A COMPARISON OF METHODS FOR ESTIMATING FLOOD PEAKS ON STREAMS IN MASSACHUSETTS

by
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Abstract

Modifications of the Potter method (Potter, 1957) and the Small Basin Study (SBS) method (Johnson and Tasker, 1974) for estimating flood peaks from basin characteristics are used to predict the 50- and 10-year peak discharges at 77 continuous and partial-record gaging stations in Massachusetts. The predicted peaks made by each method are compared with the peak discharge estimated from station frequency curves for each station. Results indicate that, while the random error for both methods is about the same, the modified Potter method systematically predicts peaks which are substantially higher (150 percent) than those estimated from station frequency curves.

Introduction

One of the tasks of engineers concerned with the design of bridge or culvert openings, roadbed elevations, flood-protection works, or flood plain zoning is to estimate the probability of recurrence of floods of various magnitudes. In 1944 Kinnison and Colby (1944) published their important paper that related frequencies of floods to drainage basin characteristics. Since then Potter (1957), Benson (1962), Green (1964), Knox and Johnson (1965), Tice (1968), and Johnson and Tasker (1974) have made contributions to statistical analysis of flood peaks on a regional basis for Massachusetts streams. Table 1 summarizes the basic differences in these methods. Note that only two of these methods apply to streams with drainage areas of less than 5 square miles (mi^2) or 13 square kilometres (km^2), the Potter method and the SBS (Johnson and Tasker) method.

The Potter method is perhaps most widely used in Massachusetts in modified form by assuming a storage index of less than 4.5 for streams with drainage areas of less than 5 mi^2 (13 km^2) and by extrapolating the estimating curves for use below 1.0 mi^2 (2.6 km^2). This results in estimates of the 50- and 10-year peak discharges on many small streams in Massachusetts which are greater than the estimates made by the unmodified method.

In 1962 the U. S. Geological Survey in cooperation with the Massachusetts Department of Public Works and the Federal Highway Administration established a network of continuous and partial-record gaging stations to collect data on annual peak discharge on small rural streams in Massachusetts. The SBS method resulted from an analysis of data collected through the 1973 water year from this network in addition to the data collected at the regular network of U. S. Geological Survey gaging stations.

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Table 1. — Summary of seven methods for estimating flood peaks in Massachusetts.

	KINNISON AND COLBY (1944)	POTTER (1957)	BENSON (1962)
Data base	27 gaging stations in and adjacent to Massachusetts.	24 gaging stations in and adjacent to Massachusetts.	164 gaging stations in New England; 33 of which are in Massachusetts.
Method used to determine discharge-frequency relation at gaging stations.	Discharge frequencies were determined from precipitation frequencies, a rain-fall-runoff relation, and unit hydrographs.	The array of observed annual peaks were plotted on extreme-value probability paper. The upper end of the frequency curve was determined by a least-squares fit of those peaks having an indicated recurrence interval of 5 or more years.	A discharge-frequency curve was drawn by eye through each set of points determined from the record of annual peaks to average the trend of plotted points.
Method used to develop estimating relationships.	Graphical multiple regression.	Graphical multiple regression.	Step-backward multiple regression using 14 independent variables.
Significant independent variables.	Drainage area, storage factor, slope factor, and lag-time factor.	Drainage area, rainfall index, and storage index.	Drainage area, basin slope, storage factor, temperature factor, and orographic factor.
Form of estimating relations.	Equations.	Coaxial graph.	Equations.
Minimum size of basin to which applicable.	Smallest basin used in developing equations — 12.3 mi^2.	1.0m^2	15 mi^2

GREEN (1964) (does not apply to Hoosic River basin)	KNOX AND JOHNSON (1965)	TICE (1968) (applies only to Hoosic River basin in Massachusetts)	SMALL BASINS STUDY (SBS) (Johnson and Tasker, 1974)
146 gaging stations in New England; 30 of which are in Massachusetts.	43 gaging stations in and adjacent to Massachusetts.	487 gaging stations from New York to Virginia; 3 of which are in Massachusetts.	92 gaging stations in and adjacent to Massachusetts.
Same as Benson.	Same as Benson.	Same as Benson.	The array of observed annual peaks were fitted to a log-Pearson Type III frequency distribution.
Graphical.	Step-backward multiple regression using 6 independent variables.	Graphical.	Step-forward multiple regression using 12 independent variables.
Drainage area and hydrologic areas.	Drainage area, basin slope, and orographic factor.	Drainage area and hydrologic areas.	Drainage area, basin slope, and precipitation index.
Several graphs.	Equations.	Several graphs.	Nomographs.
15 mi^2	10 mi^2	5 mi^2	0.25 mi^2

In this report the 50- and 10-year peak discharges estimated by the modified Potter method and the SBS method are compared with the peak discharges determined from station frequency curves at 52 stations with drainage areas of less than 5 mi^2 (13 km^2) and 25 long-term gaging stations with larger drainage areas. The 52 stations have drainage areas ranging from 0.25 mi^2 (0.64 km^2) to 4.96 mi^2 (12.8 km^2) and the twenty-five long-term stations have drainage areas ranging from 12.3 mi^2 (31.9 km^2) to 497 mi^2 (1290 km^2).

Station Frequency Curve

In general, the station frequency curves were determined by fitting the observed array of annual peak discharges to a log-Pearson Type III frequency distribution, which is the base method recommended by the Hydrology Committee, Water Resources Council (1967) as a uniform technique for Federal agencies. For the twenty-five long-term stations having periods of record ranging from 33 to 63 years and averaging 49 years, the skew coefficient computed from the logarithms of the observed annual peak discharges was used in fitting the frequency distribution. Where historical information was available, it was used to modify the upper end of the long-term frequency curve. For the fifty-two small drainage area stations having an average period of record of 11 years, the generalized skew coefficients given by Hardison (1974) were used.

Comparison of Estimated and Predicted Flood Peaks

Any difference between observed and predicted data is referred to as error, which may be divided logically into two sources: random error and systematic error (bias). Random error may be measured by the standard deviation about the mean of the residuals (difference between logarithms of predicted and observed values). These values (table 2) are represented graphically in figures 1 through 4 as one-half the distance between the two dashed lines. Systematic error may be measured by the mean of the residuals (table 2), which are represented graphically by the solid lines in figures 1 through 4.

The stations used to make this comparison were among those used to develop the SBS method. Therefore, conclusions drawn from the results of this comparison are valid only to the degree that the sample of stations used represents all of the streams in Massachusetts. In addition, because the station frequency curves were developed from a finite sample of annual peaks, they do not necessarily represent the true frequency of peaks at the station. Nevertheless, it may be possible to draw two guarded conclusions from the data.

First, it is apparent from table 2 that the random error for both methods is about the same. The standard deviations of residuals based on all 77 sta-

Table 2. — Mean and standard deviation of residuals. Percentages indicate relative amount estimated values differ from observed values and sign indicates whether above (+) or below (−).

Sample	Recurrence interval of estimated peak, in years.	Mean of Residuals (Systematic error)				Standard Deviation of Residuals (Random error)			
		Modified Potter method		SBS method		Modified Potter method		SBS method	
		LOG UNITS	%	LOG UNITS	%	LOG UNITS	%	LOG UNITS	%
25 long-term stations.	50	+0.2890	+95	−0.0541	−12	0.2760	68	0.2217	53
	10	+0.3036	+101	−0.0312	−7	0.2714	67	0.1843	44
52 small drainage area stations.	50	+0.4567	+186	−0.0598	−13	0.2316	56	0.2456	60
	10	+0.4333	+171	−0.0160	−4	0.1959	47	0.2086	50
All 77 stations.	50	+0.4023	+153	−0.0580	−12	0.2575	65	0.2367	57
	10	+0.3912	+146	−0.0209	−5	0.2297	55	0.2000	48

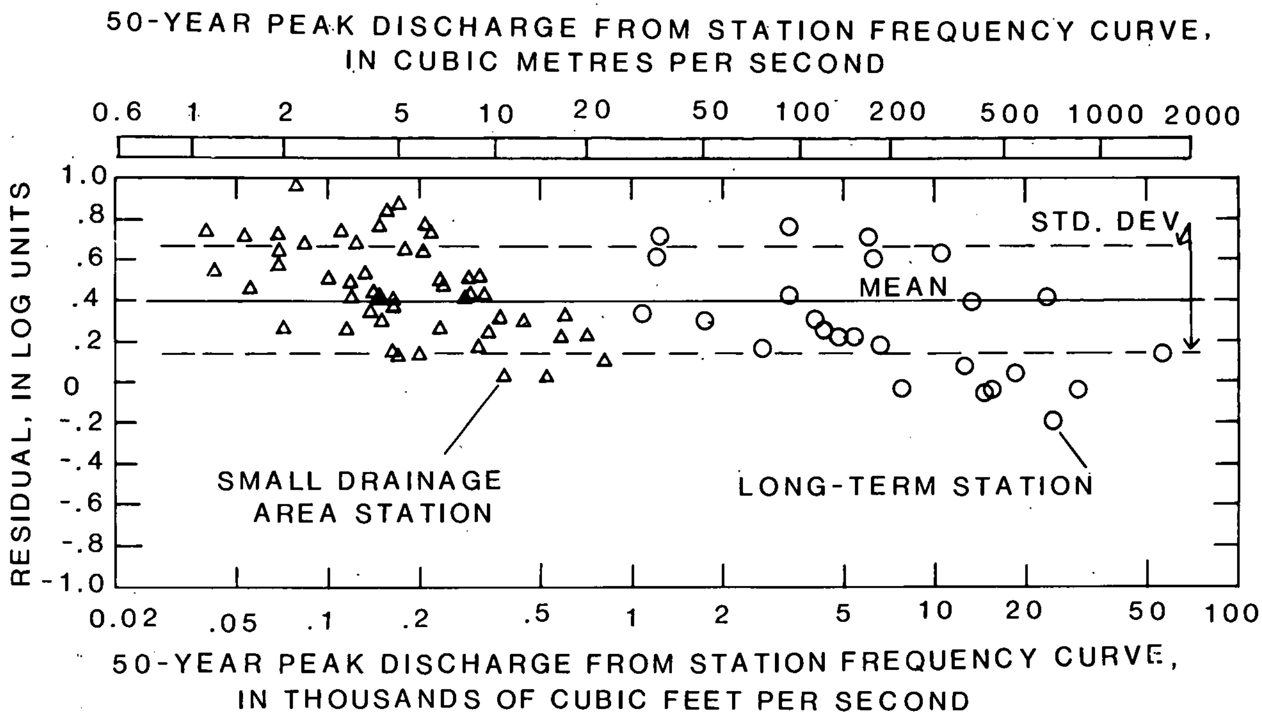

Figure 1. — Relation of residuals from modified Potter method for 50-year peak discharge to the 50-year peak discharge from station frequency curve.

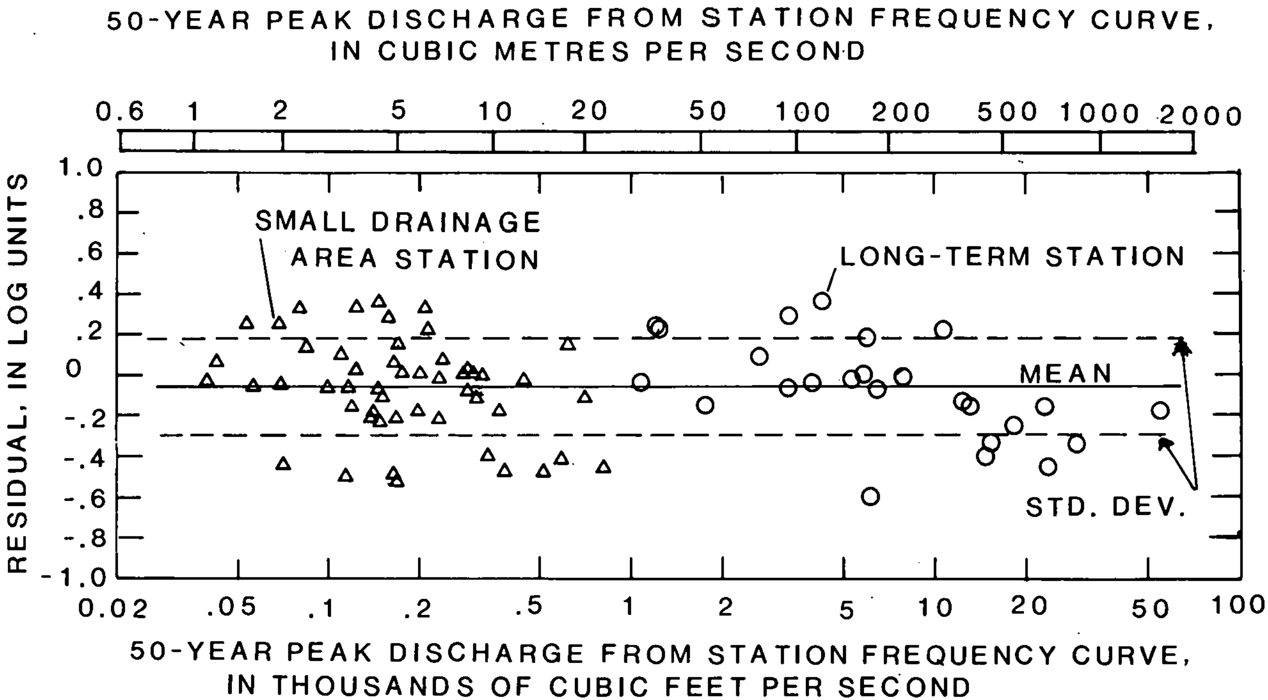

Figure 2. — Relation of residuals from SBS method for 50-year peak discharge to the 50-year peak discharge from station frequency curve.

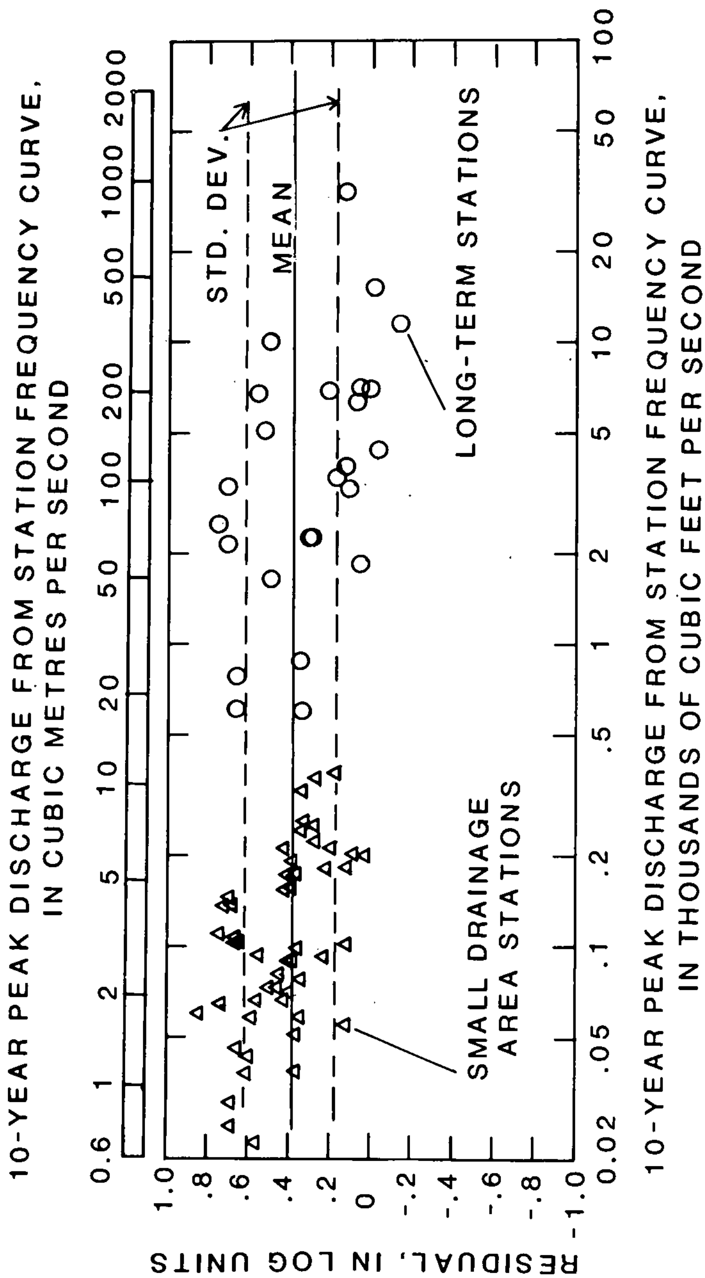

Figure 3. — Relation of residuals from modified Potter method for 10-year peak discharge to the 10-year peak discharge from station frequency curve.

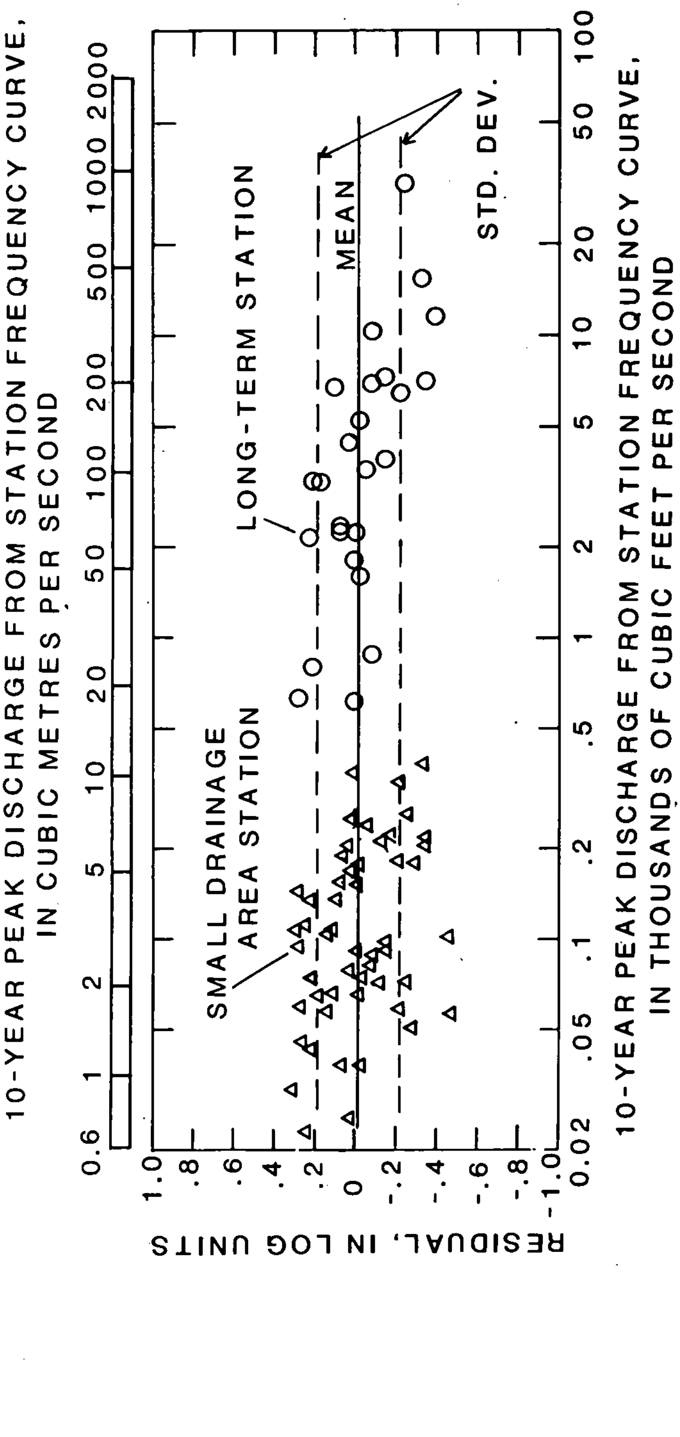

Figure 4. — Relation of residuals from SBS method for 10-year peak discharge to the 10-year peak discharge from station frequency curve.

tions for the 50- and 10-year peaks are for the modified Potter method 65 and 55 percent and for the SBS method 57 and 48 percent, respectively. Second, the modified Potter method systematically predicts values of peak discharge which are substantially higher than those estimated from station frequency curves at the U. S. Geological Survey network of gaging and partial-record stations in Massachusetts. Based on the 77 stations, the modified Potter method predicted values of the 50- and 10-year peaks averaging about 150 percent higher than those of the station frequency curves.

Discussion of the SBS Method

The SBS method used longer periods of streamflow records for the larger streams and a number of observations (although short term) on many small streams which were not available to Potter. A plot of the algebraic sign of the residuals for the 50-year peak on a map does not indicate a geographical bias in the method; however, the method predicts values of the 50-year peak discharge which average 12 percent lower (table 2) than the values estimated from the station frequency curves and used as a basis for comparison. This is due largely to the manner in which the skew coefficients for each station were determined.

In the SBS method, Johnson and Tasker computed station frequency curves based on skew coefficients determined from logarithms of the observed annual peaks (station skew). The average station skew for the 52 small drainage area stations was −0.1. In this report the generalized skew coefficients (map skew) given by Hardison (1974) were used. The values of map skew in Massachusetts vary from +0.4 to +0.6 and result in estimates of the 50-year peak discharge at gaging stations which, on the average, are higher than those used by Johnson and Tasker. Hardison (1974, p. 752) states that the use of these map skew coefficients results in more accurate estimates of the 50- and 100-year peak discharges at short-record sites. If the map skew of Hardison rather than the skew values computed from flood records actually allows more reliable estimates of long-term flood-frequency relations, the estimates of 50- or 100-year peak flows at ungaged sites by the SBS method may average about 12 percent low.

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References

Benson, M. A., 1962, Factors influencing the occurrence of floods in a humid region of diverse terrain: U. S. Geol. Survey Water-Supply Paper 1580-B, 64 p.

Green, A. R., 1964, Magnitude and frequency of floods in the United States, part 1-A: U. S. Geol. Survey Water-Supply Paper 1671, 260 p.

Hardison, C. H., 1974, Generalized skew coefficients of annual floods in the United States and their application: Water Resources Research, v. 10, no. 4, p. 745-752.

Hydrology Committee, Water Resources Council, 1967, A uniform technique for determining flood flow frequencies: Washington, D. C., Water Resources Council Bulletin No. 15, 15 p.

Johnson, C. G., and Tasker, G. D., 1974, Progress report on flood magnitude and frequency of Massachusetts streams: U. S. Geol. Survey open-file report 74-131, 41 p.

Kinnison, H. B., and Colby, B. R., 1944, Flood formulas based on drainage basin characteristics: Am. Soc. of Civil Engineers, Proc., vol. 70, no. 3, p. 267-294.

Knox, C. E., and Johnson, C. G., 1965, Flood-frequency formulas for Massachusetts: U. S. Geol. Survey open-file report, 11 p.

Potter, W. D., 1957, Peak rates of runoff in the New England Hill and Lowland area: U.S. Department of Commerce, Washington, D. C.

Tice, R. H., 1968, Magnitude and frequency of floods in the United States, Part 1-B: U.S. Geol. Survey Water-Supply Paper 1672, 585 p.