.79
3	0.89	0.96	0.01	98	100	0.011	120
4	2.23	0.1	0.01	61	0	0.15	486
5	0.36	0.96	0.03	98	100	0.011	650



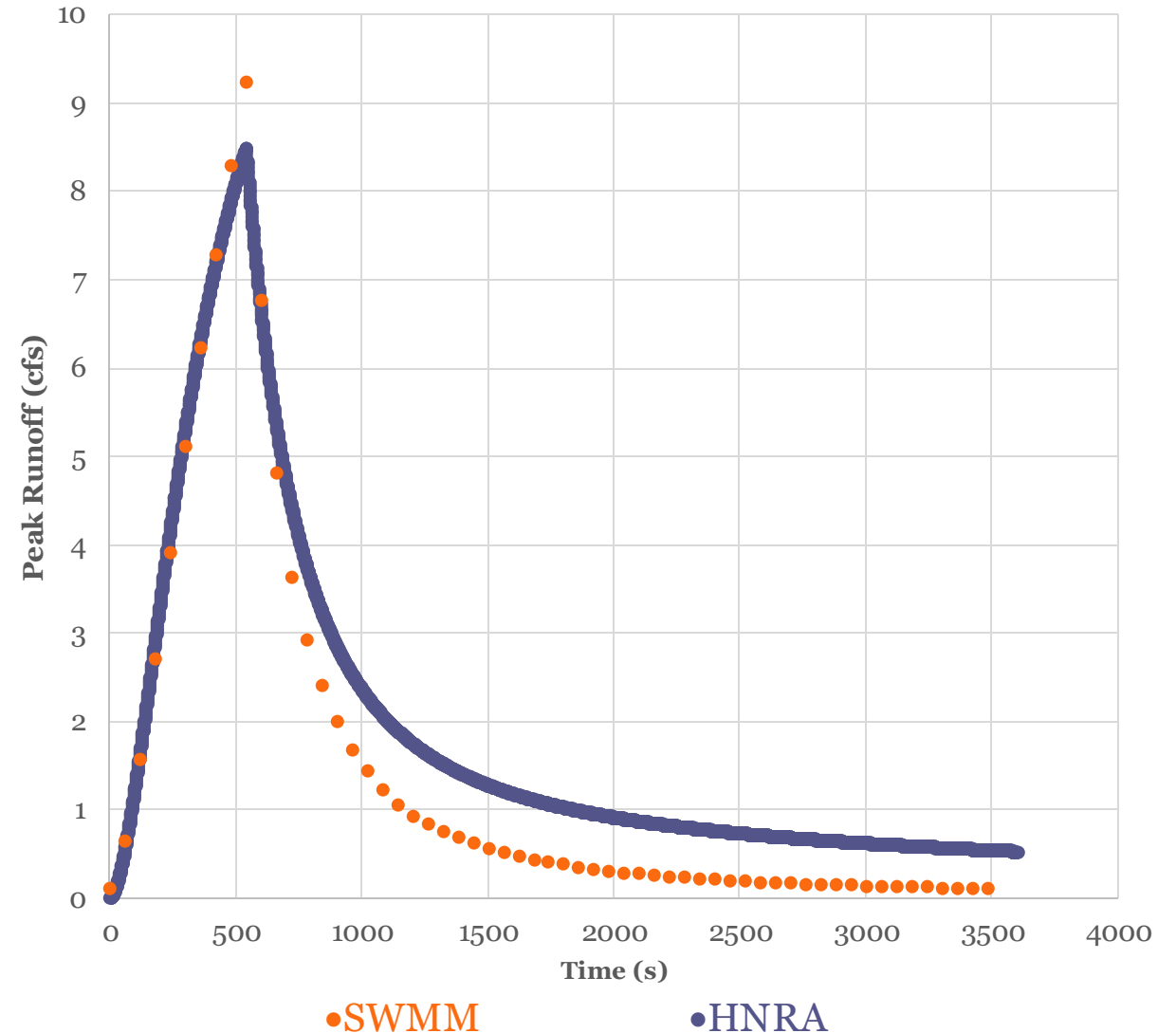
Test 2 - Outflow hydrographs for $T_r=5$ years

- For $T_r=5$ yr, the critical rainfall duration was 9 minutes
- Same hyetograph used in SWMM, but considering CN
- Peak was very similar, but flows during the HNRA recession were larger
 - No further abstraction in HNRA if there is no rainfall
 - CN abstraction continues in SWMM



Test 2 - Outflow hydrographs for Tr=25 years

- Tr=25 yr, the critical rainfall duration was 10 minutes
- SWMM peak flow was 8% larger than HNRA's, but hydrograph remained very similar



Summary and Future work

- Rational Method continues popular, and this is to some extent due to the low data requirements
 - This work was motivated by the goal of creating a more representative Rational Method by using existing concepts in SWMM
- Expand the testing to include wider range of subcatchments
- Include routing time in channel/sewers to HNRA
- Create a user-friendly tool to run HRNA for state DOTs in US
- Create in the same platform a converter from Rational Method data into SWMM input files for simpler overland flow applications

Thank you!

Questions?

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