STORMFLOW AS A FUNCTION OF WATERSHED IMPERVIOUS AREA

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INTRODUCTION

In recent years the idea that an entire watershed contributes to the generation of surface runoff has been questioned. Researchers studying small watersheds have suggested that only a fraction of the drainage actually contributes to stormflow. This theory is called the partial source area concept. Many hypotheses have been put forth to explain how the source areas vary (if at all) and how the water reaches the channel. An application of the partial area concept to two watersheds in Utah's Wasatch Mountains suggests that the partial source area for some drainages may simply be the fraction of the watershed which is functionally impervious.

DEVELOPMENT

The U.S. Soil Conservation Service developed the runoff curve number method to estimate surface runoff depths from rainstorms (USDA, 1956). The curve number, also called the "hydrologic soil-cover complex number" is presumed to characterize a drainage's hydrologic response to storms based on certain soil and vegetative types, cover density and antecedent moisture conditions. Most commonly, the curve number for a given watershed is estimated using guidelines based on the above factors. However, Hawkins has observed (1973, 1978, 1979) that the runoff curve number (CN) for any real rainfall-runoff event may be calculated from an observed precipitation-discharge data pair. He terms the curve number thus computed an observed CN. Hawkins (1973) demonstrated that, for several small forested watersheds in the western U.S., observed CN varies with storm size. A later publication (1979) contends that the observed variation may be the result of a constant partial source area for stormflow. If this source area is constant (or nearly so) for a given watershed, then the direct runoff (Q) is a proportion (C) of the total precipitation (P), or, $Q = CP$ (Eq. 1), where C is simply the fraction of the total drainage area which is impervious. Impervious in this case includes saturated areas such as the channel itself and areas of impermeable rock adjacent to the stream. Other impervious areas distant from the stream network are not considered contributing areas, on the assumption that any overland flow from these areas would infiltrate before reaching the channel.

Equation 1 may be considered an expression (the integration) of the rational formula:

$$\int q \, dt = \begin{array}{c} q = CiA \\ = CA \int i \, dt \\ Q = CP \end{array}$$

C is thus Q/P, the familiar "runoff ratio."

This ratio was substituted into the equation for observed curve number from historical data pairs. Using data from 11 small, high-elevation western watersheds, Hawkins (1979) estimated the C coefficient for each drainage by an iterative least-squares method. For all but one of the 11 watersheds, over 90% of the variation in CN was accounted for by the regression onto storm size ($r^2 = 0.90$).

To test the hypothesis that the observed CN behavior is a consequence of having a small but constant source area generating streamflow, a field survey was undertaken of two of the watersheds for which C coefficients had been estimated by regression techniques (Pankey, 1980). Both watersheds were within the Davis County Experimental Watersheds (DCEW) in central Utah, in the Farmington Creek drainage. The experimental watersheds were established by the U.S. Forest Service in 1930 as a research site for the study of floods and erosion (Johnston and Doty, 1972). Consequently, a variety of hydrologic instrumentation has been installed.

The annual precipitation averages 40 inches at the mouth of Halfway Creek and 45 inches at West Chicken Creek. Annual streamflow for both drainages, however, averages 19 inches. The Halfway drainage is a 464-acre watershed facing southwest with an elevation range of 6200 to 9000 feet. West Chicken Creek drains 217 acres from an elevation of 7550 to 8400 feet, generally facing northwest. The Halfway Creek drainage is rocky with generally immature, thin soils, except in areas of gentle slopes near springs or the stream where the richer soils may support a rare aspen stand. West Chicken Creek watershed, however, is predominantly covered by aspen, with little of the shrub oak-mountain mahogany stands which characterize the Halfway drainage.

In the fall of 1979 channel surveys were made on both Halfway and West Chicken Creeks. The width of the channel was measured at no greater than 50-foot intervals or upon abrupt changes in width or geometry. Included in each measurement was the width of the live stream plus the width of impervious material within five feet of the channel, or the width of the dry channel or erosion pavement. Any saturated area (i.e., enough moisture to wet boot soles) was also measured. In the cases of large areas, which could not be measured exactly (e.g., beaver ponds on West Chicken Creek or rock outcrops and springs on Halfway Creek), the approximate boundaries of a regular geometric shape which inscribed the area in question were measured.

Measurement along a stream continued until the channel became well vegetated and/or indistinct. West Chicken Creek was measured along the entirety of the live stream for that time in the field. Because of the steep and rugged character of Halfway Creek and the number of tributaries, estimates of some of the tributaries were made using aerial photographs. The photographs used for this purpose had been taken one month prior to the field work. Channel lengths and widths measured in the field provided the reference for photo point scales for a given elevation.

RESULTS AND DISCUSSION

The comparison between the estimates of the impervious areas for Halfway and West Chicken Creeks and the runoff ratios, C, as reported in Hawkins (1979) for those drainages is shown in Table 1.

Table 1. A comparison of the field-surveyed impervious fraction with the runoff ratio (C) from Hawkins (1979) for Halfway and West Chicken Creeks, Davis Co., Utah.

Drainage	Impervious Fraction	C Regression Estimate
Halfway Creek	0.0058	0.0105
West Chicken Creek	0.0045	0.0075

Generally, the runoff ratio C is twice the measured impervious fraction. Thus, if Q = CP were to be used to estimate runoff for Halfway Creek and the true value of C was 0.0105, using a C of 0.0058 would result in underestimating the runoff by 45%. Conversely, if C was actually 0.0058 and 0.0105 was used, the runoff would be overestimated by a factor of 1.8. Such margins of error would generally be considered unacceptable.

However, if each value of C is thought of as an estimate of the runoff-generating zone within an entire drainage area, and where such estimates may range from a fraction of a percent to 100%, then the field measurements and the values from the runoff curve calculations are in agreement. The estimates for Halfway Creek differ by only 0.47% of the total drainage area, and the estimates for West Chicken Creek differ by 0.3%.

There are a number of explanations as to why the measured impervious fractions and the C coefficients do not agree more closely. There is undoubtedly some error in measurement, both in the collection of the rainfall-runoff data used in regression and in the field estimates of impervious areas. The values for C probably also include residual errors in prediction associated with the iterative least-squares procedure.

The field measurements of impervious and saturated areas were made at a time when the watersheds would be at the lowest moisture content for the water year. Thus areas which may be contributory in the wetter summer would not have been detected. An ideal time to measure the channel and impervious areas would be during a storm, but the size and complexity of the study areas preclude this. The field surveys constitute a single point measurement (at least temporally), whereas the least-squares generated C values are an average for 14 to 16 storms over 5 or 20 years of record.

Hawkins, in the 1979 article, cautions that Q = CP may hold only for storms in which there is no precipitation excess due to exceeded infiltration capacity nor any antecedent moisture.

Finally, the discrepancy between the measured impervious fraction and the runoff ratio may be due to additional stormflow processes taking place, such as the lateral flows into concave areas suggested by Zaslavsky and Sinai (1981).

SUMMARY AND CONCLUSION

Analysis of historical rainfall-runoff data using regression techniques suggests that surface runoff may be expressed as a constant proportion (C) of the precipitation (Q = CP). This implies that a relatively constant runoff source area is contributing all of the stormflow, where the runoff ratio, C, is that fraction of the watershed which is impervious and is in proximity to a stream channel. C coefficients for eleven high-altitude watershed were estimated using an iterative least-squares procedure. Field measurements of the impervious areas of two of those watersheds were found to be within 0.3 to 0.5% of the total drainage areas when compared to the regression-generated estimates. This supports the hypothesis that surface runoff is produced by the functionally impervious portions of a watershed.

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