

1 United States Department of Agriculture

2 Natural Resources Conservation Service

3 Part 630 Hydrology

4 National Engineering Handbook

5 **Chapter 9: Hydrologic Soil-Cover Complexes**

6 **Acknowledgements**

7 Chapter 9 was originally prepared by **Victor Mockus**, (deceased) hydraulic engineer, USDA Soil
8 Conservation Service, and was published in 1964. It was reprinted with minor revisions in 1969. This
9 version was prepared by the Natural Resources Conservation Service (NRCS)/Agricultural Research
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12 A previous revision was prepared by the Natural Resources Conservation Service (NRCS)/Agricultural
13 Research Service (ARS) Curve Number Work Group.

14 This September 2017 revision is based on the publication originally developed by that work group, which
15 was composed of scientists and engineers from:

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21 The authors and contributors to this September 2017 revision are indebted to their original work.

22 **Authors and Contributors:** This September 2017 revision was prepared by the Curve Number Task
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34

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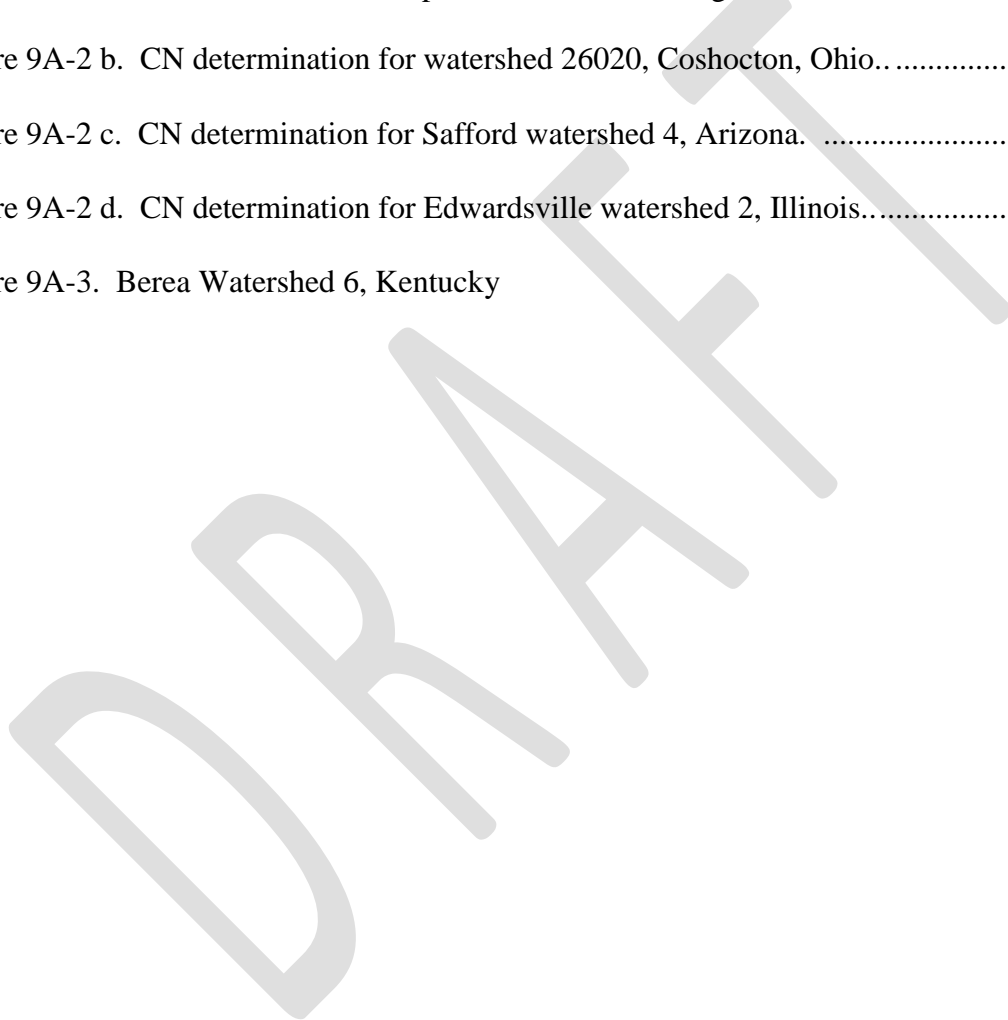
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83 630.0900 General

84 A combination of a hydrologic soil group (soil) and a land use and treatment class (cover) is a
85 hydrologic soil-cover complex that defines a Curve Number (CN). This chapter provides tables
86 and graphs of runoff curve numbers (CNs) assigned to such complexes. The CN indicates the
87 runoff potential of a complex during periods when the soil is not frozen or there is no snow on
88 the ground. CNs are used to estimate runoff from rainfall, only. A higher CN indicates a higher
89 runoff potential and specifies which runoff curve or Figure 10–2 in National Engineering
90 Handbook, Part 630 (NEH 630 (USDA NRCS (1999)), Chapter 10, is to be used in estimating
91 runoff for the complex. Applications and further description of CNs are given in NEH 630,
92 Chapters 10 and 12.

93

94 630.0901 Determinations of complexes and Curve Numbers**95 (a) Agricultural land**

96 Complexes and assigned CNs for combinations of soil groups of NEH 630, Chapter 7 and land
97 use and treatment classes of NEH 630, Chapter 8, are shown in Table 9–1. Impervious surfaces
98 and water surfaces, which are not listed, are always assigned a CN of 97.

99 (1) Historic assignment of CNs to complexes

100 Table 9–1 was initially developed as follows:

101 The data literature was searched for watersheds in single complexes (one soil group and one
102 cover); watersheds were identified for most of the listed complexes.

103 A median CN for each watershed was obtained using rainfall-runoff data for all storms
104 producing the annual peak runoff. The watersheds were generally less than 1 square mile in area,
105 the number of watersheds for a complex varied, and the storms were of one day (24 hours) or
106 less duration.

107 A plot of rainfall versus runoff was developed for all the watersheds in the same complex and the
 108 median value was selected. A curve for each cover was drawn with greater weight given to CNs
 109 based on data from more than one watershed, and each curve was extended as far as necessary to
 110 provide CNs for ungauged complexes.

111 All but the last three lines of CN entries in Table 9–1 are taken from these curves. For the
 112 complexes in the last three lines of Table 9–1, the proportions of different covers were estimated
 113 and the weighted CNs computed from previously derived CNs.

114 Table 9–1 has been significantly changed since developed in 1954 and CNs for crop residue
 115 cover treatment have been added. CNs for selected urban condition were developed
 116 subsequently and are shown in other tables. These urban CNs are based on limited data and are
 117 currently being used by several government agencies across the county. CNs for the National
 118 Land Cover Data (NLCD) set have been added.

119 **(2) Use of Table 9–1**

120 Chapters 7 and 8 of NEH 630 describe how soils and covers of watersheds or other land areas are
 121 classified in the field. After the classification is completed, CNs are selected from Table 9–1 and
 122 applied as described in Chapter 10. The principle use of CNs is for estimating runoff from
 123 rainfall. Some examples of applications are given in Chapter 10.

124 **Table 9- 1.** Runoff Curve Numbers for agricultural lands¹

Cover description			CN for Hydrologic Soil Group			
Land Use or Cover type	Land Treatment ²	Hydrologic condition ³	A	B	C	D
Fallow	Bare Soil	-----	70	81	88	91
		Poor	69	80	87	86
	Crop residue cover (CR)	Good	67	77	84	85
Row crops	Straight row (SR)	Poor	64	75	84	88
		Good	59	69	80	85
	SR + CR	Poor	63	74	82	86
		Good	56	68	76	80

	Contoured (C)	Poor	62	73	77	84	
		Good	56	68	76	81	
	C + CR	Poor	61	71	77	82	
		Good	57	76	75	80	
	Contoured & Terraced (C &T)	Poor	55	64	72	74	
		Good	58	63	71	73	
	C & T + CR	Poor	54	63	71	75	
		Good	52	62	70	74	
	Small grain	SR	Poor	57	69	79	84
			Good	55	68	77	82
SR + CR		Poor	56	68	77	81	
		Good	42	64	74	79	
C		Poor	55	67	76	80	
		Good	52	66	75	79	
C + CR		Poor	53	66	75	79	
		Good	51	64	74	79	
C & T		Poor	52	64	73	76	
		Good	50	62	71	75	
C & T + CR		Poor	51	63	71	75	
		Good	49	61	69	74	
lose-seeded or broadcast legumes or rotation meadow		SR	Poor	58	70	80	85
			Good	51	63	70	75
	C	Poor	53	66	76	78	
		Good	43	59	75	80	
	C & T	Poor	56	66	74	77	
		Good	52	59	69	76	
Pasture, grassland, or range – continuous forage for grazing ⁴	Poor	60	73	81	85		
	Fair	40	61	73	79		
	Good	31	52	67	74		
Meadow – continuous grass, protected from grazing and generally mowed for hay	Good	23	49	63	71		
Brush – brush – forbs – grass mixture with brush the major element ^{5,6}	Poor	39	59	70	77		
	Fair	27	47	62	70		
	Good	23	39	57	66		
	Poor	48	66	76	81		

Wood – grass combination (orchard or tree farm) ⁷		Fair	35	57	69	76
		Good	25	49	64	73
Woods ⁸		Poor	37	58	70	77
		Fair	28	51	66	73
		Good	23	46	62	70
Forests		See Table 9-3				
Farmstead – buildings, lanes, driveways, and surrounding lots		-----	50	67	76	81
Roads (and right of way)	Dirt	-----	64	76	82	85
	Gravel	-----	69	80	85	88

125 ¹ Average runoff condition, and $I_a = 0.05S$.

126 ² Crop residue cover applies only if residue is on at least 5 percent of the surface throughout the year.

127 ³ Hydrologic condition is based on combinations of factors that affect infiltration and runoff, including (a) density
128 and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes,
129 (d) percent of residue cover on the land surface (good $\geq 20\%$), and (e) degree of surface toughness.

130 ⁴ Poor: < 50% ground cover or heavily grazed with no mulch.

131 Fair: 50 to 75% ground cover and not heavily grazed.

132 Good: >75% ground cover and lightly or only occasionally grazed.

133 ⁵ Poor: <50% ground cover.

134 Fair: 50 to 75% ground cover.

135 Good: > 75% ground cover.

136 ⁶ If the CN is less than 30, use $CN = 30$ for runoff computations.

137 ⁷ CNs shown were computed for areas with 50 percent woods and 50 percent grass (pasture) cover. Other
138 combinations of conditions may be computed from the CNs for woods and pasture.

139 ⁸ Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.

140 Fair: Woods are grazed, but not burned, and some forest litter covers the soil.

141 Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

142

143 Table 9-1 was derived from the original table values using $Ia/S = 0.05$. The original table values
 144 with $Ia/S = 0.20$ were developed from available data and other information.

145

146 **(b) National and commercial forest: forest-range**

147 **(1) Forest-range in Western United States**

148 In the arid and semiarid forest-range regions of the United States, soil group, cover type, and
 149 cover density are the principle factors used in estimating CNs. Table 9-2 shows the relationships
 150 between these factors and CNs for soil-cover complexes. The figures are based on information in

151 **Table 9- 2.** Runoff Curve Numbers for arid and semiarid rangelands¹

Cover description		CN for Hydrologic Soil Group			
Land Use or Cover type	Hydrologic condition ²	A ³	B	C	D
Herbaceous – mixture of grass, weeds and low-growing brush, with brush the minor element	Poor		74	82	90
	Fair		63	75	85
	Good		53	67	71
Oak-Aspen – mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		58	67	73
	Fair		41	50	58
	Good		25	36	41
Pinyon-juniper – pinyon, juniper, or both; grass understory	Poor		70	81	86
	Fair		52	66	74
	Good		33	52	63
Sage-grass – sage with an understory of grass	Poor		59	74	80
	Fair		42	55	62
	Good		28	38	46
Desert shrub – major plants include saltbush, greasewood, creosote bush, black brush, bursage, paloverde, mesquite, and cactus	Poor	55	70	80	84
	Fair	46	67	75	81
	Good	40	60	73	79

152 ¹ Average runoff condition, and $I_a = 0.05S$. For range in humid regions, use Table 9-1.

153 ² Poor: < 30% ground cover (litter, grass, and brush over story).

154 Fair: 30 to 70% ground cover.

155 Good: > 70% ground cover.

156 ³ Curve Numbers for HSG A have been developed only for desert shrub.

157

158 Table 2–1, part 2, of the USDA Forest Service's Handbook on Methods of Hydrologic Analysis
159 (USDA 1959) and limited field data. The amount of litter is taken into account when estimating
160 the density of cover. Table 9–2 also lists CNs for arid and semiarid rangelands.

161 (Classical) Forest Watersheds: At one extreme are the well-watered and well-forested
162 watersheds, often with multiple canopies and abundant litter and low-intensity management.
163 Organic material is copious and evident. These are characterized by humid climates – at least
164 seasonally - and display high infiltration abilities, often live (flowing) headwater streams, and
165 may be found in steep topography. Intermittent channels and rills are rare, and there may be
166 extensive areas with no evidence of overland flow. There is negligible bare soil except on roads
167 and disturbances. True forests approximate the “climax” vegetation type for the humid region.
168 The current NEH CN table listings for “Woods” are not appropriate because of Complacent-
169 Violent runoff behavior during extreme rainfall events. [Runoff behaviors are described in detail
170 in Appendix 2 of this chapter.]

171 While frequently found on National Forests and/or classified as Commercial forests, these
172 characteristics alone are insufficient to specify the above condition. Many examples are found in
173 traditional small forested watershed research sites of the USDA-Forest Service. In high-elevation
174 snow-dominated watersheds, summer rainfall event runoff is infrequent. For example, at Wagon
175 Wheel Gap in Colorado, elevation circa 9500 feet, there was only a single summer runoff event
176 in ten (10) years of data collection.

177 There is no currently accepted alternative to the Curve Number method at this level of
178 technology to treat these situations. Similarly, there are no techniques for the systematic

179 estimation of silvicultural actions on runoff relations from such watersheds. The effects of fire
180 however, may be profound - though frequently short-lived - and are described elsewhere in
181 Chapter 12 of the NEH.

182 Forests (in name only): At the other extreme are such tree-associated lands as parks, cemeteries,
183 savannahs, oak woodlands, grass-forest transitions, pinyon-juniper landscapes, orchards, and
184 vineyards, characterized by finer soils and lower organic matter. Other typical land uses include
185 grazed farm woodlots, horticultural efforts, or grazing. Evidence of overland flow may be seen in
186 ephemeral channels, gullies, and rilling. Usually, on gentler slopes, these source areas
187 watersheds are assumed to be CN compliant. Within the known limits of the CN method, the
188 NEH listings for “Woods” are more appropriate here.

189 Mixtures and Others: For cases between the well-forested watersheds and those in name only,
190 professional judgment and site familiarity is required. The difference between these two
191 extremes are the differences in the cover, climate, soils, geology, land slopes, land use and flow
192 source processes.

193 There is also an effect of drainage area. Larger drainage areas of well-forested lands often
194 contain a mixture of watershed types and soils, often with urban, agricultural or pastoral lands
195 intermingled. These mixes may exhibit Standard response, albeit with low CNs in the 45-65
196 range. In these cases, it is suggested that a distributed source model (a model that considers the
197 runoff from each contributing area in a watershed) be applied to include the high CN portions
198 (roads, urban, agriculture) and the low CN heavily forested portions, and direct channel portions
199 of CN=100.

200 Hydrologic Soils Group (HSG) A soils: These soils have high infiltration but may overlay an
201 impervious layer at varying depths resulting in delayed surface and subsurface responses
202 observed in event hydrographs. HSG A soils have very little runoff even with frequently
203 occurring storms (mainly from rainfall falling on roadways and waterways). As rainfall return
204 period increases, a point will be reached in which the storage of the porous soil above the
205 impervious layer is reached, and nearly all rainfall will appear as runoff. HSG A soils are

206 generally not suited for the CN method and the method should not be assumed valid (see Table
 207 9-3).

208 Current knowledge is insufficient for providing precise guidance when modelling HSG A soils,
 209 and additional research is needed. Other hydrologic response models such as Wildcat5 (Hawkins
 210 and Barreto-Munoz, 2016) and TopModel (Bevin, 2012) should be considered for use in HSG A
 211 watersheds. In the absence of alternative modeling approaches, a conservative approach would
 212 be to assign a high CN (e.g., 90+) when designing for extreme events having life and property
 213 implications downstream such as flood control dams.

214 HSG B and C Soils: The Complacent-Violent response is possible on these soils, particularly on
 215 steeper slopes with the classical forest as described above. As the soil becomes less permeable,
 216 the CN method becomes an appropriate tool. As the tree cover becomes more like the Forest-in-
 217 name-only or a frequently harvested commercial forest, the CN for woods become a more
 218 suitable choice. The recommendation of distributed modeling approaches for regions with mixed
 219 tree cover, and other vegetation types is highly recommended with HSG B and C soils,
 220 especially on steeper topographies. As with HSG A, one may use a high CN on steeper forest
 221 soils when life and property considerations are judged to be significant such as design of flood
 222 control dams. Professional judgment is required, and consultation with a soil scientist regarding
 223 the nature of the soil profile is strongly recommended.

224 HSG D Soils: Because the HSG D soil has a relatively low permeability, the Complacent-Violent
 225 behavior is unlikely. Thus, the CN method is expected to be relevant in classical forests,
 226 commercial forests, forests-in-name-only, and in mixed and other cover types.

227 **Table 9- 3.** Limitations on the use of Curve Numbers in forests

Soil Group	Slope	Subsurface Flow	Available Storage	Precipitation Event	Use of CN Method
Group A	High	Yes	Moderate	Extreme	Not Recommended
Group A	Low	No	High	2--100 yr	Possible
Group B or C				2--100 yr	Questionable

Group D	High	Yes	Moderate	2--100 yr	Acceptable
Group D	Low	No	Low	2--100 yr	Acceptable

228 The factor of significance decreases from left to right in the table.

229

230 Table 9-3 provides additional insight to the problems associated with the use of the CN method
 231 in forested watersheds. Tollner (2017) has presented on this topic.

232

233 **(c) Urban and residential land**

234 Several factors, such as the percentage of impervious area and the means of conveying runoff
 235 from impervious areas to the drainage system, should be considered in computing CNs for urban
 236 areas (Rawls et al., 1981). One must determine if the impervious areas connect directly to the
 237 drainage system or do they outlet onto lawns or other pervious areas where infiltration can occur.

238 The urban and residential CNs shown in Table 9–4 were developed for typical land use
 239 relationships based on specific assumed percentages of impervious area. These CN values were
 240 developed on the assumptions that

- 241 • pervious urban areas are equivalent to pasture in good hydrologic condition,
- 242 • impervious areas have a CN of 98 and are directly connected to the drainage system, and
- 243 • the cover types listed have assumed percentages of impervious area as shown in Table 9–6.

244 **(1) Connected impervious areas**

245 An impervious area is considered connected if runoff from it flows directly into the drainage
 246 system. It is also considered connected if runoff from it occurs as shallow concentrated flow that
 247 runs over another pervious area and then into a drainage system.

248

249 **Table 9- 4.** Curve Numbers for urban conditions¹

Cover type and hydrologic condition	Average percent impervious area ²	CN for Hydrologic Soil Group			
		A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) ³					
Poor condition (grass cover < 50%)	--	60	73	81	85
Fair condition (grass cover 50% to 75%)	--	40	61	73	79
Good condition (grass cover > 75%)	--	31	52	67	74
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	--	97	97	97	97
Streets and roads:	--				
Paved; curbs and storm sewers (excluding right of way)	--	97	97	97	97
Paved; open ditches (including right of way)	--	77	85	89	97
Gravel (including right of way)	--	69	80	85	88
Dirt (including right of way)	--	64	76	82	85
Western desert urban areas:					
Natural desert landscaping (pervious areas only) ⁴		55	62	80	84
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)	--	94	94	94	94
Urban districts:					
Commercial and business	85	85	89	92	93
Industrial	72	75	84	88	90
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	70	80	86	89
1/4 acre	38	52	68	77	82
1/3 acre	30	48	64	76	81
1/2 acre	25	45	62	74	80
1 acre	20	42	60	73	79
2 acres	12	37	57	70	76
Developing urban areas:					

Newly graded areas (pervious areas only, no Vegetation)	--	70	81	88	92
---	----	----	----	----	----

250 ¹ Average runoff conditions and $I_a = 0.05S$.

251 ² The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as
 252 follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 97, and
 253 pervious areas are considered equivalent to open space in good hydrologic condition.

254 ³ CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of
 255 open space type.

256 ⁴ Composite CNs for natural desert landscaping should be computed using Figures 9-3 or 9-4 based on the
 257 impervious area percentage (CN=98) and the pervious area CN. The pervious area CNs are assumed equivalent
 258 to desert shrub in poor hydrologic condition.

259

260 If all of the impervious area is directly connected to the drainage system, but the impervious area
 261 percentages in Table 9–4 or the pervious land use assumptions are not applicable, use Equation
 262 9–1.

$$263 \quad CN_c = CN_p + (P_{imp}/100)(97 - CN_p) \quad [9-1]$$

264 where:

265 CN_c = composite runoff Curve Number,

266 CN_p = pervious runoff Curve Number, and

267 P_{imp} = percent imperviousness.

268 **(2) Unconnected impervious areas**

269 If runoff from impervious areas flows on to a pervious area as sheet flow prior to entering the
 270 drainage system, the impervious area is unconnected. To determine CN when all or part of the
 271 impervious area is not directly connected to the drainage system, use:

- 272 • Equation [9–2] if the total impervious area is less than 30 percent of the total area or

273 • Equation [9–1] if the total impervious area is equal to or greater than 30 percent of the total
274 area, because the absorptive capacity of the remaining pervious areas will not
275 significantly affect runoff.

$$276 \quad CN_c = CN_p + (P_{imp}/100)(97 - CN_p)(1 - 0.05R) \quad [9-2]$$

277 where:

278 CN_c = composite runoff Curve Number,

279 CN_p = pervious runoff Curve Number,

280 P_{imp} = percent imperviousness, and

281 R = ratio of unconnected impervious area to total impervious area.

282 **Low Impact Development (LID).** LID measures are being used in urban and urbanizing areas
283 to help mitigate the impact of increased impervious cover conditions. LID measures can include
284 pervious pavement, green roofs, infiltration beds, and planting pot. Local agencies should be
285 consulted about the proper method and requirements of the local ordinances.

286 The following tables for certain features of urban areas with selected LID measures have been
287 developed from the literature and are examples of what can be used (Tables 9-5 and 9-6).

288 Green roofs are roofs have live vegetation with a limited soil profile and drainage from the roof
289 if the profile is saturated. Permeable pavement is generally used in parking lots or other areas of
290 lower traffic and the purpose is to reduce runoff by increasing the permeability.

291

292 **Table 9- 5.** Curve Numbers for green roofs

Roof Thickness (in)	2	3	4	6	8
CN	92	89	84	80	70

293

294 Curve Numbers in Table 9-5 are based on a paper by Fassman-Beck et al. (2016). The
 295 information was developed from available data.

296 **Table 9- 6.** Curve Numbers for permeable pavement over HSG subbases

Subase (inches)	HSG B	HSG C	HSG D
6	69	79	90
9	53	57	70
12	32	46	62

297 Average runoff condition, and $I_a = 0.05S$

298

299 The values in Table 9-6 are based on the assumption there is adequate positive drainage within
 300 the pavement conditions. It there is no positive drainage, the CN is equal to fallow or bare soil.
 301 They were taken from information provided by Schwartz (2010) and Ballester (personal
 302 communication, 2016). Both tables were developed from data.

303

304 **(d) Karst Hydrology and the CN Method**

305 The CN method is not applicable to watersheds which have karst conditions influencing the
 306 hydrology. The primary reason is that the karst terrain creates subsurface flow conditions that
 307 can dominate over surface soil conditions in controlling rainfall losses. The Virginia Department
 308 of Conservation and Recreation in Technical Bulletin No.2 Hydrologic Modeling and Design in
 309 Karst (2017) recognizes that a karst loss factor (i.e., a factor describing surface runoff loss into
 310 underlying limestone bedrock) is not the same as other calculation factors, such as Curve

311 Numbers, that describe losses on the land surface. Although Malago et al. (2016) for Island of
312 Crete watersheds and Amin et al. (2017) for the Spring Creek, Pennsylvania, USA, watershed
313 used the SWAT model (Arnold et al., 1998) and its underlying use of the CN method, they did so
314 by treating the CN value as an optimization parameter. Malago et al. (2016) varied the CN by
315 $\pm 15\%$ but did not state the final set of calibrated CNs for the 22 watersheds in the study which
316 ranged in area between 21 km^2 and 523 km^2 . The flow data were monthly outflow totals and not
317 rainfall-runoff events. In the work by Amin et al. (2017), the authors used the SWAT model
318 (Arnold et al., 1998) and a variation called Topo-SWAT that incorporates the topographic
319 wetness index proposed by Beven and Kirkby (1979). The watershed in Amin et al. (2017) was
320 370 km^2 in area, the streamflow data were daily discharge values, and the calibrated CN_{II} was 47
321 (calibrated downward from an initial value of about 63). Use of large models such as SWAT
322 with many calibration parameters may obscure the most representative CN value because of
323 competing adjustments in other parameters. A caution about and reasoning for not using the CN
324 method in karst watersheds was presented by Iacobellis et al. (2015) using a case study on a
325 22.3 km^2 karst endorheic (closed basin) watershed in south-eastern Italy. Their major objection is
326 that the loss rate in the CN method goes to zero as S is satisfied whereas karst terrain will always
327 exhibit a loss rate because of the underlying bedrock conditions. However, karst dominated
328 drainage systems can contribute significant amounts of subsurface flow.

329 Because the bedrock conditions and other factors are not conducive to the underlying principles
330 of the CN method, the CN methods is not recommended for karst dominated watersheds. If local
331 information on rainfall and runoff from karst watersheds is available, then that information
332 should be used to create a predictive approach better suited for the area.

333

334 **630.0902 Curve Number Variation with Slope**

335 Despite its conceptual effects, there is no mention in the current handbooks of the influence of
336 watershed or plot slope on CN. There is no direct accounting for the influence of slope on CN.

337

338 In general, the slopes of the agricultural watersheds Mockus was familiar with were perhaps 5%
 339 or less. Slope may not play a major role in the volume of runoff in the data set he analyzed or
 340 the watersheds he visited. He may have been talking about the estimation of peak flow rather
 341 than the estimation of runoff volumes. Other researchers have found a variety of effects as
 342 shown in Table 9-7.

343 **Table 9- 7.** Summary of slope effects on CN

Source	Effect ΔCN/%slope	Remarks
Hawkins and Ward (1998)	-2.87	5 plots, Jornada Range, NM, $r^2 = 0.37$
Garg et al. (2003)	-1.30	AGNPS model, 5 watersheds, central OK
VerWeire et al. (2005)	-1.72	27 watersheds, GIS studies
Neitsch et al. (2002)	+0.25 to +0.90	SWAT model inputs 5% land slope
Getter et al. (2007)	+0.25	Green Roofs, $r^2 = 0.88$
Fassman et al. (2015)	+0.33	Lining roofs, $r^2 = 0.02$
Hastings, NE, ARS data	+2.45	Rain-fed agricultural

344
 345 The Neitsch et al. (2002) reference refers to work done by the ARS to develop a slope
 346 adjustment equation for the various continuous computer models, which adjusted equations in
 347 the model to achieve agreement between the output and watershed data. Whether the ARS used
 348 watershed data to develop the adjustments is not known. The equation developed and used by
 349 others for a slope adjustment is:

350
$$CN_{2\alpha} = 1/(3(CN_3 - CN_2)(1 - 2e^{-13.86\alpha})) + CN_2 \quad [9-3]$$

351 where:

352 CN_2 and CN_3 are the SCS CN for soil runoff conditions 2 (average) and 3 (wet), and

353 α (m/m) is the slope.

354 The $CN_{2\alpha}$ is then used, instead of CN_2 , in the subsequent calculations of the runoff volume. A
355 value of $Ia/S = 0.20$ was used.

356 Research from China indicates the CN varies with slope as (Huang et al., 2005):

$$357 \quad CN_{2\alpha} = CN_2(322.79 + 15.63\alpha)/(\alpha + 323.52) \quad [9-4]$$

358 where:

359 α is the watershed slope (m/m), and

360 CN_2 is the Curve Number for ARC II from the SCS handbook with $Ia/S = 0.20$.

361 The slopes varied from 0.14 to 1.4%. Measured runoff volumes with natural (not simulated)
362 rainfall were analyzed. The cover on the plots was alfalfa and pasture on a loess soil.

363 There have been several papers from India that indicate that CNs varied with the slope of the
364 experimental plot. One paper using plot data and rainfall data from sugar cane on a HSG C soil
365 indicated that the NEH-4 values and the plot data were quite close. The results for a range of
366 slopes of 1%, 3% and 5% are 87.82, 89.72, and 91.83, respectively, as compared to 85 to 88 for
367 sugar cane from NEH-4 (Anubhav et al., 2013). These results suggest CN values increase with
368 slope.

369 Another paper from India indicates that for maize plot data with natural rainfall the derived CN
370 values for 1% plot slope were nearly equal to that derived from NEH-4 table for 1% slope
371 whereas NEH-4 values were lower than those derived for the 3% and 5% slopes (Raj Kaji et al.,
372 2013). These results suggest slope increases CN values.

373 A paper by Ebrahimian et al. (2012) using information from watersheds in Iran indicated that
374 there is some variation in CN with slope, although his study failed to show a strong effect of
375 slope on runoff generation in the watershed. Assessment of slope on runoff generation should be
376 studied in additional detail. The Iran watershed studied was in watersheds with mainly range
377 cover crop, a wide range of HSGs, and natural rainfall events.

378 There are a variety of results, including some counter-intuitive negative relations, but there is a
379 lack of consistency or general affirmation. There is no final committee consensus decision on
380 the impact of slope. It should be noted that if there is concern with the impact of slope on Curve
381 Number, then additional local studies and local decisions should be employed.

382

383 **630.0903 Curve Number Variation with Season**

384 Studies suggest that CN values for selected land uses or cover types vary by season or month.
385 The physical reason is that the stage of the vegetation has an impact on rainfall losses. However,
386 a lack of data has not permitted researchers to establish the magnitude of the variation.

387 Price (1998) in a MS thesis entitled “Seasonal Variation in Runoff Curve Numbers” found that
388 there was some seasonal variation. Price (1998) indicated that for forest in humid areas the CN
389 varies, with the average of the monthly asymptotic CNs (with $Ia/S = 0.20$) ranging between
390 57 and 91 for cropped watersheds and between 64 and 92 for grassland watersheds. The
391 monthly average CN for the forest land use, ranging between 41 and 85, is generally lower
392 than those for the other two land use types. Price (1998) also reported some variation in
393 seasonal CNs in arid and semiarid land uses. The CN value generally decreased as the
394 vegetation or cover increased.

395 Tedela et al. (2012) reported some seasonal variation in CNs in humid forest in the eastern
396 US. They selected the dormant and growing seasons as the groupings with the difference
397 ranging between 3 and 14 CN units (with $Ia/S = 0.20$) lower in the growing season.

398 Even if seasonal variation is exhibited in watersheds, it has minor impact because of the concept
399 of single-event-runoff-determination hydrology. One of the underlying principles of single-
400 event hydrology using CNs is that it represents the average conditions of the watershed when
401 flooding occurs. It is recognized, however, that seasonal variation of CNs is important in
402 simulation models.

403

404 630.0904 Regional Variation

405 Similar crops and cover on similar HSGs do not necessarily have the same CN values. For
406 example, corn on an HSG B soil in Iowa and in Maryland may have different CNs. Analysis of
407 the available documentation and available data are limited so general conclusions supporting that
408 concept have not been developed.

409

410 630.0905 Drainage Area Limitations

411 There is no directly stated NRCS guidance in NEH4/630 limiting watershed size in application
412 of the CN method. The one oblique piece of advice in NEH4/630 is “These [drainage units]
413 should be no greater than 20 square miles and should have a homogeneous drainage pattern.”
414 Twenty square miles is 12800 acres, 51.83 square kilometers, or 5183 hectares.

415 The drainage areas of the 199 watersheds in 24 locations from which the first CN tables were
416 constructed (omitting Culbertson, Montana) vary from 0.24 to 46,080 acres with the middle 60%
417 between 3 and 300 acres with a median of 19.7 acres. Though specific watersheds used are not
418 known, soils homogeneity was a major criterion in the original selections. Because of an
419 awareness of spatial variability of soils and land use properties, spatial variability was and is a
420 concern when computational simplicity encourages the lumped parameter (area-weighted CN)
421 form.

422 Various local and modeling applications references suggest drainage area limits from about 5 mi²
423 to about 100 mi². Ponce (1989) suggests application for mid-sized catchments, or roughly 100-
424 5000 km². Pilgrim and Cordery (1992) mention its application to “Small to medium ... drainage
425 basins.” Singh (1989) comments that “the method can be applied to large watersheds with multiple
426 land uses.” Boughton (1989) mentions application to “catchment sizes from 0.25 ha to 1000 km²”,
427 the latter is supported by Williams and LaSeur (1976). These upper ranges approximate the
428 statutory upper limit for PL566 watersheds of 250,000 acres.

429 In regions of more uniform rainfall, the CN has been applied at the river basin scale with
430 favorable results. For example, analysis of basin-wide rainfall-runoff data (Singh, 1971) from

431 Salt Creek, Illinois (334 mi), gives a CN value of 71 consistent with handbook expectations. The
432 CN method has been usefully and rationally applied on a 414 km² basin in Panama (Calvo et al.,
433 2006), and the 69.1 km² Little Vermillion River in Illinois (Walker et al., 2005). A conspicuous
434 example of river basin application appears in NEH4: Amicalola Creek, Georgia, shows CN
435 definition on drainage areas of 84.7square miles (219.4 km²).

436 In an extension of the CN method to large watersheds, Hong et al. (2007) have estimated global
437 runoff from major river basins around the world. Their study applied the CN method to river
438 basins using satellite rainfall data and other remote sensing information in a simple rainfall-
439 runoff simulation in order to obtain an approximation of runoff. River basins modeled included
440 the Amazon, Mississippi, and Yangtze, each with areas exceeding 1 million km². Hong et al.
441 (2007) report that the global-averaged CN is 72.803.

442

443 **630.0906 Local Information Tables**

444 *Local tables* refers to CN tables generated by technical, social, or administrative agreements with
445 or without resort to local data. They may be heavily judgment- or experience-based, and may
446 have data to bolster the values, and use extrapolation, extension, and interpolation. Similarly,
447 they may be consensus-based, i.e., groups do not know the CNs for the area, but agree on what
448 will be used. They are agreed usage conventions, and are common in applied hydrology. It is
449 thought that some of the original tables in the NEH 630 may have been consensus-based.

450 This local-tables approach suggests that for practical local application such tables can be
451 expected. However, they should not be anonymous and should list the authors by name, the
452 dates, locations, authority, conditions, and the basis for use. Otherwise with time, such sources
453 become encased in unknown authority, and without a clear source, become unchallengeable and
454 treated as fact.

455

456 **630.0907 Examples**

457 The following examples demonstrate how to evaluate the effect varying percent impervious
 458 pavement and/or connected or non-connected have the CN for land cover conditions other than
 459 what is listed in Table 9-4.

460 **Example 9–1** Calculation of composite urban residential CN with different percentage of
 461 impervious area than that assumed in Table 9–4.

462 **Given:** Table 9-4 gives a CN of 62 for 1/2-acre lot in HSG B with an assumed impervious
 463 area of 25 percent. The pervious area CN is 52.

464 **Problem:** Find the CN to be used if the lot has 20 percent impervious area.

465 **Solution:** Solve Equation [9-1] with CN_p , the pervious runoff CN, equal to 52 and the P_{imp} , the
 466 percent imperviousness, equal to 20:

$$467 \quad CN_c = 52 + (20/100)(97-52)$$

$$468 \quad CN_c = 61.$$

469 The CN difference between 62 in Table 9-4 and the computed value of 61 reflects the slight
 470 difference in the percent of impervious area.

471 **Example 9–2** Calculation of a composite urban residential CN with different CN for the
 472 pervious area than that assumed in Table 9–4.

473 **Given:** Table 9-4 gives a CN of 62 for 1/2-acre lot in HSG B with an assumed impervious
 474 area of 25 percent. The pervious area CN is 52.

475 **Problem:** Find the CN to be used if the lot's pervious area has a CN of 69, indicating fair
 476 condition instead of good condition.

477 **Solution:** Solve Equation [9-1] with $CN_p = 69$ and the $P_{imp} = 25$:

478 $CN_c = 69 + (25/100)(97-69)$

479 $CN_c = 76.$

480 The CN difference between 62 in Table 9-5 and the computed value of 76 reflects the difference
481 in pervious area CN.

482 If runoff from impervious areas enters a pervious area as sheet flow prior to entering the drainage
483 system, the impervious area is unconnected. To determine CN when all or part of the impervious
484 area is not directly connected to the drainage system, use:

- 485 • Equation [9-2] if the total impervious area is less than 30 percent of the total area
- 486 • Equation [9-1] if the total impervious area is equal to or greater than 30 percent of the total
487 area, because the absorptive capacity of the remaining pervious areas will not
488 significantly affect runoff.

489 $CN_c = CN_p + (P_{imp}/100)(98 - CN_p)(1 - 0.05R)$ [9-2]

490 where:

491 CN_c = composite runoff curve number,

492 CN_p = pervious runoff curve number,

493 P_{imp} = percent imperviousness, and

494 R = ratio of unconnected impervious area to total impervious area.

495 **Example 9-3** Determine the composite CN with unconnected impervious areas and total
496 impervious area less than 30%

497 **Given:** A 1/2-acre lot in HSG B has an assumed impervious area of 20 percent, 75 percent of
498 which is unconnected. The pervious area CN is 52 from Table 9.4.

499 **Problem:** Find the CN to be used for the lot.

500 **Solution:** Solve Equation [9-2] with $CN_p = 52$; $P_{imp} = 20$, and R , the ratio of unconnected
501 impervious area to total impervious area, equal to 0.75:

$$502 \quad CN_c = 52 + (20/100)(97-52)(1 - 0.05(0.75))$$

$$503 \quad CN_c = 52 + (0.20)(45)(0.825)$$

$$504 \quad CN_c = 59.4 \text{ (round to 59 as the closet whole value).}$$

505 The CN difference between 52 and the computed value of 59 reflects the difference of
506 unconnected pervious area on CN.

507

508 **630.0908 Appendices**

509 **Appendix 1 – Suggested Curve Number Assignments for the National Land Cover** 510 **Database (NLCD): Ia/S = 0.05 Basis**

511 The following text and descriptions are excerpted directly from Moglen (2016). The original
512 table was modified for this update and the Curve Number values were converted to the Ia/S =
513 0.05 basis.

514 Recognizing that assignment of Curve Numbers is now generally done through automated
515 algorithms that interpret GIS characterizations of both land use/land cover and hydrologic soil
516 group information, the demand for tables that assign Curve Number values as a function of
517 widely-available datasets is assured. This Appendix 1 provides a suggested tabulation of Curve
518 Numbers for one of these most available datasets: The National Land Cover Database (NLCD)
519 (US Geological Survey, 2017). NLCD datasets are available for 1992, 2001, 2006, and 2011.

520 NLCD products are prepared by the multi-resolution land characteristics (MRLC) consortium
521 which includes the following federal agencies: the US Environmental Protection Agency
522 (USEPA), the National Oceanic and Atmospheric Administration (NOAA), the US Forest
523 Service (USFS), the US Geological Survey (USGS), the Bureau of Land Management (BLM),

524 the US Department of Agriculture (USDA), the National Park Service (NPS), the National
 525 Aeronautics and Space Administration (NASA), the US Fish and Wildlife Service (USFWS),
 526 and the US Army Corps of Engineers (USACE).

527 Table 9A-1 shows suggested Curve Number assignments based on NLCD land cover
 528 classifications and Hydrologic Soil Group (HSG). Although these assignments have been well-
 529 vetted, care and critical evaluation from the analyst must be exercised. Curve Number values in
 530 Table 9A-1 are based on $Ia/S = 0.05$.

531 The analyst engineer must be particularly sensitive to the distinction between land use and land
 532 cover. On this issue, Moglen and Kim (2007, p162-163) state, “*Land use* records the human
 533 activities land like agriculture, or recreation, and requires information not detectable from
 534 imagery alone, such as parcel boundaries. In contrast, *land cover* records what covers the land
 535 surface, like wetlands, grass, or roads, and can generally be determined from remote observation.
 536 These approaches are different. For example, the medium density residential land use might
 537 include residential, roads/transportation, and deciduous forest land covers. A land cover
 538 classification algorithm might choose forest as the dominant land cover for a number of pixels in
 539 an older residential neighborhood with rooftops, sidewalks, driveways, and storm drainage
 540 infrastructure, although a forest would generate runoff much differently than such a residential
 541 neighborhood. A system based on land use would recognize such an urban neighborhood in spite
 542 of the mature trees. Thus, land use and land cover are not interchangeable, and using one or the
 543 other to calculate imperviousness may lead to predictable biases.”

544 **Table 9A- 1.** NLCD land cover classes, descriptions, and associated CNs. A, B, C, and D
 545 Hydrologic Soil Groups

Major Land Cover Class and Code Value	Classification and Description	HSG A-Soils	HSG B-Soils	HSG C-Soils	HSG D-Soils
Water					
11	Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.	100	100	100	100

12	Perennial Ice/Snow - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.	Not Applicable N/A	N/A	N/A	N/A
Developed					
21	Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	52	68	78	84
22	Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.	81	88	90	93
23	Developed, Medium Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	84	89	93	94
24	Developed High Intensity -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.	88	92	93	94
Barren					
31	Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris,	70	81	88	92

	sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.				
Forest					
41	Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.				
42	Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.				
43	Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.				
Shrubland					
51	Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.		42	55	62
52	Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.		42	55	62

Herbaceous					
71	Grassland/Herbaceous - areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.		63	75	85
72	Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.		63	75	85
73	Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.	74	74	74	74
74	Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.	79	79	79	79
Planted/Cultivated					
81	Pasture/Hay - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	40	61	73	79
82	Cultivated Crops - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	62	74	82	86
Wetlands					

90	Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water with high water table or standing water. See classification 50 for dry conditions.	86	86	86	86
95	Emergent Herbaceous Wetlands - areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	80	80	80	80

546 CNs in the table are based on $Ia/S = 0.05$.

547 The CNs in Table 9A-1 were developed primarily from information in Tables 9-1 and 9-2.

548 Classes 51, 52, 71 and 72 have no CNs for HSG A soils because of the lack of data plus there are
 549 minimal HSG A soils in semi-arid and arid climates assignment. The Curve Number method is
 550 not recommended for forests, so no Curve Numbers are listed for code values 41, 42, and 43.

551

552 **Appendix 2 - Determination of Curve Numbers from Data**

553 **Introduction**

554 Curve Number estimates based on soils plus land use and condition are listed in previous tables.
 555 Alternatively, if local rainfall-runoff data are available, then CNs may be determined by data
 556 analysis, and used to check or adjust table entries, or determine local or seasonal variations for
 557 land or soil types not included.

558 Prior versions of the NEH contained only minimal instructions for determination of CNs from
 559 rainfall-runoff data, or how the original CN table entries were determined. The current
 560 availability of data sets in electronic form has enhanced the local determination of CNs and

561 comparisons with the NEH entries. The task is to find the CN that best describes the data,
562 consistent with the intended application or interpretation, and within the limits of the data.

563 Two main approaches are suggested here, aligning with two alternative interpretations and
564 applications:

565 The *Process* interpretation that recognizes and roughly mimics the single event physical
566 processes inferred with Mockus' original concepts and the variability encountered. It uses
567 "natural" data meaning Precipitation (rainfall P) and Runoff (Q) from the same event (P:Q pairs).

568 The *Frequency Matching* (or rank-ordered) interpretation, which uses the CN equation based on
569 return-period rainfalls to the same return-period runoffs. For example, the 50-year rainfall leads
570 to the 50-year runoff. This is in keeping with the original major use of the method, and is **the**
571 **primary definition of CN in this NEH update**. This interpretation uses rank-ordered (or
572 simply, ordered) data, and the procedure usually shows the asymptotic behavior (CN approaches
573 a steady value with increasing precipitation depth, P) for a watershed. CN determination is
574 based on this approach.

575 Variations in this approach include the following. The graphical fitting of CN to transfer annual
576 series or partial duration rainfall frequency to runoff frequency has been done by Hjelmfelt
577 (1980, 1983), and McCutcheon et al. (2006).

578 The interpretation of CN technology as a soil moisture management algorithm in daily time step
579 (continuous) models is not considered in this update.

580 In addition, the CNs appropriate to the three different interpretations above are not necessarily
581 congruent. For example, a CN found using the frequency matching approach is not necessarily
582 appropriate to use in a daily time step model, and vice-versa.

583 The procedures outlined here are applicable to *Standard* response watersheds only, and
584 infrequently to *Violent* response. The *Complacent* response is not consistent with the CN
585 method but is discussed in context with the other two types. These three types of response are

586 shown in the following sections. The subscripts 05 and 20 are used to denote application to the
587 cases of $Ia/S=0.05$ and $Ia/S= 0.20$, respectively.

588 **General**

589 **Runoff equations:** The basic runoff equation, for the case of $Ia/S=0.05$ is:

$$590 \quad Q = (P-0.05S_{05})^2/(P+0.95S_{05}) \quad \text{for } P>0.05S_{05} \quad [9A-1]$$

591 This solves for S for any P:Q pair with $0 \leq Q \leq P$

$$592 \quad S_{05}=20[P+9.5Q-\sqrt{(90.25Q^2+20QP)}] \quad [9A-2]$$

593 giving

$$594 \quad CN_{05}=1000/(10+S_{05}) \text{ where } S_{05} \text{ is in inches.} \quad [9A-3]$$

595 Thus any P:Q pair with $0 \leq Q \leq P$ can define a Curve Number

596 **Data bias:** Experience has shown that “small” storms usually do not produce significant
597 recorded runoff. But they are numerous and will occasionally produce runoff under unusual
598 surface conditions or short-duration high intensities. These become a part of the data record and
599 produce high CNs with Equations [9A-2] and [9A-3]. Thus, there is a bias to high CNs for small
600 storms. This finding is characteristic of CN rainfall-runoff data sets and is seen clearly in the
601 following appendix figures. It should also be noted that events with no runoff (i.e., $Q=0$) are
602 usually not included in data sets, further adding to the upward bias.

603 However, with increasing storm size P, achieving a $Q>0$ runoff response increases. At and
604 above a sufficiently large storm threshold, most storms will produce runoff, and the bias effect is
605 diminished. For example, as seen in Figure 9A-1a, at about $P = 0.50$ inches, the loose *cloud* of
606 plotted points clearly separates from the line of $Q=0$. Above this rainfall depth all points are
607 assumed bias-free. In prior work with $Ia/S=0.2$, this was taken to occur at $P/S_{20} \approx 0.5$. This
608 strategy is applied in the process definition of CN.

609 The trend of these CNs, as seen in their means and medians, is a decline with increasing rainfall
610 P. With sufficient sample size and sufficiently large storms, CNs often approach a near-constant
611 (*asymptotic*) value, illustrated in several figures in this appendix. This stable-value strategy is
612 exploited in the return-period matching definition of CN, i.e., the ordered, asymptotic approach.
613 Conveniently, both approaches – process and ordered - can be described in a single figure of CN
614 vs P for both the natural and rank-ordered data sets.

615 **Preliminary determinations.** An analysis should first determine that the data displays
616 Complacent response, Standard response, or – with large enough samples – a fixed Violent
617 response. This is accomplished by plotting Q against P, and CN against P and affirming the
618 behavior by inspection. If a **Complacent** response (no trend towards an asymptotic value) is
619 shown, or if the trends are indeterminate, the data are inadequate to define CN by the methods
620 presented here.

621 **Methods for Complacent Response**

622 The Complacent case or response is a distinctive low, linear runoff response to a rainfall that has
623 a constant Q to P ratio of $Q/P = C$ or $Q = CP$ for non-trivial values of storm rainfall P. Values of
624 the runoff fraction C are found in the range of about 0.003 to 0.07.

625 The runoff fraction C has been found to be related to the watershed's fractional surface area of
626 water surface (Hawkins and Pankey, 1981). However, this behavior can also occur on cropped
627 land given sufficient cover. Sartori et al. (2011) give examples for sugarcane in Brazil under full
628 cover on lateritic soils for up to 3 inches of event rainfall with C values ranging from 0.008 to
629 0.016.

630 Although the runoff fraction C is sometimes regarded as a disused rule-of-thumb, this response
631 type does occur, but with very small C values. The Complacent case can occur for watersheds
632 with runoff sources from small impervious near-channel contributing areas, with the remainder
633 of the drainage in non-runoff surfaces. A general example of this situation is well-developed
634 humid upland forests with deep soils, base flow streams and the direct channel interception.

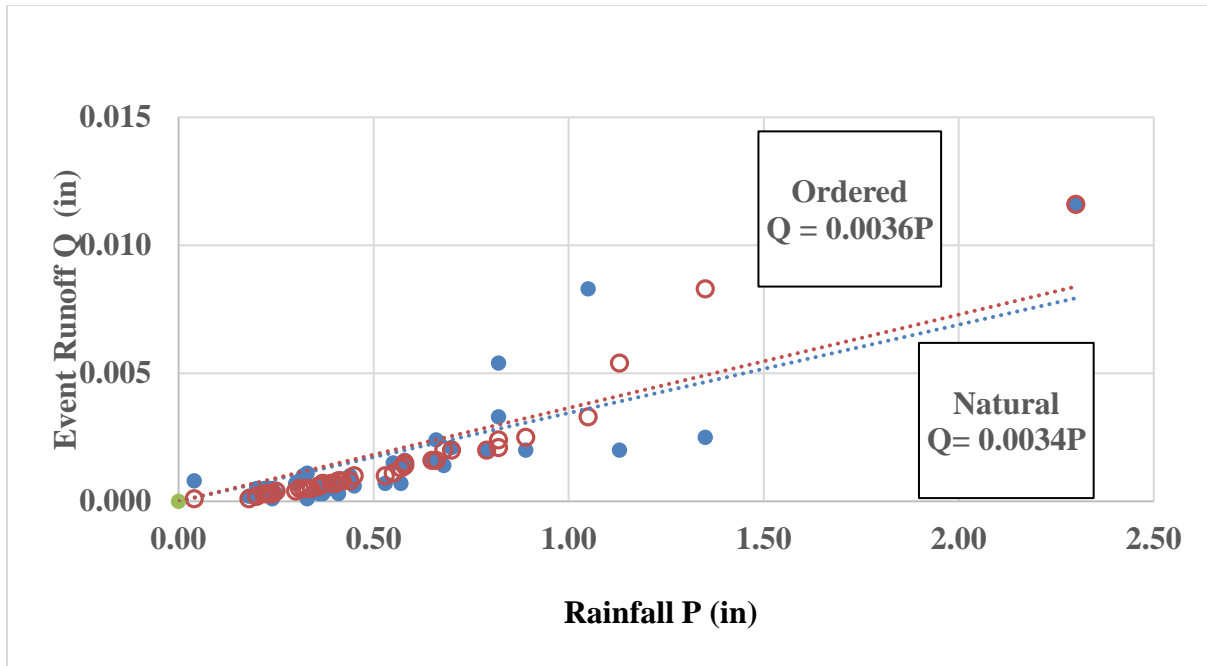
635 When CN values are calculated from P:Q pairs and then plotted with P, the result is a
 636 monotonically decreasing relationship between CN and P. An example of this relationship is
 637 presented in Figure 9A-1 for the West Donaldson Creek watershed in Oregon.

638 The mathematical nature of this CN-P behavior stems from the $Q = CP$ behavior of the
 639 Complacent mode. If the ratio Q/P can be expressed as equal to αP^β , the Complacent case occurs
 640 when $\beta = 0$ and $\alpha = C$. CN values can be calculated from P:Q data pairs by using Equations [9A-
 641 2] and [9A-3] and by substituting CP for Q into Equation [9A-2] resulting in

$$642 \quad S_{05} = aP \quad [9A-4]$$

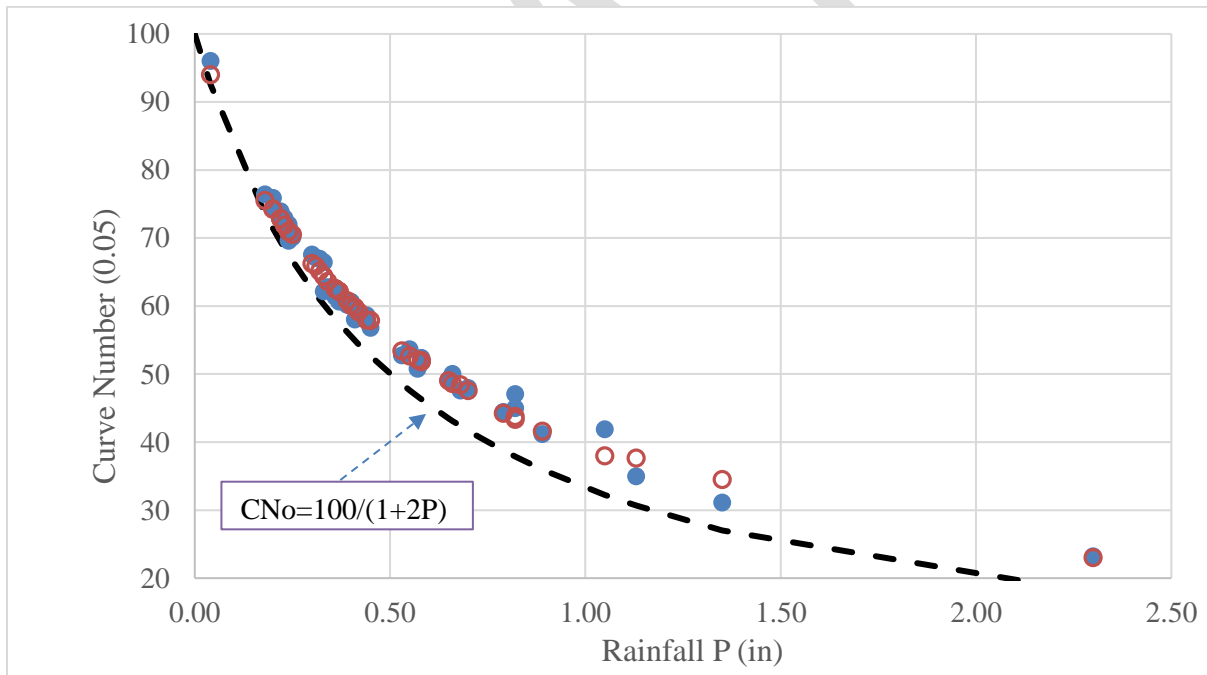
643 where $a = 20 [1 + 9.5C - \sqrt{(90.25C^2 + 20C)}]$. At $C = 1$, $S_{05} = 0$ and $Q = P$. For all $0 < C < 1$, S is a
 644 constant fraction of P and will monotonically increase as P increases. Because CN is inversely
 645 related to S , the CN computed from P will monotonically decrease with P which is seen in the
 646 CN-P plots for Complacent watersheds such as West Donaldson Creek. For this update, the
 647 Complacent response is represented by C less than ~ 0.070 . This limit is based on judgment and
 648 experience. Higher “C” responses do exist, but are rare in the observed data.

649



650

651 **Figure 9A-1 a.**



652

653 **Figure 9A-1 b.**

654 **Figures. 9A-1a and 9A-1b.** Rainfall (P) -Runoff (Q) and Complacent Curve Numbers for West
 655 Donaldson Creek, Oregon. Drainage Area=960 acres. 1979-1984. N=48 events, for the case of

656 $I_a/S=0.05$. Figure 9-1a is runoff Q and rainfall P and Figure 9-1b is calculated CN_{05} and P . Data
657 from US Forest Service (Higgins et al., 1989). In both figures, the open circles are for rank-
658 ordered $P:Q$ pairs, the closed circles are for natural data. The dashed line is the limit of $Q>0$ or
659 where $P=0.05S_{05}$.

660

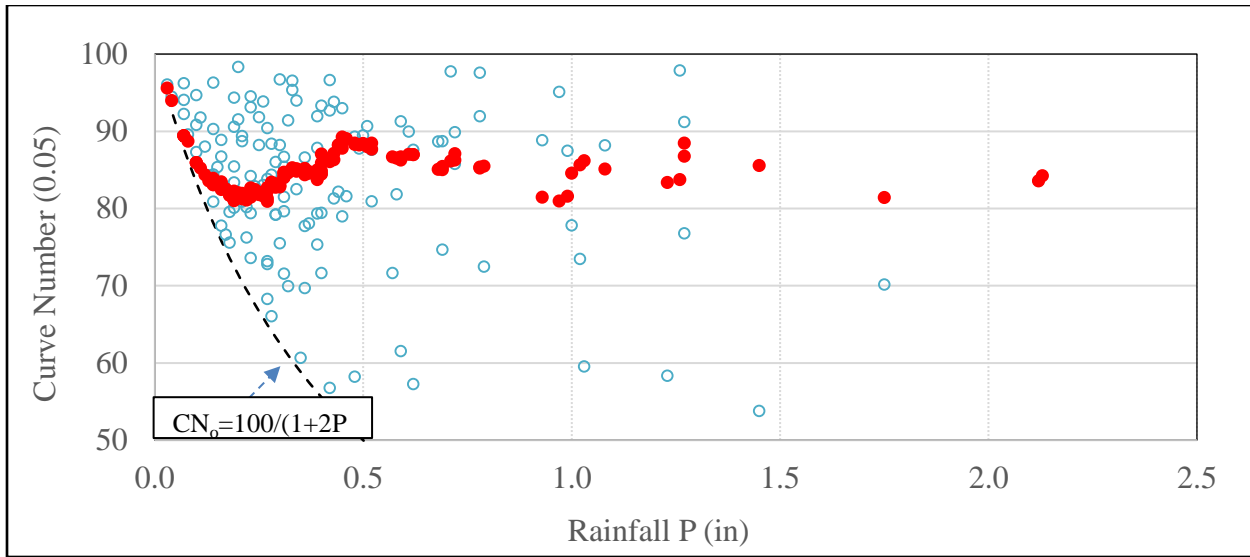
661 In contrast is the Standard mode where the ratio of Q/P increases with P until at large P the ratio
662 Q/P approaches 1.0. When this is the case, CN values become asymptotic to a constant value.
663 Therefore, one method to determine if a watershed exhibits a Complacent or a Standard mode is
664 to calculate Q/P from ordered data and determine if that ratio increases with increasing P (i.e.,
665 $\beta>0$ in the previous discussion). For a Complacent response, the Q/P ratio will not vary
666 significantly with P , but for a standard response the ratio will increase with P .

667 **Methods for Standard response**

668 **Event or “Process” (natural) definition of CN.** Use measured $P:Q$ pairs and all events of
669 $0<Q\leq P$. The goal is to find the CN that best describes the data, consistent with the application or
670 interpretation.

671 Limits: All $P:Q$ data points cannot be used to determine a valid CN . Computational limits are
672 imposed because of a high CN bias for small storms. As a result, calculated CNs decline with
673 increasing rainfall P .

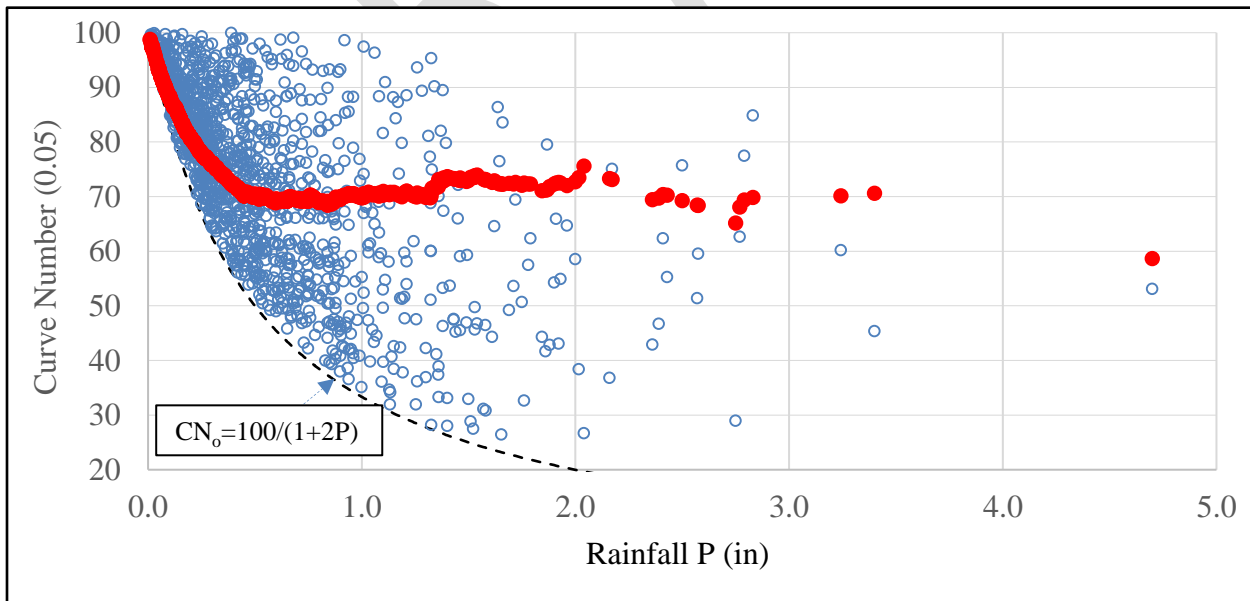
674 Using Equations 9A-2 and 9A-3 the CNs are plotted against P . This is illustrated in Figures 9A-
675 2. The line of $P=I_a$ is given as well, because it shows the lower possible limit (no runoff). The
676 data are not shown here. For $I_a/S=0.05$, $P=I_a$ limit is $CN_0=100/(1+2P)$.



677

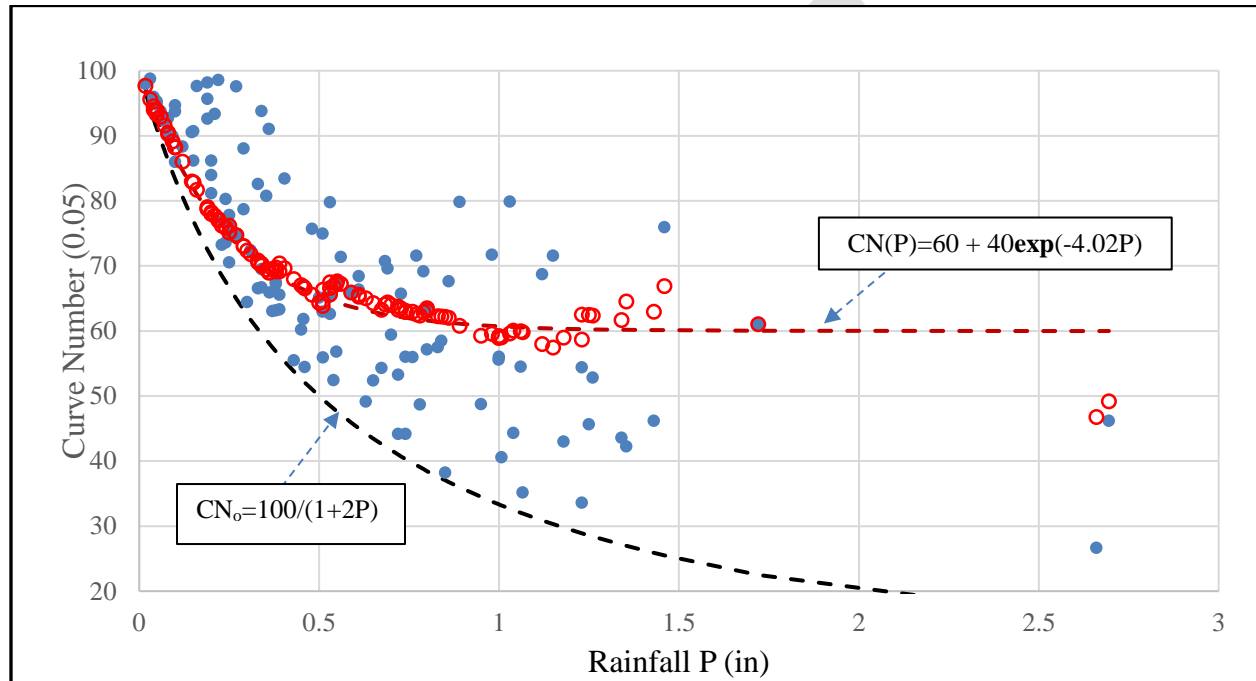
678 **Figure 9A-2 a.** CN determination for plot CL4, Jornada Range, New Mexico. Drainage Area
 679 (DA) = 43.1 ft². (Hawkins and Ward, 1998). N=133 events from July 1989 to October 1994. CNs
 680 for both natural and rank-ordered data are shown, and the CN_∞ for the ranked data is selected
 681 from the plot as about 85. The calculated mean CN₀₅ for P ≥ 0.30 inches is 85.5 with a standard
 682 deviation of 1.8 units. Analysis done for the case of Ia/S=0.05. CN₀ is the locus of all points of
 683 P=Ia.

684



685

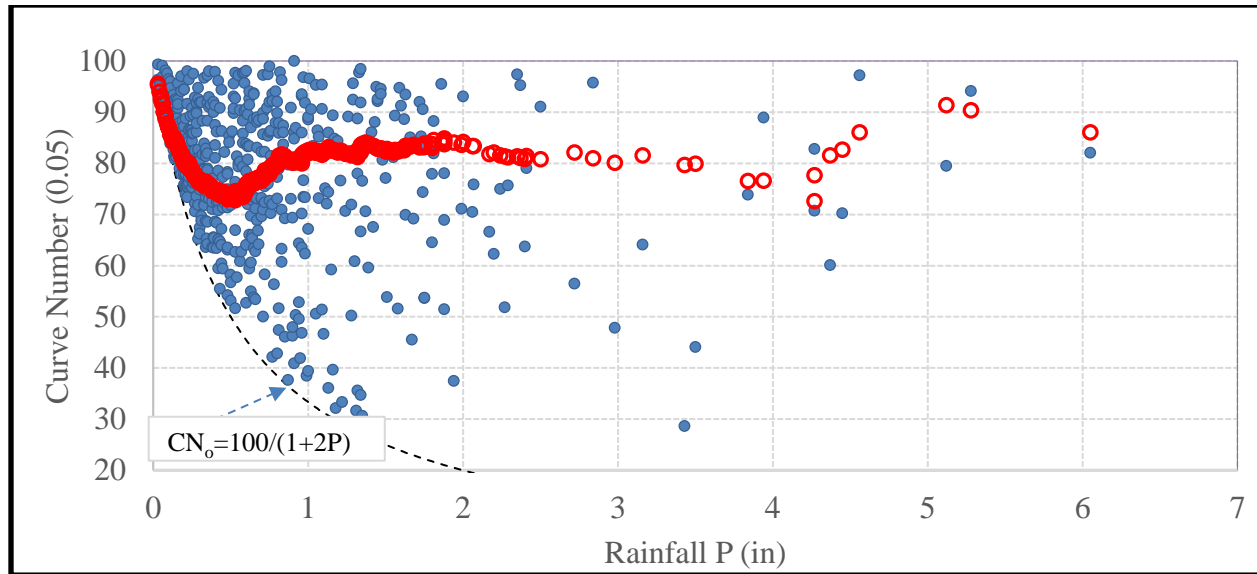
686 **Figure 9A-2 b.** CN determination for watershed 26020, Coshocton, Ohio. DA= 723 ac.,
 687 N=1289 events from 1940 to 1986. CNs for both natural and rank-ordered data are shown, and
 688 the CN_{∞} for the ranked data is selected from the plot as 70. The calculated mean $CN_{0.5}$ for P from
 689 0.5 to 3.5 inches is 70.1, with a standard deviation of 1.2 units. The non-conforming point at
 690 P=4.7 inches is not considered. Analysis done for the case of $Ia/S=0.05$. CN_0 is the locus of all
 691 points of $P=Ia$.



692

693 **Figure 9A-2 c.** CN determination for Safford watershed 4, Arizona. DA= 1.56ac, for 121
 694 events from 1940 to 1986. For the ranked data and $P > 1$ inch, CN_{∞} is selected from the plot as 60,
 695 and calculated as 59.5, with a standard deviation of 2.4 units. For the natural data and $P > 1$ inch,
 696 the calculated mean is 51.8 with a standard deviation of 13.8 CNs, the median is CN is 46.1. The
 697 fitted asymptotic line is $CN(P) = 60 + 40 \exp(-4.02P)$

698



699

700 **Figure 9A-2 d.** CN determination for Edwardsville watershed 2, Illinois. DA=50.0 ac, for 174
 701 events from 1939 to 1954. For the ranked data and $P > 0.80$ in, the CN is estimated from the plot
 702 as 81, and calculated as 82.0 with a standard deviation of 1.8 units. For the natural data and
 703 $P > 1.3$ in, ($n=85$) the mean CN is 74.5 with a standard deviation of 18.2 units. The median is
 704 78.0.

705 In the figures, the threshold minimum rainfall is judged by inspection as the point where the
 706 group of plotted data (Q) separates from the line of $Q=0$. It is assumed that all rainfalls in excess
 707 of this P value produce runoff and there is no exclusion bias in the remaining sample.

708 The defining CN is the one observed at a stable value evidenced at higher rainfalls. This is also
 709 consistent with original use of the CN method for extreme events. For the natural data cases
 710 shown in Figures 9A-2, the means and medians of the unbiased sample points were calculated
 711 and listed in Table 9A-2.

712 It should be noted that if there is no evident group departure of the natural runoffs from the $Q=0$
 713 line in the plotted figures, this procedure is assumed to give a biased estimate. Also the validity
 714 of the estimates is a function of the unbiased sample size, or 'n' in the above table; the larger the
 715 unbiased sample "n" the more reliable (less sampling error) is associated with the determination.
 716 Sampling statistics apply as in as in any determination of the mean or median.

717 **Table 9A- 2.** Data for fitted CNs for selected illustrative cases, natural data case

Watershed	DA	P_t	N	n	mean (SD)	median
Name and Location	(ac)	(in)	#	#	CN ₀₅	CN ₀₅
CL4-Jornada NM Plot	.001	0.5	133	34	80.6(13.5)	86.6
Coshocton Oh 26020	1.26	1.8	1289	28	54.8(15.5)	54.6
Safford 4 AZ	723	1.0	121	20	51.1(13.8)	46.1
Edwardsville IL	49.95	1.3	546	85	75.5(18.2)	78.0

718 Notes: P_t is the lower limit of data used to calculate CN, and n is the number of points >P_t. N = total P:Q pairs.

719

720 **Frequency matching definition; Asymptotic determination:** Use rank-ordered P:Q data (all
721 events of 0 < Q ≤ P) and apply the asymptotic behavior concept.

722 As previously described, first separately rank-order the P and Q points and match the P and Q
723 by rank order. The CNs for these P:Q points are calculated, and the points are plotted as shown
724 in the figures. The line of Q=0, or CN₀ = 100/(1+2P), should be included on the plot.

725 The near-constant values achieved as rainfall increases are selected from the plot. Examples are
726 given – along with the natural data CN plot - in Figures 9A-2. Both scaled and calculated values
727 are given in Table 9A-3. The bold-faced entries are the CN₀₅ estimates from these data along
728 with their standard deviations. These are equivalent to CN_∞. It should be noted that the
729 procedure creates a spurious correlation because the CN-P plot has P included in the CN
730 calculation, and is thus on both axes. Therefore, the r-squared metric is affected.

731 **Table 9A- 3.** Data for fitted CNs for selected illustrative cases, rank-ordered (asymptotic) case

Watershed	DA	P_t	N	n	Scaled	Calculated
Name and Location	(ac)	(in)	#	#	CN ₀₅	CN ₀₅ (SD)

CL4-Jornada NM Plot	.001	0.5	133	77	85	85.5(1.8)
Coshocton Oh 26020	1.26	0.5	1289	783	70	70.1(1.2)
Safford 4 AZ	723	1.0	121	20	60	59.5(2.4)
Edwardsville IL	49.95	1.3	546	174	81	82.0(1.8)

732 Notes: Pt is the lower limit of data used to calculate CN, and n is the number of points > Pt. N = total P:Q pairs

733

734 If the constant value is ***not*** clearly apparent, or if there are insufficient points to define it, but it is
 735 judged to approach a constant value, then one should extrapolate the curve graphically by eye,
 736 using careful judgement, to a steady-state (asymptotic) value. This value is then selected as CN_∞.

737 If the data are insufficient for reliable visual extrapolation, then one can fit the asymptotic
 738 equation to the data set as:

$$739 \quad CN(P) = CN_{\infty} + (100 - CN_{\infty})\exp(-kP) \quad [9A-5]$$

740 This can be accomplished by non-linear fitting programs or by trial and error. The result yields
 741 CN_∞ as a fitting parameter. The exponent “k” is necessary to do the fitting, but has no other use.
 742 Fitting Equation [9A-5] is also an option in any other of the above cases.

743 **Exponential coefficient “k”**

744 In the calibration the asymptotic P:CN behavior, values of CN_∞ are taken from plots and
 745 calculation based on the judgment of the analyst. The complete description also requires the
 746 exponential coefficient “k.” No general tables relating k to CN_∞ or other factors have been
 747 developed.

748 However, k estimates for specific data sets can be made once CN_∞ has been determined. It is
 749 done by the following procedure;

- 750 • Determine CN_∞ as described

751 • Select/assume a representative CN point on the mass of the P-sensitive (i.e., draw-down”
 752 portion) portion of the data to match. Call it CN(P). Note the P value.

753 • Complete the asymptotic equation for the assumptions

754 $CN(P) = (100 - CN_{\infty})\exp(-kP)$

755 • Solve for k

756 For example, in the Safford 4 case previously presented, $CN_{\infty} = 60$ is used, and the representative
 757 drawdown point of $CN(P)=70.6$ and $P=0.33$ in is taken from the data set (not shown here). Thus
 758 substituting in the previous equation for $CN(P)$ gives $70.6 = (100-60)\exp(-0.33k)$

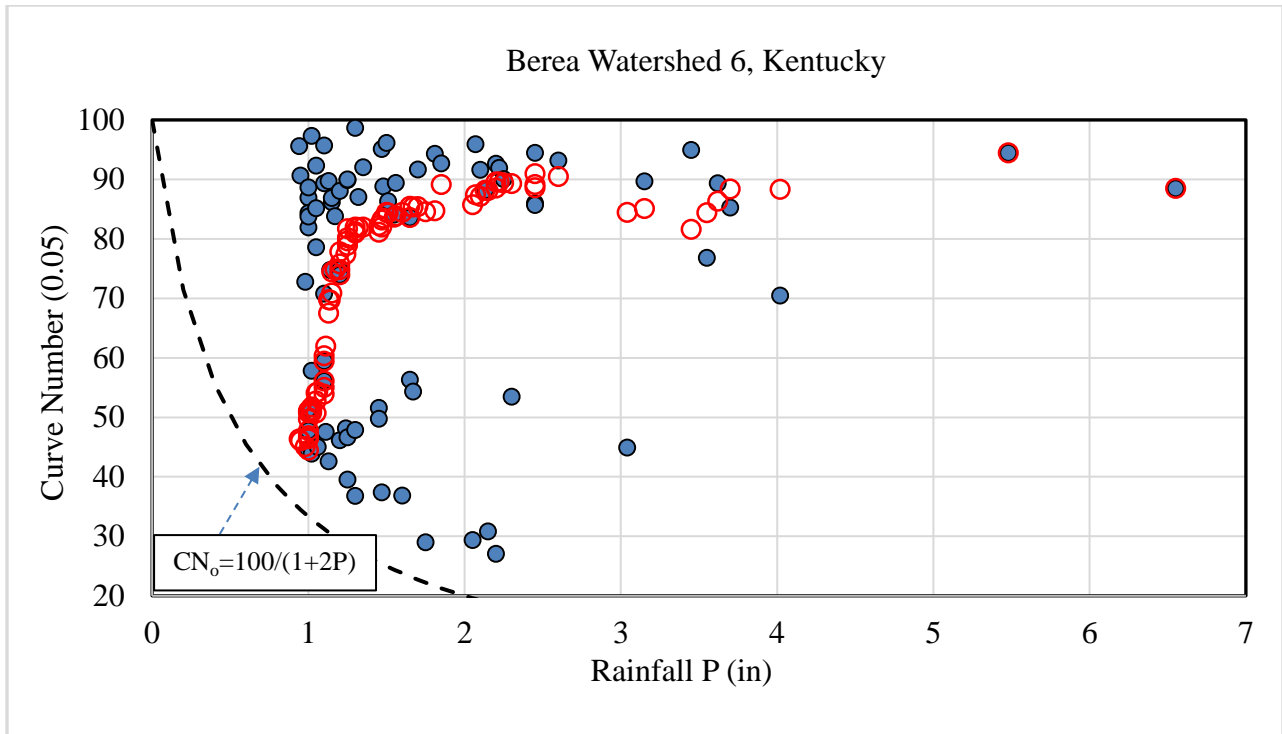
759 This equation can be used find $k = 4.0243\text{in}^{-1}$. With this k value, an estimate of a prediction error
 760 for these approximate conditions can be made. This is not a least squares fitting, although a
 761 variance reduction calculation (“ r^2 ”) can be made for these conditions.

762

763 **Methods for Violent response**

764 As described elsewhere in this report, the Violent behavior type is inconsistent with the CN
 765 method and is better described as a high fraction, high rainfall threshold response. However, it
 766 does asymptotically approach a constant CN (CN_{∞}) as P grows larger after the violent response P
 767 threshold has been surpassed as shown in Figure 9A-3 for the Berea Watershed 6, Kentucky.

768 Because of this runoff type’s overall rarity in rainfall-runoff records, and the larger rainfalls
 769 depths required to express it, example data sets are scarce. The simple analysis shown here is in
 770 accord with those previously given for the Standard asymptotic estimates. That is, the limits of
 771 the CN determination are selected by judgment and the representative CN value calculated from
 772 the data. For the Berea Watershed 6, Kentucky, the lower limit (threshold) of P was taken as 2.00
 773 inches. A comparison of CN values for the Berea 6 watershed is shown in Table 9A-4.



774

775 **Figure 9A- 3.** Beria Watershed 6, Kentucky. CN_{05} and rainfall P for natural (closed dark
 776 circles, ●) and ordered (open circles, ○). The dashed line is the locus of all points of $Q=0$, or
 777 $CN_0=100/(1+2P)$. $DA=299$ ac. Data is of US Forest Service origin, provided by J. D. Hewlett
 778 from University of Georgia. The data, for all $P>23$ mm, was also used in a prior paper, Hewlett et
 779 al. (1984).

780

781 **Table 9A- 4.** Violent response summary for CN_{∞}

	N	n	CN_{05}	Standard Deviation
Approach	#	#		
Ordered data	84	23	88	2.6
Natural data	84	23	77	22.1

782 N is the total number of points; n is the number used to calculate CN .

783

784 The ordered data calculated value of $CN_{05} = 88$ agrees with visual estimates. Note, however, the
785 bimodal uncertainty displayed by the natural data, splitting into distinct clusters. About half of
786 the storms in the 1- to 3-inch rainfall range show a CN in a cluster of 30 to 55, while the
787 remainder show higher CNs in the 75-95 range. The natural and ordered values converge with
788 increasing rainfall P. In either case, the high CNs are inconsistent expectations for this well-
789 forested watershed.

790 **Other issues**

791 Annual Peak series: Historic NEH methods used the median CN from the P and Q for annual
792 flood peak series as the defining value. A clear disadvantage of this approach is that it requires a
793 long period of record. Annual flood series give but a single point from a year of data collection.
794 In addition, the median event for an annual series defines a de-facto 2-yr return period. As such,
795 it minimizes the widely observed downward trend of CN with increasing P.

796 An alternative approach is to complete dual-plotted frequency curves of P and Q, in either annual
797 or partial duration series. This differs from the annual peak series median described above, and
798 has been successfully demonstrated by Hjelmfelt (1980), and McCutcheon et al. (2006).

799 Ordered Data: The ordered data methods above short-cut the long data requirement by using
800 individual events over a shorter period of record. In such, the ordered P and Q still matches
801 return periods, but for the more frequent events, and by plotting the resulting CNs against P the
802 asymptotic relationship results. Steady-state CNs found at higher rainfalls will likely include P:Q
803 pairs in the annual series as well. Prior work by Hjelmfelt (1980), Hawkins et al. (2009),
804 McCutcheon et al. (2006), and Tedela et al. (2007, 2012) illustrate the convenience and efficacy
805 of this approach. The precedent for this approach in hydrologic engineering is given by Schaake
806 et al. (1967).

807 Calibration on peak flows and hydrograph models: Where the CN equation is used as a time-
808 incremental generator of rainfall excess in hydrograph models, several other factors of timing
809 and routing are involved as well. Thus fitting on complete hydrographs or event peak flows
810 obscures the single role of CN in the calculation. An example of this given in Titmarsh et al.
811 (1989). This approach is not recommended for estimating CNs for a watershed.

812 Asymptotic phenomenon: Several hypotheses may be offered for observed asymptotic response:

- 813 1) Mixtures of source runoff properties across the contributing area which generate runoff as
 814 P grows larger and the watershed becomes more extensively wetter. Illustration of this
 815 possibility is given in Appendix 2 of Chapter 10.
- 816 2) Data censoring that excludes Q=0 events from analysis. This has been explored and the
 817 effects demonstrated in Hawkins et al. (2015).
- 818 3) Differences between natural runoff generating processes and the basis for the CN
 819 equation.

820 The asymptotic response is seen with both ordered and natural data, but is clearly more evident
 821 in the ordered set. Regardless of the source cause, a steady-state CN is usually approached as P
 822 grows larger, and these values have been found (Van Mullem, 2016) to approximate those
 823 observed in the traditional Ia/S = 0.20 tables based on soils and land use/condition (Rietz and
 824 Hawkins, 2000)

825 Confirmation Bias in Rainfall-Runoff data: Only data points of Q>0 are found in most rainfall-
 826 runoff data sets and analysis, and thus in determining CN. As larger storms are included, fewer
 827 events of no runoff occur, and thus lower data-defined CNs may be included in the sample. See
 828 Hawkins et al. (2015). This source of bias alone gives a CN compared to what actual on-the-
 829 ground conditions would encounter.

830 Use of 0.20 and Conversions: If Ia/S = 0.20 is used, then the equivalent of Equation [9A-2] is

$$831 \quad S = 5[P+2Q-\sqrt{(4Q^2+5PQ)}] \quad [9A-6]$$

832 If data determined CNs exist using Ia/S = 0.20, then the *approximate* conversion is

$$833 \quad S_{05} = 1.42S_{20} \quad \text{and} \quad [9A-7a]$$

$$834 \quad CN_{05} = CN_{20}/(1.42-0.0042CN_{20}) \quad [9A-7b]$$

835 and conversely

836 $S_{20} = 0.7043S_{05}$ [9A-8a]

837 $CN_{20} = 1.42CN_{05}/(1+0.0042CN_{05})$ [9A-8b]

838 These equations are appropriate for asymptotic values and ordered data conditions.

839 General considerations: From experience, CNs determined from measured P:Q data are more
840 accurate and well-defined under the following conditions:

- 841 1. Larger data sets: i.e., more P:Q observations at higher P values (higher N)
- 842 2. Bigger storms, thus higher P values included in the sample
- 843 3. Higher intrinsic (natural) CNs.

844

845 **630.0909 References**

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