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EVALUATING PARTIAL AREAS OF WATERSHED RUNOFF[a]

Discussion by Kenneth G. Renard,[2] Fellow, ASCE

The author is to be commended for a very logical and descriptive explanation of a phenomenon widely recognized in rainfall-runoff analyses but seldom treated analytically. The results should have immediate application in three areas besides those suggested by the author: in urban hydrology, where progressively larger amounts of impervious area occur; in roadbuilding in forested watersheds; and in water quality analysis where partial area runoff affects pollution.

Lane et al. (1978) performed experimental work to validate a distributed-nonlinear runoff model. The work involved the application of water-soluble chemicals to four geomorphologically homogeneous areas as defined from soils, slopes, and channel density. That the water-soluble chemicals were not measured at the watershed outlet hydraulically most distant was taken as proof that partial area runoff was occurring. If the watershed was assumed to contribute runoff uniformly over the entire area, the assumed runoff rate (at a specific point), expressed as runoff per unit area, is in error by the factor of the proportion of area contributing. As the authors state, "Errors in estimating surface runoff rates could carry over into estimated values for mean shear stress and resulting erosion rates. Moreover, in studies of non-point processes, it is essential to identify the high runoff-erosion areas of watersheds."

The author relates his bucket model to: (1) Spatial variability in surface storage; and (2) variable antecedent wetness. The analogy of this conceptual development to the curve number (CN) model used by the U.S. Department of Agriculture's (USDA) Soil Conservation Service provides the most logical explanation for the shape of the *P*-*Q* curves associated with different CNs. The writer's experience has seldom reproduced the nice relationships shown in Figs. 5(*a*) and 6(*a*).

Most watershed (*P*-*E*)-*Q* data show a wide scatter described to resemble a "shotgun pattern" (see Simanton et al. 1973; Springer et al. 1980).

The writer feels that much of the scatter experienced in the aforementioned (*P*-*E*)-*Q* relationships are related to temporal differences in the precipitation pattern. Consider the four different hyetographs of Fig. 7, each having the same total precipitation. Precipitation excess will be largest for the shortest duration if a watershed is not intensity and infiltration rate activated. In the bucket model, spatial variability in surface storage or temporal variability in antecedent wetness alone will not explain the differences in precipitation excess to be expected. The effect of increasing precipitation duration conceptualized with the bucket model in Fig. 8 is similar to that postulated by the author in Fig. 3 but for different reasons.

Hawkins (1977) states that problems arise with the curve number model (and with the bucket model) "from the lack of a time dimension in the basic mechanics of the [CN] method. Without time considerations, neither infiltration nor intensity can be incorporated. The time concept must be intro-

[a]August, 1987, Vol. 113, No. 3, by Walter C. Boughton (Paper 21734).

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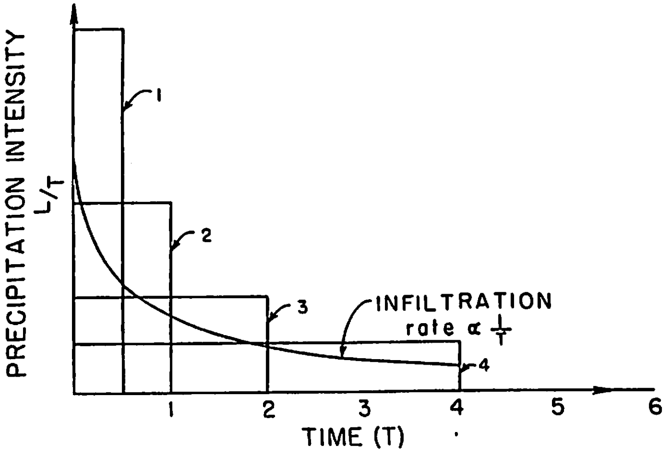

FIG. 7. Schematic Diagram of Four Different Hyetographs

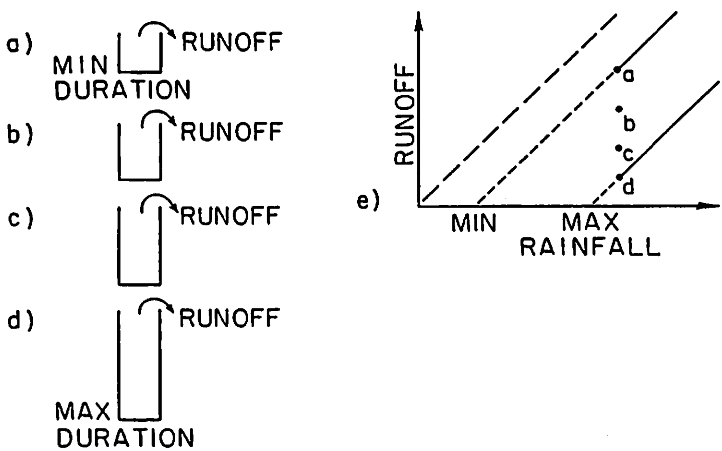

FIG. 8. Effect of Precipitation Duration on "Bucket Model"

duced through new relationships or assumptions." He then presented an approach to the problem.

To develop an intensity-runoff relationship, Hawkins ordered the precipitation intensity duration hyetograph and superimposed a constant loss rate, ϕ (the classical phi index). This procedure has the disadvantage that two storms of different cumulative rainfall may be identical when described by an ordered intensity-duration characteristic. For a triangular storm with a constant ϕ index, the following relationship can be developed:

$$Q = \frac{\left(P - \frac{\phi T}{2}\right)^2}{P} \quad \text{(1)}$$

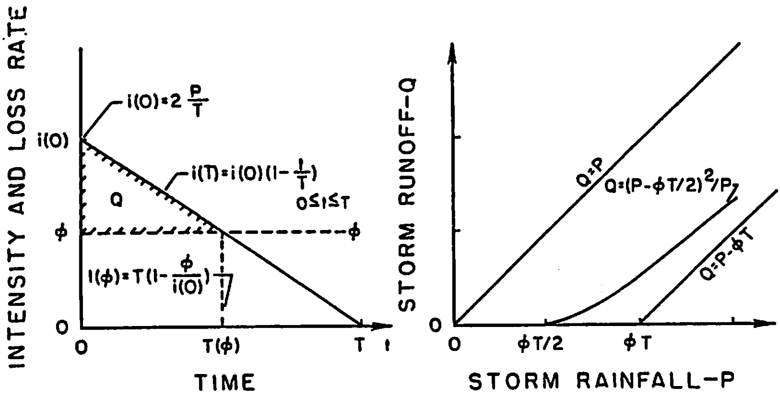

FIG. 9. Illustrative Example of Intensity-Duration Accounting and Resulting Rainfall-Runoff Relationship (from Hawkins 1977)

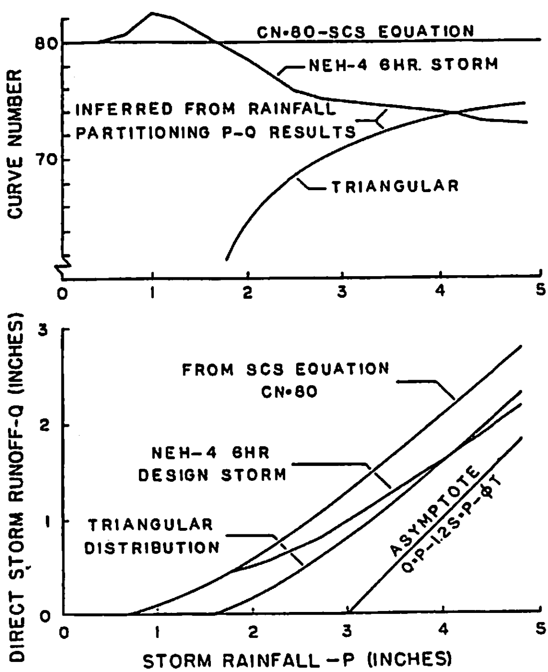

FIG. 10. Comparisons of Runoff and Apparent Curve Number for Six-Hour Storm with CN = 80, by NEH-4 Method and by Rainfall Partitioning for NEH-4 Six-Hour Design Storm and Triangular Distribution of Storm Intensities

where Q = storm runoff; P = storm rainfall; ϕ = loss rate; and T = storm duration with an assumed triangular intensity distribution. Graphically, the results can be shown as in Fig. 9 where $i(o)$ = intensity at time zero. With additional manipulation, he showed that the CN and storm runoff changed dramatically with different intensity relationships (i.e., a dimensionless distribution and with the triangular intensity-duration) as compared to the classical SCS runoff equation (or bucket model) (Fig. 10). Thus, the importance of the intensity pattern can hardly be ignored. Hawkins (1982) further demonstrated a relationship between storm average intensity and storm average runoff rate as well as apparent loss rate (infiltration). He used both plot and natural watersheds as evidence of his conceptualization. He stated that "from the standpoint of practical applied hydrology, intensity variable loss rates are a substantial departure from conventional wisdom and usage. The extent of such happenings, as witnessed in real hydrologic data . . . should be delineated by climatic, geographic, and land use types, so that it can be either recognized or ignored as appropriate."

Appendix. References

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Closure by Walter C. Boughton[3]

I thank Renard for his comments and for the opportunity to clarify some matters of importance. I have modified an illustration by Dunne (1983)—see Fig. 11—in order to emphasize that runoff-producing mechanisms are different in different climatic and biophysical regions, and to show a possible pattern of the mechanisms in mainland Australia.

The notion that storm runoff is produced on all watersheds only by a Hortonian infiltration-excess mechanism is clearly untenable. On the east coast of Australia, there is a great deal of evidence to show that the dominant mechanism by which storm runoff is produced on most catchments is saturation overland flow. The bucket models described in my paper are a convenient means of simulating runoff from partial areas of saturation overland flow, and to relate those partial areas to areas of different surface storage capacity over a watershed. The models are clearly inappropriate for use on watersheds where either subsurface stormflow or Hortonian infiltration-excess is the dominant mechanism producing storm runoff.

I believe that the major climatic regions in which Hortonian infiltration-excess is the dominant storm runoff producing mechanism are arid regions

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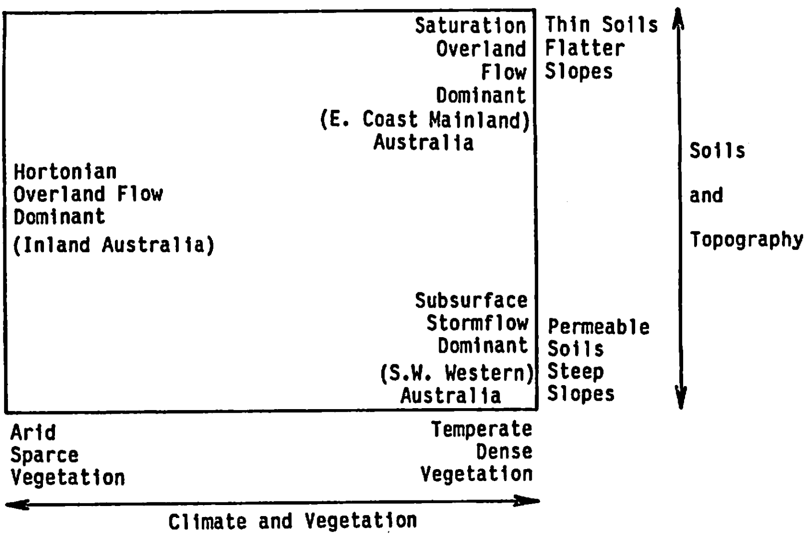

FIG. 11. Proposed Influences of Climate, Soils, Vegetation, and Topography on Runoff-Generating Processes (Adapted from Dunne 1983)

where the sparse cover of vegetation allows the formation of a surface seal by storm rainfall. The low rate of infiltration through the surface seal is the reason for the Hortonian infiltration-excess runoff in these areas. If my view is correct, then the saturation overland flow models in my paper would be more appropriate for use in areas with good ground cover of vegetation but not in arid regions or areas where the vegetation cover has been removed, e.g., croplands and cultivated areas.

Renard comments that careful data selection must have been used to produce the clear relationships in Figs. 5(*a*) and 6(*a*). This is absolutely correct and, indeed, is an essential part of the procedure described in the paper. The data points in Figs. 5(*a*) and 6(*a*) were carefully chosen for zero or near-zero antecedent moisture by careful daily water balance calculation. In my variations in antecedent moisture—temporal differences in the precipitation patterns—produce scatter in rainfall-runoff relationships in areas where saturation overland flow is the dominant storm runoff producing mechanism. As Renard points out, Hawkins has demonstrated that interpreting the curve number model as an infiltration-excess model of runoff production leads to the incongruous result that the infiltration loss is dependent on rainfall intensity. Interpreting the curve number model as a saturation overland flow model in which runoff depends only on antecedent moisture and total depth of rainfall is a much simpler interpretation and is more consistent with available data in regions such as the east coast of mainland Australia where saturation overland flow appears to be the dominant mechanism producing storm runoff.

Appendix. Reference

Dunne, T. (1983). "Relations of field studies and modelling in the prediction of storm runoff." *J. Hydrol.*, 65, 25–48.