The origin and Derivation of Ia/S in the Runoff Curve Number System

by
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Abstract:

In response to legislative authorities of 1944 and 1954, the Natural Resources Conservation Service (NRCS), formally the Soil Conservation Service (SCS), began the development of a Hydrology Guide for use in watershed planning. This effort became Section 4 "Hydrology " of the National Engineering Handbook. This development created the SCS Runoff Curve Number Equation. This paper explains the development of the relationship of Ia to S.

Introduction:

The development was started in 1954 by various hydrologists at Engineering and Watershed Planning Units across the country. Much of the work was based on information in Exhibit A in the Appendix B of the Survey Report on the Grand (Neosho) River Watershed, USDA Washington DC (Mockus 1949), analysis of basic data from research plots, and literature. At this same time, the research effort of the SCS was transferred to the Agricultural Research Service (ARS).

Development:

L. K. Sherman (Sherman 1949) was one of the first to propose plotting direct runoff versus storm rainfall. Building on this concept, Mockus authored Exhibit A of the Neosho River Basin Report that contained a procedure for estimating runoff given certain watershed parameters.

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1. Soils: types, areal extents, and locations
2. Land use: kinds, areal extents, and locations
3. Antecedent rainfall
4. Duration of a storm and associated rainfall amount
5. Average annual temperature and date of storm

These were combined into an index of b which was solved from the equation

(1)

$$b = 0.074(10)^{0.229M}C^{1.06l}/[T^{1.990}D^{1.333}(l0)^{2.27l}(S/D)]$$

where:

M = 5-day antecedent rainfall, inches
C = cover practice index
T = seasonal index, which is a function of date and temperature (^{o}F)
D = duration of storm, hours
S = soils index, inches per hour

The metric form of this equation was never developed.

The resulting b value was used as the second independent variable with P being the initial variable in a graph of precipitation versus runoff in which

(2)

$$Q = P[l-(10)^{-bP}]$$

Q = direct runoff,
P = storm rainfall,

This equation does not include a term to account for initial abstraction. It is interesting to note that this equation was also in a draft hydrology handbook for Region 5 in Lincoln NE (SCS 1950).

The 1954 draft Hydrology Guide, (SCS 1954), simplified this concept into a graph of P versus Q, where,

(3)

$$Q = KP^2/(KP +1)$$

Where:

Q = the amount of direct runoff
P = the amount of storm rainfall
K = the constant for a specified watershed condition and units

The above equation can also be written:

(4)

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

where:

$$S = 1/K \quad (5)$$

S is the soil water storage or infiltration, whichever is the least for a given watershed condition. Equation (4) is closely related to Horton's infiltration equation.

Equation (4) does not provide for initial abstraction or depression storage of runoff that takes place in the early stages of storms. The equation can be re-arranged to meet the need for such abstractions, but in its present form it was considered adequate for watersheds larger than about 41 hectares or 100 acres. It was assumed that the variability of storm rainfall on larger areas and the subsequent error in average rainfall over the area generally is more than the initial abstraction or storage. Sample runoff curve numbers are shown in Table 1.

The runoff curve numbers for a given watershed condition in Table 1 were developed from watershed data. At the present time, no examples of the original plots exist.

Table 1, Sample Runoff Curve Numbers from 1954 Hydrology Guide (Ia = 0)

Cover	Practice	Condition or Rotation	Hydrologic Soil Group			
			A	B	C	D
Fallow	St. Row[3]		67	81	89	92
Row Crops	St. Row	Poor	54	73	84	89
	"	Good	42	66	80	86
	Contoured[4]	Poor	49	68	79	84
	"	Good	37	61	75	81
	C and T[5]	Poor	27	53	69	74
	"	Good	22	50	67	73
Small Grains	St. Row	Poor	37	63	79	84
	"	Good	32	60	77	83
	Contoured	Poor	32	58	75	79
	"	Good	27	55	72	78
	C and T	Poor	27	53	69	74
	"	Good	22	59	67	73

After much discussion between various hydrologists in SCS, ARS and the ForestService (FS) and additional analysis of watershed data, Ia was introduced into

[3] Straight Rows
[4] Contoured
[5] Contoured and Terraced

Equation (4). The 1959 version of the Hydrology Guide indicates that a relationship between initial abstraction (Ia) and S was developed. This relationship is

$$Ia = 0.2S. \quad (7)$$

Ia is assumed to include interception, initial infiltration, surface storage and other factors. This relationship of Ia to S was based on data from large and small watersheds with surface runoff. The data came from various parts of the country.

There was an indication that further refinement of Ia is possible but not recommended, since under usual field conditions very little is known of the magnitudes of interception, initial infiltration and surface storage. Guesses based on research data will only enlarge the standard deviation of the estimates of S and, therefore, Q (SCS 1959). After inclusion of initial abstraction into Equation (4), the resulting equation is

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad (7)$$

This is the present form of the NRCS runoff equation. The sample curve numbers for this form of the equation are shown in Table 2. The runoff curve number were developed from watershed data.

Table 2, Sample Runoff Curve Numbers from 1959 Hydrology Guide (Ia = 0.2S)

Cover	Practice	Condition or Rotation	Hydrologic Soil Group			
			A	B	C	D
Fallow	St. Row		77	86	91	74
Row Crops	St. Row	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	C and T	Poor	66	74	80	82
	"	Good	62	71	78	81
Small Grains	St. Row	Poor	65	76	84	88
	"	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	"	Good	61	73	81	84
	C and T	Poor	61	72	79	82
	"	Good	59	70	78	81

It is interesting to note the comparison for response of a given land use, hydrologic soil group and condition for a range of precipitation for the two Ia relationships. This is shown in Figure 1.

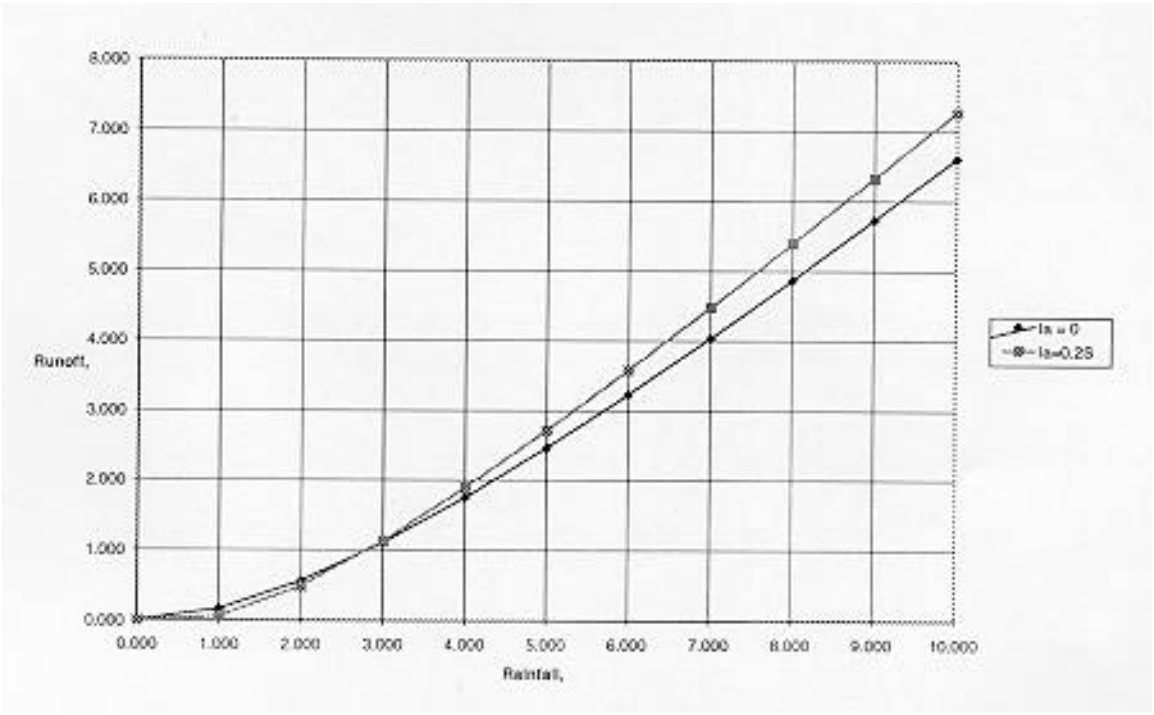

Figure 1, A Comparison of Runoff for Various Precipitation Values for Straight Row B Hydrologic Soils Group for Ia = 0 and Ia = 0.2S

Conclusions:

The development of the NRCS runoff equation was based on watershed data and work of the hydrologist at the time, including Horton, Sherman and others. In initial efforts inclusion of initial abstraction was not considered; but as the development continued initial abstraction was included into the runoff equation. The relationship of Ia to S was based on actual watershed data. The refinement of the runoff equation was a cooperative effort of hydrologists from the FS, ARS, and NRCS. There were numerous meetings of the hydrologists of these agencies to prepare the current version of the Hydrology Handbook.

Comparison of the runoff curve numbers in Tables 1 and 2 indicate that for the same land use and condition, different runoff curve numbers exist. This leads to the conclusion that each relationship of Ia to S requires an unique set of runoff curve numbers. Simple revision of the relationship of Ia to S to something other than Ia = 0.2S requires more than a simple change of the runoff equation. There is no linear relationship between the runoff curve numbers for the two Ia conditions. It also requires a new set of runoff curve numbers developed from analysis of small watershed data.

References:

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