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distributed. To be sure, it is the hope of the hydrologist that representative values of these properties may be obtained. However, considering the spatial random distribution of conductivities, degrees of saturation and porosity, it is not surprising that fitted parameters such as f_0 and k_f vary considerably from plot to plot. This variation is not sufficient to condemn Horton's equation and is irrelevant in arguing for use of the authors' model.

A lack of correlation was noted by the authors between the Horton coefficients and land slope. We can see no reason for suspecting that such a correlation should exist. Infiltration capacity is a function of soil properties and moisture conditions. Slope plays an important role in runoff, but we see no physical reason for slope to affect infiltration capacity.

The authors' comment that the early infiltration history does not appreciably affect the simulation of runoff from urban and rural watersheds perhaps reflects their modeling experience. However, it has been our experience that the simulated runoff is often very sensitive to the character of the infiltration response. In fact in watersheds of less than about 500 acres, the simulation of infiltration response may be the most critical factor in correctly modeling surface water runoff. We submit that the excessive early infiltration predictions noted by the authors may indeed present a serious drawback.

Appendix.—References

10. Parlange, J.-Y. and Smith, R. E., "Ponding Time for Variable Rainfall Rates," *Canadian Journal of Soil Science*, Vol. 56, May, 1976, pp. 121–123.
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Discussion by Richard H. Hawkins,[a] M. ASCE

The authors have made still another application of the widely used rainfall runoff relationships found (but not really *derived*) in the Soil Conservation Service's National Engineering Handbook (6), or "NEH-4." It is widely used because it is well institutionalized and convenient. For the pragmatic user not craving a solid foundation of reason and the protocol of scientific documentation, it has been found "to work." It can reflect land condition, and an infiltration or loss function is implicit. Despite valid criticisms, it is the state-of-the-art, and its acceptance signals the demand for such a tool in applied hydrology.

The foundation equations as given by the authors are

$$Q = \frac{P_e^2}{P + S} \quad \text{(9)}$$

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$$\text{and} \quad CN = \frac{1{,}000}{10 + S} \qquad (10)$$

in which P_e is "effective rainfall," or P – IA; and IA is an initial abstraction. The NEH-4 assigns a value of $0.2S$, but the authors judge to be $0.1S$. Carrying out polynomial division on Eq. 9 yields

$$Q = P_e - \left(S - \frac{S^2}{P_e + S}\right) \qquad (11)$$

Substituting $P_e = P - \text{IA}$ gives

$$Q = P - \text{IA} - \left(S - \frac{S^2}{P - \text{IA} + S}\right) \qquad (12)$$

The "losses" to runoff are then

$$\text{Losses} = P - Q = \text{IA} + S\left(1 - \frac{S}{P - \text{IA} + S}\right) \qquad (13)$$

Much of the discussion to follow draws on the preceding algebra and logic.

Infiltration Rate.—Infiltration rates may be inferred from (12) by differentiation. Denoting "Losses" as L, and acknowledging both IA and S to be constant

$$dL = \left(\frac{S}{P - \text{IA} + S}\right)^2 dP; \quad P > \text{IA} \qquad (14)$$

$$\text{and} \quad \frac{dL}{dt} = \left(\frac{S}{P - \text{IA} + S}\right)^2 \frac{dP}{dt}; \quad P > \text{IA} \qquad (15)$$

Recognizing that dL/dt is infiltration rate f, and dP/dt is rainfall intensity i, then

$$f = \left(\frac{S}{P - \text{IA} + S}\right)^2 i; \quad P > \text{IA} \qquad (16)$$

As demonstrated in the model by the authors, and approached in Eq. 7, this shows that the SCS formula makes infiltration rate a function of rainfall intensity and cumulative storm rainfall P, and of the watershed parameters IA and S (at the start of the storm). In dimensionless form, Eq. 16 becomes

$$\frac{f}{i} = \left(\frac{P - \text{IA}}{S} + 1\right)^{-2} \qquad (17)$$

This is shown in Fig. 4 for the case or IA = $0.2S$, which is the SCS assertion. Note that as $P \rightarrow \infty$, $f \rightarrow 0$, and not a positive residual value analagous to Horton's equation; and also that the function resembles conventional notions of infiltration behavior. It does presume that the input intensity is constant. This should offer some added insight to the good fits obtained with Neal's data: Neal's intensities were constant. Numerous other investigators have shown continuous decreasing infiltration rates with time in response to *variable* storm patterns. Clearly, a conflict arises if the SCS equation and its consequent derivatives are taken as a representation of reality. Attempting to bend Eq. 7 to such data could lead to disastrous results.

Rainfall-Runoff Relations.—The graphical presentation of the SCS rainfall-runoff geometry (Fig. 1) contains both a questionable assumption and erroneous algebra. Examination will show a constant linear relationship of rainfall with time, or an assumed uniform intensity. While this matches the necessity for a pleasing infiltration relationship outlined in the above paragraphs, it is certainly unpalatable from a real world standpoint, and a weak foundation for a credible hydrology. The extent to which this assumption is incorporated into the development of the SCS technology is not known, or at least not stated in the available literature.

Fig. 1 also states that $F + IA \rightarrow S$ as $P \rightarrow \infty$. This is not so. From Eq. 13 it can be easily seen that $F + IA$ (= losses) approaches $S + IA$ as $P \rightarrow \infty$, or $1.2S$ with the SCS assertion; $1.1S$ with the authors' belief of $IA = 0.1S$.

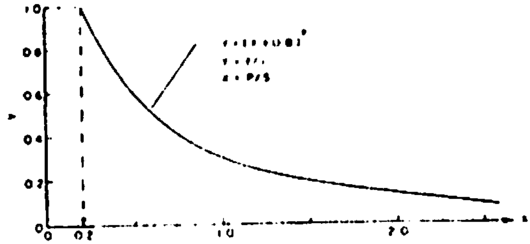

FIG. 4.—Dimensionless Expression of Infiltration Rate from the SCS Equation

These points cannot be laid wholly at the feet of the authors. Fig. 1 is a faithful reproduction from SCS literature, and dates back to early publications on the methodology. Hopefully, future editions of NEH-4 will justify or explain the uniform intensity assumption, and rectify the soil-water accounting.

Modeling Choices.—The authors justify the CN method for modeling infiltration rates by arguing that other infiltration equations require the questionable use of coefficients from ". . . previous studies whose site conditions are completely unknown." The SCS equation is almost identically at fault, it uses two coefficients, IA and S, chosen from an institutionalized listing with a healthy dollop of unquestioning faith, and used in a model that never underwent critical review and discussion (as is this paper) by the hydrology community. The rationale that

> ". . . the hydrologic soil-cover-complex curve number CN is a parameter whose quantification is based on extensive field studies and soil classifications mapped over most of the United States,"

gives an overoptimistic impression of reliability. As a trial, the authors might try to cite technical reviewed or journal references on the reliability of handbook CNs, field determination from hydrology data, the physical linkage between soil groupings and CNs, etc. The pickings are indeed slim. Using curve numbers to calculate infiltration rates only masks the problem, and transfers the burden of belief to a handbook technique which borders on a black box.

This discussion was written while on sabbatic leave with USDA, Science and Education Administration, Southwest Watershed Research Center, Tucson, Ariz.