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Impacts of Vegetation, Porous Hot Mix Asphalt, Gravel, and Bare Soil Treatments on Stormwater Runoff from Roadway Projects

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NJDOT Research Showcase:
Lunchtime Edition
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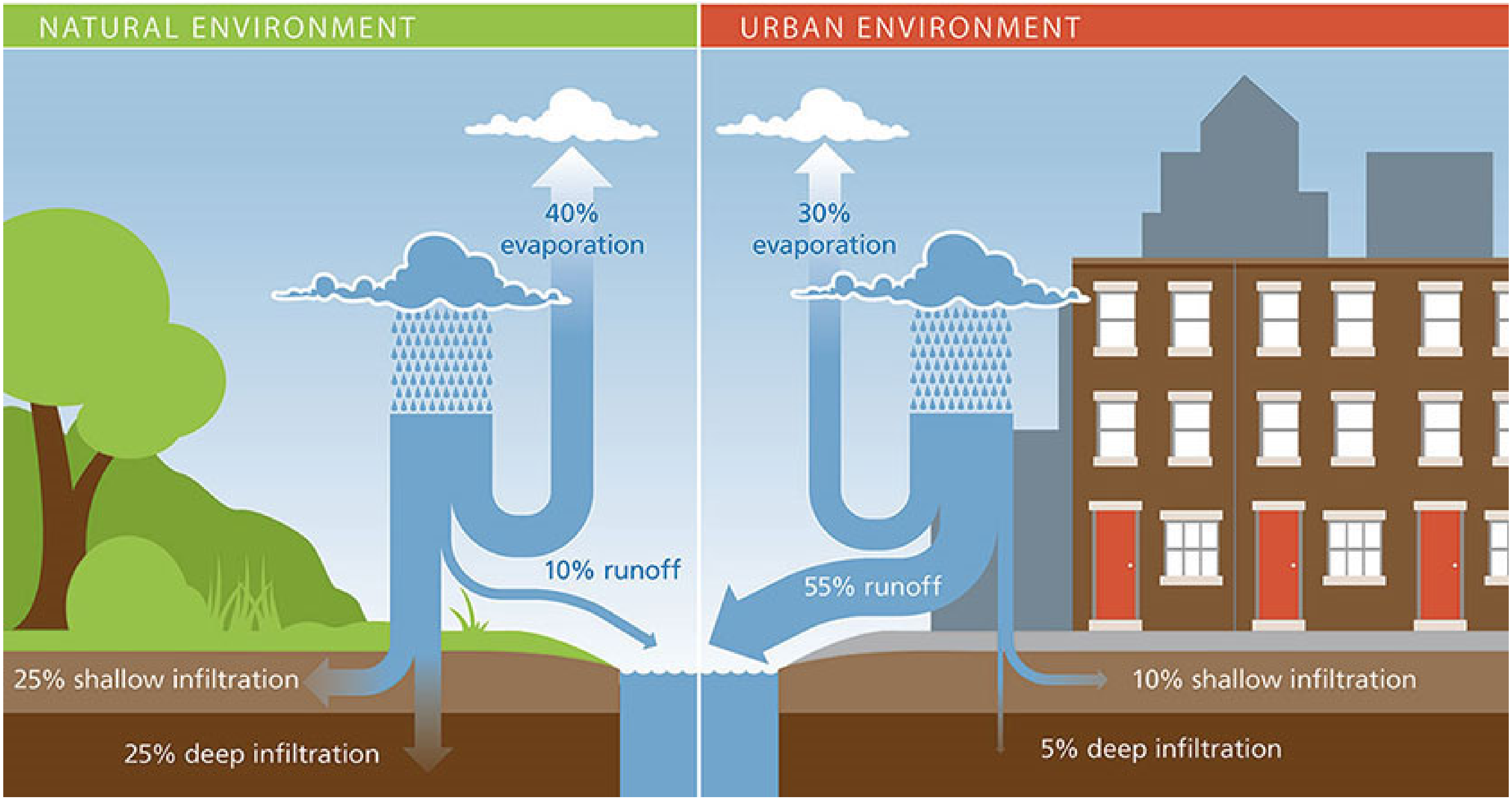
Outline

1. Introduction to Stormwater Management and Land Treatments
2. Introduction to NJDOT-Sponsored Research Project
3. Laboratory Testing Methods
4. Laboratory Testing Results and Analysis
5. Translation for Field Applications
6. Future Implementation of Research Results

Effects of Urbanization on Natural Hydrology:

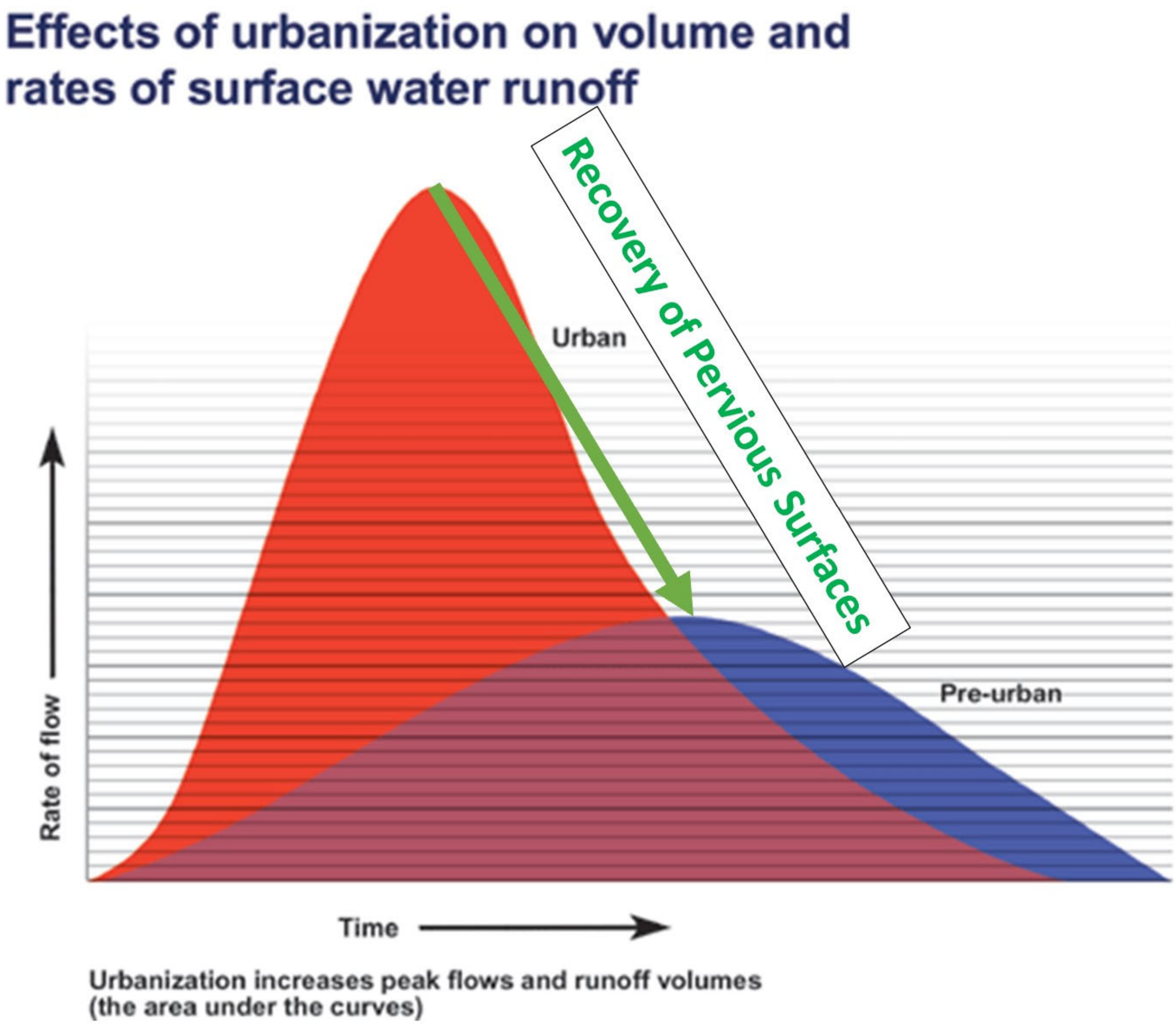
Increase in Impervious Area Leads to Increase in Runoff



(https://www.pwdplanreview.org/upload/img/Introduction-Figure1-150529.jpg)

Restoration of Natural Hydrology through Recovery of Pervious Surfaces,

Green Stormwater Infrastructure (GSI), and Stormwater Best Management Practices (BMPs)



(Base graph: http://ec.gc.ca/eau-water/default.asp?lang=en&n=72fdc156-1)

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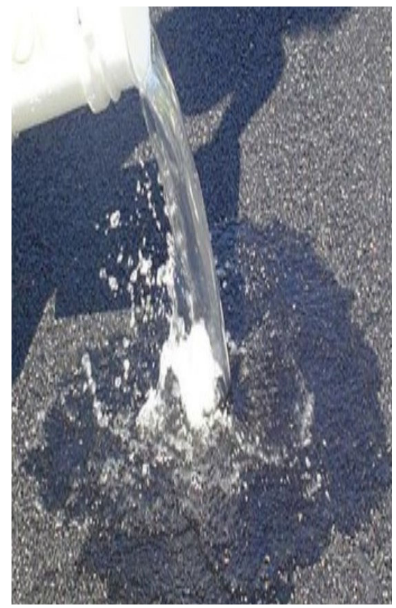
- Transportation agencies are required to assess and mitigate the stormwater runoff impacts of certain roadway projects.

- An agency may need to reconstruct unpaved areas within the Right of Way (ROW), median, and/or under guide rails in roadway projects by applying land treatments.

- Surface materials that have recently been utilized by New Jersey Department of Transportation (NJDOT) under and adjacent to guide rails include gravel, vegetation, porous hot mix asphalt (HMA), and bare soil with polyester matting.



An example NJDOT highway project site with porous hot mix asphalt at the shoulder and under the guide rail along Route 27 at Six Mile Run)

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Evaluation of Coefficients Related to Runoff from Roadway Projects

Project Sponsor: New Jersey Department of Transportation (NJDOT)

Project Manager: Priscilla Ukpah

Principal Investigator: Qizhong (George) Guo
Co-Principal Investigators: Robert Miskewitz and John Hencken
Research Assistants: Lin Zheng, Diego Meneses, et al.
Center for Advanced Infrastructure and Transportation (CAIT), Rutgers University

Under Guidance of NJDOT Technical Advisory Panel (TAP)

Final Report Number and Date:

FHWA-NJ-2023-004
March 2023

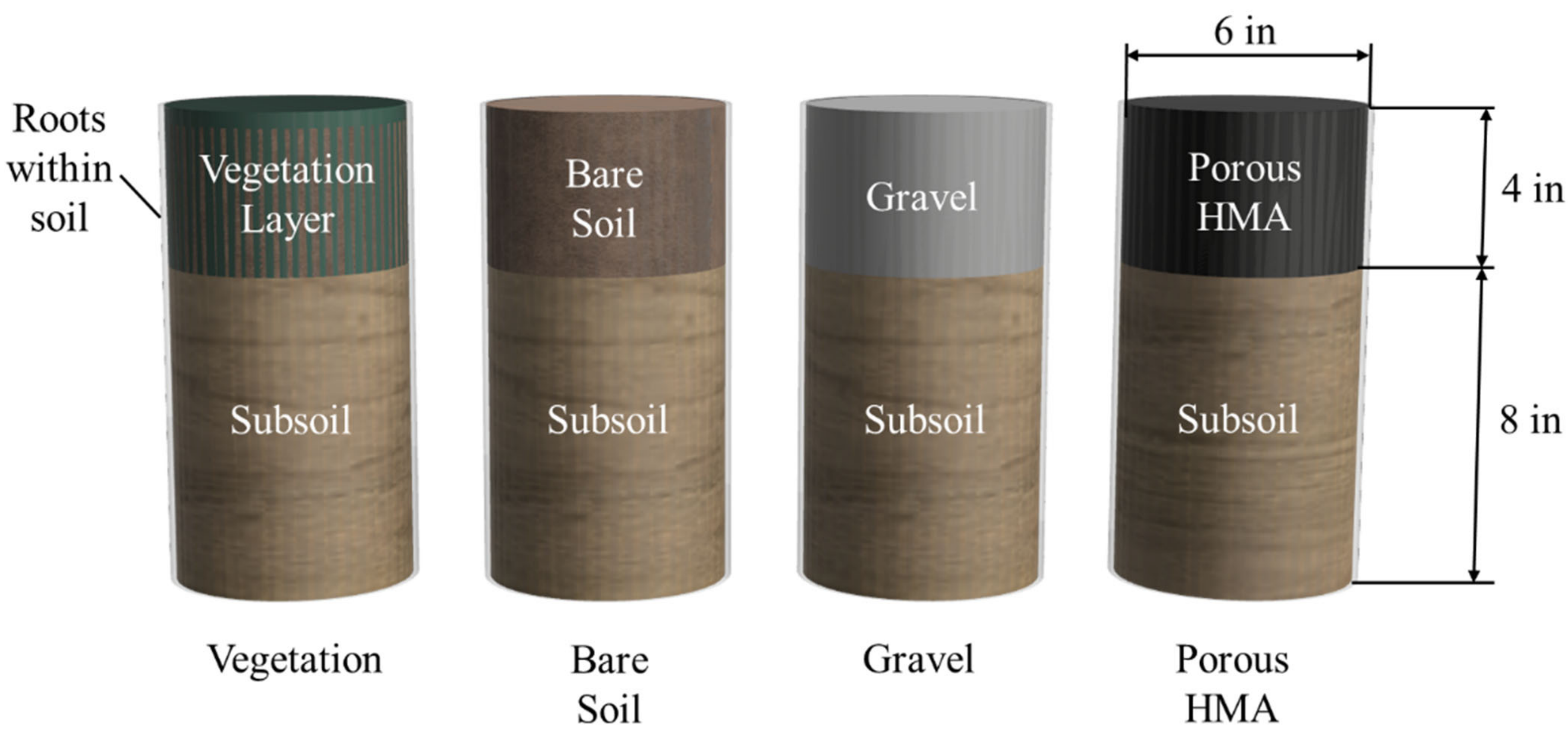
Literature Search

The literature did not reveal data that could be directly used or adopted due to the discrepancy in field conditions between existing studies and NJDOT specifications

Photos of Gravel, Vegetation, and Porous Hot Mix Asphalt used in the Laboratory Tests

(a) Gravel (b) Vegetation (c) Porous HMA

Laboratory Soil Columns
to Mimic Four Different Land Covers/Treatments



*HMA – Hot mix asphalt

Lab Testing Setup (Photo)

Nozzles from Hydrology Apparatus

Hydrology Apparatus

Soil Column

Runoff tube

Infiltration tube

Runoff bucket

Infiltration bucket

Balance

Laboratory Test Matrix

Land Treatment	Subsoil Hydraulic Conductivity(in/h)	Rainfall Intensity (in/hr)	Rainfall Duration (hr)
Bare Soil	10.0	9.0	Varies from 2 to 4
Grave	8.0	4.0	
Vegetation	6.0	1.0	
Porous HMA	5.5	0.3	
	4.0		
	2.0		
	1.5		
	1.0		
	0.5		
	0.1		

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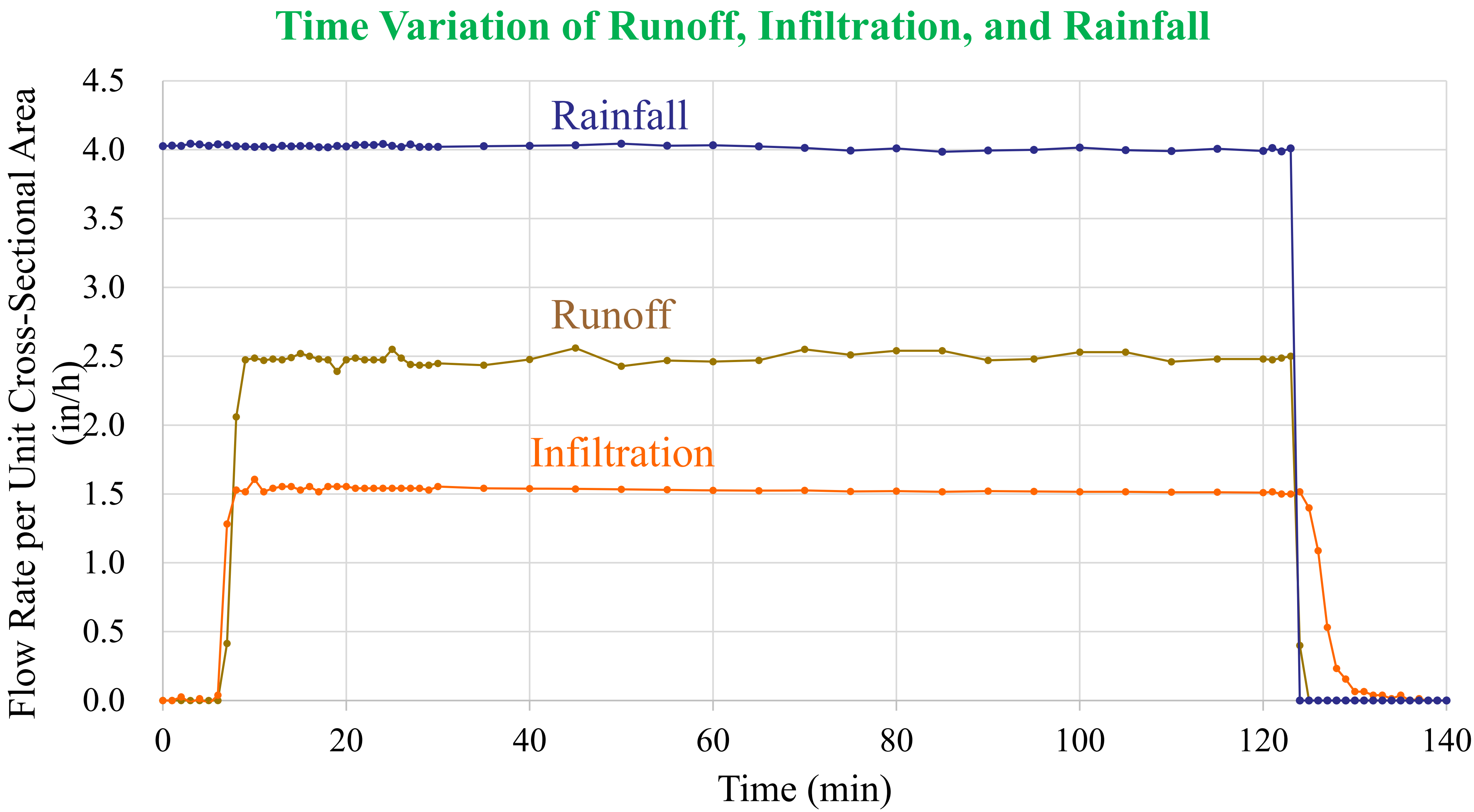
Lab-Testing Raw Results (typical) – for entire duration of test rainfall



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Fitting Methodology for Curve Number Using NRCS TR-55 Curve Number Method

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

$$I_a = 0.2S \qquad (2)$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (3)$$

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

$$Q = \frac{[P - 0.2 \times (\frac{1000}{CN} - 10)]^2}{P + 0.8 \times (\frac{1000}{CN} - 10)} \qquad (5)$$

Q: **Runoff (inch) - measured**

P: **Rainfall (inch) - measured**

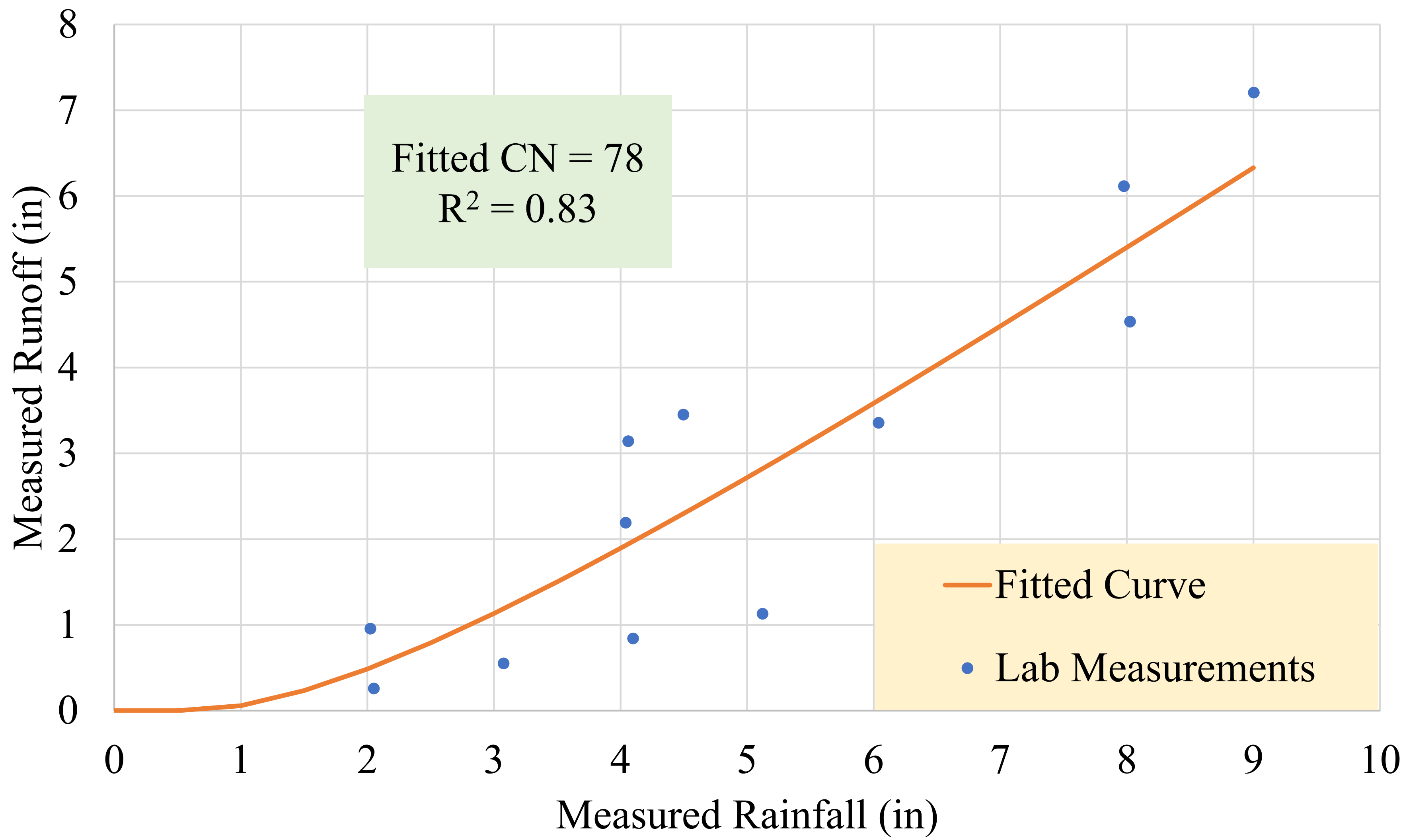
I_a: Initial abstraction (inch) – calculated by Equation (2)

S: Potential maximum retention after runoff begins (inch) - calculated by Equation (4)

CN: **Curve number – to be fitted** in Equation (5)

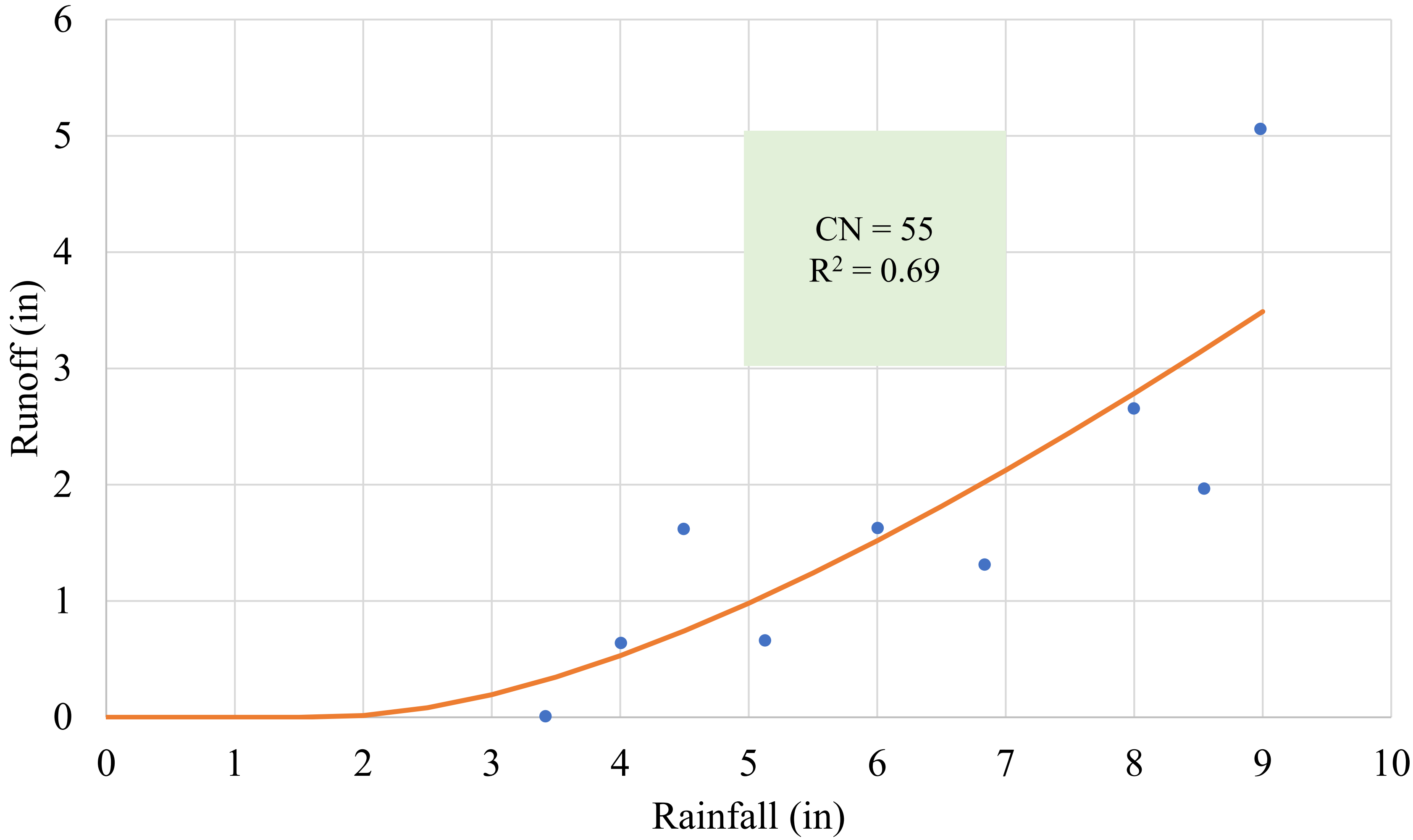
Curve Number Fitted using NRCS TR-55 Curve Number Method

An Example of Land Treatment of **Bare Soil**, Measured Steady Infiltration Rate of 1.50 inch/hour



Curve Number Fitting using NRCS TR-55 Curve Number Method

An Example of Land Treatment of **Gravel**, Measured Steady Infiltration Rate of 2.12 inch/hour



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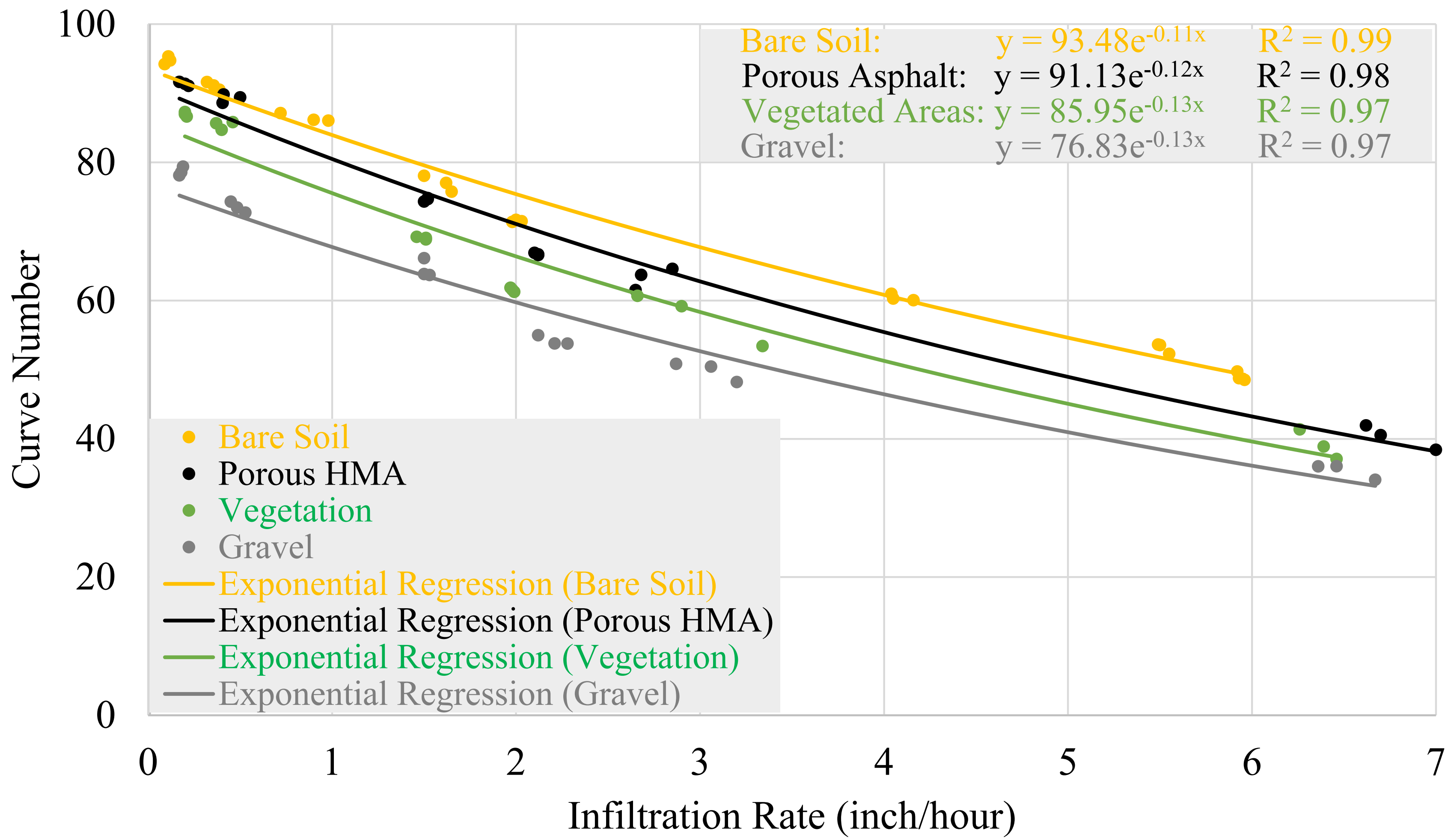
Fitted Equations for Curve Number (CN) vs. Infiltration Rate

Developed from Lab-Testing Results



Notes: Each data point represents an individual test soil column with a combination/composition of the land treatment at the upper portion and the subsoil at the lower portion.

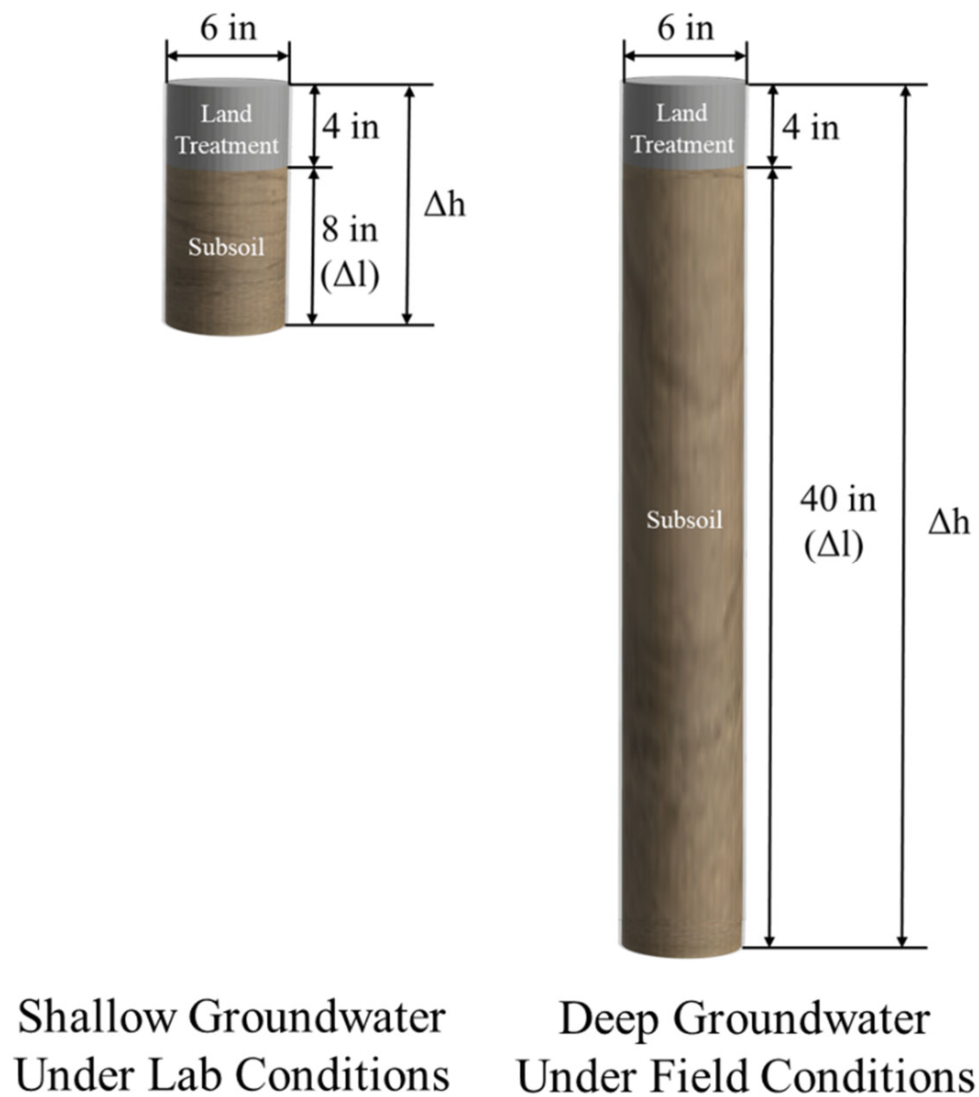
Laboratory Conditions vs. Field Conditions

The laboratory test design in this research project was aimed to be representative of the typical field conditions. However, two (2) laboratory conditions may deviate significantly from the field conditions as follow:

(1) The laboratory tests were conducted in a vertically confined soil column without the lateral flow. Therefore, to apply the laboratory results, infiltration in the field, in both the upper land treatment layer and the lower subsoil layer, should be one-dimensional in the vertical direction with a negligible lateral flow.

(2) Depth to the groundwater table (i.e., the height of the test subsoil column) in the laboratory tests is only 8 inches. The depth to the groundwater table is commonly much larger than 8 inches in the field (e.g., larger than 40 inches). Thus, the hydraulic gradient imposed on the test soil column in the laboratory is much larger than that commonly imposed in the field. Translation of the curve numbers obtained under the laboratory condition to that under the field condition is necessary.

Comparison of Short and Tall Soil Test Columns or Shallow and Deep Groundwater Tables



Translation of Curve Numbers Obtained from Laboratory Tests for Field Applications

Under field conditions, the depth to the groundwater table is commonly deep (most likely deeper than 40 inches). The hydraulic gradient over the subsoil column is close to 1.0. For example, the hydraulic gradient is equal to 1.1 when the depth of the land treatment is 4 inches and the depth of the subsoil is 40 inches ((40+4)/40 = 1.1) and can be approximated as 1.0. Therefore, the infiltration rate under laboratory conditions can be set equal to the subsoil hydraulic conductivities under field conditions.

That is, the regression equation of curve number versus the infiltration rate obtained from the laboratory measurements can be applied to the field conditions after replacing the laboratory-measured infiltration rate with the field-measured subsoil hydraulic conductivity.

Criteria for assignment of hydrologic soil group (HSG)

Depth to water impermeable layer [1]	Depth to high water table [2]	K_{sat} of least transmissive layer in depth range	K_{sat} depth range	HSG [3]
<50 cm [<20 in]	—	—	—	D
50 to 100 cm [20 to 40 in]	<60 cm [<24 in]	>40.0 μm/s (>5.67 in/h)	0 to 60 cm [0 to 24 in]	A/D
		>10.0 to ≤40.0 μm/s (>1.42 to ≤5.67 in/h)	0 to 60 cm [0 to 24 in]	B/D
		>1.0 to ≤10.0 μm/s (>0.14 to ≤1.42 in/h)	0 to 60 cm [0 to 24 in]	C/D
		≤1.0 μm/s (≤0.14 in/h)	0 to 60 cm [0 to 24 in]	D
	≥60 cm [≥24 in]	>40.0 μm/s (>5.67 in/h)	0 to 50 cm [0 to 20 in]	A
		>10.0 to ≤40.0 μm/s (>1.42 to ≤5.67 in/h)	0 to 50 cm [0 to 20 in]	B
		>1.0 to ≤10.0 μm/s (>0.14 to ≤1.42 in/h)	0 to 50 cm [0 to 20 in]	C
		≤1.0 μm/s (≤0.14 in/h)	0 to 50 cm [0 to 20 in]	D
>100 cm [>40 in]	<60 cm [<24 in]	>10.0 μm/s (>1.42 in/h)	0 to 100 cm [0 to 40 in]	A/D
		>4.0 to ≤10.0 μm/s (>0.57 to ≤1.42 in/h)	0 to 100 cm [0 to 40 in]	B/D
		>0.40 to ≤4.0 μm/s (>0.06 to ≤0.57 in/h)	0 to 100 cm [0 to 40 in]	C/D
		≤0.40 μm/s (≤0.06 in/h)	0 to 100 cm [0 to 40 in]	D
	60 to 100 cm [24 to 40 in]	>40.0 μm/s (>5.67 in/h)	0 to 50 cm [0 to 20 in]	A
		>10.0 to ≤40.0 μm/s (>1.42 to ≤5.67 in/h)	0 to 50 cm [0 to 20 in]	B
		>1.0 to ≤10.0 μm/s (>0.14 to ≤1.42 in/h)	0 to 50 cm [0 to 20 in]	C
		≤1.0 μm/s (≤0.14 in/h)	0 to 50 cm [0 to 20 in]	D
	>100 cm [>40 in]	>10.0 μm/s (>1.42 in/h)	0 to 100 cm [0 to 40 in]	A
		>4.0 to ≤ 10.0 μm/s (>0.57 to ≤1.42 in/h)	0 to 100 cm [0 to 40 in]	B
		>0.40 to ≤4.0 μm/s (>0.06 to ≤0.57 in/h)	0 to 100 cm [0 to 40 in]	C
		≤0.40 μm/s (≤0.06 in/h)	0 to 100 cm [0 to 40 in]	D

(Source: NRCS, National Engineering Handbook, 2009)

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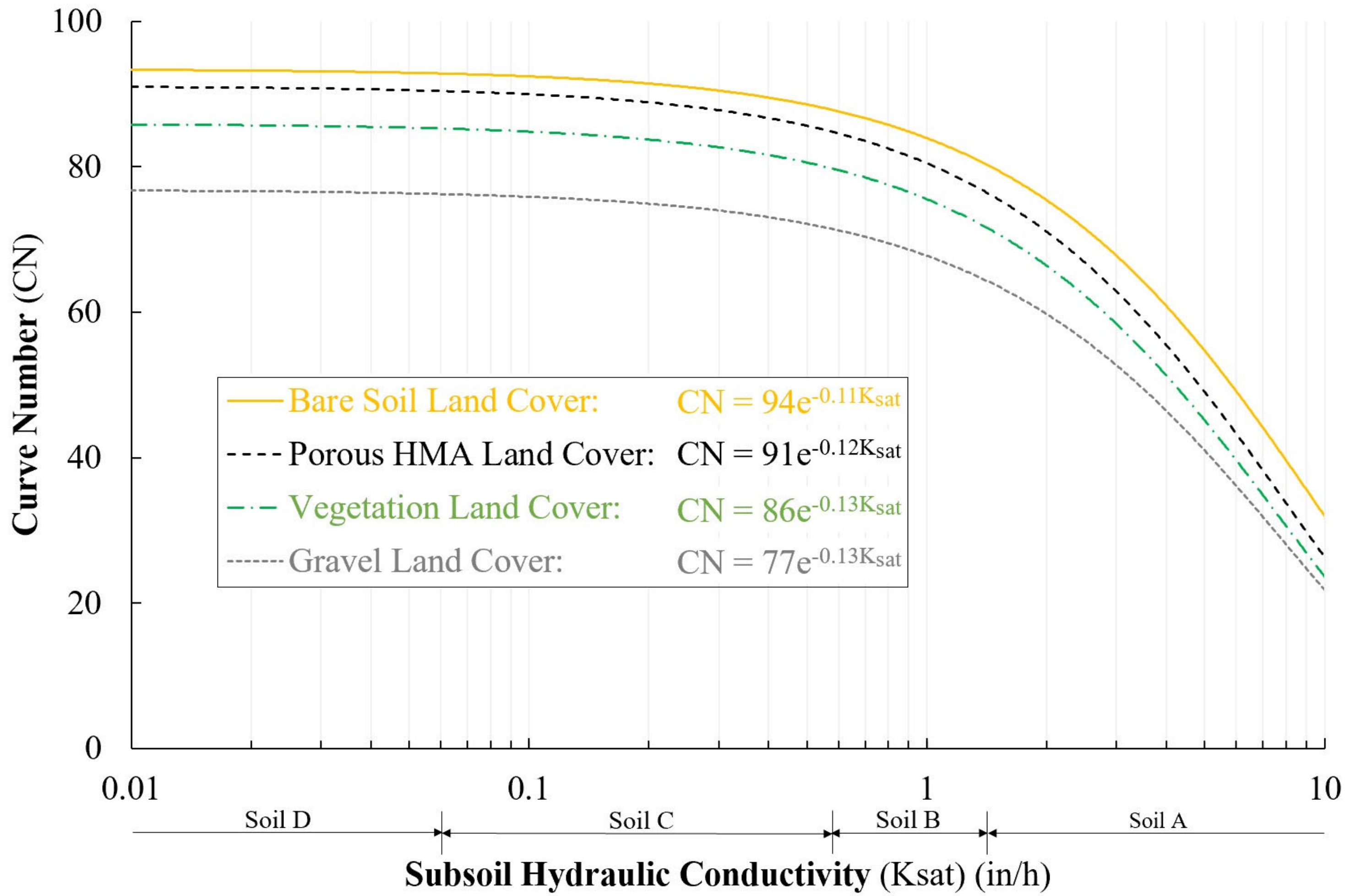
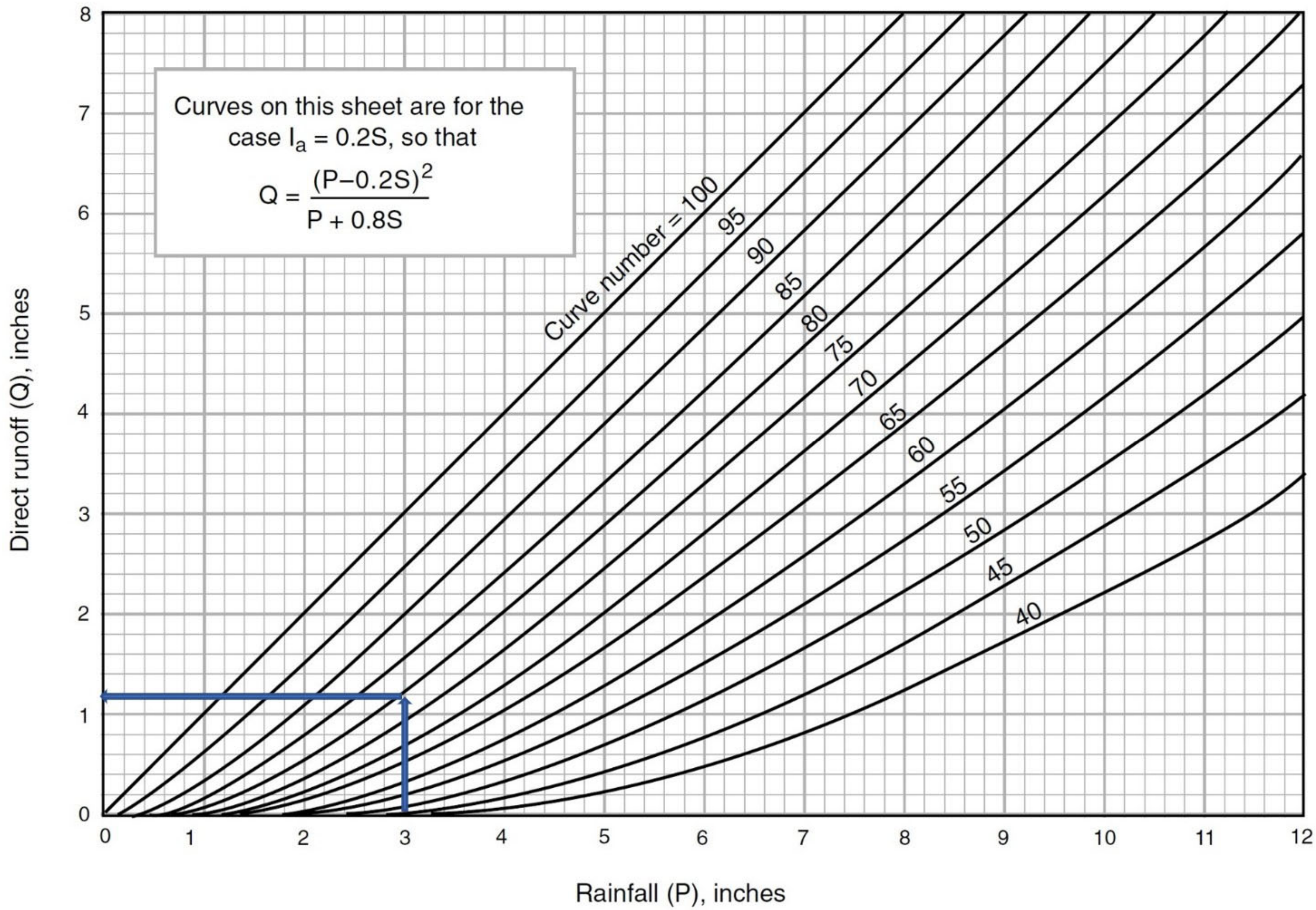
Recommended Application Curves for Curve Number (CN) Based on the Measured Subsoil Hydraulic Conductivity *or the assigned Hydrologic Soil Groups*



Notes: The curves in the above graph are for the cases where the depth to the groundwater table is larger than 40 inches. Assignment of the hydrologic soil group based on the soil conductivity is in the National Engineering Handbook Hydrology Chapters (NRCS 2009).

Prediction of Runoff from Rainfall using NRCS TR-55 Curve Number Method



(Natural Resources Conservation Service. Urban Hydrology for Small Watersheds. Technical Release No. 55 (TR-55). 1986).

Comparison of Curve Numbers obtained from Research Project with Established Curve Numbers (where available)

- Curve Numbers (CNs) for bare soil and vegetation are similar to the established CNs for dirt (including right-of-way) and open space (lawns, fair condition) in TR-55, respectively.
- **The obtained Curve Numbers for gravel are significantly smaller than the established CNs for gravel (including right-of-way) in TR-55.**
- The Curve Numbers for porous HMA were obtained from the research project but are not available in TR-55 for comparison.

Hydrologic Soil Group (Depth to Groundwater Table > 40 in)	Hydraulic Conductivity (in/h)	Bare Soil		Gravel		Vegetation		Porous HMA	
		TR-55 for *Dirt* (NRCS 1986)	Rutgers Research Results	TR-55 (NRCS 1986)	Rutgers Research Results	TR-55 for *Lawns (Fair Condition)* (NRCS 1986)	Rutgers Research Results	TR-55 (NRCS 1986)	Rutgers Research Results
A	>1.42	72	<79	76	<64	49	<72	Not Available	<76
B	0.57-1.42	82	79-87	85	64-72	69	72-80		76-85
C	0.06-0.57	87	87-92	89	72-76	79	80-86		85-90
D	<0.06	89	>92	91	>76	84	>86		>90

*Assignment of hydrologic soil group based on the hydraulic conductivity is in the National Engineering Handbook Hydrology Chapters (NRCS 2009). The assignments in the above table are for cases where the depth to the groundwater table is larger than 40 inches.

Future Implementation of Research Results

- This project will help NJDOT and other transportation agencies seek regulatory entities' acceptance of the curve numbers that are non-existing for *porous hot mix asphalt* land treatment/cover, different for *gravel* land treatment/cover, etc.

- This research project also has broader scientific, engineering, and societal impacts as it has demonstrated the effectiveness of stormwater runoff reduction (and climate resilience) by restoring natural hydrology (water cycle) through the recovery or creation of pervious surfaces.