VARIETY OF ANTECEDENT RUNOFF CONDITIONS FOR RANIFALL-RUNOFF WITH THE CURVE NUMBER METHOD

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A fundamental task in applied hydrology, engineering, and watershed management is to know, predict, and understand a watershed's response to a design rainstorm event based on its land condition, and usually for an ungauged watershed. To meet this need on an institutional and nationally consistent basis in the mid-1950s, the USDA Soil Conservation Service (SCS) developed the Curve Number Method, intended for small rain-fed agricultural watersheds.

The method is briefly described as follows: Runoff depth (Q) from a rain storm of depth (P) is given by:

$$Q= (P-0.2S)2/(P+0.8S) \text{ for } P>0.2S, Q=0 \qquad [1]$$

where S is defined as the maximum possible difference between P and Q once runoff has begun (i.e., P>0.2S), and is in unit of depth. For ease of use and understanding, S was transformed into a dimensionless variable "Curve Number" or CN, which varies from 0 to 100, and is defined as

$$CN = 1000/(10+S) \qquad [2]$$

where S is in inches. To operate the CN method, a "CN" is required, and tables of CN as a function of soils type, land cover and use/condition were supplied in handbooks by the SCS.

In the data analysis that led to the method's development, it was noted that the relationship between rainfall depth (P) and event runoff depth (Q) contained good deal of scatter. This is illustrated in Figure 1. In order to give a central trend definition to the runoff response for the watersheds, the median CN for annual flood events was taken as watershed-defining CN.

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However, the scatter required explanation, and it was attributed to the differences in on-site moisture (Antecedent Moisture Condition, or "AMC") at the onset of the storms. The central trend CN was understood to be at "AMC II", or a median moisture condition for annual floods. High deviants were thought to be caused by wet conditions, and labeled as "AMC III", and low departures were taken to be from dry watersheds, called "AMC I."

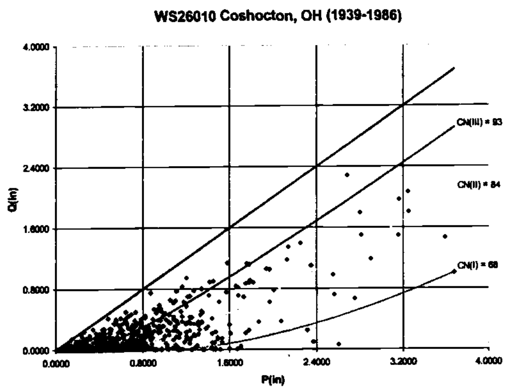

Figure 1. Illustration of event runoff variability for 879 events at Coshocton, Ohio, with the handbook AMC bands superimposed. The drainage area is 1.37 acres.

The SCS (now NRCS) then generated standard conversions from AMCII to Conditions I and II. These are also shown superimposed in Figure 1, and are abbreviated in Table 1. Table 1 is given in graphical form in Figure 2, which forms the basis for much of what follows. The original development or data analysis for Table 1 and Figure 2 has not been documented in either the open literature or in surviving NRCS files.

Table 1. Abbreviated Handbook CN-AMC relationships

CN(II)	CN(I)	CN(III)	S(II)	Ia(II)
100	100	100	0	0
95	87	98	0.526	0.11
90	78	96	1.11	0.22
85	70	94	1.76	0.35
80	63	91	2.50	0.50
75	57	88	3.33	0.67
70	51	85	4.28	0.86
65	45	82	5.38	1.08
60	40	78	6.67	1.33
55	35	74	8.18	1.64
50	31	70	10.00	2.00
45	26	55	12.2	2.44
40	22	60	15.0	3.00
35	18	55	18.6	3.72
0	0	0	-	-

Source: condensed from NEH4 Table 10.1. S(II), Ia in inches.

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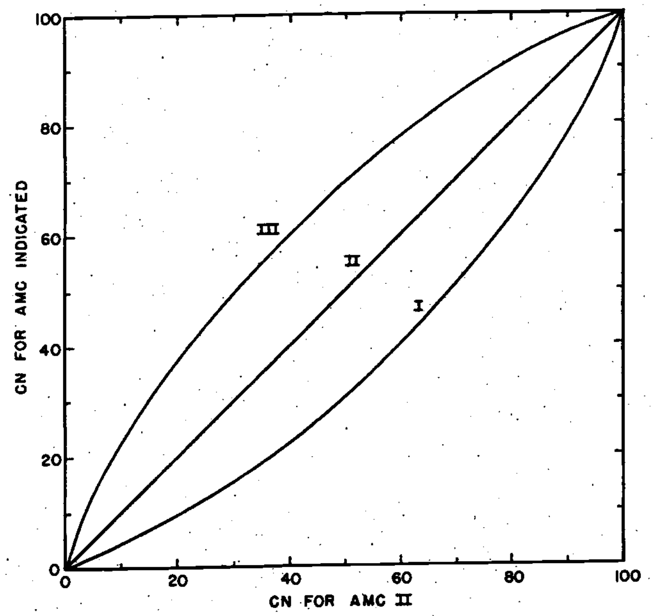

Figure 2. Graphical representation of the data from Table 1, taken from NRCS Hydrology Guide Table 10.1

This acknowledged event-to-event variability was originally explained by aligning AMC status with 5-day prior rain by seasons. This is shown in Table 2.

Eventually, with widespread and substantial critique, this approach was dropped, and is no longer espoused by NRCS. A new terminology and hypothesis was developed: AMC became ARC (Antecedent Runoff Condition), and the observed unexplained departures attributed to all the storm, watershed, data, and model factors (including error) that influence departures from the central trend (defined as the median, or CN at ARC-II). Thus the ARC factors include, but are not limited to, prior moisture.

Table 2. Antecedent Moisture Classes defined by 5-day prior rainfall

Condition	----- 5-Day prior rainfall (in) ----- Dormant Season	Growing Season
I	<0.50	<1.4
II	0.50-1.10	1.40-2.1
III	>1.10	>2.1

Source: Table 4.2 (discontinued) NEH4, Ch 4. For historical and information purposes only. No longer endorsed or supported by NRCS; DO NOT USE.

PROBABILITIC DESCRIPITIONS

Hjelmfelt, Kramer, and Burwell. Given that runoff variability is not well explained satisfactorily by site moisture or prior rain, Hjelmfelt, Kramer, and Burwell (1982) examined the probabilistic nature of the departures. Using 12 mid-western USDA research watersheds with records from 7 to 24 years, the CNs for annual floods were found. With the rainfall depth P and runoff depth Q, S is found by solving equation [2] via the quadratic formula to

$$S = 5[P + 2Q -(4Q2+5PQ)0.5] \qquad [3]$$

and then CN is determined from equation [2]. The CNs so found were assumed to be log-normally distributed, the 50% item (i,e, the median) taken to be defining CN at ARC II, and the cumulative probabilities for the ARC I and ARC-III determined by interpolation using the full handbook version of Table 1 and the known properties of the lognormal distribution.

Surprising order emerged: the table-defined ARC-III was found to be quite close to the 90 percent CN. That is, 90 percent of the CNs were less than the found value (10% greater), implying that 90% of the runoffs at a given rainfall would be less that that calculated with that CN and P. Similarly, ARC I was found to be quite close to the 10 percent CN. That is, 10 percent of the CNs were less than the found value (90% greater), implying that 10 percent of the runoffs at a given rainfall would be less than that calculated with that CN and P. In short, in the language of cumulative distributions, ARC-I was 10 %, ARC-II was 50% , and ARC- III at 90 percent. The ARCs describe "error bands." These findings influenced the abandonment of the prior rainfall-based AMC categories (i.e., Table 2) as described earlier.

The results of the Hjelmfelt et al work is shown in Figure 3 Note the close alignment of the found points with the handbook AMC classes.

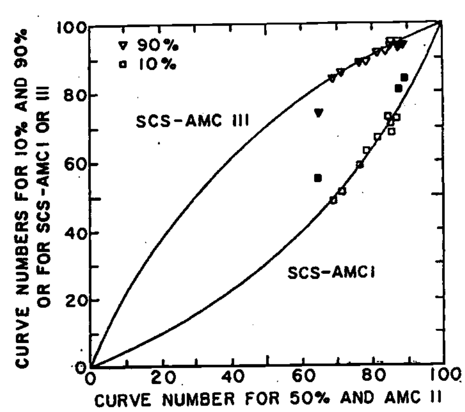

Figure 3. Hjelmfelt et al findings for 10 and 90 percent CNs plotted on NRCS handbook AMCI and III relationships.

Larger sample study

This new "random" description of CN (and Q) variability influenced to the abandonment of the prior rainfall-based AMC categories (i.e., Table 2) as described earlier.

Table 3. Results Summary

Handbook Table Condition	ARS(N=63)	Data Sets USGS(N= 51)	Combined (N=114)
AMC I	88.2(0.28)	87.8(0.27)	88.0 (0.27)
AMC II		defined as 50%	
AMC III	12.9(0.41)	11.8(0.30)	12.4 (0.38)
Spread I to III	75.3	76.0	75.6

Note: Table entry is average and standard deviation of the "greater than" cumulative rank percentage for the ARC indicated.

However, the sample was quite limited: only 12 watersheds of modest record length and geographical spread. Here a larger sample is examined, and a greater variety of locations is covered. The study here includes a much larger sample: 114 watersheds from USDA and US Geological Survey sources (only 99 considered here), and for a minimum period of 20 years. In all, 3548 annual flood events were used. As with Hjelmfelt et al, CNs were determined from P and Q data, the results arrayed, and the probabilities of the Table AMC I, II, and II determined. One departure here from the Hjelmfelt et al procedures is that the cumulative probabilities were found by interpolation of the raw found CN's with Gumbel/Weibull plotting positions:

$$PP=m/(n+1) \quad [4]$$

where m is the rank order, and n is the sample size.

The results are shown in Figure 4. The points again cluster around the Handbook Table I and III designations, with variation attributable to the large sample sizes. Not surprisingly, the findings support the generalization of extreme events (i.e., 10% and 90%) defining AMC I and AMC III. However, taken on the table MRC percentages, the mean results are slightly different, as given in Table 3.

DISCUSSION, SUMMARY, CONCLUSION

This analysis found that approximately ¾ (that is 75.6%) of all annual peak events fell between the handbook stated ARC I and III limits. This is a tighter band than previously found. It speaks surprisingly well for the handbook tables, especially given their lack of documented origins and open literature review.

However, it should be remembered that the professional and scientific interest is in the rainfall runoff, not the Curve Number Method itself. The CN method and its appurtenances is only a means of approaching the rainfall-runoff target. Natural variability in runoff does occur, and the CN method's ARC bands do seem to give a useful descriptive handle on that variability.

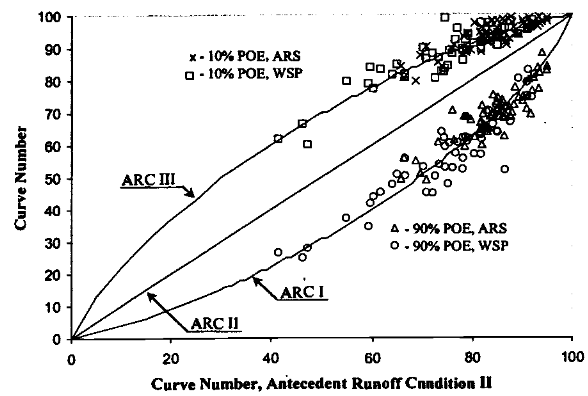

Figure 4. Distribution of CN I and CN III with 10% and 90% Probability of Exceedance (POE), annual series maximum runoff flow rate for all Agricultural Research Service (ARS) and United States Geological Survey (WSP) watersheds.

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