United States Department of Agriculture
Natural Resources Conservation Service

NRCS Runoff Curve Number Hydrology
Development, Status, and Updates

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Outline

1. Introduction
2. History and Development of the CN Method
3. Need for Updates
4. ASCE-NRCS Partnership for Developing Updates to NEH Part 630
5. Summary and Conclusions

Introduction

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- **What is the Runoff Curve Number Method?**
  - **NRCS' approach to solving hydrology (runoff from rainfall) for ungaged watersheds**
  - Intended to be a simple procedure to estimate total storm runoff from total storm rainfall as an integrated loss function concept
  - Used to describe typical watershed response from infrequent rainfall anywhere in the country, for watersheds with the same land use, soil hydrologic group, and surface runoff conditions

Introduction

- **What is the Runoff Curve Number Method?**

The Curve Number Runoff Equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \text{for } P > I_a$$

$$Q = 0 \quad \text{for } P \le I_a$$

where: Q = runoff volume (inches)

P = rainfall (inches)

I_a = initial abstraction or rainfall before runoff begins (inches)

S = maximum potential retention (inches)

= 5 times initial abstraction, or $I_a = 0.2S$

The CN is a transformation of S:

$$CN = \frac{1000}{10 + S}$$

Introduction

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What do you get from the CN Method?

- Runoff Volume

What DON'T you get from the CN Method?

- Peak Discharge
- Hydrograph

Introduction

- **Uses of the CN Method:**
  - Single event modeling
    - Developed through observation of extreme [rainfall] events and attempted quantification of runoff from these events
  - Continuous models
    - Adaptation of CN method to continuous models requires treating each day or time step as a discrete extreme (?) event
  - Other

History & Development

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- **Victor Mockus**
  - Father of the CN Method (also developed the SCS standard unit hydrograph; watershed lag equation; convex method of flood routing)
  - Established how technical expertise in Federal Gov't could be used to carry out important policy changes by providing an equitable distribution of Federal funding to states with the most significant [soil erosion and flooding] problems through development and publication of the curve number relationship between rainfall and runoff
  - Primary author of Section 4 – Hydrology of the National Engineering Handbook (now NEH Part 630, Hydrology)

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- **Mockus' goal:**
  - Determine an equation for a curve to:
    - describe a pattern where a curve drawn through a plot of total storm runoff versus total storm rainfall for many storms on a watershed was concave upwards and showed no runoff for small storms; and
    - as storm size increased for the curve to become asymptotic to a line parallel to a line of equality (rainfall=runoff)
- An appropriate curve resulted from using a relationship among rainfall, runoff, and retention (rainfall not converted into runoff)

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- **Why was it needed?**
  - SCS needed a planning and design hydrology that…
    - Showed ***land condition***
    - Used ***soils data***
    - Could be ***applied uniformly*** across the nation to equalize competition among states for projects (PL-566)
    - Met the ***data limitations*** (Available were daily rainfalls from a few research watersheds and some emerging soils technology)

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- **What was available?**
  - SOME (not a lot) of data from experimental watersheds
  - Slide rules
  - Graph paper
  - Creativity
  - Sense of urgency

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Table 1. Research watersheds used in the determination of NEH4 Curve Numbers

State	Location	State	Location
Arizona	**Safford**	**New Mexico**	**Albuquerque**
Arkansas	**Bentonville**	**New Mexico**	**Mexican Springs**
California	**Santa Paula**	**New York**	**Bath**
California	**Watsonville**	**Ohio**	**Coshocton**
Colorado	**Colorado Springs**	**Ohio**	**Hamilton**
Georgia	**Americus**	**Oklahoma**	**Muskogee**
Idaho	**Emmett**	**Oregon**	**Newberg**
Illinois	**Edwardsville**	**Texas**	**Garland**
Maryland	**Hagerstown**	**Texas**	**Vega**
Montana	**Culbertson**	**Texas**	**Waco**
Nebraska	**Hastings**	**Virginia**	**Danville**
New Jersey	**Freehold**	**Wisconsin**	**Fennimore**

Source: Rallison(1980)

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- **Development of the Curve Number Equation**

$$Q=(P-0.2S)^{2}/(P+0.8S) \quad \text{for } P>I_a$$

$$Q=0 \qquad \text{for } P\leq I_a$$

where: Q = runoff volume (inches)

P = rainfall (inches)

I_a = initial abstraction or rainfall before runoff begins (inches)

S = maximum potential retention (inches)

= 5 times initial abstraction, or $Ia=0.2S$

and: $CN=1000/10+S$

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$$F/S = Q/P$$

where: F = actual retention after runoff begins (inches)

S = maximum potential retention after runoff begins, $S \geq F$, (inches)

Q = actual runoff (inches)

P = actual rainfall, $P \geq Q$, (inches)

I_a = initial abstraction (inches) = 0

To satisfy the conservation of mass: F = P – Q

Substituting: $P - Q/S = Q/P$ Solving for Q: $Q = P^{2} / P + S$

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- When $I_a \neq 0$, $P = P - I_a$ and equation becomes:

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

- Initial abstraction consists of:
  - Interception (can be estimated from cover and surface conditions)
  - Infiltration during early parts of the storm (highly variable – dependent upon rainfall intensity, soil crusting, soil moisture)
  - Surface depression storage (can be estimated from cover and surface conditions)
- After much debate and discussion (and perhaps a jug of martinis?), a decision was made to use an assumption that $I_a = 0.2S$, resulting in the equation:

$$Q = (P - 0.2S)^2 / P + 0.8S$$

(and don't forget! For $P \leq Ia$, $Q = 0$)

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- Transforming the S parameter into something more “useful” results in the Curve Number:

$$CN = 1000/10+S$$

where CN is dimensionless and ranges from 0 (no rain ever becomes runoff) to 100 (all rain is always runoff)

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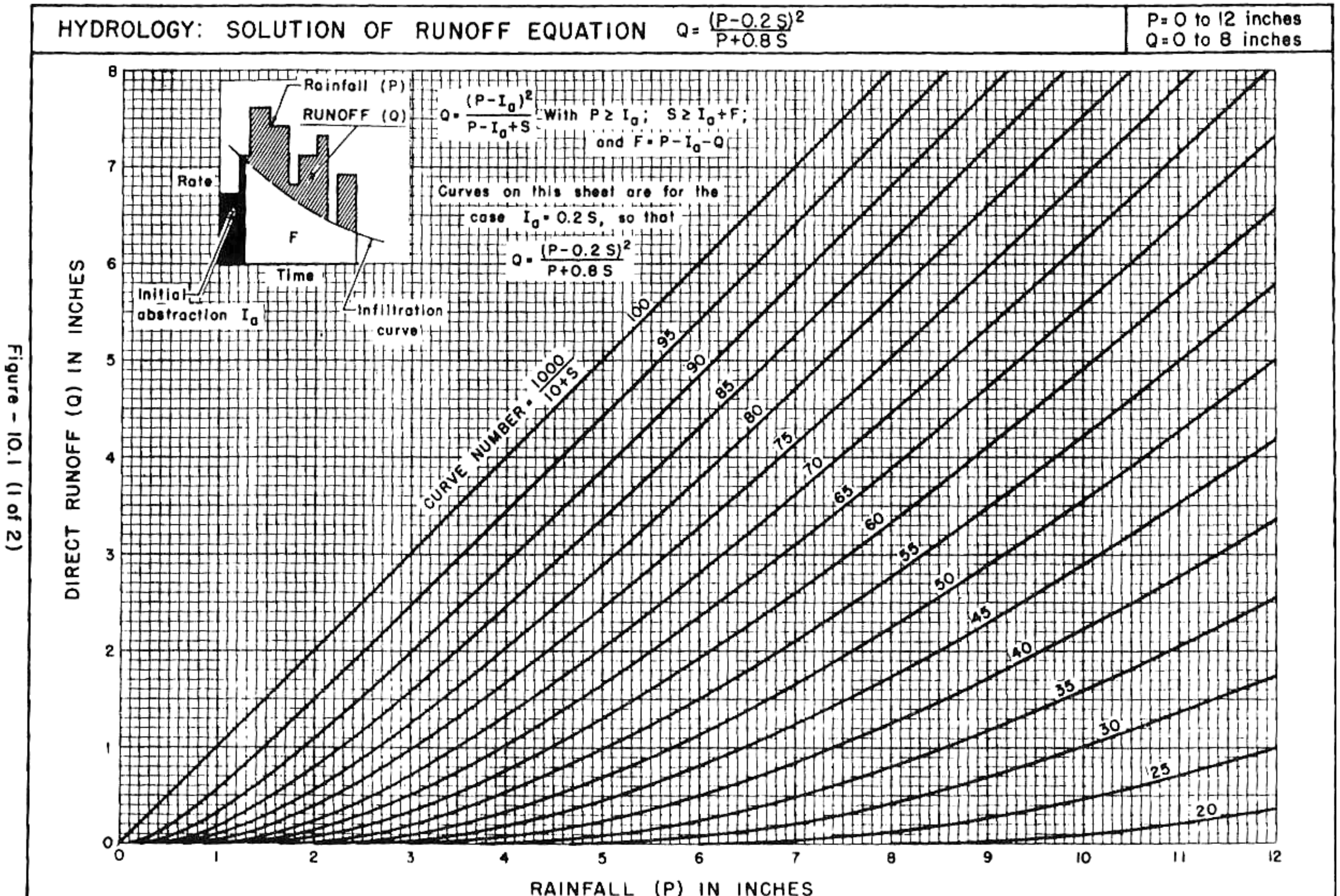

REFERENCE
Mockus, Victor; Estimating direct runoff amounts from storm rainfall: Central Technical Unit, October 1955

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - HYDROLOGY BRANCH

STANDARD DWG. NO.
ES- 1001
SHEET 1 OF 2
REVISED 10-1-64

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- What does a CN represent?
  - Land use
  - Hydrologic cover condition
  - Soils
  - Antecedent runoff condition
- NEH Part 630, Chapter 9, presents tables of runoff curve numbers for land uses determined using rainfall/runoff data and the runoff equation assuming $I_a/S = 0.2$

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Table 9–1 Runoff curve numbers for agricultural lands [1/]

Cover description: cover type	Cover description: treatment [2/]	Cover description: hydrologic condition [3/]	CN for hydrologic soil group: A	B	C	D
Fallow	Bare Soil	---	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C & T)	Poor	66	74	80	82
		Good	62	71	78	81
	C & T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C & T	Poor	61	72	79	82
		Good	59	70	78	81
	C & T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C & T	Poor	63	73	80	83
		Good	51	67	76	80

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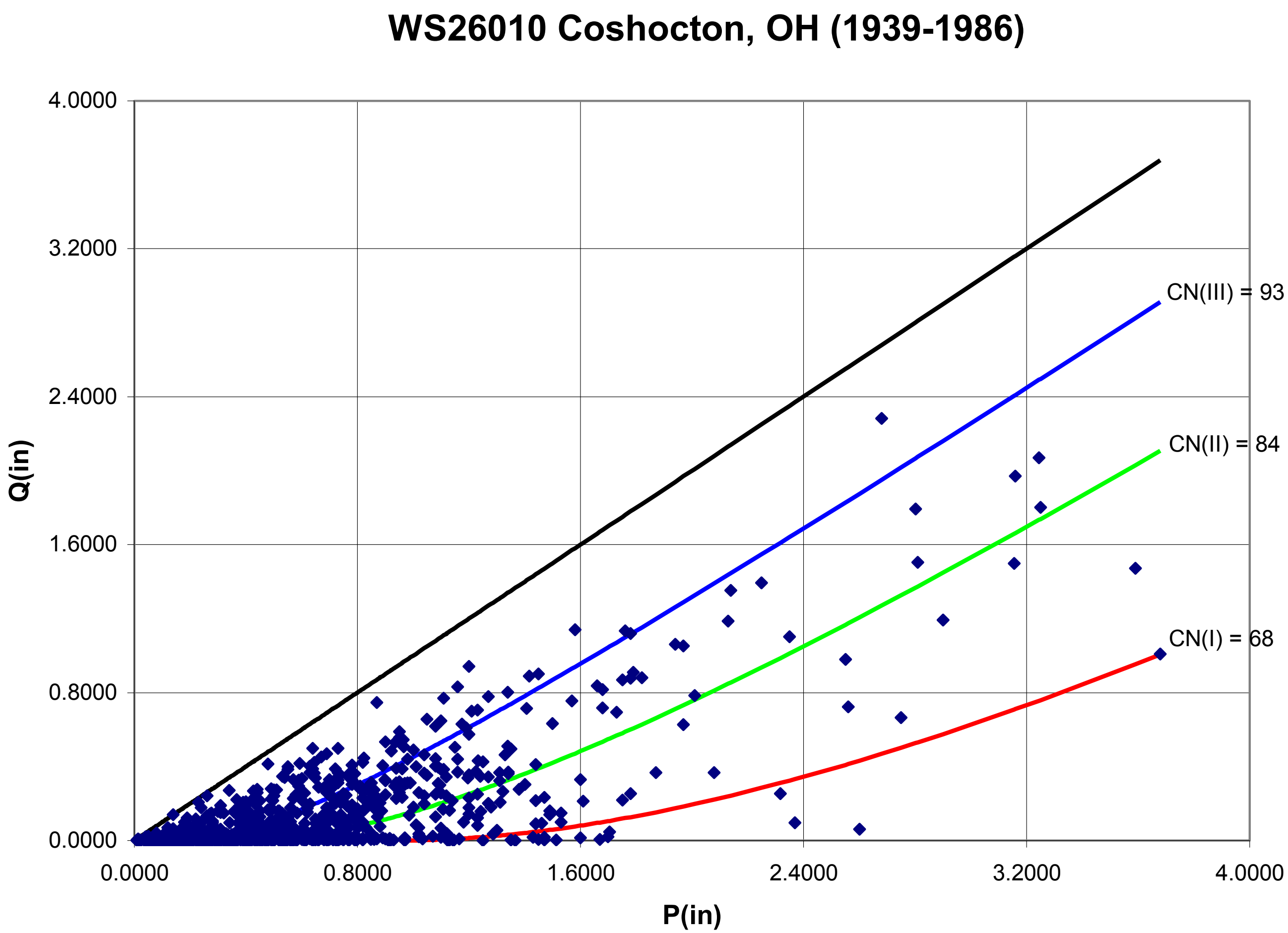
- **BUT…. Where did the CNs come from?**



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- Plots of rainfall versus runoff from experimental watersheds data
  - Typically daily rainfall values (24-hour?)
  - Provides P (measured), Q (measured), and I_a (observed)
  - Solve for S
  - Solve for CN

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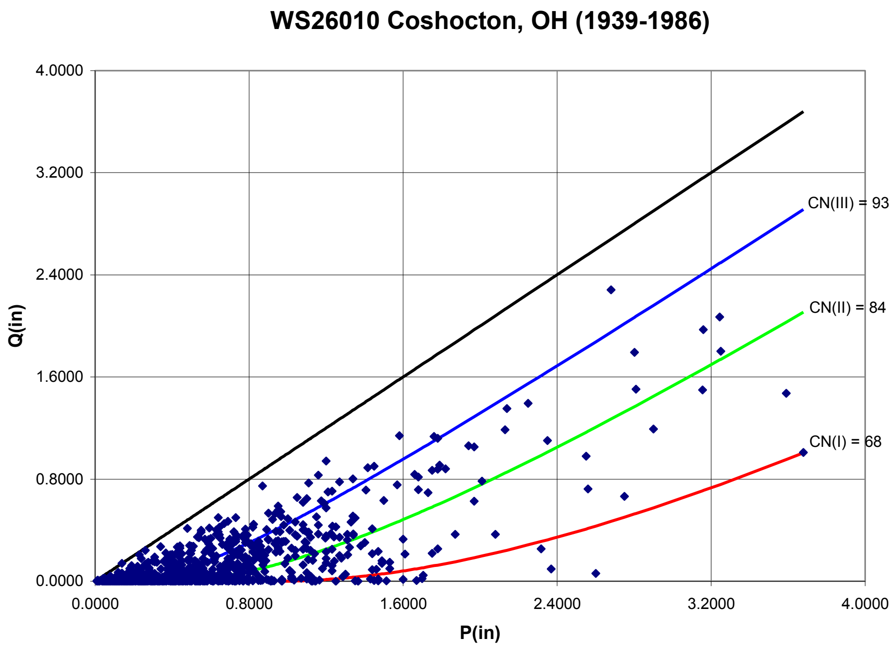
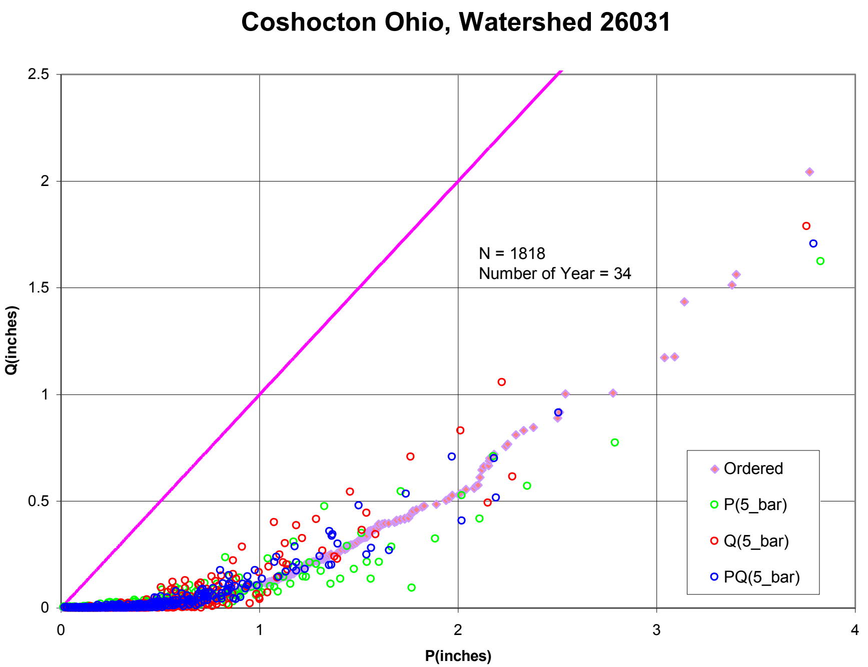
Documentation?? *(Or lack thereof…)*

- Most files and supporting data used in the development have been lost, destroyed, or misplaced over the years
- CN method never underwent a critical open review
- Supporting data was never published
- What survives are tradition, written summaries, customs of entrenched usage, institutional memory

Need for Updates

- **Some Issues:**
  - Natural vs. Ordered Data
  - Antecedent runoff condition?





Need for Updates

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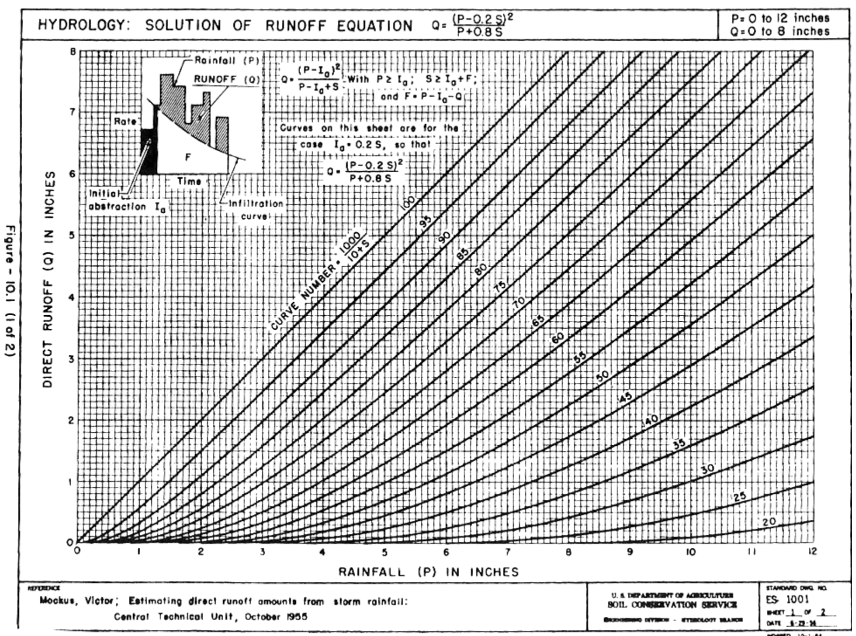
- **Some Issues:**
  - Storm characteristics
    - Intensity?
    - Distribution?
    - Duration?
  - Seasonal data (hydrologic cover condition during what time of year)
  - Land use
  - Slopes
  - Drainage area

Need for Updates

- **Some Issues:**
  - Initial abstraction – is I_a = 0.2S the right value?
  - Watershed response – Mockus' work assumed (and sought) a uniform response
    - Concave upward
    - Constantly increasing or no negative change in slope



Need for Updates

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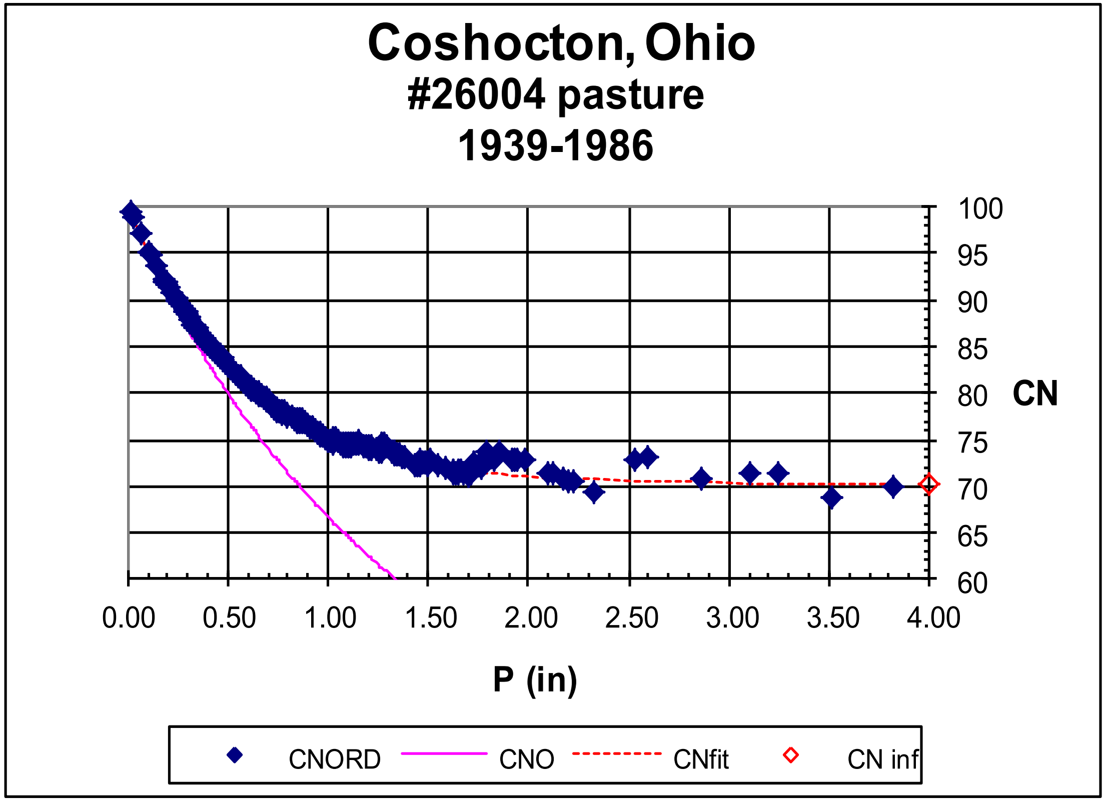
- **Some Issues:**
  - In reality, there are multiple watershed responses
    - Asymptotic



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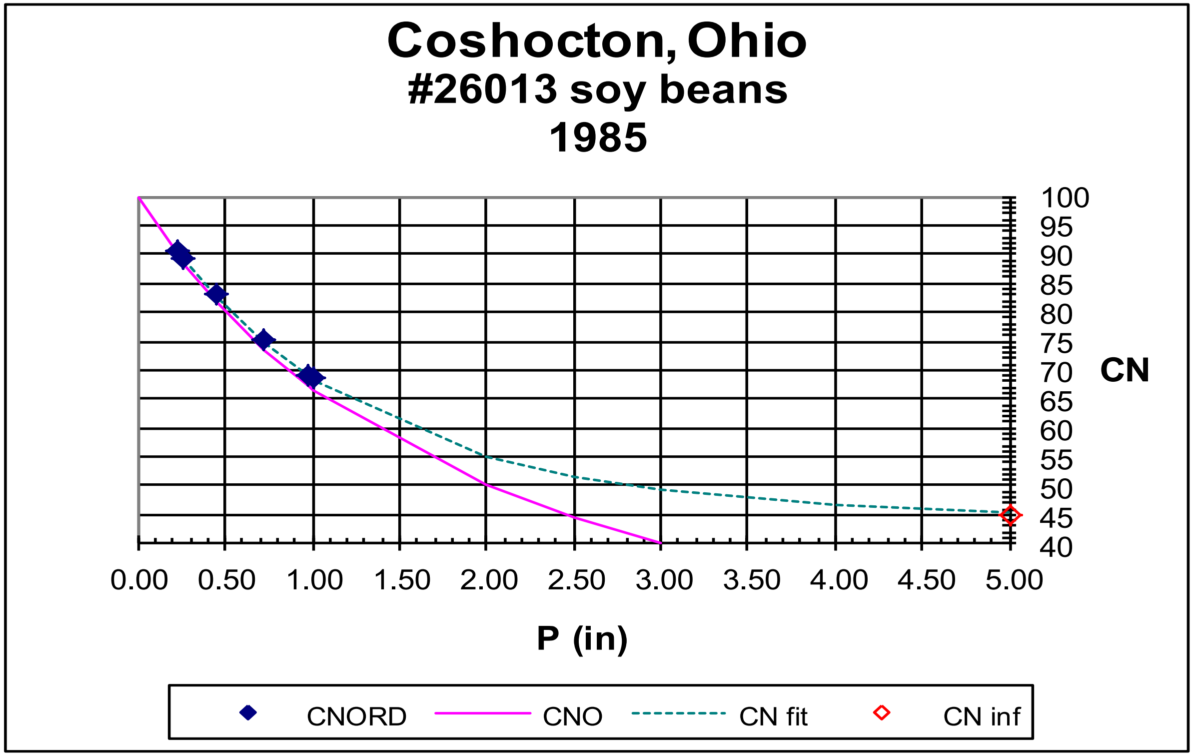
- **Some Issues:**
  - In reality, there are multiple watershed responses
    - Complacent



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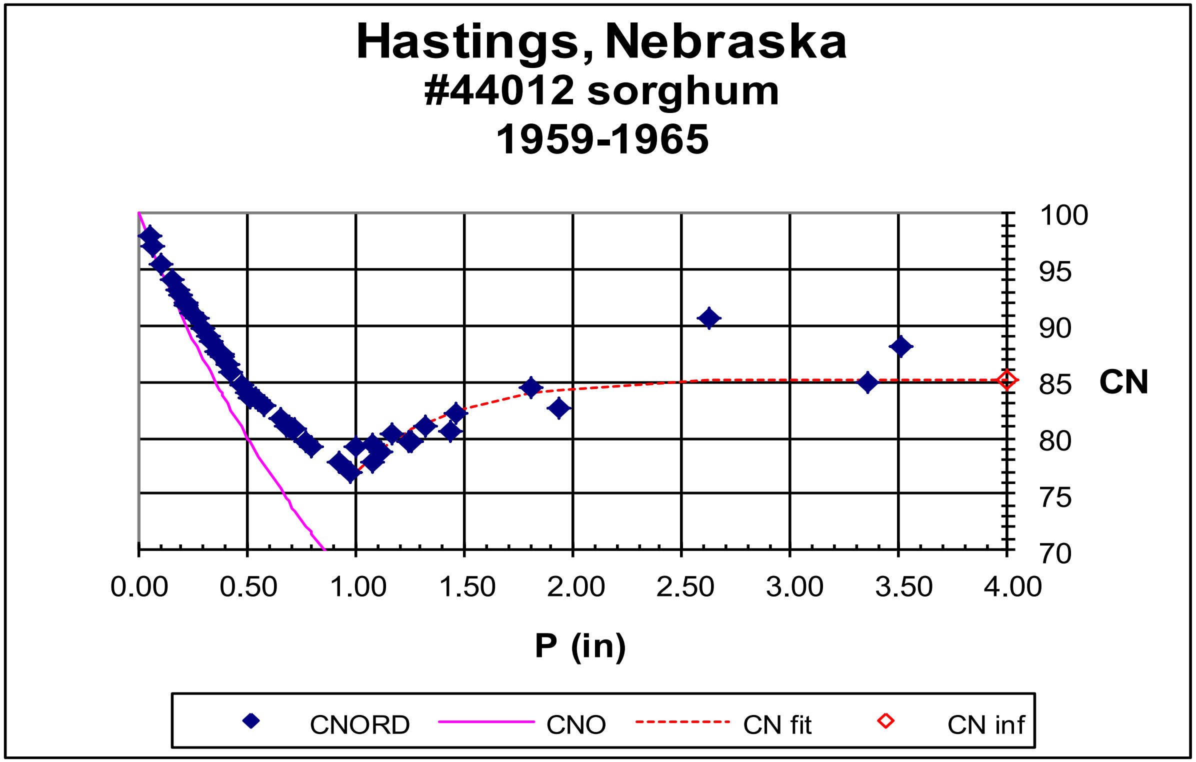
- **Some Issues:**
  - In reality, there are multiple watershed responses
    - Violent



Need for Updates

- **Some Issues:**
  - Regional issues (is AMC II in Ohio really the same as AMC II in Arizona?)
  - Does the CN Method really “fit” the complacent and violent watershed responses?
  - When should other methods of analyzing hydrology be used?

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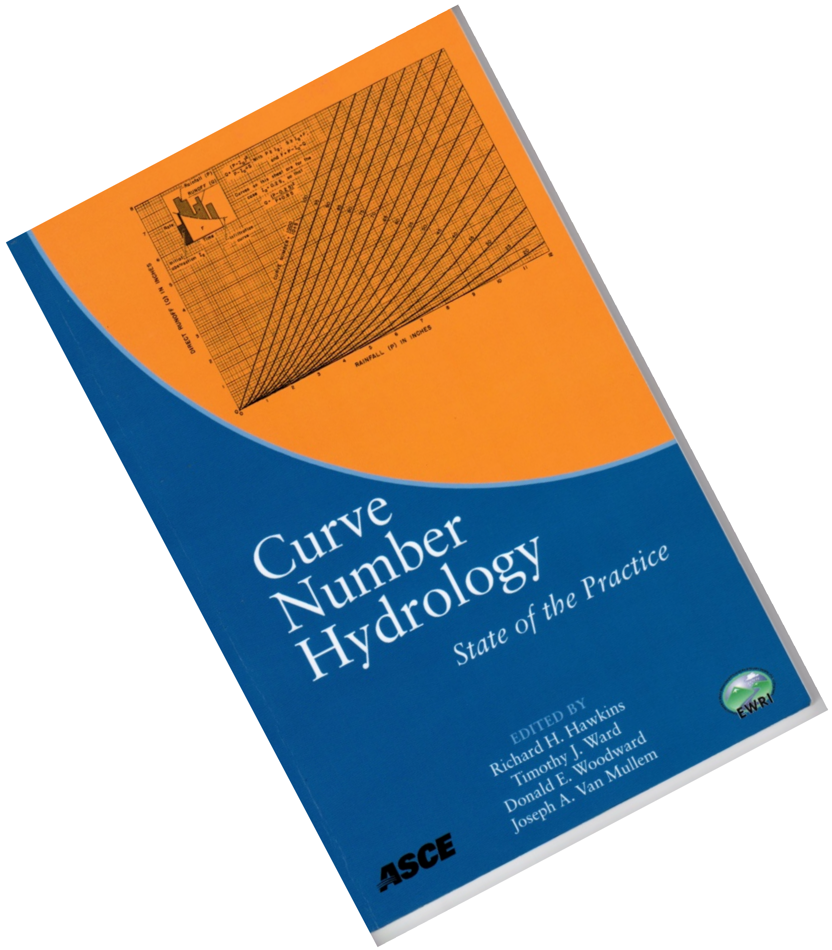
- **Some Issues:**
  - What about….
    - Forested watersheds?
    - Small storms and water quality planning?
    - Local calibrations for CN?
    - New land uses/type?
    - Effects of fire?
    - Non CN watersheds?
    - Urbanization issues?
    - LID issues?
    - Karst?

Need for Updates

- ASCE "Curve Number Hydrology – State of the Practice"



ASCE – NRCS Partnership

- **Cooperative Agreement (signed August 2015) to update NRCS' NEH Part 630, Chapters 8, 9, 10, and 12**
  - Chapter 8: Land Use and Treatment Classes
  - Chapter 9: Hydrologic Soil-Cover Complexes
  - Chapter 10: Estimation of Direct Runoff from Storm Rainfall
  - Chapter 12: Hydrologic Effects of Land Use and Treatment

ASCE – NRCS Partnership

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- **Why ASCE?**
  - Authors of the ASCE monograph, "Curve Number Hydrology – State of the Practice" serve on the ASCE-WMTC-CN Task Committee
- **Who else is involved?**
  - Universities
  - ASABE
  - State/Local Government representation
  - Private individuals

ASCE – NRCS Partnership

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- **Time Line**
  - ASCE to deliver drafts of subject chapters to NRCS by September 30, 2017
  - NRCS will review internally and make a decision about implementation
  - Request for review will also be solicited outside of NRCS through ASCE

Summary / Conclusions

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- Love it or hate it, it's here to stay.
- Is it "science"?
  - Questionable
- Does it "work"? Does it approximate reality?
  - For the most part
- Where does that leave us today?
  - NRCS working to incorporate the latest findings

Contact

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Special Thanks

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- ***Don Woodward,*** *P.E., F. ASCE, NRCS National Hydraulic Engineer (retired), Member ASCE CN Task Committee*
- ***Richard H. (Pete) Hawkins****, PhD, P.E., F.ASCE, F.EWRI, Professor Emeritus, School of Natural Resources and Environment, Watershed Resources and Ecohydrology, Department of Agricultural and BioSystems Engineering, Department of Hydrology and Water Resources, University of Arizona, Tucson AZ, Chair ASCE CN Task Committee*
- ***Tim J. Ward,*** *Ph.D., P.E., F.ASCE, F.EWRI, M. NSPE, Dean and Professor, School of Engineering, Manhattan College, Riverdale, NY, Member ASCE CN Task Committee*

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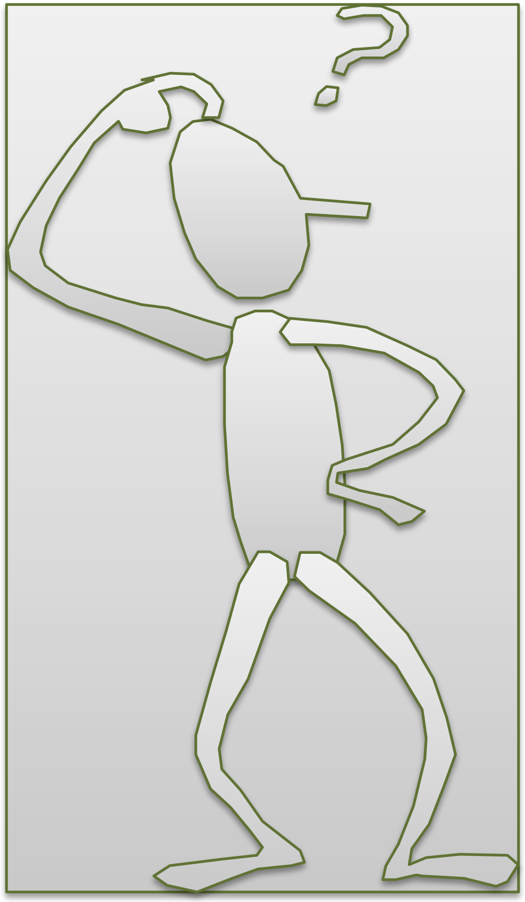

References:

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- USDA – Natural Resources Conservation Service, National Engineering Handbook (NEH), Part 630, Chapters 8, 9, 10, and 12 (available http://directives.sc.egov.usda.gov/viewDirective.aspx?hid=21422)
- ASCE, "Curve Number Hydrology – State of the Practice", Prepared by the ASCE/EWRI Runoff Curve Number Hydrology Task Committee, 2009
- Notes on Victor Mockus, provided by Don Woodward
- Slides from ASCE-EWRI, 2015 Watershed Management Symposium, "Curve Number Rainfall-Runoff: Professional Application Workshop", provided by Richard Hawkins, Don Woodward, and Tim Ward