FLOOD SKEW IN HYDROLOGIC DESIGN ON UNGAGED WATERSHEDS

By Richard H. McCuen[1] and Theodore V. Hromadka II,[2] Members, ASCE

ABSTRACT: The skew of a peak-discharge frequency curve is an important determinant of the magnitude of events having small exceedance probabilities. Unfortunately, methods for estimating skews for ungaged locations provide highly inaccurate estimates. This appears to be the result of a lack of understanding of the primary causes of variation in skew. An analysis of existing hydrologic methods indicates that the skew assumed with these methods for ungaged locations is different than the mean skew for gaged sites in the same area. Furthermore, the design methods suggest that watershed storage is the primary factor affecting skew, with an increase in skew as the volume of watershed storage is decreased. Variables that show greater potential for providing accurate estimates of skew are discussed, and a relationship for estimating the effect of imperviousness on skew is provided.

INTRODUCTION

Flood frequency analyses at gaged locations can be made using the U.S. Water Resources Council guidelines of *Bulletin 17B* (1982). The guidelines recommend the log Pearson type III distribution with a weighted skew coefficient. Discussions of the accuracy of the skew coefficient have been provided by Tasker (1978) and McCuen (1979). Wallis et al. (1974) provided the means of estimating the mean-square error of station skew for random variables from a log Pearson type III distribution. Even for stations where record lengths of 24 yr exist, the mean-square error will still exceed 0.2. A mean-square error of 0.3 was reported (Wallis et al., 1974). The standard error of the skew map in *Bulletin 17B* was shown to be greater than 0.5, which is relatively large when compared to the standard deviation of the gaging station skew values of 0.65. Such errors in skew can have a very significant effect on a computed peak discharge. For example, the values of Table 1 for Fishkill Creek at Beacon, New York, show the 100-yr peak discharge for different values of skew. The weighted skew coefficient was shown to be 0.7 (USGS 1982). A standard error of 0.5, such as that for the *Bulletin 17B* skew map, suggests that a skew in the range from 0.2–1.2 might be expected; even larger values are possible. The values of Table 1 indicate that a deviation of one standard error in the skew coefficient could cause an error of about 20% in the computed 100-yr peak discharge. Thus, estimates of skew that are more accurate than those provided by the *Bulletin 17B* map are needed.

Prediction equations that relate the skew coefficient to watershed and meteorologic characteristics are a possible alternative to the use of a map

---

[1] Prof., Dept. of Civ. Engrg., Univ. of Maryland, College Park, MD 20742.

[2] Dir. of Water Resour. Engrg., Williamson and Schmid, 17782 Sky Park Blvd., Irvine, CA 92714, and Res. Assoc., Princeton Univ., Princeton, NJ 08540.

Note. Discussion open until October 1, 1988. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on March 9, 1987. This paper is part of the ***Journal of Irrigation and Drainage Engineering***, Vol. 114, No. 2, May, 1988. ©ASCE, ISSN 0733-9437/88/0002-0301/$1.00 + $.15 per page. Paper No. 22440.

TABLE 1. Variation of Estimated 100-yr Peak Discharge (cfs) for Selected Skew Coefficients: Fishkill Creek at Beacon, New York

True skew (1)	Skew factor (2)	log Q_p (3)	Q_p (cfs) (4)
0.2	2.47226	3.9756	9,450
0.3	2.54421	3.9933	9,850
0.4	2.61539	4.0107	10,250
0.5	2.68572	4.0280	10,650
0.6	2.75514	4.0451	11,100
0.7	2.82359	4.0619	11,550
0.8	2.89101	4.0784	12,000
0.9	2.95735	4.0947	12,400
1.0	3.02256	4.1107	12,900
1.1	3.08660	4.1265	13,400
1.2	3.14944	4.1419	13,900

for estimating skew. One would hope that the expected errors in estimates of skew could be reduced using such prediction equations. Unfortunately, preliminary results suggest that relationships based on predictor variables frequently used in regionalization of hydrologic variables do not substantially reduce the error (McCuen 1979).

Flow skew is an important input to many hydrologic designs. Yet, hydrologists lack an accurate method for estimating flood skew. The previous illustration suggests that neither the *Bulletin 17B* map nor regression equations provide significant improvements in accuracy over that provided by the mean value of all station skew values in the country, which is approximately zero. In addition to the lack of accuracy in existing empirical methods for estimating skew, there is a surprising lack of understanding of just what causes variation in flood skew. Accurate methods of estimating flood skew can be developed once the factors affecting flood skew are identified and delineated.

While skew at gaged locations is a known problem, it is not usually recognized that methods for estimating peak discharge on small, ungaged watersheds have inherent assumptions about skew. These assumptions affect hydrologic designs, such as flood plain delineation, stormwater management structure design, and the design of small water-supply reservoirs. Because errors in skew can affect flood peak estimates, parameters in hydrologic models that are related to the skew of computed flood frequency relationships should be examined. Furthermore, examination of model assumptions may lead to the identification of variables that would provide accurate predictions of skew at ungaged locations.

The objectives of this paper are (1) To identify the parameters of peak-discharge prediction methods that affect the skew of the computed flood flow frequency curve; (2) to make a preliminary assessment of factors that affect skew; (3) to hypothesize variables that could be used in developing equations for predicting skew; and (4) to show the effect of urbanization of skew.

A recent study (USWRC 1981) indicated that the Rational method and the SCS TR-55 method were two of the most widely used techniques for estimating peak-discharge frequency curves at ungaged locations. These methods are widely used because of their computational simplicity and their ability to reflect the hydrologic effects of land-cover changes such as urbanization. Although the methods are conceptually simple, they can still provide a framework for discussion of the causes of variation in the skew coefficient.

Rational Method

The Rational method has been used for many decades as the primary method for estimating peak discharge rates for small ungaged watersheds. The method can be interpreted to assume that the exceedance probability p of the peak discharge q_p in cfs is the same as the rainfall intensity i in in./hr:

$$q_p = CiA \qquad (1)$$

in which C = the runoff coefficient; and A = the drainage area in acres. Assuming that both A and C are independent of the exceedance probability, then for a selected watershed, Eq. 1 can be written as

$$q_p = Ki \qquad (2)$$

where K = a constant equal to CA. Therefore, the skew coefficient of the frequency curve of q_p must equal the skew of the frequency curve of i. The implications of this is that the use of the Rational method assumes that the skew of the peak-discharge frequency curve is dependent on the skew of the rainfall intensity which, according to usual practice, has a duration equal to the time of concentration.

To illustrate the relationship between the skews of the rainfall intensity and peak discharge, the peak discharge rates for exceedance probabilities of 0.5, 0.2, 0.1, 0.04, 0.02, and 0.01 (i.e., return periods of 2, 5, 10, 25, 50, and 100 yr) were computed for hypothetical watersheds with fixed times of concentration of 0.083, 0.25, and 2 hr. The base 10 logarithms of both rainfall intensities and peak discharges for the six exceedance probabilities were used to determine the skew coefficients. For Baltimore, Maryland, the skew coefficients for both rainfall and runoff were approximately 0.3, and for Tucson, Arizona, the skew coefficients were approximately 0.2. It is interesting to compare the skew coefficients for runoff that are assumed when the Rational method is used with the skew coefficients specified on the skew map of the WRC (1982) for the two areas. The *Bulletin 17B* skew map indicates skew coefficients of 0.7 and −0.2 for Baltimore and Tucson, respectively. Therefore, a skew coefficient of 0.7 is used at gaged locations in Baltimore, while a skew coefficient of 0.3 is used at ungaged locations when the Rational method is used. Similarly, a skew coefficient of −0.2 is used at gaged locations in Tucson, while a skew coefficient of 0.2 is used at ungaged locations. Thus, there are differences of 0.4 between the skew for gaged and ungaged locations in both Baltimore and Tucson. The values of Table 1 for the Beacon, New York, watershed indicate that a departure in the skew of 0.4 can result in significant differences in the computed peak discharge rate.

In Eq. 2 and the subsequent analyses, the assumption was made that C was constant. A number of tables of runoff coefficients indicate that C will increase for exceedance probabilities of 0.04 or less (i.e., return periods of 25 yr and greater). Rawls et al. (1981) suggested that the tabled value of the runoff coefficient should be increased by about 0.08 in single-family residential areas when the exceedance probability is 0.04 or less. For such cases the Rational method has the form

$$q_p = C_p iA \qquad (3)$$

in which the subscript p on C indicates that the runoff coefficient is a function of the exceedance probability. The skew of the flood frequency curves derived with Eq. 3 for times of concentration of 0.083 and 0.25 hr are about 0.6. This represents an increase in the skew of 0.3 when comparing Eq. 3 with Eq. 2, i.e., when C_p is used rather than C. This indicates that the skew coefficient increases when the runoff coefficient is modified to reflect the loss of storage associated with the less frequent events. The rationale for using C_p, as opposed to C, is that the watershed storage decreases as the magnitude of the storm increases. Thus, the skew coefficient increases as the storage is decreased.

SCS TR-55 Graphical Method

The SCS TR-55 graphical method (SCS 1975) is also widely used for estimating peak discharge rates on small, ungaged watersheds. The peak discharge equals the product of the unit peak discharge q_u, in cfs/mi²/in. of runoff, the runoff depth in in. Q, and the drainage area in mi² A:

$$q_p = q_u AQ \qquad (4)$$

The unit peak discharge is a function of the time of concentration. The runoff depth is a function of the 24-hr rainfall depth P (in inches) for the selected exceedance probability and the runoff curve number CN, which is an index of the land cover and soil type. If a method for computing the time of concentration that does not vary with the exceedance probability such as the velocity method is used, then the skew of the peak-discharge frequency curve depends on the skew of the runoff-depth frequency curve. Because the CN is not a function of the exceedance probability, the skew of the runoff depth frequency curve is a function of the skew of the 24-hr rainfall-depth frequency curve and the structure of the SCS runoff equation as follows:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (5)$$

in which S = the maximum potential watershed storage, which is a function of the CN

$$S = \frac{1{,}000}{CN} - 10 \qquad (6)$$

For large values of CN and P, the relationship between Q and P is nearly linear, and thus the skew of the peak-discharge frequency curve approaches that of the 24-hr rainfall-depth frequency curve. However, for smaller CNs, Eq. 5 provides a highly nonlinear relationship between P and Q, with the effect of relatively small changes in Q for large changes in P. Thus, for small values of CN, the form of the runoff equation affects the skew of the computed peak-discharge frequency curve.

To examine the skew of the peak-discharge frequency curve, frequency curves were computed for CNs ranging from 45–90. A minimum value of 45 was used to avoid peak discharges of 1 cfs or less for the event with an exceedance probability of 0.5. For curve numbers of 45, 60, 75, and 90, skew coefficients of −1.3, −0.5, 0.2, and 0.3 were computed for the peak-discharge frequency curves for Baltimore, Maryland. The frequency curves were based on peak discharges for the six exceedance probabilities used previously. The skew of the 24-hr rainfall frequency curve was computed to be 0.3. Thus, it appears that for low CNs, which correspond to high watershed storage, the skew is highly negative and increases as the CN increases. In terms of watershed storage, the skew appears to decrease as the watershed storage increases; also the upper limit of the skew of a q_p frequency curve appears to be set by the skew of the rainfall frequency curve. A similar analysis was performed for Tucson, Arizona, with a similar association between skew and storage observed. In the analyses for both Baltimore and Tucson, the skew of the peak discharge relationship was quite different from the skew indicated by the *Bulletin 17B* skew map. The map is limited in its ability to reflect variation in skew, since it can only reflect factors that vary geographically. This fact is supported by the large standard error of the skew map. The map does not reflect variation in factors that control watershed storage.

Effect of Surface Depression Storage on Skew

While pond and swamp storage is often very localized, most watershed storage is spatially distributed over the entire watershed. McCuen (1983) provided a method for measuring the effect of depression storage volumes on peak rates of runoff; the design method is applicable to storage that does not have a significant effect on the time of concentration. That method was used to evaluate the effect of surface storage on the skew of the peak-discharge frequency curve. Surface storage equivalent to 0.3 area-in. of runoff were assumed, and the peak-discharge frequency curves for both the "no-surface storage" and "surface storage" conditions were computed. The 0.3 area-in. represents about 25% of the runoff volume for the 2-yr storm and 6% of the 100-yr event. The skew coefficient decreased by 0.1. Again, it appears that increases in surface storage decrease the skew of the peak-discharge frequency curve.

EFFECT OF CHANNEL STORAGE ON SKEW

In addition to watershed storage, one might suspect that channel storage would affect the peak discharge skew. The SCS TR-55 tabular method (SCS 1975) was used to evaluate the potential effect of channel storage. The tabular method is based on numerous evaluations of the TR-20 computer program (SCS 1969) which, when used to develop the tabular method, used the convex method for channel routing. The routing parameter of the convex method is an indicator of storage. When using the tabular method, the level of channel storage is affected by the travel time through a stream reach. In design, the storage coefficient cannot be specifically changed to examine the change in skew relative to change in the routing coefficient.

Using the tabular method, the skew of the peak-discharge frequency curve for Baltimore was computed for a time of concentration of 0.5 hr, travel times of 0, 1, 2, and 4 hr, and curve numbers of 45, 75, and 90. There was not a significant change in skew as travel time changed; however, the skew increased as the *CN* increased with values of -1.3, 0.2, and 0.3 for the *CN* values of 45, 75, and 90, respectively. This suggests that watershed storage has a much greater effect on skew than does channel storage.

A second method was used to examine the effect of channel storage on skew. The method used the SCS tabular method to generate inflow runoff hydrographs for travel times of zero and the Muskingum method for routing the inflow hydrograph through stream reaches. Inflow hydrographs were developed for a drainage area of 500 acres with a time of concentration of 1.5 hr and curve numbers of 45, 60, 75, and 90. When routing using the Muskingum method, storage coefficients K of 0.5, 1.0, and 2.0 and inflow-outflow weights x of 0.1, 0.2, and 0.3 were used. While the skew of the flood-frequency curve downstream varied with *CN*, there was no significant variation in skew with changes in K and x. Thus, this simple modeling approach suggests that channel storage is not a primary determinant of flood skew for small ungaged watersheds.

IMPLICATIONS FOR REGIONALIZATION OF SKEW

Given the importance of skew in determining the shape of a flood-frequency curve, there has been interest in developing the means of predicting skew at both gaged and ungaged sites. Regression equations have not proven to provide sufficient reductions in the standard error of estimate (Hardison 1975; McCuen 1979); this may be the result of the incorrect selection of predictor variables. Attempts at developing regression equations have used predictor variables such as the drainage area and the mean annual rainfall. Over a large region, the results of the previous analyses suggest that these predictor variables do not affect skew, probably because the variables do not reflect the storage of the watersheds used in developing the regression equations. For the regression equations developed by McCuen (1979), the mean percentage of area in storage was less than 1%. Storage appears to be an important variable, but it did not prove to be a significant predictor variable in the regression analyses because watersheds with a large variation in pond storage were not included in the data set used to develop the *Bulletin 17B* skew map.

Methods of regionalizing skew can be divided into the regression equation approach and the mapping approach. While regression offers an approach to estimating skew that can include many predictor variables, it is constrained by the relatively simple linear and power model structures. Mapping is an alternative that provides for nonlinear variation of skew, but it is limited to the extent that variation in causative factors can be expressed on a map. Past attempts to map skew have only expressed skew in terms of the spatial variation of station skew for stations where gages with relatively long record lengths are located. Unfortunately, this approach has resulted in maps of relatively poor accuracy, with the standard error of prediction being not much less than the standard error of the mean. Thus, the mapping approach cannot be considered successful.

If watershed storage is the factor that effects variation in skew, then a new direction must be taken for estimating skew at ungaged locations. The first step is to develop a set of random variables that reflect watershed storage. Certainly the percentage of ponds and swamps would be a candidate variable. While interception and depression storage are small and difficult to measure, they still contribute to watershed storage and should, therefore, be evaluated and used as predictor variables. In addition to surface storage, measures of subsurface watershed storage should be developed. Variables that depend on soil texture may reflect storage. Thus, the parameters of the Green-Ampt equation (Brakensick and Rawls 1983) may be used for predicting skew. Also, the runoff *CN* reflects soil type, as well as land cover and, therefore, may be a useful indicator of storage. The percentage of impervious cover, which is one input in computing the *CN*, also affects the watershed storage available; increasing the percentage of impervious cover decreases the available watershed storage, which may change the skew. In summary, an analysis of existing design models leads to a new set of predictor variables that should be investigated for estimating skew. While some of these variables may show regional trends and thus be mapped, there is likely to be very little systematic regional variation in storage that is amenable to mapping. Thus, the regression approach appears to offer the most hope for increasing the accuracy of watershed skew estimates.

EFFECT OF URBANIZATION ON SKEW

The study of simple hydrologic models has suggested that watershed storage is a dominant factor in controlling the flood skew coefficient. Urbanization, which has a significant effect on watershed storage, was hypothesized to be a variable that may affect flood skew. The data of Table 2 summarize the characteristics of eight urbanized watersheds in Los Angeles. The watersheds have been urbanized over a period of 50 yr or more, and so the flood records were adjusted using a relationship between the exceedance probability, the percentage of impervious cover, and the peak discharge rate to reflect a constant percentage of imperviousness for

TABLE 2. Summary of Statistics for Los Angeles Watersheds

Watershed (1)	Area (mi^2) (2)	1985 percent imperviousness (3)	Adjusted station skew (4)	Years of record (5)
Dominguez Channel	37.1	61	−0.23	16
Compton Creek at 120th Street	14.5	55	0.33	27
Compton Creek near Greenleaf Drive	22.6	55	0.075	56
Alhambra Wash	15.2	45	0.25	54
Eaton Wash	22.8	45	0.22	28
Arcadia Wash	8.5	45	0.15	28
Rubio Wash	10.9	40	−0.28	54
Verdugo Wash	26.8	25	−1.00	55

a given watershed over a period of record. The skew coefficient of the logarithms of the adjusted annual maximum flood record was computed and is given in Table 2. The adjusted skew coefficient g was regressed on the percent of imperviousness I with the following result:

$$g = -1.2623 + 0.02591\,I \quad \ldots\ldots (7)$$

The linear equation resulted in a correlation coefficient of 0.656, which is significant at the 5% level of significance. The one-tailed hypothesis was used since the previous analyses of the simple hydrologic models suggest that the skew should increase as the imperviousness increases (i.e., as the watershed storage decreases). The standard error for Eq. 7 is 0.36, which is less than the standard error for the *Bulletin 17B* map of about 0.5. Thus, the regression was both statistically significant and appears to be more accurate than the map.

The regression equation of Eq. 7 suggests that the rate of change of skew g with imperviousness I is 0.026. For a change of 20% in imperviousness, the predicted skew would change by 0.52, for example, from the map skew values of −0.45 for Los Angeles to 0.07. To provide an independent test of this sensitivity rate, the results from the analysis with the TR-55 for the CN from 45 to 90 resulted in a change in skew of 1.5, which yields $\Delta g/\Delta CN$ = 0.05. For a B-soil, the change in CN for a unit change in I is 0.37. Thus, the change in g for a change in I is approximated by

$$\frac{\partial g}{\partial I} = \frac{\Delta g}{\Delta CN} \cdot \frac{\Delta CN}{\Delta I} = 0.05\ (0.37) = 0.0185 \quad \ldots\ldots (8)$$

This rate does not differ greatly from the rate obtained from the regression of Eq. 7 of 0.026. For the change in imperviousness of 20%, the CN approach results in a change in g of 0.37, rather than the 0.52 computed independently. This approximation suggests that Eq. 7 is not an unreasonable indication of the effect of imperviousness on the flood skew.

It should be emphasized that Eq. 7 should be only used to estimate the effect of imperviousness on skew in and near Los Angeles; it should not be used to estimate specific values of skew. Skew also appears to be a function of location due to the effects of meteorological conditions, such as the type of storm events and the resulting skew of the rainfall intensity-duration-frequency curve.

CONCLUSIONS

Flood frequency analysis has been viewed primarily as a statistical problem, with only limited thought given to the geomorphological causes. In a review of the literature on the subject for the 1979–1982 quadrennium, Greis (1983) demonstrated the tendency for research to concentrate on statistical aspects of flood frequency analysis; however, Greis (1983) concluded that ". . . many of the directions of flood frequency analysis here and abroad reflect an increasing tendency not only to view the flood problem as a problem in statistical analysis but also to search for new interpretations or approaches which may relate more to the ultimate design goals of the flood frequency exercise or approaches which are more rooted in the underlying geomorphology or geology. The contributions of these approaches and interpretations can only strengthen the statistical procedures which, most probably, will remain the basis of flood frequency work in the near future." This paper is intended to be a start in the direction of providing a geomorphological framework for estimating skew, whether it is through the regression or mapping approach to prediction. The results of this rather cursory study strongly suggest that for small watersheds, watershed storage is the control variable.

The next step is to identify predictor variables that reflect watershed storage and, therefore, can be used to develop more accurate prediction methods. A set of watershed storage variables has been identified herein. However, two alternative courses of action were discussed. First, an attempt to map skew on the basis of variation in the more important predictor variables may be made. However, it may not be reasonable to expect skew to vary systematically over large regions; this view is supported by the large error variation of existing maps of skew. Second, one may attempt to develop prediction equations that relate skew to the predictor variables that reflect watershed storage. The success of this approach will depend on the validity of the hypothesis that variables that represent watershed storage affect skew and on the ability to identify the structure of the relationship. The analysis of data from Los Angeles suggests that the percentage of imperviousness is related to flood skew. Improvements in prediction accuracy may result from the use of variables that are more physically related to watershed storage in urban areas. The presence of control structures or changes in roughness may prove to be important variables.

In addition to watershed storage, the hydrologic design models suggest that rainfall is a factor in determining skew. The data that were used to develop the *Bulletin 17B* skew map do not fully support this hypothesis since the mean skew for adjacent 1° × 1° cells are quite variable. While such a comparison does not support a high degree of association, there is a much higher degree of association between skew and rainfall when watershed storage is low. Thus, a complete analysis of the skew problem cannot ignore rainfall. However, the effect of rainfall on skew cannot be fully assessed using the simple hydrologic design models because the means for variation in rainfall do not exist.

The difficulty in estimating skew has been a reason that some have argued for a zero-skewed distribution such as the lognormal distribution. After all, the mean of the 2,943 values of station skew used to develop the WRC map was −0.05, which is certainly near zero when one considers that the standard error is 0.65. Others have expressed interest in distributions that require more parameters, such as the five-parameter Wakeby distribution. It is doubtful that a distribution with five parameters will provide the statistical solution to the problem since generally applicable and accurate relationships are not available for estimating the parameters of such distributions or even for the less complex and parameter-intercorrelated three-parameter distributions. Thus, there is merit to the call for solving the skew estimation problem before attempting to address the variance separation problem that would be associated with such multiparameter distributions.

APPENDIX. REFERENCES

Brakensick, D. L., and Rawls, W. J. (1983). "Green-Ampt infiltration model parameters for hydrologic classification of soils." *Advances in irrigation and drainage: surviving external pressures*, J. Borelli, V. R. Hasfurther, and R. D. Burman (eds.), ASCE, New York, N.Y., 226–233.

Estimating peak flow frequencies for natural ungaged watersheds. (1981). U.S. Water Resources Council, Hydrology Committee, Washington, D.C.

Gries, N. P. (1983). "Flood frequency analysis: a review of 1979–1982." *Rev. Geophys. Space Phys.*, 21(3), 699–706.

"Guidelines for determining flood flow frequencies." (1982). *Bulletin 17B*, Interagency Advisory Committee on Water Data, Hydrology Subcommittee, U.S.G.S., Reston, Va.

Hardison, C. H. (1975). "Generalized skew coefficients of annual floods in the United States and their applications." *Water Resour. Res.*, 10(5), 745–752.

McCuen, R. H. (1979). "Map skew???" *J. Water Resour. Plng. Mgmt. Div.*, ASCE, 105(WR2), 269–277.

McCuen, R. H. (1983). "Methods for design of infiltration based stormwater control methods." *Technical Report*, Dept. of Civil Engineering, Univ. of Maryland, College Park, Md.

Rawls, R. J., Wong, S. L., and McCuen, R. H. (1981). "Comparison of urban peak flow methods." *Technical Report*, Dept. of Civil Engineering, Univ. of Maryland, College Park, Md.

Soil Conservation Service. (1969). "Computer program for project formulation." *Technical Release No. 20*, USDA, Washington, D.C.

Soil Conservation Service. (1975). "Urban hydrology for small watersheds." *Technical Release No. 55*, USDA, Washington, D.C.

Tasker, G. D. (1978). "Flood frequency analysis with a generalized skew coefficient." *Water Resour. Res.*, 14(2), 373–376.

Wallis, J. R., Matalas, N. C., and Slack, J. R. (1974). "Just a moment." *Water Resour. Res.*, 10(2), 211–219.