Ohio: Magnitude and Frequency. Division of Water, Ohio Department of Natural Resources, Columbus, Bull. 45, 1977.
10. G.L. Bodhaine and D.M. Thomas. Magnitude of Frequency of Floods in the United States: Part 12--Pacific Slope Basins of Washington and Upper Columbia River Basin. U.S. Geological Survey, Arlington, VA, Water Supply Paper 1687, 1964, 337 pp.
11. H. Hulsing and N.A. Kallio. Magnitude and Frequency of Floods in the United States: Part 14--Pacific Slope Basins in Oregon and Lower Columbia River Basin. U.S. Geological Survey, Arlington, VA, Water Supply Paper 1689, 1964.
12. H.F. Matthai. Magnitude and Frequency of Floods in the United States: Part 6-B--Missouri River Basin Below Sioux City, Iowa. U.S. Geological Survey, Arlington, VA, Water Supply Paper 1680, 1968.
13. J.L. Patterson and C.R. Gamble. Magnitude and Frequency of Floods in the United States: Part 5--Hudson Bay and Upper Mississippi River Basins. U.S. Geological Survey, Arlington, VA, Water Supply Paper 1678, 1968.
14. P.R. Speer and C.R. Gamble. Magnitude and Frequency of Floods in the United States: Part 3-A--Ohio River Basin Except Cumberland and Tennessee River Basins. U.S. Geological Survey, Arlington, VA, Water Supply Paper 1675, 1965.
15. C.A. Thomas, H.C. Broom, and J.E. Cummans. Magnitude and Frequency of Floods in the United States: Part 13--Snake River Basin. U.S. Geological Survey, Arlington, VA, Water Supply Paper 1688, 1963.
16. C.A. Thomas, W.A. Harenberg, and J.M. Anderson. Magnitude and Frequency of Floods in Small Drainage Basins in Idaho. U.S. Geological Survey, Boise, ID, Water Resources Investigations 7-73, 1973.
17. C.H. Hardison. Estimates of 100-Year Flood Magnitudes at Ungaged Sites. U.S. Geological Survey, Reston, VA, Open File Rept., 1973.
18. J.C. Schaake, Jr., J.C. Geyer, and A.W. Knapp. Experimental Examination of the Rational Method. Journal of Hydraulics Division, Proc., ASCE, Vol. 93, No. HY6, 1967, pp. 353-370.
19. B.M. Reich. Rapid Flood-Peak Determination on Small Watersheds. Trans., American Society of Agricultural Engineers, Vol. 11, No. 2, 1968, pp. 291-295.
20. Computer Program for Project Formulation: Hydrology. Central Technical Unit, Soil Conservation Service, U.S. Department of Agriculture, Tech. Release 20, Supplement 1, 1969.
21. Urban Hydrology for Small Watersheds. Soil Conservation Service, U.S. Department of Agriculture, Tech. Release 55, 1975.
22. HEC-1, Flood Hydrograph Package User's Manual. Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA, 1973.
23. E.J. Kent, R. Burke III, and S.L. Yu. Source Control of Storm Water Through Joint Use of Constructed Storage and Soil Management. Proc., 1981 International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, Univ. of Kentucky, Lexington, 1981, pp. 453-464.

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Abridgment

Magnitude and Frequency of Urban Floods in the United States

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A nationwide study of flood magnitude and frequency in urban areas was made for the purpose of reviewing available literature, compiling an urban flood data base, and developing methods of estimating urban flood-flow characteristics in ungaged areas. The literature review contains synopses of 128 recent publications related to urban flood flow. A data base of 269 gaged basins in 56 cities and 31 states, including Hawaii, contains a wide variety of topographic and climatic characteristics, land use variables, indices of urbanization, and flood-frequency estimates. Regression equations were developed that provided unbiased estimates of urban flood discharges for ungaged sites for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. Of primary importance in these equations is an independent estimate of the equivalent rural discharge for the ungaged basin. The equations essentially adjust the equivalent rural discharge to an urban condition. The primary adjustment factor, or index of urbanization, is the basin development factor. This factor is a measure of the extent of development of the drainage system in the basin and includes evaluations of storm drains (sewers), channel improvements, and curb-and-gutter streets. It offers a simple and effective way of accounting for drainage development and runoff response in urban areas. Other parameters in the equations include size of drainage area, channel slope, rainfall intensity, lake and reservoir storage, impervious area, and basin lag time.

With urban growth and development, there is an ever-increasing need for flood information and estimating techniques for use in areas where little or no data exist. In 1978, the Federal Highway Administration (FHWA) provided funds to the U.S. Geological Survey to make a nationwide study of urban flood frequency. The purposes of the study are to (a) review literature on urban flood studies; (b) compile a nationwide data base of flood-frequency characteristics, topographic and climatic characteristics, land use variables, and indices of urbanization for as many urbanized watersheds as possible; and (c) analyze the data for the purpose of defining estimating techniques that can be used in ungaged urban areas. This paper briefly describes the results of the study. A more detailed description of the study is provided elsewhere (1).

LITERATURE REVIEW

The first phase of the study was to search the available literature and compile a bibliography of reports that describe urban runoff, primarily those reports that relate to the magnitude and frequency of peak discharge. Shortly after the start of this review, it was learned that a similar literature review was being done by the Agricultural Research

Figure 1. Metropolitan areas included in study of nationwide urban flood frequency.

Service (ARS) of the U.S. Department of Agriculture; thereafter, the Geological Survey and ARS worked together and combined their reviews into a joint publication. The published report (2) contains synopses of 128 recent publications for urban flood-flow frequency.

DATA BASE

The second phase of the study was the compilation of a comprehensive data base for drainage basins affected by urbanization. Information obtained from the district offices of the Geological Survey revealed that almost 600 urbanized watersheds with at least three years of runoff data were available nationwide. Sites were selected for this study according to the following criteria:

1. The watersheds had to have at least 15 percent of their drainage area covered with commercial, industrial, or residential development.
2. Reliable flood-frequency data had to be available for the watershed. These could be based on actual peak flow records, if records were available for 10 or more years, or on synthesized data, if such data were based on a rainfall-runoff model specifically calibrated by using actual flood and rainfall data for that basin.
3. The period of actual flood data, or the period of calibration for synthesized data, was a period of relatively constant urbanization. This was the most difficult criterion to meet, and in some cases only part of a long record could be used. As a general guideline, "relatively constant urbanization" was defined as a change in development of less than 50 percent during the period of record.

An appraisal of all available watersheds resulted in a final list of 269 watersheds that met the selection criteria. These watersheds represent a broad spectrum of hydrologic conditions and metropolitan areas, from the East Coast to the West Coast and Hawaii. Watersheds are included for 31 states and 56 cities or metropolitan areas. Figure 1 shows the geographic distribution of the metropolitan areas.

The data compiled for each urban watershed include a comprehensive list of topographic and climatic variables, land use variables, indices of urbanization, and flood-frequency estimates. The data base is not provided in this paper due to space limitations, but a major part of the data base is presented in the report by Sauer, Thomas, Stricker, and Wilson (1).

Several parameters were evaluated for each basin in an attempt to measure the degree to which a basin has been urbanized. Among the parameters evaluated are the percentage of the basin occupied by impervious surfaces, population and population density determined from U.S. Bureau of the Census data for 1970, and the basin response time or lag time.

The most significant index of urbanization was a basin development factor (BDF) that provides a measure of the efficiency of the drainage system. This parameter, which proved to be highly significant in the regression equations, can be easily determined from drainage maps and field inspections of the drainage basin. The basin is first subdivided into thirds and within each third four aspects of the drainage system are evaluated and assigned a code. The four aspects are (a) channel improvements, (b) channel linings, (c) storm drains or sewers, and (d) curb-and-gutter streets. The code is assigned one if the aspect is present in at least 50 percent of that third of the basin and zero if it is present in less than 50 percent. The maximum value of BDF for a fully developed drainage system would be 12. Guidelines for determining the various drainage system codes are described more fully by Sauer, Thomas, Stricker, and Wilson (1).

Two primary sets of flood-frequency estimates, in cubic feet per second, for selected recurrence intervals, were defined for each station. One set represents an estimated flood-frequency relation for

Table 1. Regression equations.

Type	Equation	R^2	Standard Error of Regression: Log Units	Standard Error of Regression: Avg (%)
Seven parameter	$UQ2 = 2.35A^{0.41}SL^{0.17}(RI2+3)^{2.04}(ST+8)^{-0.65}(13-BDF)^{-0.32}IA^{0.15}RQ2^{0.47}$	0.93	0.1630	±38
	$UQ5 = 2.70A^{0.35}SL^{0.16}(RI2+3)^{1.86}(ST+8)^{-0.59}(13-BDF)^{-0.31}IA^{0.11}RQ5^{0.54}$	0.93	0.1584	±37
	$UQ10 = 2.99A^{0.32}SL^{0.15}(RI2+3)^{1.75}(ST+8)^{-0.57}(13-BDF)^{-0.30}IA^{0.09}RQ10^{0.58}$	0.93	0.1618	±38
	$UQ25 = 2.78A^{0.31}SL^{0.15}(RI2+3)^{1.76}(ST+8)^{-0.55}(13-BDF)^{-0.29}IA^{0.07}RQ25^{0.60}$	0.93	0.1705	±40
	$UQ50 = 2.67A^{0.29}SL^{0.15}(RI2+3)^{1.74}(ST+8)^{-0.53}(13-BDF)^{-0.28}IA^{0.06}RQ50^{0.62}$	0.92	0.1774	±42
	$UQ100 = 2.50A^{0.29}SL^{0.15}(RI2+3)^{1.76}(ST+8)^{-0.52}(13-BDF)^{-0.28}IA^{0.06}RQ100^{0.63}$	0.92	0.1860	±44
	$UQ500 = 2.27A^{0.29}SL^{0.16}(RI2+3)^{1.86}(ST+8)^{-0.54}(13-BDF)^{-0.27}IA^{0.05}RQ500^{0.63}$	0.90	0.2071	±49
Three parameter	$UQ2 = 13.2A^{0.21}(13-BDF)^{-0.43}RQ2^{0.73}$	0.91	0.1797	±43
	$UQ5 = 10.6A^{0.17}(13-BDF)^{-0.39}RQ5^{0.78}$	0.92	0.1705	±40
	$UQ10 = 9.51A^{0.16}(13-BDF)^{-0.36}RQ10^{0.79}$	0.92	0.1720	±41
	$UQ25 = 8.68A^{0.15}(13-BDF)^{-0.34}RQ25^{0.80}$	0.92	0.1802	±43
	$UQ50 = 8.04A^{0.15}(13-BDF)^{-0.32}RQ50^{0.81}$	0.91	0.1865	±44
	$UQ100 = 7.70A^{0.15}(13-BDF)^{-0.32}RQ100^{0.82}$	0.91	0.1949	±46
	$UQ500 = 7.47A^{0.16}(13-BDF)^{-0.30}RQ500^{0.82}$	0.89	0.2170	±52

the urbanized basin during a period of constant urbanization, and the other represents the estimated relation for an equivalent rural basin. Flood-frequency data for equivalent rural conditions at each study basin were estimated from the applicable Geological Survey statewide flood-frequency reports. For each station, peak discharge was estimated for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals by using log-Pearson Type III procedures as recommended by the Water Resources Council (3).

ESTIMATING PROCEDURES FOR UNGAGED URBAN SITES

The third phase of the study was to relate urban flood magnitude and frequency to watershed characteristics so that flood magnitude and frequency could be estimated for ungaged watersheds. Many attempts were made to derive a practical, easy-to-use method, most of which involved multiple linear regression of several dependent and independent variables. This paper describes the more significant results. The three sets of estimating equations are referred to as the seven-parameter, three-parameter, and seven-parameter alternative estimating equations.

Seven-Parameter Estimating Equations

Peak discharges for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year urban floods were related to seven independent variables by multiple linear regression techniques as shown by the equations given in Table 1. The significant variables account for the effect of basin size (A), channel slope (SL), basin rainfall (RI2), basin storage (ST), man-made changes to the drainage system (BDF), and impervious surfaces (IA). Regional runoff variations are accounted for in the equations through the use of the equivalent rural peak discharge (RQ). With regard to suitability and accuracy, these equations provide a good method for estimating the effects of urbanization on magnitude and frequency of peak discharge. From the 269 sites available for analysis, 55 were omitted because of known detention storage, 10 were omitted because detention storage effects were uncertain, and 5 were omitted because of missing data. Therefore, the equations are derived by using 199 sites.

The most significant variable in each of the equations is the equivalent rural discharge (RQ), which provides the key for explaining geographic variations of runoff experienced in various parts of the United States. Consequently, the equations can be used in urban areas throughout the United States with no expected geographic bias. As noted earlier, the equivalent rural discharge is estimated by using the applicable Geological Survey statewide flood-frequency report.

The second most significant variable is the basin development factor (BDF). This variable is somewhat subjective but seems very effective in explaining variations of urban peak discharges. BDF is used on a reverse scale (13 - BDF) in the equations because it was found that this greatly improved the linearity of the equation and reduced the standard error.

Contributing drainage area (A) was the third most significant variable in all equations. The high degree of significance of A implies that a given amount of urbanization will affect small basins differently than large basins. The other variables, slope (SL), rainfall intensity (RI2), storage (ST), and impervious area (IA), were all much less significant than RQ, BDF, and A, but overall offered enough improvement to warrant inclusion in the equations. SL is limited to an upper value of 70 ft/mile. For channels with slopes greater than 70 ft/mile, a value of 70 was used. This limitation was found to be effective in reducing the standard error of regression and is logical in that very steep slopes may not cause significant increases in peak discharge.

Three-Parameter Estimating Equations

Dropping the least significant variables from the seven-parameter equations increases the standard error of regression but also greatly reduces the amount of data and effort required for application. The three-parameter equations given in Table 1, which include only the independent variables RQ, BDF, and A, can be used to estimate urban peak discharges for ungaged sites. These equations were based on the same 199 sites used to derive the seven-parameter equations.

Seven-Parameter Alternative Estimating Equations

A third set of estimating equations, the seven-parameter alternative equations, was developed by including lag time (LT) as an independent variable. The alternative equations differ from the seven-parameter equations discussed earlier in that LT replaces storage (ST) as an independent variable. The standard errors of regression for these equations are less than for the seven-parameter equations, but this resulted because only 164 sites were used for calibration. The reduction in standard error was shown to be a function of the number of stations by using the same independent variable as in the seven-parameter equations in computing regression equations for the 164 stations. The shorter-record crest-stage stations with larger time-sampling errors were deleted from the 164 station equations, which probably contributed to the lower standard error.

The seven-parameter alternative equations are more difficult to apply than the equations in Table 1 because the variable LT is not easily determined and requires access to both rainfall and runoff hydrograph data applicable to the basin. The alternative equations have not been reproduced for this paper but are available in the report by Sauer, Thomas, Stricker, and Wilson (1).

Limitations of Significant Variables

The effective or usable range of basin and climatic variables to be used in the estimating equations described in this paper is given below:

Variable	Min	Max
A ($miles^2$)	0.2	100
SL (ft/mile)	3.0	70
RI2 (in)	0.2	2.8
ST (%)	0	11
BDF	0	12
IA (%)	3.0	50
LT (h)	0.2	45

If values outside these ranges are used, the standard error may be considerably higher than for sites where all variables are within the specified range. The maximum value of SL for use in the equations is 70 ft/mile, although numerous watersheds used in this study had SL values up to 500 ft/mile.

Effects of Detention Storage

If temporary in-channel storage, or detention storage, is significant, it will tend to reduce peak discharges. The estimating equations defined by this study were calibrated without including those stations known to be affected by temporary detention storage and therefore represent conditions relatively free of the effects of detention storage. The recommended way to determine the effect of detention storage in a specific watershed is through the use of reservoir and channel routing techniques, which is beyond the scope of this study.

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A copy of the complete data base for the study can be obtained by writing to Chief, Data Management Section, U.S. Geological Survey, Mail Stop 437, National Center, Reston, Virginia 22092.

REFERENCES

1. V.B. Sauer, W.O. Thomas, Jr., V.A. Stricker, and K.V. Wilson. Flood Characteristics of Urban Watersheds in the United States: Techniques for Estimating Magnitude and Frequency of Urban Floods. FHWA, Rept. FHWA-RD-81-178, 1981.
2. W.J. Rawls, V.A. Stricker, and K.V. Wilson. Review and Evaluation of Urban Floodflow Frequency Procedures. U.S. Department of Agriculture, Bibliographies and Literature of Agriculture 9, 1980, 62 pp.
3. Guidelines for Determining Floodflow Frequency. Water Resources Council, Washington, DC, Bull. 17A, 1977.

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Comparison of Prediction Methods for Soil Erosion from Highway Construction Sites

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The disturbance of land by construction is almost invariably accompanied by sudden, sometimes drastic increases in the potential for soil erosion. The amount of sediment eroded and delivered to a stream should be minimized within practical economic limits. Prediction methods for soil erosion from highway construction sites are compared. All but one of the methods, a new rational method, are currently being used to predict soil erosion. The accuracy of the methods varied from 55 to 85 percent based on a mean error analysis. The best predictive method determined from the data analyzed was a new rational method.

The disturbance of land by construction is almost always accompanied by sudden, sometimes drastic increases in soil erosion. Erosion controls should be selected through a process of comparing the costs of controls at each site with the environmental, economic, and other benefits or forgone damages to be obtained in the local region. The first step in such a process, of course, should be the prediction of quantities of material to be eroded.