September 29, 2017

Ms. Claudia Hoeft, P.E., F. ASCE
National Hydraulic Engineer
Conservation Engineering Division
USDA - NRCS
1400 Independence Ave, SW, Room 6136-S
Washington, DC 20250

Dear Ms Hoeft:

Attached are the results of the joint ASCE-ASABE effort with NRCS support to update Curve Number rainfall-runoff hydrology as historically seen and used in the NRCS NEH 630 Chapters 8, 9, 10, and 12. These results and work products are in accord with the Memorandum of Understanding Agreement A-3A75-16-603 and Cooperative Agreement 67-3A75-15-144.

The revisions in this update was a volunteer effort by members of the American Society of Civil Engineers (ASCE) Committee on Watershed Management, Curve Number Task Group, in the Environmental and Water Resources Institute (EWRI). The American Society of Agricultural and Biosytems Engineers (ASABE) participated and contributed through its representave, Dr. E.W. Tollner.

This revision was reviewed and checked continuously during its development and assembly process by the Task Group. Task Group meetings were held at quarterly intervals and the final draft was reviewed by a select, three-member external review team. The review team members were Wilbert Thomas Jr. (Michael Baker International, and USGS retired), Dr. Bill Elliot (U.S. Forest Service), and Karen Kabbes (Kabbes Engineering) The attached submission reflects their contributions and the Task Group thanks them for their input.

A general recommendation included is that the chapter order be re-arranged, It is suggested that the order should be, as shown by the current chapter numbers and titles, as:

Chapter 10	Estimation of Direct Runoff from Storm Rainfall
Chapter 9	Hydrologic Soil-Cover Complexes
Chapter 8	Land Use and Land Treatment Classes
Chapter 12	Hydrologic Effects of Land Use and Land Treatment

While technical details of the update are covered in the revised chapters, a structured **Executive Summary** of limitations, methods, assumptions, findings, recommendations, and suggested future directions follow in this letter of transmittal.

On behalf of the Task Group, we thank you for your cooperation, participation, interest, and understanding. Undoubtedly, we will be in contact during the anticipated post-project follow-ups.

Richard H. Hawkins
Richard H. Hawkins, Ph.D., P.E., F. ASCE, F. EWRI, and Chair, ASCE Curve Number Task Group *rhh*

Tim J. Ward
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Executive Summary to the Curve Number Update Project

Limitations and constraints:

- Limit to event rainfall depth (P) and runoff depth (Q) only
- No continuous models
- No time rates were considered
- No work on hydrographs, times of concentration, or the remainder of the "SCS methods"
- State of the current art insofar as possible
- Professional audience, advanced level from 1954
- Maintain current level of simplicity
- Lumped model to fit data and application as in prior offerings
- *Pro bono*

Decisions and sources in the development are based on:

- Data analysis and existing literature wherever possible
- Heritage from NEH procedures, continuity from prior examples, e.g., ARC
- Assertion, judgement, default, fiat, as in 1954 precedents, i.e., λ_{05} and $S_{05} = 1.42S_{20}$
- Primary focus on USA conditions and findings, and experiences of the authors

Technical foundations, assumptions and agreements:

- Keep basic form of equation; $Q = [P-\lambda S_\lambda]^2/[P+(1-\lambda)S_\lambda]$
- Keep basic S-CN transformation; $CN_\lambda = 1000/(10+S_\lambda)$ in inches
- Existing NEH table CNs are equivalent to CN_∞
- Use of frequency-matching application to P:Q pairs
- Preserved general ARC concepts

FINDINGS - State-of-Art findings and consensus agreements

- CN method not universally appropriate to all watersheds
- Rainfall-Runoff patterns exist, in three general classes

Complacent	Not CN compatible
Standard	CN compatible as limit with $P \rightarrow \infty$. Most data sets here
	Asymptotic form: $CN(P)=CN_\infty+(100-CN_\infty)e^{(-kP)}$
Violent	Marginally/questionably appropriate but consequential

- Ia/S - or λ - is more appropriately 0.05
  - Use $Q =(P-0.05S_{05})^2/(P-0.95S_{05})$ for $P>0.05S_{05}$
  - Requires re-definition of S; consensus conversion is $S_{05}=1.42S_{20}$
- CN secondary effects, maybe

Land-use effects	Assumed and widely shown but not in all storms
Seasonal	Some demonstrated on wetter sites
Rainfall depth	As seen in Standard-asymptotic pattern
Prior rainfall/moisture	Some demonstrated but not universal

Event duration	Not widely demonstrated in data sets
Event intensity	Expected, but not widely demonstrated
Event time distribution	Not widely studied
Land/channel slope	Variable and diverse results; no consensus.

RECOMMENDATIONS – Procedural and methodology-application:

- Use distributed source area accounting:
  $Q = \Sigma\alpha_i[(P-0.05S_{05i})^2/(P+0.95S_{05i})]$ i=1 to # of areas; for $P>0.05S_{05i}$
  A major finding: This simulates the asymptotic CN:P behavior seen in data sets**.**
- Provide statement on Q error for uncertainty in CN
- For local, judgment-based tables of CN, need documentation and provenance
- CN determination from P:Q data pairs procedures are given for Standard asymptotic pattern
- P:Q data ordering is used to advantage as frequency matching
- CN method not recommended for Complacent and Violent patterns
- CN method not recommended for extreme classical forested watersheds; Alternative non-CN procedures or models are recommended/needed.
- CN method not recommended for karst conditions
- Updated ARC tables based on $\lambda = 0.05$; re-interpreted in probabilistic terms; use of NEH 3- and 5-day prior rainfall criteria is strongly discouraged
- Greatly enlarged CN tables, all based on $\lambda = 0.05$

Professional observations:

- Many land uses not covered by current tables; ground truth is difficult
- Local judgements of CN values are unavoidable
- Soils are important, but HSGs not always reliable indicators
- Original work by SCS was incompletely documented
- Use of ordered data is contentious but fits with observations of CN values
- Data quality obscures primary and secondary effects and makes them harder to determine
- Rainfall depth P by itself explains the most variation in direct runoff Q
- CN method is subset of general rainfall-runoff hydrology
- Most CN contention centers on the physical interpretation of the "model"
- Original Mockus equation is a soil block and is infiltration-based.

Research/development suggestions:

- Further refinement and evidence of CN secondary effects

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- Ia/S is a function of P, intensity, or something else?
- Critique/defense of rank-ordering data pairs
- Field comparison of HSG and CN tables
- Testing and confirming tables for existing local-judgement CN tables.

Introspection on limitations:

- Nothing for $\lambda = 0.05$ equivalent to the $P/S_{20}>0.46$ for $\lambda = 0.20$
- All in inches of depth, not metric
- Does not provide lumped standard asymptotic in design; no "k" parameter from CN_∞
- Violent patterns are incompletely understood; this lack of understanding results from their rarity and from loss of data collection systems during these events
- Examples look good and illustrate/good, but all data do not look as good
- Need better watershed descriptors to identify potential Complacent, Standard, and Violent patterns; how to identify the patterns from field examination and GIS analysis
- Did not show frequency plot of P and Q to determine CN
- Boundaries between Complacent and Standard patterns are not always clear
- Used natural data interpretation $Q = f(P)$ in ordered data CN analysis
- Plotting independent event Q against P is interpreted as Q(t) and P(t) or the progression of runoff during an individual design storm
- Distributed source area accounting does not allow mixing of runoff patterns, e.g., Standard patterns with Complacent patterns.
- CN as a function of P is biased insofar as only $0<Q<P$; no $CN<CN_o$ values are in the data sets; truncating the data sets give biased relationships; CN_o is a function of P
- By necessity, all of the basic data are not provided
- Omitted some complicating details, e.g., $\sigma_{x50}=1.25\sigma_x$

Possible future directions and enhancements:

- Inclusion of Type I and Type II effects from calibration; CNs are higher because data sets ignore Q = 0.00
- Need to investigate/promote "forest" hydrology models
- Runoff behavior is unknown for extreme storms beyond data limits
- Extension to other NRCS methods such as hydrographs
- CN as an environmental index
- Centralize a catalog of computed CNs in the "Cloud"?
- Elaboration of the general P:Q model which encompasses CN
- Encourage practitioners to publicize/publish case studies imparting their wisdom on using CN method hydrology

- Investigating and compiling the use of rainfall simulation or ring-infiltrometer systems to delineate on-site CNs
- CN History and technical development should be written.