Estimating Peak Flow Frequencies for Natural Ungaged Watersheds

A Proposed Nationwide Test

U.S. Water Resources Council

Hydrology Committee—1981

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Hydrology Committee - Water Resources Council

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Federal Highway Administration
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Soil Conservation Service
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U.S. Army Corps of Engineers
U.S. Geological Survey
Water and Power Resources Service

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Indiana State Highway Commission
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Pennsylvania Department of Environmental Resources
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Vartan Associates
Western Canada Hydraulic Laboratories, Inc.
Wiley and Wilson

Academic

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Mississippi State University
Pennsylvania State University
University of Hawaii at Mauoa
University of Idaho
University of Maryland

Note: Sixteen individuals not affiliated with any of the groups listed above participated in the pilot test.

SUMMARY

An interagency Work Group of the Hydrology Committee of the Water Resources Council was assigned the task of developing consistent national guidelines for defining peak flow frequencies at ungaged stream locations. The guide was to consist of an agreed-upon set of procedures applicable at locations with watersheds ranging from less than one to several thousand square miles and for which man-made effects are negligible. Procedures were to be selected for evaluation from those currently in use and available from Federal agencies or in the published literature. The selection criteria were: (1) accuracy, how close the frequency estimates made using the procedure are to an acceptable standard; (2) reproducibility, the ability of different people to get the same results using the same procedure; and (3) practicality, a user decision based upon cost effectiveness. Procedures to be evaluated were not restricted to those capable of application by individuals with limited experience; however, they were not to be so complex as to require extensive training and advanced mathematical knowledge to apply.

This report describes and documents the initial phases of this task of developing a national guide including the design of a nationwide test based on the results of a pilot test. The studies conducted by the Work Group and its conclusions are summarized in the following paragraphs.

- A classification scheme was adopted for categorizing procedures based on the assumptions made and methods used for estimating flow frequencies. The adopted scheme consisted of eight categories: (1) statistical estimation of peak flows for a given exceedance probability; (2) statistical estimation of moments; (3) index flood; (4) transfer methods; (5) empirical equations; (6) single storm event; (7) multiple discrete events; and (8) continuous record.

- A literature review of 240 publications was conducted to identify procedures for possible inclusion in the guide and studies that had compared procedure performance. The limited information found on comparison of procedure performance supported the experience of practicing hydrologists that, at a given site, potentially large differences can be expected between flood estimates made using different procedures.

- The practices of Federal agencies, state highway departments, and the private sector were investigated to determine which procedures and categories were used most often. There was no consensus on procedure use although 11 procedures accounted for 85 percent of the applications in the private sector and were among those most often used by the Federal agencies.

- The many differing procedures used in practice and the lack of agreement about their use precluded selecting procedures to include in a national guide without developing objective information about procedure performance.

- o A nationwide test of procedure performance was proposed that would provide an objective and authoritative means to discriminate between procedures based upon the criteria of accuracy, reproducibility, and practicality. The test would involve application of selected procedures by different people to a nationwide sample of sites. The selected sites would cover the range of conditions encountered in practice. Each site would have a stream gage with sufficient record to provide a basis for evaluating accuracy. At each site, sufficient estimates by different people would be made to evaluate reproducibility.

- o As the scale of such a test presented problems of experimental design, quality control, and management, a pilot test was designed and conducted to aid in the design of and provide guidance for performing a nationwide test. The pilot test consisted of five independent estimates of peak flow frequency (1-, 10-, and 50-percent-chance floods) at 70 sites (42 in the Midwest and 28 in the Northwest) using up to 10 different procedures. The procedures tested are listed in Table V-1. About 200 persons participated in the test making about 1800 procedure applications. Test sites were restricted to those watersheds with negligible man-made effects and where a gaged streamflow record of 20 or more years existed.

- o The pilot test results confirmed that it is possible to detect differences in procedure performance and that from a nationwide test it would be possible to objectively select procedures to include in a guide based upon the criteria of accuracy, reproducibility, and practicality. The pilot test results provide the information on experimental processes necessary to design and carry out a nationwide test. Conclusions about procedure performance derived from the pilot test can not be used for national guidelines because: (1) The test was limited to two regions; (2) a large percentage of the testing was done by persons unfamiliar with the procedures or the hydrology of the regions tested; (3) the test was limited to ten procedures in four categories, of which only nine procedures were viable; and (4) all procedure applications were made assuming no site flood data were available. The testers' lack of experience with procedures or knowledge of field conditions was considered most limiting for procedures whose parameters are generally determined from field experience and visits. Denying the use of site data for calibration of those watershed modeling procedures which are seldom used in an uncalibrated mode adversely affected the results of those applications and prevented drawing conclusions on their performance.

- o Three levels of nationwide testing are proposed (ranging from testing costs of $5.5 to $11.6 million) that would permit discrimination between procedures at different levels of hydrologic and statistical significance. The proposed testing is further subdivided into a series of small subunits, each designed to answer specific questions. These subunits include: (1) nationwide evaluation of the procedures in Categories 1 through 5 and simple Category 6 procedures including the effect of user experience and knowledge of the site; (2) evaluation of the complex procedures of Category 6 when calibrated to regional or site flood data; (3) evaluation of the procedures of Category 7 or 8; and (4) evaluation of procedures for and benefits from incorporating site historic flood information and/or short site gage records into the procedures of Categories 1 through 5 and the simple Category 6 procedures.

- The benefits from the guide to be developed from the testing program would exceed the test costs. The Federal Government alone spends an estimated $10 million annually on flood-frequency estimates. These estimates are used to design structures and make land-use decisions involving billions of dollars. Because the guide would permit more consistent hydrologic analyses needed for national programs, it will: (1) enhance the opportunity for equitable treatment of individuals affected by Federal, state, and local land-use management programs; (2) simplify coordination between regulatory agencies; (3) reduce the time and effort to make hydrologic estimates; and (4) focus research needs on those areas required to improve the accuracy and reproducibility of peak flow frequency estimates.

I. INTRODUCTION

Each year estimates of flood flow frequencies are made at thousands of locations where flood records are limited or nonexistent. Estimates are needed for a variety of purposes including: (1) land-use planning; (2) site selection for homes and commercial and industrial structures; (3) design of highway, farm, and other drainage structures; and (4) design of flood protection measures, both structural and non-structural. Accuracy requirements differ with purpose. A variety of procedures is currently being used by Federal and state agencies and by private consultants, sometimes at the same location. This leads to different estimates, unequal treatment in application of Federal programs, and needless conflict and confusion. Thus, there is an acute need for an accurate, practical, and consistent approach to such estimates.

This need was recognized in House Document 465, 89th Congress, Second Session, August 1966, which recommended that the Water Resources Council establish a panel to "present a set of techniques for frequency analysis based upon the best known hydrological and statistical procedures." In response, the Water Resources Council has issued four publications, the most recent being Bulletin 17 and the June 1977 revision, Bulletin 17A, "Guidelines for Determining Flood Flow Frequency," which address the problem of consistent flood-frequency estimates where systematic stream gaging records are of sufficient length to warrant statistical analysis. This report was the first step in developing the necessary guidelines for determining flow frequencies at ungaged sites.

The present task, as defined by the Hydrology Committee of the Water Resources Council, is to develop agreed-upon sets of procedures for determining peak flow frequencies for ungaged watersheds or gaged watersheds where systematic records are of insufficient length (generally less than 10 years) to warrant statistical analysis. Procedures are to be applicable to streams where there is negligible effect on peak flow from man-made changes. The procedures are to be selected from those currently in use, available from Federal agencies, or in the published literature. A set of procedures is to be selected that is applicable to different parts of the country and to drainage areas ranging in size from less than 1 square mile to several thousand square miles. Three criteria are to be used in the selection process--accuracy (how close results are to an acceptable standard), reproducibility (the ability of different people to get the same results using the same procedure), and practicality (a user decision based upon cost effectiveness). Procedures selected are not restricted to those capable of field computation by individuals with limited experience and education. They should not, however, be so complex as to require extensive training and advanced mathematical knowledge to apply. The Hydrology Committee assigned this task to a Work Group consisting of representatives of Federal agencies with flood-related programs.

Based upon Work Group studies and experience it is not possible, in this report, to recommend agreed-upon sets of procedures. More comprehensive nationwide testing is needed before certain procedures can be recommended for use. This report does describe the results of a pilot test of procedure performance and recommends a nationwide test that is needed to develop guidelines for selecting procedures. It is hoped this report will be reviewed by Federal and state agencies, private consultants, and universities so that future studies may benefit from the experience and judgments of a broad cross section of professional hydrologists. The report, in addition to describing the pilot test results, provides information about the test experience to guide others who might undertake such a study.

The report outlines:

1. The classification scheme adopted to sort the many flow frequency estimating procedures into similar categories.

2. A review of current knowledge about different procedures including: (a) the results of the literature search to identify procedures and to learn of previous testing to discriminate between procedures and (b) the extent of procedure use in practice.

3. The need for nationwide comparative field testing of procedures to objectively and credibly evaluate their performance and the need for a pilot test to evaluate test concepts.

4. The design and implementation of a pilot test of ten procedures at 70 sites in the Midwest and Northwest regions of the United States.

5. The results of the pilot test and recommendations for a nationwide test.

II. CLASSIFICATION OF PROCEDURES

A. Classification System

In order to select procedures from among the many that are currently used to define peak flow frequencies, it is useful to first establish a classification scheme for categorizing procedures having common characteristics. By grouping similar procedures, it may be possible to draw inferences from the testing about all procedures in a category. The categories in the classification scheme should be different by at least one significant element. Procedures assigned to a category should be similar in important characteristics, and differences in these characteristics should be apparent when comparing procedures assigned to different categories.

The Work Group considered several methods of classifying flood flow frequency procedures. The classification system finally adopted has eight categories, each of which differs in the assumptions and processes used to obtain flow-frequency estimates.

Table II-1 lists the eight categories and summarizes, for each, the primary product from the procedure for meeting the Work Group objectives and other useful products. For the most part, procedures are easily identified as belonging to one of the eight categories. Procedures that could be placed in more than one category were classified in the category most representative.

B. Description of Categories

The eight categories and a brief summary of their assumptions and limitations are:

1. Statistical Estimation of Peak Flow for a Given Exceedance Probability

   Equations are developed by regression analysis for direct estimation of peak flows using watershed and/or climatic characteristics and peak flow frequency values from station data.

   The major assumptions are: (a) The independent variables represent fixed values and hence do not have probability distributions; (b) the residuals from the regression equation are normally distributed; (c) the variance about the regression equation is constant throughout the range of independent variables; and (d) the values of the dependent variable are mutually independent.

   The advantages of these procedures are: (a) The standard error of the estimating equation is known for the gaged areas used in its development; (b) the estimates are valid for basins which are hydrologically similar to those used in the derivation; (c) the procedures are usually quick and easy to use; and (d) the procedures permit direct calculation of peak flow frequency values.

Table II-1
CATEGORIES OF PROCEDURES

Category	Products: Primary[1]	Products: Other[2]
1. Statistical estimation of Q_p Q_p = f (basin characteristics B, channel geometry G, climatic characteristic C)	Q_p	
2. Statistical estimation of moments Q_p = f (moments) moments = f(B,G,C,)	Frequency curve	
3. Index flood estimation Q_p = f (ratio Q_i) Q_i = f(B,G,C)	Q_p	
4. Estimation by transfer of Q_p	Q_p	
5. Empirical equations	Q_p	
6. Single storm event: rainfall frequency α runoff frequency	Q_p	Hydrograph possible
7. Multiple discrete events	Frequency curve	Flood hydrograph
8. Continuous record	Frequency curve	Continuous hydrograph

1. The major output from the procedure for meeting the objectives of the Work Group.

2. Other products useful in certain applications such as reservoir design.

Note: Q_p = peak discharge for a given exceedance probability.

Q_i = peak discharge from an index flood relationship.

The limitations of these procedures are: (a) The prediction equations are valid only for conditions used in their derivation and (b) the prediction equations cannot realistically be applied beyond the range of basin and climatic characteristics used in their development; at times, data are not available to sample from the complete range of variables in the regions.

2. Statistical Estimation of Moments

The moments (mean, standard deviation, and skew) of a probability distribution of peak flows are related to watershed and/or climatic characteristics using either graphical or statistical methods.

Many of the assumptions, advantages, and limitations are the same as for Category 1 procedures. The only difference is the ability of Category 2 procedures to develop a frequency curve from the three moments. This ensures consistent results for the various exceedance probabilities when estimating flood peaks for a given watershed. However, there is no direct evaluation of the standard error of estimate for the Category 2 procedures.

3. Index Flood

This is a special case of Category 2 using an index flood equation and a set of index ratios. The index flood equation relates peak discharge for a selected exceedance probability to watershed and/or climatic characteristics. Peak discharge estimates for other exceedance probabilities are estimated by multiplying by the appropriate index ratios.

Because procedures in this category are based upon regression analysis, the assumptions, advantages, and limitations of regression techniques are applicable. One additional assumption is that the variation in the slope and shape of the discharge frequency curve at individual stations is small within the selected region. Thus, an average frequency curve slope is used for a given region. As with Category 2 procedures, no direct evaluation of the standard error of estimate is made.

4. Transfer Methods

These methods involve either an extrapolation of peak flow values upstream or downstream or interpolation between stream gages for which frequency curves have been determined. Flood peak discharge may also be estimated by cross correlation of gage data from a nearby stream with similar basin characteristics.

The major assumption is that the watershed to which the data are being transferred is similar to the watershed from which data are available. The advantage of these procedures is that they normally require a minimum amount of work, although determining the correct factor of proportionality for transfer may be more difficult than commonly acknowledged. When interpolating between two gages on the same stream with markedly different drainage areas, the interpolation must recognize these differences. If the transfer is not along the same river reach, the selected gage location must have similar hydrologic characteristics, including watershed size, as the ungaged location. The procedures are limited to those locations where gage records are available in the immediate vicinity.

5. Empirical Equations

Category 5 is a catchall category which includes the many flood formulas developed without using regression or unit hydrograph techniques. The rational formula is the classic example and the one most used in current practice.

Empirical equations normally provide a simple means to estimate flood discharges for small areas. The rational formula continues to be widely used because its application is simple and easily understood. The formula takes advantage of the fact that one acre-inch per hour of runoff nearly equals one cubic foot per second and assumes that for rainfall exceeding the time of concentration, the rate of runoff equals the rate of rainfall reduced by an appropriate factor. When computing a discharge of selected frequency, the discharge frequency is assumed equal to the rain frequency.

The advantage of the rational formula is the ease of application. The limitations are the simplified assumptions of the rainfall-runoff process, the coefficient is generally selected by judgment, and the assumption that the flood frequency equals the rainfall frequency used in the computation.

6. Single Storm Event

This method uses a storm of specified frequency and time and areal distribution and a unit hydrograph model (either with or without calibration to the watershed) to compute a flood hydrograph. The computed peak discharge frequency is assumed equal to the rain frequency used in the computation. In some applications, storm adjustments are made so that the estimated peak discharge of a given frequency matches that for a gaged location within the watershed.

In application there are two basic approaches: (1) a systematized application for rapid calculations for small watersheds such as the procedures developed by the Soil Conservation Service (SCS) and described in TR-55 and

(2) a complete evaluation of each segment of the physical process (a more complex watershed model) which is usually calibrated to watershed or regional data when available and study needs warrant the effort. Three elements are inherent in both approaches to making flood estimates: (1) the storm; (2) a process to convert rainfall to precipitation excess or runoff; and (3) a process to convert runoff to a flood hydrograph.

There are various processes for estimating precipitation excess including simple antecedent precipitation index relations and complex conceptual models. Processes for developing flood hydrographs are usually based upon unit hydrographs or a combination of unit hydrographs and flood routing.

The major assumption of these procedures is that through a conversion of rainfall to a flood hydrograph the resulting peak flow frequency is equal or proportional to the storm frequency used in the computation.

The primary advantages of these procedures include: (1) the capability to generate entire flood hydrographs; (2) the ability to evaluate the effects of changes in watershed conditions or structures upon flood flows; (3) the ability to account for unusual natural storage and stream network conditions; and (4) the ability to calibrate the procedure to a particular watershed when appropriate site and/or regional data are available.

The limitations include: (1) The models must be developed based upon regional experience if adequate flood records are not available; (2) the assumption that the rain frequency used in the computation is equal or proportional to the flood frequency; and (3) the effort required to apply the procedure because of the evaluation of the elements of the physical processes.

7. Multiple Discrete Events

In this category, watershed models are used to estimate one or more peak flows for each year from the largest recorded precipitation events. A frequency curve is determined from the computed maximum annual flood peaks.

There are many different models for estimating flood flows from specific storm events. Each involves assumptions about how best to convert rainfall to precipitation excess and precipitation excess to a flood hydrograph. Because the process requires the use of precipitation records obtained over a long period of time, there must be adequate precipitation data available within or near the basin. Synthetic precipitation is sometimes generated which has the same statistical characteristics as the precipitation regime over the basin.

The advantages of this category of procedures include: (1) the ability to calibrate the watershed model to a particular watershed when flood records are available; (2) the ability to generate a flood series from observed storm rainfall rather than assume the computed flood peak has the same frequency as the storm adopted to compute the flood peak; and (3) the ability to evaluate the effect of watershed changes or projects upon flood flows.

The limitations include: (1) The watershed model must be based upon regional experience if adequate flood records are not available; (2) the number of events which must be analyzed for each year to assure selection of the maximum annual flood peak; (3) the need for a long representative record of watershed precipitation; and (4) the effort required to obtain a flood-frequency estimate.

8. Continuous Record

In this category, watershed models are used to develop a continuous flow hydrograph from a continuous record of precipitation and other climatic factors. The precipitation can be either observed or simulated. The procedures are usually based upon detailed calibration of a watershed model to the basin. A frequency curve is determined from the predicted maximum annual flood peaks.

The same assumptions, advantages, and limitations cited for Category 7 are applicable. The major difference is that continuous soil moisture accounting can be used to estimate precipitation excess. This requires a long term daily record of precipitation and evaporation which requires considerable computational effort.

III. REVIEW OF CURRENT KNOWLEDGE

A. Literature Review

A literature search was made to identify potential procedures for testing and their characteristics, and comparative studies of procedure performance (McCuen et al., 1977). Computer data bases searched were those included in the Water Resources Scientific Information Center (WRSIC), National Technical Information Service (NTIS), and the Science and Education Administration Current Awareness Literature Search. Announcements soliciting published or unpublished articles were placed in publications of the following professional societies: American Society of Civil Engineers, American Water Resources Association, American Society of Agricultural Engineers, and American Geophysical Union. Individual requests were made to the Water Resources Centers and state water agencies.

Because of personnel and time limitations, some publications submitted for review were not evaluated. Some publications were judged not applicable and others were very similar to publications that had been evaluated. For example, the U.S. Geological Survey (USGS) has independent peak flow estimation equations for each state. Only a few of these publications were evaluated because they are often similar in both development technique and results, even though they may differ in the size and accuracy of the data base.

A total of 240 different publications was reviewed by this literature search.

Numerous publications described the use of more than one procedure. Some of these publications also provided a comparison of the results achieved using the different procedures. Publications that include a comparison of procedures are given in Table III-1. It was found that the comparisons were all limited in some respect. For example, some publications involved data obtained for a very limited region while others used only a limited amount of data. In some cases the procedures were not compared as to their ability to predict peak discharge. Thus, it is impossible to provide conclusive statements about the accuracy, reproducibility, and practicality of either specific procedures or general categories of procedures based upon information obtained from published studies.

Three important conclusions of this literature evaluation are: (1) There is a noticeable lack of consistency in the structure and presentation of results of peak flow frequency studies; (2) the literature does not accurately reflect what methods are currently being used in hydrologic planning and design; and (3) the literature does not provide the information about procedure accuracy, reproducibility, and effort to apply (including computer requirements) that is necessary for

Table III-1

LIST OF PUBLICATIONS COMPARING PROCEDURES

Allison, S. V. 1967. Review of small basin runoff prediction methods. American Society of Civil Engineers Proceedings, Journal of the Irrigation and Drainage Division 93(IR1):1-6.

Benson, M. A. 1962. Evolution of methods for evaluating the occurrence of floods. U.S. Geological Survey Water Supply Paper 1580-A, 30 pp. Washington, D.C.

Betson, R. P., R. L. Tucker, and R. M. Haller. 1969. Using analytical methods to develop a surface runoff model. Water Resources Research 5(1):103-111.

Bowers, C. E., A. F. Pabst, and S. P. Larson. 1972. Computer programs in hydrology. Water Resources Research Center Bulletin No. 44, 172 pp. University of Minnesota, Minneapolis.

Chow, V. T. 1962. Hydrologic determination of waterway areas for the design of drainage structures in small drainage basins. University of Illinois Engineering Experiment Station Bulletin No. 462, 104 pp. Urbana, Ill.

Cordery, I., and D. H. Pilgrim. 1970. Design hydrograph methods of flood estimation for small rural catchments. Paper No. 2832. Civil Engineering Transactions, 1974. The Institution of Engineers, Australia.

Cruff, R. W., and S. E. Rantz. 1965. A comparison of methods used in flood-frequency studies for coastal basins in California. U.S. Geological Survey Water Supply Paper 1580-E, 56 pp. Washington, D.C.

Fleming, G., and D. D. Franz. 1971. Flood frequency estimating techniques for small watersheds. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 97(HY9)1441-1460.

Fletcher, J. E., A. L. Huber, F. W. Haws, and C. G. Clyde. 1976. Runoff estimates for small rural watersheds and development of sound design method. Research Report and Manual, 2 volumes. Utah Water Research Laboratory, Utah State University, Logan.

Lara, O. G. 1974. Floods in Iowa: A comparative study of regional flood frequency methods. Iowa Natural Resources Council Bulletin No. 12, 63 pp. Iowa City.

Pickens, J. B. 1977. Applicability of selected runoff formulas to Stark County, Ohio, watersheds. M.S. thesis, 207 pp. Ohio State University, Columbus.

Rantz, S. E. 1971. Suggested criteria for hydrologic design of storm-drainage facilities in the San Francisco Bay Region, California. U.S. Geological Survey, unpublished open-file report, 69 pp. Menlo Park, Calif.

Reich, B. M. 1960. Annotated bibliography and comments on the estimation of flood peaks from small watersheds. Technical Report CER60BMR52, 66 pp. Civil Engineering Department, Colorado State University, Fort Collins.

Reich, B. M., and D. R. Jackson. 1971. Flood prediction methods for Pennsylvania highway crossings. 192 pp. Civil Engineering Department, Pennsylvania State University, University Park.

Woo, D. C. 1974. Flood peak estimates from small rural watersheds. Public Roads 38(3):117-119.

World Meteorological Organization. 1975. Intercomparison of conceptual models used in operational hydrological forecasting. Operational Hydrology Report No. 7, 172 pp. Secretariat of the World Meteorological Organization, Geneva.

potential users to select a procedure from among the many that are in the literature.

B. Procedure Use

A review of practices by Federal agencies, state highway departments, and the private sector was made to determine the frequency of use of both individual procedures and categories of procedures and the nature of the projects for which they are used. Although based on small and informal sampling, the results are believed representative and are shown in Tables III-2 and III-3.

Table III-2 indicates the percentage of projects undertaken by the Federal, state, and private sectors in which the various categories of procedures were used. The percentages are for procedures used to provide estimates for modest to important projects. Categories 1, 5, and 6 procedures are used most frequently by Federal agencies. Category 7 procedures are used almost exclusively by the U.S. Geological Survey (USGS) to enhance short records for small watersheds in developing Category 1 procedures. Category 1 procedures are replacing Category 3 procedures.

Data for Federal agencies have been limited to reflect larger projects such as major bridges, dams, and flood protection works. Many of these projects require the development of a design hydrograph; thus, procedures providing only peak discharge are not entirely adequate. In addition, the value of these projects and the consequences of overdesign or underdesign warrant the use of procedures with greater apparent accuracy and greater resource requirements. If all projects, including the many small drainage and conservation structures designed by the Soil Conservation Service (SCS), were included in the summary, Category 6 procedures would account for 93 percent of the total applications, Category 1 would account for 3.5 percent, and Category 5 would account for 2.5 percent.

Data for the state highway departments represent primarily highway drainage and bridge design projects. Empirical equations (Category 5) continue to dominate usage for small watersheds, accounting for approximately 38 percent of all applications. Category 1 and 4 procedures account for most of the remaining applications, with 38 and 19 percent, respectively, primarily on larger watersheds that are more likely to be gaged.

An earlier survey of procedures used by state highway departments was conducted by Morris (1970) in 1970-71. Although the data from that survey are not directly comparable to Table III-2, there was apparently much greater use of empirical equations and transfer methods at that time. The current trend in state highway engineering is toward increased use of Category 1 procedures.

Table III-2

FREQUENCY OF USE OF PROCEDURE CATEGORIES
(in percent)

	Procedure Categories	Federal* Agencies	State Highway	Private Sector
1.	Statistical Estimation of Q_p	48	38	34
2.	Statistical Estimation by Moments	1	0	4
3.	Index Flood Method	1	4	3
4.	Transfer Method	1	19	7
5.	Empirical Equations	24	38	17
6.	Single Storm	24	1	34
7.	Multiple Discrete Events	1	0	0
8.	Continuous Record	0	0	1

*Based on small samples, modest to important projects

Table III-3

FREQUENCY OF USE OF PROCEDURES BY THE PRIVATE SECTOR
(in percent)

	Procedure	Category		Frequency of Use
1.	USGS State Equations	Statistical Estimation of Q_p	(1)	27.3
2.	Rational Formula	Empirical Equations	(5)	16.1
3.	SCS NEH-4	Single Storm Event	(6)	7.0
4.	Transfer of Q_p	Transfer of Q_p	(4)	6.9
5.	SCS TR-55	Single Storm Event	(6)	6.6
6.	SCS TR-20	Single Storm Event	(6)	5.9
7.	COE HEC-1	Single Storm Event	(6)	5.3
8.	COE Log Pearson III Basin Studies	Statistical Estimation of Moments	(2)	3.3
9.	BPR Potter	Statistical Estimation of Q_p	(1)	2.9
10.	Snyder Unit Hydrograph	Single Storm Event	(6)	2.3
11.	USGS Water Supply Papers	Index Flood	(3)	1.5
*12.	Other Unit Hydrograph	Single Storm Event	(6)	7.3
*13.	Other Regression	Statistical Estimation	(1&2)	4.8
*14.	Other Empirical	Empirical Equations	(5)	1.0
*15.	Other Index Flood	Index Flood	(3)	1.0
*16.	Continuous Simulation	Continuous Simulation	(8)	0.8
	Total			100.0

*Cumulative percentages for all other procedures in the category. Individual procedures accounting for less than 1.0 percent of total applications were not itemized.

Data for the private sector represent a broad range of activities including urban drainage and stormwater management, floodplain management, siting studies, highway drainage, and the design of numerous hydraulic structures. Because many Federal and state highway projects are subcontracted in part to the private sector, there is some overlap in the data presented for the three groups in Table III-2. Therefore, the data presented for the private sector probably provide a better overall representation of the frequency of use of the various procedures.

Category 1 and 6 procedures account for approximately 68 percent of the total applications made by the private sector, with approximately equal use of the two categories. Category 1 appears to be the preferred method for projects where only peak flow is needed and where an applicable procedure has been developed. Category 1 procedures require minimal resources to apply, which contribute greatly to their use. Category 6 procedures are preferred where the development of the entire hydrograph is necessary for flood routing and other purposes. Also, many of the Category 6 procedures can be adapted or calibrated for a wide variety of watershed conditions, which may improve accuracy.

Category 5 empirical equations account for 17 percent of the total applications by the private sector and are used primarily for minor drainage projects on small watersheds. Category 7 procedures were not used by any of the private sector organizations contacted. Presumably, this is because of the large resource requirements and the lack of readily available procedures designed for this purpose. Category 8 procedures are beginning to be used for flood flow frequency determinations. Their relatively large resource requirements have presently limited their use to projects such as planning major urban drainage and stormwater management programs where many alternatives in land use and drainage design are to be investigated.

Table III-3 lists the individual procedures used by the private sector. Although there are a large number of procedures available for use, 11 procedures account for approximately 85 percent of all applications made by the private sector. Only procedures which account for more than 0.8 percent of all applications are identified in the table.

The USGS State Equations collectively are applied most frequently and are used by the private sector for approximately 27 percent of all flood flow frequency estimates at ungaged sites. Several characteristics have contributed to their widespread use including minimal resources for application, availability, currency, coverage, regional specificity, and estimated error limits.

The group of procedures developed by SCS collectively accounts for 20 percent of all applications made by the private sector. Although the underlying concepts are the same for all SCS methods, the individual procedures provide for a tremendous range of applicability over hydrologic regions, watershed sizes, and land-use conditions. The complete hydrograph can also be synthesized using most of the SCS procedures. The widespread applicability and availability of these procedures contribute largely to their frequent use. Of particular interest is the rather rapid acceptance of Technical Release 55 (TR-55) which was published in 1975 and presently provides for approximately 7 percent of all applications.

The rational formula continues to receive widespread use, accounting for approximately 16 percent of all applications made by the private sector, despite evidence indicating its questionable accuracy (Schaake et al., 1967). The use of this procedure remains widespread primarily because of the minimal resources required to apply it and the very large number of estimates which must be made on very small watersheds. In addition, the costs of overdesign or underdesign are usually small enough that a high degree of accuracy is not warranted in these situations.

In summary, use is determined by the availability and applicability of a procedure and its ability to meet the data and accuracy needs of the project within the resource constraints. At the present time, procedures based on statistical estimation of peak flows (Category 1), single storm events (Category 6), and empirical equations (Category 5) account for 85 percent or more of all estimates of flood flow frequency at ungaged sites.

IV. TESTING NEEDS AND CONCEPT

This section summarizes the findings regarding the need for a nationwide testing of procedures, the test concept, and its objectives.

A. Nationwide Test Need

There are wide differences of opinion among hydrologists and Work Group members on how to best define flood flow frequencies at ungaged sites. This is evidenced by: (1) the large number of different procedures that have been developed and (2) the fact that eight categories of procedures were identified. A review of procedures used in practice shows no consensus, although those in Categories 1, 4, 5, and 6 are used most often.

In spite of the evident need, no comprehensive, authoritative nationwide test to evaluate the effectiveness of different procedures has been made. The limited testing that has been conducted demonstrates clearly what practicing hydrologists have encountered--there are potentially large differences among flood peak frequency estimates made at the same site using different procedures. This condition demonstrates the need for a comprehensive testing of procedures to form the basis for selecting procedures.

One reason for the lack of agreement on a single procedure for estimating peak flows is the variety of needs and hydrologic and climatic conditions under which estimates must be made. Thus, no one procedure may meet all needs or be applicable under all conditions encountered. A nationwide testing and evaluation of procedures must recognize the following needs and conditions: (1) the accuracy requirements of a project; (2) the required hydrologic output (i.e., peak discharge only or an entire flood hydrograph); (3) the availability of data including precipitation, soils, land use, gaged runoff, and historic data; and (4) the resources required to make an estimate.

In addition to obtaining different flow-frequency estimates using different procedures, application of the same procedures at the same site by different hydrologists can result in widely different estimates. Thus, the reproducibility of a procedure, the ability of different people to get the same answer using the same procedure at a site, is also a factor in evaluating procedures in a nationwide test.

B. Nationwide Test Concept

The Work Group task was to develop an agreed-upon set of procedures to determine peak flow frequencies for ungaged watersheds. The task did not involve generation of new procedures but rather selection from among those in use or in the literature. This required an objective, authoritative means to discriminate between procedures based on the criteria of accuracy, reproducibility, and practicality.

A nationwide test was proposed that would involve application of selected procedures by different people to a nationwide sample of sites. These selected sites would cover the range of conditions and watershed sizes encountered in practice. Each site would have a gage record of at least 20 years to establish a base frequency curve for use in evaluating accuracy. At each site, sufficient estimates by different people using the same procedure would be made to evaluate reproducibility. Sufficient information would be obtained from each tester to define his skill and experience levels and to determine the resources used to develop the estimates to evaluate practicality.

It was anticipated that practicing hydrologists from a wide range of Federal and state agencies, consulting firms, and educational institutions would do the testing. This hands-on experience and participation in guide development would enhance the understanding and acceptance of the recommended nationwide guide.

C. Pilot Test Objectives

The scale of such a nationwide test posed significant problems of experimental design, quality control of data collection, and logistics. A pilot test was developed and conducted by the Work Group to determine if statistical methods could be used to discriminate between procedures and to develop the information necessary to design a cost-effective nationwide testing program. The pilot test had three primary objectives:

1. To determine how to conduct the nationwide test from the data collection and management standpoint. Information was needed about: (1) the record sheet design to assure objective testing; (2) the kinds of information to provide to the tester; (3) the errors that can be expected and their effects on results; (4) the necessary steps to reduce mathematical and data handling errors; and (5) the manpower requirements and management procedures for conducting the test.

2. To determine appropriate methods, statistical and otherwise, for analyses of the nationwide test data and to develop necessary techniques and computer programs for the analyses.

3. To provide a basis for the design of a nationwide test regarding: (a) sample sizes (number of watersheds and replicates); (b) regional versus national testing; (c) procedures to test; (d) magnitudes of differences between procedures that can be detected; (e) tester selection; and (f) unanticipated questions.

V. PILOT TEST DESIGN

The pilot test consisted of the application of selected procedures at selected sites by different people. The sites selected had stream gage records of sufficient length to evaluate procedure performance. This section describes the structure of the pilot test, the criteria selected to compare procedures, and the statistical methods used to analyze the data. Results and conclusions of the analyses are provided in section VIII.

A. Test Structure

1. Procedure Selection

An initial screening of the procedures found in the literature search was made to identify procedures that: (1) are least restrictive in application by geographic, physiographic, and climatic conditions; (2) estimate the 50-, 10-, and 1-percent-chance peak flows; (3) are readily available and currently used; and (4) are frequently used. This screening reduced the numerous procedures identified in the literature review to approximately 36. The limited resources for the pilot test dictated eliminating procedures in Categories 7 and 8 because of the extensive resources required for testing. Restricting the pilot study to the Midwest and Northwest regions of the United States further reduced the number of procedures. Procedures applicable to these regions were selected to provide a representative sample of procedures with as much potential variation as available resources would permit.

The procedures chosen for testing are listed in Table V-1 by category and numbered as identified for use in the statistical analyses in section VIII. They include procedures in Categories 1, 3, 5, and 6 with more than one procedure in all but Category 3 to test variability within categories. A brief description of the procedures that were tested is given in Appendix 1. These are not the descriptions provided to the testers.

2. Site Selection

Site selection was limited to the Midwest and Northwest regions of the United States and to locations with stream gage records of 20 or more years in length to evaluate procedure performance. In balancing resource constraints and sample size, it was reasoned that a larger sample in two regions would provide more information for the design of a nationwide test than a smaller sample in more regions. It was anticipated that the effectiveness of different categories of procedures might vary between regions with different climate, physiography, and data availability. The Midwest and Northwest regions were selected as

Table V-1

PROCEDURES SELECTED FOR TESTING

Number	Procedure		Reference
	Statistical Estimation of Q_p (Category 1)		
2	Fletcher Procedure		Fletcher et al., 1976
4	U.S. Army Corps of Engineers Snowmelt		U.S. Army Corps of Engineers, 1962
1	U.S. Geological Survey State Equations	Washington	Cummans, J. E., Collins, M. R., and Nassar, E. G., 1975
		Illinois	Curtis, G. W., 1977
		Indiana	Davis, L. G., 1974
		Missouri	Hauth, L. D., 1974
		Montana	Johnson, M. V., and Omang, R. J., 1976
		Ohio	Webber, E. E. and Bartlett, W. P., Jr., 1977
	Index Flood Estimation (Category 3)		
5	U.S. Geological Survey Index Flood Method	USGS Region 12	Bodhaine, C. L. and Thomas, D. M., 1964*
		USGS Region 14	Hulsing, H. and Kallio, N. A., 1964*
		USGS Region 6-B	Matthai, H. F., 1968*
		USGS Region 5	Patterson, J. L. and Gamble, C. P., 1968*
		USGS Region 3-A	Speer, P. R. Gamble, C. R., 1965*

Table V-1 (Continued)

PROCEDURES SELECTED FOR TESTING

Number	Procedure	Reference
	USGS Region 13	Thomas, C. A., Broom, H. C., and Cummans, J. E., 1963*
	Idaho	Thomas, C. A., Harenberg, W. A., and Anderson, J. M., 1973*
	Empirical Equations (Category 5)	
6	Rational Formula	Schakke, J. C., Jr., Geyer, J. C., and Knapp, J. W., 1967
3	Reich Procedure	Reich, B. M., 1968
	Single Storm Event: Rain Frequency Proportional to Runoff Frequency (Category 6)	
9	Soil Conservation Service, Technical Release No. 20	Soil Conservation Service, 1969
7	Soil Conservation Service, Technical Release No. 55 - Charts, Appendix D	Soil Conservation Service, 1975
8	Soil Conservation Service, Technical Release No. 55 - Graphical, Chapter 5	Soil Conservation Service, 1975
10	U.S. Army Corps of Engineers HEC-1	U.S. Army Corps of Engineers, 1973

*Open-File Report by Hardison (1973) was used in conjunction with these reports to obtain the 1-percent-chance flood representing the differences in watershed conditions, data availability, and procedure response to be expected within regions throughout the Nation. The criteria used for site selection are given in Table V-2.

Test sites were selected from a list of USGS gaging stations virtually unaffected by man with 20 or more years of record to provide a geographical distribution within each region for each of five size categories (less than 3, 3 to 10, 10 to 50, 50 to 100, and greater than 100 square miles) with emphasis on the longer records. Size categories were chosen to conform with procedure size applicability. Table V-3 is a summary of the number of sites selected by region and state. Table V-4 lists the sites used in the pilot test by region and drainage area categories.

The principal source of gage information was the USGS Peak Flow File (Lepkin and DeLapp, 1979). Additional gage information was provided by the U.S. Department of Agriculture (Science and Education Administration-Agricultural Research (SEA-AR) and Forest Service) but was not used due to the limited time to make the data compatible with the USGS data files. Supplementary data on the location of rainfall gages near selected stream gages was furnished by the National Weather Service (NWS).

The most difficult of the criteria to evaluate was the time stationarity of the stream gage record. Information provided by the USGS regarding man-made effects was supplemented, wherever possible, by local agency hydrologists. This screening resulted in deleting a number of sites from the original list.

The annual flood peak record lengths at the 70 stream gage sites selected for the pilot test are displayed by groups in Figure V-1. The graph shows the distribution by regions of the systematic record lengths in years. The systematic record is the annual peak flow data observed systematically at a stream gage. Thirty-seven (54 percent) of the gages have systematic record lengths between 20 and 30 years. The record period and systematic record lengths for each site are listed in Table V-4. Additional historic data were used to adjust the systematic record length of ten gages in determination of the gage estimate (Appendix 2 and Table A2-1).

The short record lengths are generally associated with the smaller watershed sizes. Table V-5 contains the breakdown of record lengths by watershed size groups. Twenty-two (60 percent) of the systematic record lengths between 20 and 30 years are associated with watersheds under 10 square miles.

Table V-2

SITE SELCTION CRITERIA FOR PILOT TEST

Purpose/Goal	Criteria
1. Watersheds tested should be representative of those ungaged watersheds encountered by potential users.	1. Watersheds considered for testing shall be from one acre to 1000 square miles.
2. Watersheds should not be developed or urban in nature.	2. The watersheds considered for testing shall be virtually unaffected by man-made controls as defined by USGS. Experimental watershed practices must not affect flood peaks.
3. The flood record from the selected watersheds should be sufficient to provide reliable flood-frequency estimates.	3. The period of record shall be 20 years or more. The years need not be continuous.
4. Observations used in various procedures will reflect current watershed conditions obtained from maps, photos, and/or field visits. The frequency estimates should be based on gaged records representative of these conditions.	4. At least one year of the gaged records shall be in the 1970's or, if discontinued earlier, shall be currently in the same condition represented by the data record.
5. Adequate quality control should be exercised over the streamflow records.	5. Agencies supplying data for the test shall be responsible for seeing that: A. Data are readily available. B. Quality assurance is routinely practiced in both collection and archiving data. C. Data are supplied in a form and format so that it can be filed similar to USGS WATSTORE files. D. Criteria 1 to 4 are met.

Table V-3

NUMBER OF SITES SELECTED BY REGION AND STATE

Drainage Area (Sq. Mi.)	State								Total
	OH	IN	IL	MO	ID	MT	OR	WA	
0-3	2	-	4	2	-	-	1	4	13
3-10	2	-	2	4	-	1	2	2	13
10-50	1	3	2	2	1	1	2	1	13
50-100	3	2	3	2	1	1	2	4	18
>100	2	1	3	2	1	-	2	2	13
Total	10	6	14	12	3	3	9	13	70

Midwest = 42 Northwest = 28

Testing Without Resource Packages

Drainage Area (Sq. Mi.)	State			Total
	OH	IN	WA	
3-10	1	-	1	2
10-50	-	1	-	1
Total	1	1	1	3

Table V-4

WATERSHEDS TESTED

Midwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
		0-3 Sq. Mi.					
21	05586500	Hurricane Creek nr. Roodhouse, IL	39.4889 39°29'20"	90.4167 90°25'00"	2.30	1951-77	27
22	03344250	Embarras River Trib. nr. Greenup, IL	29.2333 39°14'00"	88.1555 88°09'20"	0.08	1956-77	22
23	05418800	Mill Creek Trib. nr. Scales Mound, IL	42.4528 42°27'10"	90.2528 90°15'10"	0.86	1956-75	20
24	07011500	Green Acre Branch nr. Rolla, MO	37.9139 37°54'50"	91.7269 91°43'37"	0.62	1948-75	28
25	06821000	Jenkins Branch at Gower, MO	39.6247 39°37'29"	94.6003 94°36'01"	2.72	1950-76	27
26	03125000	Home Creek nr. New Phila., OH	40.4683 40°28'06"	81.4028 81°24'10"	1.64	1937-76	40
27	03265100	Hog Run Tr. at Laura, OH	40.0083 40°00'30"	84.4239 84°25'26"	0.46	1950-76	27
28	05599640	Green Creek Trib. nr. Jonesboro, IL	37.4653 37°27'55"	89.3111 80°18'40"	0.44	1956-75 1977	21

Table V-4 (Continued)

WATERSHEDS TESTED

Midwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
		3-10 Sq. Mi.					
29	0556600	East Branch Panther Creek nr. Gridley, IL	40.7667 40°46'00"	88.9097 88°54'35"	6.30	1950-72	23
30	06820000	White Cloud Cr. nr. Maryville, MO	40.3894 40°23'22"	94.9092 94°54'33"	6.06	1949-71 1973-76	27
31	07064500	Big Creek nr. Yukon, MO	37.2325 37°13'57"	91.8497 91°50'59"	8.36	1950-75	26
32	07185500	Stahl Creek nr. Miller, MO	37.1950 37°11'42"	93.8436 93°50'37"	3.86	1951-76	26
33	05591500	Asa Creek at Sullivan, IL	39.6197 39°37'11"	88.6047 88°36'17"	8.05	1951-77	27
34	03139990	Little Mill Cr. nr. Coshocton, OH	40.3642 40°21'51"	81.8389 81°50'20"	7.16	1937-71	35
35	03241600	Shawnee Cr. at Xenia, OH	39.6756 39°40'32"	83.9256 83°55'32"	4.21	1948-76	29
36	06931500	Little Beaver Creek nr. Rolla, MO	37.9350 37°56'06"	91.8364 91°50'11"	6.41	1948-75	28

Table V-4 (Continued)

WATERSHEDS TESTED

Midwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
			10-50 Sq. Mi.				
37	06907500	South Fork, Blackwater R. nr. Elm, MO	38.8189 38°49'08"	94.0356 94°02'08"	16.6	1954-76	23
38	06931000	Beaver Cr. nr. Rolla, MO	37.8792 37°52'45"	91.7958 91°47'45"	13.7	1949-58 1960-77	28
39	05582500	Crane Creek nr. Easton, IL	40.2461 40°14'46"	89.8611 89°51'40"	26.5	1950-77	28
40	05597500	Crab Orchard Creek nr. Marion, IL	37.7311 37°43'52"	88.8892 88°53'21"	31.7	1952-77	26
41	05524000	Carpenter Creek at Egypt, IN	40.8661 40°51'58"	87.2056 87°12'20"	44.8	1949-51 1953-77	28
42	03354500	Beanblossom Creek at Beanblossom, IN	39.2625 39°15'45"	86.2481 86°14'53"	14.6	1952-77	26
43	03347500	Buck Creek nr. Muncie, IN	40.1347 40°08'05"	85.3736 85°22'25"	35.5	1955-78	24
44	03147900	Timber Run nr. Zanesville, OH	39.9500 39°57'00"	82.0519 82°03'07"	10.1	1947-76	30

Table V-4 (Continued)

WATERSHEDS TESTED

Midwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
		50-100 Sq. Mi.					
45	03093000	Eagle Creek at Phalanx Station, OH	41.2611 41°15'40"	80.9544 80°57'16"	97.6	1927-34 1938-76	47
46	03218000	L. Scioto R. above Marion, OH	40.6286 40°37'43"	83.1697 83°10'11"	72.4	1939-76	38
47	03364500	Clifty Creek at Hartsville, IN	39.2736 39°16'25"	85.7028 85°42'10"	91.4	1948-77	30
48	05519500	West Creek nr. Schneider, IN	41.2144 41°12'52"	87.4933 87°29'36"	54.7	1949-51 1954-72	22
49	05557500	East Bureau Creek nr. Bureau, IL	41.3350 41°20'06"	89.3814 89°22'53"	99.0	1937-73 1975-77	40
50	05469500	South Henderson Creek at Biggsville, IL	40.8569 40°51'25"	90.8639 90°51'50"	82.9	1940-76	36
51	05502040	Hadley Creek at Kinderhook, IL	39.6931 39°41'35"	91.1486 91°08'55"	72.7	1940-77	38

Table V-4 (Continued)

WATERSHEDS TESTED

Midwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
			50-100 Sq. Mi.				
52	06897000	East Fork Big Creek nr. Bethany, MO	40.2972 40°17'50"	94.0319 94°01'55"	95.0	1934-72	39
107	06909500	Moniteau Creek nr. Fayette, MO	39.1208 39°07'15"	92.5611 92°33'40"	81.0	1949-77	29
108	03241500	Massies Creek at Wilberforce, OH	39.7228 39°43'22"	83.8828 83°52'58"	63.2	1953-76	24

Table V-4 (Continued)

WATERSHEDS TESTED

Midwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
			>100 Sq. Mi.				
53	05556500	Big Bureau Creek at Princeton, IL	41.3653 41°21'55"	89.4986 89°29'55"	196	1937-77	41
54	06895000	Crooked River nr. Richmond, MO	39.3328 39°19'58"	93.9794 93°58'46"	159	1948-71 1973-75	27
55	06930000	Big Piney River nr. Big Piney, MO	37.6661 37°39'58"	92.0506 92°03'02"	560	1922-70 1972-77	55
56	05587000	Macoupin Creek nr. Kane, IL	39.2342 39°14'03"	90.3944 90°23'40"	868	1921-33 1941-77	50
57	05572000	Sangamon River at Monticello, IL	40.0308 40°01'51"	88.5889 88°35'20"	550	1908-13 1915-77	69
58	03339500	Sugar Creek at Crawfordsville, IN	40.0489 40°02'56"	86.8994 86°53'58"	509	1939-77	39
59	03159500	Hocking River at Athens, OH	39.3289 39°19'44"	82.0878 82°05'16"	943	1916-76	61
60	03261500	G. Miami River at Sidney, OH	40.2869 40°17'13"	84.1500 84°09'00"	541	1913-76	64

Table V-4 (Continued)

WATERSHEDS TESTED

Northwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
			0-3 Sq. Mi.				
76	12465300	Broadax Draw Trib. nr. Wilbur, WA	47.8408 47°50'27"	118.8031 118°48'11"	1.12	1955-74	20
77	13343660	Smith Gulch Trib. nr. Pataha, WA	46.4900 46°29'24"	117.4450 117°26'42"	1.85	1955-74	20
78	12204400	Nooksack River Trib. nr. Galcier, WA	48.9083 48°54'30"	121.8055 121°48'20"	1.15	1956-60 1962-76	20
79	14148700	Fern Creek nr. Lowell, OR	43.8639 43°51'50"	122.6847 122°41'05"	0.44	1954-56 1958-77	22
80	12010600	Lane Creek nr. Naselle, WA	46.3722 46°22'20"	123.7833 123°47'00"	2.15	1950-70	21

Table V-4 (Continued)

WATERSHEDS TESTED

Northwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
			3-10 Sq. Mi.				
81	14037500	Strawberry Creek above Slide Cr. nr. Prairie City, OR	44.3417 44°20'30"	118.6555 118°39'20"	7.00	1931-77	47
82	14134000	Salmon River nr. Government Camp, OR	45.2653 45°15'55"	121.7167 121°43'00"	8.70	1911-12 1927-77	53
83	12437950	East Fork Foster Creek Trib. nr. Bridgeport, WA	47.9500 47°57'00"	11°9.6306 119°37'50"	4.75	1957-76	20
84	12356000	Skyland Creek nr. Essex, MT	48.2917 48°17'30"	113.3861 113°23'10"	8.09	1946-52 1954 1959-75	25
85	12047100	Lees Creek at Port Angeles, WA	48.1055 48°06'20"	123.3819 123°22'55"	4.77	1949-70	22

Table V-4 (Continued)

WATERSHEDS TESTED

Northwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
		10-50 Sq. Mi.					
86	14141500	Little Sandy River nr. Bull Run, OR	45.4153 45°24'55"	122.1722 122°10'20"	22.3	1913 1920-77	59
87	14314500	Clearwater River above Trap Cr. nr. Tokee Falls, OR	43.2444 43°14'40"	122.2861 122°17'10"	41.6	1928-77	50
88	13251500	Weiser River at Tamarack, ID	44.9469 44°56'49"	116.3814 116°22'53"	36.5	1937-71 1974-75	37
89	12350500	Kootenai Creek nr. Stevensville, MT	46.5372 46°32'14"	114.1586 114°09'31"	28.9	1948-53 1958-73	22
90	12196000	Alder Creek nr. Hamilton, WA	48.5283 48°31'42"	121.9494 121°56'58"	10.7	1944-76	33

Table V-4 (Continued)

WATERSHEDS TESTED

Northwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
			50-100 Sq. Mi.				
91	14075000	Squaw Creek nr. Sisters, OR	44.2339 44°14'02"	121.5658 121°33'57"	54.8	1908-09 1911-14 1916-18 1920 1926-27	62
92	12097500	Greenwater River at Greenwater, WA	47.1536 47°09'13"	121.6344 121°38'04"	73.5	1912 1930-76	48
93	13330000	Lostine River nr. Lostine, OR	45.4389 45°26'20"	117.4264 117°25'35"	70.9	1913 1926-77	53
94	13092000	Rock Creek nr. Rock Creek, ID	42.3564 42°21'23"	114.3033 114°18'12"	80.0	1910-13 1939 1944-74	36
95	12041500	Soleduck River nr. Fairholm, WA	48.0444 48°02'40"	123.9578 123°57'28"	83.8	1918-21 1934-76	47
126	12361000	Sullivan Creek nr. Hungry Horse, MT	48.0292 48°01'45"	113.7028 113°42'11"	71.3	1948-56 1960-76	26
128	12408500	Mill Creek nr. Colville, WA	48.5789 48°34'44"	117.8656 117°51'56"	83.0	1940-76	37
129	12500500	N.F. Ahtanum Creek nr. Tampico, WA	46.5644 46°33'52"	120.9158 120°54'57"	68.9	1908 1910-21 1932-76	58

Table V-4 (Continued)

WATERSHEDS TESTED

Northwest

Pilot Test Number	USGS Station Number	Gage Name	Latitude	Longitude	Area (Sq. Mi.)	Record Period	Record Length (Years)
		>100 Sq. Mi.					
96	12457000	Wenatchee River at Plain, WA	47.7631 47°45'47"	120.6650 120°39'54"	591	1911-29 1934-76	64
97	12035000	Satsop River nr. Satsop, WA	47.0019 47°00'07"	123.4936 123°29'37"	299	1930-76	47
98	14325000	South Fork Coquille River at Powers, OR	42.8917 42°53'30"	124.0694 124°04'10"	169	1917-77	59
99	13185000	Boise River nr. Twin Springs, ID	43.6561 43°39'22"	115.7261 115°43'34"	830	1911-76	66
100	14021000	Umatilla River at Pendleton, OR	45.6722 45°40'20"	118.7917 118°47'30"	637	1904-05 1935-77	45

SYSTEMATIC RECORD LENGTH AT PILOT TEST SITES

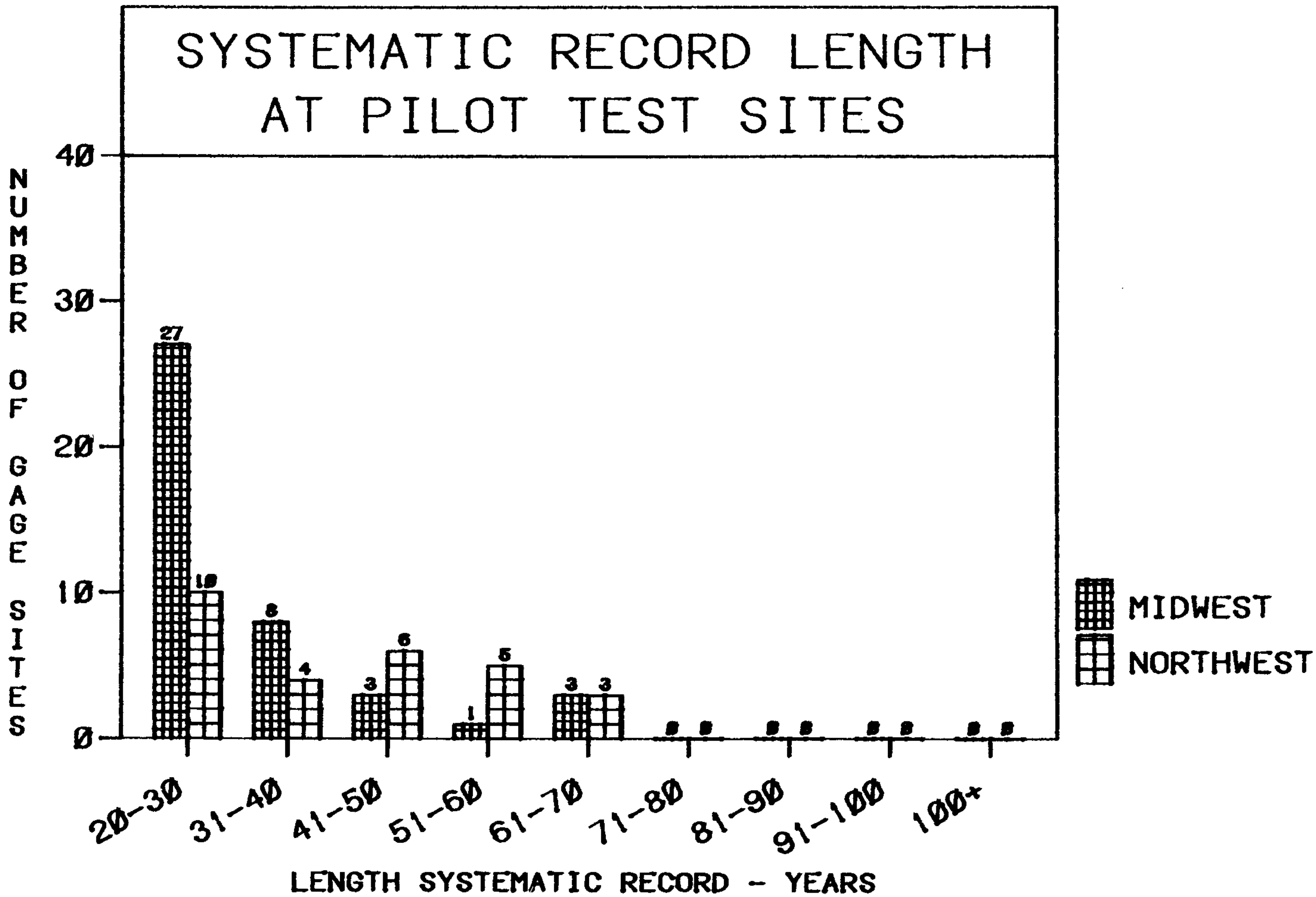


FIGURE V - 1

Table V-5

SYSTEMATIC RECORD LENGTHS
(Number of Sites)

Record Length (Years)	Watershed Size (Square Miles) 0-3		3-10		10-50		50-100		>100		Total Combined
	MW	NW	MW	NW	MW	NW	MW	NW	MW	NW	
20-30	7	5	7	3	8	1	4	1	1	--	37
31-40	1	-	1	-	-	2	5	2	1	-	12
41-50	-	-	-	1	-	1	1	2	2	2	9
51-60	-	-	-	1	-	1	-	2	1	1	6
61-70	-	-	-	-	-	-	-	1	3	2	6
Total	8	5	8	5	8	5	10	8	8	5	70

3. Application

Five independent estimates of the annual series 50-, 10-, and 1-percent-chance floods were made at each site for each applicable procedure. Selected procedures (Fletcher, Reich, rational, and TR-55 Graph) were applied one drainage area group size beyond their range of applicability. Application of the TR-20 and HEC-1 procedures was limited to watersheds with areas less than 300 square miles because of the TR-20 uniform rainfall assumptions and the desire to provide uniform testing. Table V-6 is a tabulation of the complete watershed-procedure test matrix.

B. Criteria for Comparison

The charge to the Work Group identified the three criteria for evaluating procedures--accuracy, reproducibility (consistency), and practicality. In order to evaluate accuracy and reproducibility, a standard was needed. The log-Pearson Type III flood-frequency estimate (U.S. Water Resources Council, 1977) based on a stream gage record (gage estimate) was chosen as the standard.

Following is a description of the gage estimate, the three criteria selected to evaluate the procedures (accuracy, reproducibility, and practicality), and the criterion variables (bias, reproducibility, and time to apply) selected to numerically represent the criteria in the statistical analyses.

1. Gage Estimate

In order to discriminate among the various procedures, a standard must be chosen as a basis for comparison. The estimating procedures evaluated in the pilot test were applied at stream gaging sites so that the flood-frequency estimates from the gage record could be used as the standard. The flood-frequency curves for each site were defined using, as an initial basis, methods described in U.S. Water Resources Council Bulletin 17A (1977). Values determined from these frequency curves are referred to as gage estimates in this report. A detailed description of the frequency analysis for each site and the recommended values of the 50-, 10-, and 1-percent-chance floods are given in Appendix 2.

Because of the time-sampling error associated with each record the gage estimate is not an absolute standard. For the 70 watersheds in the pilot test the average standard error of estimate for the 1-percent-chance flood is approximately 25 percent assuming the annual peak data is log-Pearson Type III distributed. This calculation is based on the average systematic record length of 34 years, average skew coefficient of -0.07, and average standard deviation of 0.30 log units. The standard

Table V-6

WATERSHED-PROCEDURE TEST MATRIX

Drainage Area (Sq. Mi.)	No. of Sites	Procedure Replicates (1) State Eq.	(2) Fletcher	(3) Reich	(4) Snowmelt	(5) Index Flood	(6) Rational	(7) TR-55 Charts	(8) TR-55 Graph	(9) TR-20	(10) HEC1	Total
Midwest												
0-3	8	40	40	40	-	-	40	40	40	-	-	240
3-10	8	40	40	40	-	-	40	-	40	15	15	230
10-50	8	40	40	40	-	40	-	-	40	20	20	240
50-100	10	50	50	-	-	50	-	-	-	15	15	180
>100	8	40	-	-	-	40	-	-	-	10	10	100
Northwest												
0-3	5	20*	25	25	25	-	25	25	25	-	-	170
3-10	5	15*	25	25	25	-	25	-	25	15	15	170
10-50	5	10*	25	25	25	25	-	-	25	10	10	155
50-100	8	25*	40	-	40	40	-	-	-	10	10	165
>100	5	10*	-	-	25	25	-	-	-	10	10	80
Total	70	290	285	195	140	220	130	65	195	105	105	1,730

*No state equations in Oregon and Idaho

Testing Without Resource Packages

Drainage Area (Sq. Mi.)	No. of Sites	(1) State Eq.	(2) Fletcher	(3) Reich	(4) Snowmelt	(5) Index Flood	(6) Rational	(7) TR-55 Charts	(8) TR-55 Graph	(9) TR-20	(10) HEC1	Total
Midwest												
3-10	1	3	3	3	-	-	3	-	3	3	3	21
10-50	1	3	3	3	-	3	-	-	3	3	3	21
Northwest												
3-10	1	2	2	2	2	-	2	-	2	-	-	12
Total	3	8	8	8	2	3	5	-	8	6	6	54

errors of the 10- and 50-percent-chance floods are less than 25 percent. The effect of the assumed frequency distribution used in developing the gage estimate on the conclusions was investigated by using alternate distributions as outlined in Appendix 2. The effect of the uncertainty in the gage estimate was not investigated in the pilot test. It should, however, be investigated in a nationwide test. One possible approach is outlined in section IX.B.3.

2. Accuracy

Accuracy is a measure of the closeness of the flood-frequency estimate to a standard. The standard chosen was the gage estimate previously described. The Work Group identified two kinds of accuracy: the accuracy of a procedure applied in an error-free situation and the accuracy typically encountered in field application.

There are two components to accuracy--variance and bias. Variance is a measure of the random variation in a set of repeated estimates when the procedure is evaluated more than once. Bias is a measure of the systematic error in a set of estimates that measures the deviation of the central tendency of these estimates from the gage estimate. If the mean square error (MSE) is used to measure accuracy then it can be shown that accuracy is related to variance and bias by:

$$\text{MSE} = \text{variance} + (\text{bias})^2 = \text{accuracy} \qquad (1)$$

The difference between an estimate and the gage estimate can be computed as follows:

$$(Y_{ijk} - Y_{oi}) = (Y_{ijk} - \bar{Y}_{ik}) + (\bar{Y}_{ik} - Y_{oi}) \qquad (2)$$

where:

Y_{ijk} = an estimate of the flood peak of selected frequency by individual j on watershed i using procedure k.

Y_{oi} = a gage estimate of the flood peak of selected frequency for watershed i.

$\bar{Y}_{ik}$ = the mean of all estimates of selected frequency on watershed i using procedure k.

The term $(\bar{Y}_{ik} - Y_{oi})$ represents the bias of procedure k as it is the difference between the mean of all flood-frequency estimates on watershed i using procedure k and the gage estimate. Bias for watershed i and procedure k is computed as follows:

$$B_{ik} = \frac{\frac{1}{m} \sum_{j=1}^{m} [Y_{ijk} - Y_{oi}]}{Y_{oi}} \qquad (3)$$

where B_{ik} is the bias for watershed i and procedure k computed across m testers; and Y_{ijk} and Y_{oi} are defined above for equation (2).

The bias estimate is standardized by dividing by the gage estimate in an attempt to remove the effect of watershed size. This standardization was used so that the bias estimates for large watersheds would be commensurate with bias estimates for small watersheds given the size of the flood peak for the watershed.

The bias component of accuracy as defined in equation (3) was used in the statistical analyses.

3. Reproducibility

The term $(Y_{ijk} - \bar{Y}_{ik})$ in equation (2) represents the variance component of the accuracy of a procedure. This is evaluated by repeated use of procedure k on the same watershed by different hydrologists; as such, it represents replication in hydrology. It represents the random error component and will be referred to as reproducibility because it is a measure of how well different testers can reproduce the same results at a site with the same procedure. Reproducibility for watershed i and procedure k is computed as follows:

$$RE_{ik} = \left[\frac{\sum_{j=1}^{m} \left[\frac{Y_{ijk} - \bar{Y}_{ik}}{Y_{oi}} \right]^2}{m-1} \right]^{0.5} \qquad (4)$$

where RE_{ik} is the reproducibility for watershed i and procedure k computed across m testers; and Y_{ijk}, $\bar{Y}_{ik}$, and Y_{oi} are defined above for equation (2).

The reproducibility estimate is also standardized by dividing by the square root of the gage estimate for the same reasons given above for bias. Reproducibility, as defined by equation (4), or the natural logarithm of its square (transformed reproducibility) was used in the statistical analysis.

4. Practicality

Practicality is a user decision which involves balancing effort and the analysis requirements. The time in hours to apply the procedure was used in the pilot test to represent practicality because it is the factor of major importance.

In the pilot test, both the time to become familiar with the procedure and the cost of applying the procedure were identified. Because the purpose was to obtain, as nearly as possible, the effort required by an experienced user of the procedure, the time to become familiar with the procedure was not included in the time to apply. Because the dollar costs incurred in applying the procedures (mainly computer costs) were small in comparison with the manpower costs, a variable which combined time to apply and dollar costs was not developed.

C. Statistical Techniques

Analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) were used to analyze the data. The objective was to determine whether statistical methods can detect meaningful differences among the procedures based on the criterion variables of bias, reproducibility, and time to apply. In the ANOVA analysis each criterion variable is analyzed separately and interactions between the procedures and other factors are investigated. In the MANOVA analysis all the criterion variables are analyzed together providing a combined evaluation of the different procedures.

1. Analysis of Variance (ANOVA)

The ANOVA analysis identifies the factors and interactions that significantly affect the individual criterion variables. The following factors were considered likely to be important in explaining the variation in the criterion variables of bias, reproducibility, and time to apply.

1. Procedure, P--the procedures listed in Table V-1.

2. Exceedance probability, R--the three frequency levels, 50-, 10-, and 1-percent-chance floods.

3. Site size, S--the five site sizes, 0 to 3, 3 to 10, 10 to 50, 50 to 100, and greater than 100 square miles determined primarily by procedure applicability.

4. Watershed factor, W(S)--the watershed factor nested within each site size factor. Each watershed is unique within a site size (0 to 3, 3 to 10, etc.) and may have some effect on the results of the analyses. Thus, a factor independent but nested within the effect of the various site sizes needs to be evaluated. The notation W(S) indicates this nesting effect.

Procedures, site sizes, and exceedance probabilities are arranged in a factorial layout; that is, each procedure is used for all three exceedance probabilities and, whenever possible, for each site size. However, not all procedures are applicable to all watersheds, and this creates an unbalanced design structure. This unbalanced design is obvious upon inspection of the watershed-procedure test matrix in Table V-6. All factors are assumed to be fixed effects.

The ANOVA equations that describe the relationship between the criterion variables and the four factors above are:

$$B = P + R + S + W(S) + P*R + R*S + R*W(S) + P*S + P*W(S) + E \quad (5)$$

$$RE = P + R + S + W(S) + P*R + R*S + R*W(S) + P*S + P*W(S) + E \quad (6)$$

$$TA = P + S + W(S) + P*S + P*W(S) + E \quad (7)$$

where B is the bias for a given watershed, procedure, and exceedance probability as defined in equation (3); RE is the reproducibility for a given watershed, procedure, and exceedance probability as defined in equation (4); TA is the time to apply for a given watershed and procedure; P, R, S, and W(S) are defined above; and E is an error term. The time to apply for each exceedance probability is the same for each watershed and procedure. Thus the exceedance probability factor R does not appear in equation (7). Terms such as P*S represent interactions of the original factors. The P*S interaction represents the failure of the procedure to produce a constant effect from one site size to another.

Because the values of bias and reproducibility used in the analysis are the average of five testers' watershed values, there is only one observation of bias and reproducibility for each watershed-procedure combination. In equations (5) and (6), the error term E consists of the third order interactions P*R*S and P*R*W(S) that were omitted from the model. In equation (7), the analysis is performed on the individual time to apply values (5 values per watershed-procedure combination) so that the error term is derived from replication rather than by combining higher order effects.

The Statistical Analysis System (SAS) (Barr, Goodnight, and Sall, 1979) general linear models (GLM) routine was used to analyze the data. Separate analyses were performed for the Northwest and Midwest regions. The GLM procedure in SAS will perform the statistical analysis for an unbalanced multifactor design. Specifically, the Type III sums of squares were used because the estimable functions associated with the sums of squares were most appropriate for the unbalanced design used in the pilot test.

The purpose of the ANOVA-GLM analysis is to identify the factors and interactions in equations (5) to (7) that are significant in explaining variation in the criterion variables. The GLM routine produces an analysis of variance table giving the sum of squares that is attributed to each factor and interaction. The hypotheses tested are that these factors and interactions are not significantly different from zero. The analysis of variance compares the portion of variability in the criterion variable, explained by each factor and interaction, to the residual variability or error (E) which is not explained by equations (5) to (7). If this comparison reveals that the variability in the criterion variable due to that factor or interaction is small relative to the residual error, then these effects are apparently negligible. However, if this comparison indicates that the variability due to the factor or interaction is large relative to the residual error, then these effects are apparently important in explaining the criterion variable. Further analysis is necessary to identify which specific factors or interactions are different. Duncan's multiple range test (Montgomery, 1976) is used to identify these factors or interactions.

Duncan's multiple range test simultaneously compares pairs of factor means and identifies which pairs of means are significantly different. The degrees of freedom and the mean square error from the GLM analysis are used as input to the Duncan's multiple range test. This test was applied to the procedure means for the various site sizes and exceedance probabilities. The results of the GLM analyses and Duncan's multiple range tests are presented in section VIII of this report.

2. Multivariate Analysis of Variance (MANOVA)

Multivariate analysis of variance (MANOVA) is used in conjunction with other statistical techniques to determine differences in procedures based on multivariate criteria--in this case, vector means. The vector means consist of the estimated values of the three criterion variables: bias, reproducibility, and time to apply. The overall analysis includes MANOVA, multiple discriminant analysis, ANOVA, and Duncan's multiple range tests.

The significance of the multivariate test is assessed using Rao's (1952) approximation to the Wilk's Lambda statistic (Wilks, 1932). If the test indicates that there is a significant difference between two or more vector means, then it is necessary to discriminate in the multicriterion space to determine which vectors are different. Because the test cannot identify which vector means are different, multiple discriminant function analysis (Cooley and Lohnes, 1971) can be used to establish the vector space in which the different means can be identified.

Discriminant function analysis is a multivariate statistical method that defines the function that best separates the procedures. This function is a linear combination of the three criterion variables. If a difference exists between procedures, the value of the discriminant function will be significant. The discriminant functions are measured in an orthogonal axis system and the discriminant analysis will reduce the axis system to the minimum subspace that is necessary to identify significant differences between procedures.

The values of the discriminant function can be used to evaluate the significance of differences between the hydrologic procedures using the three criteria simultaneously, rather than independently. The discriminant scores that are computed for the discriminant functions can be tested for significant differences using ANOVA.

If the ANOVA test indicates significant differences within discriminant functions, then it is necessary to determine which hydrologic procedures are different. It is not possible to make a comparison of each pair of procedures using a test because the probability of rejecting a true hypothesis is most likely much greater than the level of significance specified in the overall test. Thus, it is necessary to use a test that is designed specifically for making individual comparisons. Duncan's multiple range test was selected for making individual comparisons.

A computer program was developed to perform the analysis, including the multivariate analysis of variance, the discriminant function analysis, the ANOVA tests on the discriminant functions, and the Duncan tests. The MANOVA and discriminant functions programs were adapted from those supplied by Cooley and Lohnes (1971).

3. Assumptions and Limitations of ANOVA and MANOVA

There are a number of common assumptions underlying the ANOVA and MANOVA techniques. Both methods assume that the observations are normal random variables. The ANOVA model assumes that the observations on a single criterion variable are independent random variables. Furthermore, the ANOVA analysis does not specifically account for any correlative structure between criterion variables. The MANOVA analysis assumes that the criterion variable is a vector consisting of bias, reproducibility, and time to apply and that there may be correlative structure between the elements of the vector. Finally, ANOVA assumes that the observations on each individual criterion variable have constant variance, while MANOVA assumes that the vectors of responses have a common covariance matrix. Slight to moderate departures from normality have little effect on these procedures. However, the independence and constant variance assumptions are more critical. Less is known about the effects of departures from these assumptions in MANOVA than in ANOVA.

ANOVA examines each criterion variable separately, while MANOVA analyzes their joint behavior. If the criterion variables are not highly correlated, the results of the two analyses should be similar. However, if the criterion variables are correlated, then there could be some difference in results because MANOVA specifically considers this correlative structure while ANOVA does not.

ANOVA is particularly simple to interpret. Specifically, the multiple-comparisons problem is reasonably well solved. That is, once ANOVA has indicated that procedures differ, there are standard statistical methods that can be used to identify the specific differences between the procedures. MANOVA is somewhat more difficult to interpret, and the multiple-comparisons problem is not as well solved.

A common difficulty with both analyses is that factors that are ignored in the underlying statistical model are forced into the error term. Neither analysis considers the tester factor, so differences between testers inflate the error term in both analyses. The ANOVA analysis considers the main effects of procedures, site sizes, watersheds within site size, and exceedance probabilities, along with certain interactions between these factors. The MANOVA analysis considers the main effect of procedures as the only factor but performs a separate analysis for each exceedance probability. Standardization of the criterion variables was performed to attempt to minimize site size effects. To the extent that standardization does not remove its effect, the site size factor is reflected in the MANOVA error term. Watershed effects are also contained in the MANOVA error term.

The choice of a level of significance affects both analyses. Generally, the 5 percent level was used as a cutoff value for hypothesis testing and in the construction of confidence intervals. It is not presently well known how this level of statistical significance relates to engineering or hydrologic significance.

VI. PILOT TEST IMPLEMENTATION

This section documents: (1) the money and manpower resources available for testing which established the test size; (2) the materials provided to the testers; (3) the selection of testers; and (4) the management of the test. Its purpose is twofold: (1) to provide a basis for others to evaluate the testing process and (2) to provide information to guide those who may conduct similar tests in the future.

The problems were to: (1) tailor the pilot test to available resources; (2) devise a practical method to obtain flow-frequency estimates which simulated, to the extent practical, actual field conditions; (3) identify and assign people to perform the test; (4) distribute the test materials; (5) compile test results assuring objectivity and, at the same time, providing quality control; and (6) develop a computer program to manage the data and perform the basic statistical analyses.

A. Test Size

Because resources were limited, it was necessary to scale the pilot test size to the available money and manpower. The pilot test evolved as a compromise between the 100-site minimum test believed statistically and hydrologically desirable and the money/manpower contributed by the member agencies and the volunteer testing by private industry and university and state personnel. Agency commitments of cash or manpower totaled approximately 2600 man-days of effort. Based upon estimated man-days of effort needed for one application of each procedure, a basic pilot test design was adopted. It included five replicates of eight procedures in Categories 1, 3, 5, and 6 at 65 sites and five replicates of HEC-1 and TR-20 at 20 of these sites. As a result of testing contributions from the private sector, university personnel, and state governments, it was possible to expand the test of the eight procedures in Categories 1, 3, 5, and 6 from 65 to 70 sites and of HEC-1 and TR-20 from 20 to 21 sites and include some testing without resource packages at three sites. These additional test contributions are estimated to amount to approximately 288 man-days of effort.

The testing was conducted with one tester, whenever possible, applying all applicable procedures at a site. If it was not possible for one tester to apply all procedures, the testing was divided into three separate units: (1) the eight procedures in Categories 1, 3, 5, and 6; (2) HEC-1; and (3) TR-20. This provided the tester with experience in a variety of procedures and minimized the cost of testing by permitting one determination of common factors such as drainage area.

B. Test Materials

The methods to obtain flow-frequency estimates from testers received considerable attention. Considerations included the kind of information to supply, the test description to provide the tester, the information needed about the tester, and the form used to record the test data. The objective was to provide the test material in a cost-effective manner that would not bias the results but would assure uniform testing conditions.

It was expected that tester experience in using the various procedures included in the test would vary from active use to little or no experience. Some procedures required considerable material and effort to apply, while others required little. Some sites were at locations where information on soils, land use, precipitation, and other hydrologic factors needed to apply the procedure were available while other sites had only meager or incomplete data. To make testing conditions uniform for all sites and testers and to avoid creating a situation where each tester would individually contact agencies for needed data, each tester was provided with two packages of material: (1) a procedure package and (2) a resource package.

The procedure package explained the test and each procedure to be tested and provided answer or record sheets. The resource package contained the topographic maps, aerial photographs, soils maps, rainfall information, and any other resource materials needed to perform the calculations. Following are descriptions of the procedure and resource packages.

1. Procedure Package

The procedure package contained:

Instruction Letter. A letter from the Water Resources Council (Figure VI-1) describing the test program provided specific instructions on how to perform the test, restrictions about using other information, and the method for recording and returning the answers.

Assignment Form. Each tester was provided an assignment form (Figure VI-2) that listed the procedures to be applied at the indicated site and all resource package materials.

Procedure Description. A description of each procedure to be tested at the indicated site was provided. The description was either the original publication or an abstraction to cover application of the procedure to the specific site. The original documentation including figures, graphs, and other working materials was used whenever practical to avoid bias in the instructions.

UNITED STATES WATER RESOURCES COUNCIL

SUITE 800 • 2120 L STREET, NW WASHINGTON, DC 20037

MEMORANDUM

TO : Participants in pilot test to evaluate flood peak estimating procedures

FROM : Work Group on Flood Flow Frequency for Ungaged Watersheds, Hydrology Committee, Water Resources Council (WRC)

DATE : April 10, 1978

SUBJECT : INSTRUCTIONS TO PARTICIPANTS IN PILOT TEST

Introduction

The Hydrology Committee of the Water Resources Council (WRC) as directed by House Document No. 465, 89th Congress "A Unified National Program for Managing Flood Losses" is working to develop agreed upon sets of procedures for determining peak flow frequencies for ungaged watersheds. The task is assigned to an Interagency Work Group on Flood Flow Frequency for Ungaged Watersheds. The procedures recommended are to be selected from those already developed and being used based upon the criterion of accuracy, reproducibility, and practicality. Accuracy is the closeness of the estimate to the "true" value and includes both precision and bias. Reproducibility is the ability of the different people to get the same answer using the same procedure at a site. Practicality is defined as the resources required to make the estimate, both manpower and materials.

The Work Group proposes to make its recommendations based upon a comparison of the performance of candidate procedures under a wide variety of conditions. This comparison, or test, will be made on a nationwide sample of sites covering a wide variety of watersheds and climatic conditions. You are participating in a pilot test which is to provide the information to design a full test.

This pilot test (and the full test) will consist of computing flood frequencies at selected sites where a relatively long gage record is available for use by the Work Group as a standard to evaluate accuracy. Participants are urged not to refer to the gage record as this would unfairly influence results of the test. At each site enough different people will independently apply the procedures to provide a measure of reproducibility. Each person will record the man-hours, effort, and other costs required to make each estimate to provide the basis for evaluation of practicality.

Materials

Attached to this memorandum is a packet of materials which includes:

1. Assignment form which identifies the procedures and site you will be testing and a list of the materials provided;

2. A description of each of the procedures to be applied;

3. A record sheet for each procedure to list parameters and results for that procedure in a systematic manner for keypunching; and

4. A resource package including such things as topographic maps, soil reports, hydrologic soil maps, aerial photographs, aerial photo indexes, and rainfall frequency information for the test site watershed.

The maps, normally, will be sent under separate cover.

Instructions

1. Each participant should apply all procedures identified on the assignment form at a site. This may not be possible, if so, please notify the person providing you with this testing material.

2. Compute the peak discharge of the 2-, 10-, and 100-year floods following the procedures in your packet as described. Record your answers on the record sheets provided.

3. Keep a record of the time required to make each estimate. Because you will be applying different procedures to the same site, there will be certain characteristics such as drainage area which are common to all your estimates. It is expected that you will organize your work to minimize the total time required to complete the test. Thus, certain parameters such as drainage area which are common to all procedures can be estimated only once. Consequently, to provide an accurate estimate of the total time required to apply each procedure independently will require a calculation on your part. Your total time estimate will include the time which is unique to the particular procedure plus the time required to compute those factors common to other procedures. A simple example is drainage area which would be computed once for all procedures. The time required to determine drainage area would be added to the total times required for each individual procedure to estimate the total time.

4. You should make all estimates without reference to the gage record for the particular site. Each procedure should be applied independently without comparison between procedures.

   A gage record is available at the site which will be used by the Work Group to evaluate the relative accuracy of the different procedures. We ask that you do not look at the gage record until after you have completed and mailed in the results of the test. We appreciate that your curiosity will be aroused and you will want to make such a comparison. Further, you may be tempted to compare the results obtained with different procedures and possibly to adjust some of the results based upon such comparisons or from experience. Again, we ask that you restrain your curiosity until after you mail in the results so that we can have an honest, unadjusted application of each procedure.

5. In order to provide uniformity between testers, we ask that you make your estimates:

   a. By determining input parameters from the resource packet provided, or other readily available information, or by a field inspection (a field inspection is not expected).

   b. Without adjustments for historical or other flood data within the watershed, up or downstream of the site.

   c. That the time you take to become familiar with the procedure be separated from the time to apply the procedure.

6. The record sheet asks for your name and the organization for which you work. This is only for our use in management of the tests, and not for evaluating the participants.

7. If the stream name is not easily determined from the material provided, leave this entry on the record sheet blank.

8. When filling out the Pilot Test Record Sheet, please be neat. We plan to keypunch directly from this sheet.

9. Return your record sheets to the person who provided the test packet. On the back of the record sheets, include any comments about problems incurred in applying the procedure or suggestions which you think will be helpful in conducting the final test.

10. Please return any publications you do not want to retain for your own use to the person who provided you the test packet.

We appreciate your help!

Donald W. Newton
Chairman, Work Group on Flood Flow
Frequency for Ungaged Watersheds

Attachment

ASSIGNMENT FORM

TEST SITE NUMBER ________________ 1/ STATE NAME ________________

I PROCEDURES TO BE APPLIED

USGS State Equations	Fletchers	Reich	USCE Snowmelt	USGS Index Flood	Rational Method	SCS TR-55 Charts (Appendix D & E)	SCS TR-55 Graphical (TC)	SCS TR-20	USCE HEC-1
(XX)2/	(XX)	(XX)	(XX)	(XX)	(XX)	(XX)	(XX)	(XX)	(XX)

1/ The test site is marked on sheet 1 of the topographic maps by a small triangle symbol (Δ); arrows in the margin point to the site location.

2/ Pilot test record number.

II SUMMARY OF RESOURCE PACKET MATERIAL

	Number included	Under Separate Cover
Topographic maps		
Soils reports		
Hydrologic Soil group maps		
Aerial photographs		
Aerial photo indexes		
Precipitation Frequency		
NOAA Atlas 2		
Table of 2-, 10- and 100-year 48-hour		
Maps from Weather Bureau TP-40 and TP-49		
NOAA Technical Memorandum NWS HYDRO-35		

ASSIGNMENT FORM

FIGURE VI - 2

Record Sheet. Record sheets for documenting information about the site, the tester, and the results were developed for each procedure. The record sheets were set up for this data to be directly keypunched. Figure VI-3 and VI-4 are examples of typical test record sheets. All other test record sheets are shown in Appendix 3.

Documentation of the input parameters was requested for use in evaluating the reproducibility of various components of each procedure. A concern in designing the form was whether to list all possible parameters or only those parameters used in the site application. In order not to lead the tester to an answer, all potentially useful parameters for the specific procedure were listed. Space was also provided for comments about problems encountered in the application of the procedure, additional material used to obtain answers, and suggestions for conducting the nationwide test.

2. Resource Package

The resource package contained:

Topographic Maps. USGS 7-1/2-minute or 15-minute quadrangle map(s) were provided for test sites with watersheds smaller than 200 square miles and 1:250,000 scale maps were provided for sites with larger watersheds. The test site was indicated on the appropriate topographic map by a triangle symbol and marginal arrows were drawn to call attention to the site. This was the only gage information provided to the tester.

Soils Data. Detailed soils survey reports or maps were provided where available for all test watersheds smaller than 50 square miles and for test watersheds larger than 50 square miles where TR-20 and HEC-1 were to be tested. If detailed soils data were not available, the general extent of the four basic hydrologic soil groups as defined by the Soil Conservation Service (1972) was designated on topographic maps.

Aerial Photographs. Aerial photographs (1" = 1320') were provided for all test watersheds smaller than 50 square miles for identifying land use. For test watersheds between 10 and 50 square miles, aerial photo indexes (1" = 1 mile) were also provided for locating the smaller scale photos. The index sheets were only provided for watersheds over 50 square miles where TR-20 and HEC-1 were to be tested. This was due to the large number of aerial photos that would have been involved to provide coverage.

Rainfall Frequency Data. Rainfall frequency information appropriate to the test watershed was provided. For

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE ___USGS INDIANA STATE EQUATION (XX)___ *(1-3)*
2. TEST SITE NUMBER ________ *(5-7)*
3. TESTER INFORMATION *(9-17)*

Name ________________

Organization ________________

Address ________________

____

Phone No: ________ Date: ________

Years of Hydrologic Experience

1 ☐ 0-2 yrs *2* ☐ 2-5 yrs *3* ☐ 5-10 yrs *4* ☐ more than 10 yrs *(19)*

How frequently do you use this type of procedure?

1 ☐ never *2* ☐ occasionally *3* ☐ frequently *(20)*

Are you knowledgeable about the hydrology of the region?

1 ☐ no *2* ☐ somewhat *3* ☐ very *(21)*

Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

1 ☐ no *2* ☐ yes *(22)*

4. SITE LOCATION INFORMATION

State Name ________________ *(23-26)*

Stream Name ________________ *(27-34)*

Longitude ________________ *(35-41)*

Latitude ________________ *(42-47)*

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

2 year peak flood (Q_2), cfs ________________ *(48-54)*

10 year peak flood (Q_{10}), cfs ________________ *(55-61)*

100 year peak flood (Q_{100}), cfs ________________ *(62-69)*

6. RESOURCES USED

Time to become familiar with the procedure (hrs) ________ *(70-72)*

Time to apply the procedure (hrs) ________ *(73-76)*

Cost, other than manpower, to apply the procedure (explain on back) ______ *(77-80)*

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	________	(18-23)	________	(24-26)
D, Drainage density (mi/mi^2)	________	(27-32)	________	(33-35)
F, Watershed shape factor	________	(36-41)	________	(42-44)
L, Channel length (mi)	________	(45-50)	________	(51-53)
Pi, Precipitation index (in)	________	(54-59)	________	(60-62)
R, Watershed relief (ft)	________	(63-68)	________	(69-71)
Rc, Soil runoff coefficient	________	(72-76)	________	(77-80)
S, Channel slope (ft/mi)	________	(19-23)	________	(24-26)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS INDIANA STATE EQUATION

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE SCS TR-20 (XX) ______ (1-3)

TEST SITE NUMBER ______ (5-7)

3. TESTER INFORMATION (9-17)

Name ______

Organization ______

Address ______

______

Phone No: ______ Date: ______

Years of Hydrologic Experience

1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

How frequently do you use this type of procedure?

1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

Are you knowledgeable about the hydrology of the region?

1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

State Name ______ (23-26)

Stream Name ______ (27-34)

Longitude ______ (35-41)

Latitude ______ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

2 year peak flood (Q_2), cfs ______ (48-54)

10 year peak flood (Q_{10}), cfs ______ (55-61)

100 year peak flood (Q_{100}), cfs ______ (62-69)

6. RESOURCES USED

Time to become familiar with the procedure (hrs) ______ (70-72)

Time to apply the procedure (hrs) ______ (73-76)

Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. SUMMARY OF KEY COMPONENTS OF TR-20

Total drainage area at the test site (sq.mi.) ______ (19-24)

Drainage area subdivided into how many subareas ______ (25-26)

Number of stream routing reaches used ______ (27-28)

Number of structure routings (man-made of natural) ______ (29-30)

(CONTINUED ON SECOND SHEET)

7. SUMMARY OF KEY COMPONENTS OF TR-20 (continued)

Compute Card rainfall depths - storm number 01, P_2 (inches) ______________ (31-34)
- storm number 02, P_{10} (inches) ______________ (35-38)
- storm number 03, P_{100} (inches) ______________ (39-42)

Standard SCS rainfall distribution used, Table Number ______________ (43)

Main time increment in Executive Control (hrs.) ______________ (44-47)

Dimensionless hydrograph peak K factor (standard = 484) ______________ (48-53)

Was the baseflow option used? 1 ☐ yes 2 ☐ no (54)

Were regional relationships used to develop input parameters, if yes explain on back?
1 ☐ yes 2 ☐ no (55)

8. TIME ESTIMATES

a. Give approximate time to develop each of the following input parameters:

Drainage area (includes subareas) (hrs) ______________ (19-22)

Weighted runoff curve number(s) - land use & soils (hrs) ______________ (23-26)

Times of concentration (hrs) ______________ (27-30)

Reach lengths and routing coefficients (hrs) ______________ (31-34)

Stream cross-section data, if used (hrs) ______________ (35-38)

Structure data, if used (hrs) ______________ (39-42)

b. Provide a summary of your computer processing time

Number of computer runs attempted including final ______________ (44)

Total central processing unit (CPU) time (sec) ______________ (45-50)

Computer type and location ______________ (51)

9. PLEASE ATTACH YOUR FINAL SCHEMATIC DIAGRAM AND TR-20 OUTPUT LISTING TO THIS SHEET. PLEASE RETAIN THIS TEST IN YOUR FILE FOR ONE YEAR TO PROVIDE MORE COMPLETE INFORMATION IF REQUESTED.

10. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BY HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - TR-20
(Continued)

sites in the Northwest region, NOAA Atlas 2 (Miller et al., 1973) was provided and where TR-20 and HEC-1 were tested, 48-hour rainfall frequency values were also provided. For sites in the Midwest region, the following was provided: (1) NOAA Technical Memorandum NWS HYDRO-35 (Frederick et al., 1977) which provided 5- to 60-minute rain values; (2) extracts from Weather Bureau Technical Paper No. 40 (Hershfield, 1961) which provided 2- to 24-hour rain values; and (3) extracts from Weather Bureau Technical Paper No. 49 (Miller, 1964) which provided 48-hour rain values.

Additional comparative information was obtained by having some testing done without providing a resource package to the tester. This was done at three sites for the eight simple procedures and two of these sites for the HEC-1 and TR-20 procedures.

C. Testers

Each agency participating in the Work Group either provided testers directly or contracted to have testing done. Additional testers were solicited by a notice in the American Society of Civil Engineers (ASCE) Hydraulics Division newsletter. The ASCE announcement plus contacts by Work Group members resulted in more than 30 volunteers for testing including non-Federal Government employees, consultants, and persons in the academic community. Test assignments for these volunteers were coordinated through the Tennessee Valley Authority and the National Weather Service.

Assignment of sites and procedures for testing was not according to a formal test design other than to assure that sites were distributed among agencies so that no one agency had more than three replicates at a site. Each agency or volunteer identified how much testing effort they could commit in terms of dollars, manpower, number of replicates, or by identifying specific watersheds and procedures they wished to test. Thus, the tester matrix was established by the availability of testers, identified in many cases, by agencies rather than by individuals and their backgrounds. Within agencies, individual assignments were made by various selection methods, from volunteers to contracts with consulting firms. Whenever possible, particularly for TR-20 and HEC-1, assignments were made to those experienced with the procedure. However, only 32 percent of the testers had some experience in these procedures.

In all, about 200 individuals participated in the test. Of the procedure applications, 63 percent were by employees of the Federal Government, 15 percent by state and local governments, 20 percent by consultants, and 2 percent by university personnel. A list of participating groups is given in the acknowledgments section.

Because of the lack of testers experienced in the application of the HEC-1 and TR-20 programs, special training classes were sponsored by the USGS and conducted by the Corps of Engineers (COE) and SCS.

D. Test Management

Management of the test was handled by Work Group members either individually or in subgroups. This included: (1) assembly and distribution of the procedure and resource packages; (2) data collection and management; and (3) quality control of the data. Management times and costs were documented when appropriate to serve as a guide in future testing.

The testing process took 15 months from the time the Hydrology Committee gave approval to proceed with the pilot test in October 1977 to receipt of the majority of test results in January 1979. Of this time it took approximately seven months, until May 1978, to prepare, assemble, and distribute the test materials to the participants and eight months to complete the testing. Computer tabulations of test results were first available in March 1979 for evaluation and analysis.

1. Procedure And Resource Package Management

The assembly of procedure and resource packages was difficult and time consuming. The total effort required to develop, collect, and assemble the resource and procedure packages exceeded 120 man-days.

Procedure Packages. The procedure packages were designed to provide uniform instruction to the testers with as much published materials as possible. Because of the number of packages, data from original publications often had to be assembled and reproduced. Some of the publications also needed to be supplemented with additional instructions or data to provide complete guidance.

The USGS Washington State Equations were extrapolated to the 50-percent-chance flood for eight regions in the eastern part of the state. The USGS Index Flood procedures were extrapolated to the 1-percent-chance flood (Hardison, 1973).

The Fletcher, Reich, COE Snowmelt, and rational procedures were taken from publications referenced in Table V-1 and formatted especially for the pilot test.

Additional curve number tables and peak runoff charts and a graph for use in forested watersheds west of the Cascades were provided for SCS procedures applied in Oregon and Washington.

A special supplement was prepared for the SCS TR-20 procedure to update the user's manual, give guidance as to the level of detail desired for the test, provide the current SCS input forms, and supply a choice of SCS standard storm rainfall distributions.

The HEC-1 user's manual was supplemented by a special instruction package. Subsequently, rainfall-runoff data for about three localized storms in a few nearby watersheds were provided to USGS testers and anyone else requesting them. Also, regionalized unit hydrograph characteristics at nearby stream gage sites were provided if HEC-1 calibration was available in the region.

The current official versions of TR-20 (February 14, 1974) and HEC-1 (January 1973) computer programs were to be used by the testers. To help ensure this, program tapes were passed between agencies and arrangements were made for those without access to the programs. The private sector was informed of the above, but no control was exercised over where they obtained their computer programs.

Resource Packages. Materials for the resource packages were provided by the agency normally providing each type of material. The USGS provided topographic maps, the SCS provided soils data with financial assistance for reproduction from the Water Resources Council (WRC), the SCS provided aerial photographs with financial assistance from the Federal Highway Administration (FHA), and the National Weather Service (NWS) provided the rainfall frequency data.

The task of collecting the material and marking the topographic maps required approximately 90 man-days of effort. The maps were marked with watershed pilot test number, map sheet number, and test site location. The watershed area was blocked out on two additional sets of maps to ensure adequate map coverage and provide the basis for acquiring soils data and aerial photography coverage as needed. The aerial photographs cost approximately $10,000. The topographic maps, soils data, and rain frequency data were donated.

Providing soils data proved difficult as only a few published soil maps covered whole or portions of the test watersheds. SCS personnel in state or local offices were asked to interpret available soils information in order to provide the remainder of the soils data. As a result, the majority of the soils data were furnished on topographic maps with the hydrologic soil groups outlined for a region that extended beyond the watershed divide. In a few cases, the soils data were listed by percent area.

2. Data Collection And Management

The data collected from the pilot test were the completed test record sheets received from the individual testers. A computer program was specifically written to manage the pilot test data. The data from the record sheets were transcribed to a data tape for easier handling. The data tape, therefore, was the data base for analysis of the pilot test and included all tester responses with the exception of tester comments. These comments were a significant part of the test evaluation and are described in section VII.

The test record sheets were planned to make it relatively simple to keypunch the answers directly. Most of the agencies keypunched the data received from their testers. The remainder was done by the USGS. Peak flow estimates were usually rounded to three places; otherwise, data were keypunched exactly as received unless there were missing or obviously questionable data.

3. Quality Control

Each agency was responsible for collecting and reviewing responses from their assigned testers. This included working with the tester to fill in missing data and to correct obvious errors in filling out the record sheets, obvious computational errors, and transposed numbers. Both original data and corrected data were keypunched, verified, and submitted for processing. The USGS acted as the final collection agent for analysis of the test results.

Summary tables of the flows, times, and input parameters were generated. These tables were checked by the Work Group for keypunch and computational errors. The following corrections were made: (1) All state and site codes were made consistent for each watershed; (2) all keypunch errors were corrected; and (3) times to apply were corrected to be equal to or greater than the sum of times to obtain the individual parameters.

Other errors were noted such as: (1) recording the data in the wrong units (e.g., square miles instead of acres); (2) data which seemed to be reversed on the data sheets (e.g., 100-year rainfall less than the 2-year rainfall); and (3) computational errors (e.g., multiplication of C, i, and A in the rational formula did not give the recorded Q). Computational errors were not corrected because it was impossible to equally check all procedures for these types of errors. The potential effect of these errors on the analyses was evaluated and is discussed in section VIII.B.3.a.

E. Data Base

The data base collected for this study is available from the National Technical Information Service (NTIS), Springfield, Virginia, in printed copy and/or computer readable form (magnetic tape). The data base is divided into two parts: (1) the data contained on the record sheets and (2) the criterion variables used in the analyses (the watershed values of bias and reproducibility, and the five separate times to apply for each watershed). Figure VI-5 is an example of the printed copy of the data contained on the record sheets.

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS - PILOT TEST
JANUARY 1979

ILLINOIS WATERSHED=021
USGS STATE EQUATION

TESTER	12	32	75	142	149
PEAK FLOWS					
GAGE ESTIMATE Q50% (CFS)	195	195	195	195	195
GAGE ESTIMATE Q10% (CFS)	563	563	563	563	563
GAGE ESTIMATE Q 1% (CFS)	1250	1250	1250	1250	1250
ESTIMATED Q50% (CFS)	366	384	403	360	380
ESTIMATED Q10% (CFS)	846	888	923	825	890
ESTIMATED Q 1% (CFS)	1510	1580	1640	1475	1580
TESTER INFORMATION					
TIME TO BECOME FAMILIAR (HR)	0	1.0	0.3	0.5	.4
TIME TO APPLY (HR)	1.4	2.2	1.00	2.5	.7
COST ($)	0		0	0	0
HYDROLOGIC EXPERIENCE	4	4	2	4	1
FREQUENCY OF PROCEDURE USE	3	1	1	2	2
HYDROLOGIC KNOWLEDGE OF REGION	1	2	1	1	1
FIELD INSPECTION	1	1	1	1	1
INPUT PARAMETERS					
DRAINAGE AREA (SQ MI)	2.21	2.34	2.93	2.22	2.4
REGIONAL FACTOR	1.11	1.11	1.11	1.11	1.11
RAINFALL INTENSITY INDEX	3.39	3.4	3.38	3.39	3.4
MAIN CHANNEL SLOPE (FT/MI)	26.36	26.09	20.7	25.0	25
TIME TO ESTIMATE INPUT PARAMETERS (HR)					
DRAINAGE AREA	0.9	.5	0.3	1.0	.2
REGIONAL FACTOR	.02	.15	0.1	0.1	.1
RAINFALL INTENSITY INDEX	.03	.5	.10	0.1	.1
MAIN CHANNEL SLOPE	.15	1.0	0.2	1.0	.2

EXAMPLE OF THE PRINTED COPY OF THE DATA CONTAINED ON THE RECORD SHEETS

FIGURE VI-5

VII. EVALUATION OF TESTING PROCESS

An important objective of the pilot test was to evaluate how to conduct a nationwide test from the standpoint of data collection and management. It was recognized that apparent differences in procedure performance could result from the manner in which the pilot test was designed and conducted to simulate field conditions. This section provides an evaluation of the testing process including comments by the testers to guide future testing.

A. Work Group Evaluation

1. Procedure Packages

Procedure Descriptions. Some problems were encountered in reproducing the procedure descriptions directly from publications. A few of the maps and figures needed in the application of the Reich and USGS State Equations and Index Flood procedures were difficult to read after they were reduced and copied.

In future testing the original text should be provided whenever possible and all supplemental descriptions should be carefully reviewed for clarity. The supplemental description of the TR-20 procedure written specifically for the pilot test was confusing to some testers. This supplement was written to update the user's manual and to provide information on the level of detail and effort desired in the pilot test.

The test should be designed to evaluate the performance of procedures under conditions encountered in practice. Thus, care must be exercised to ensure that the testing process is as neutral as possible in the application of the procedure.

Record Sheets. The record sheets, in general, provided the test information in a convenient form for direct keypunching. Some test questions need to be revised. The question about years of experience was ambiguous and should be expanded to specifically identify the years of experience in making flood-frequency estimates for ungaged watersheds. The description in the instruction letter and the question on the record sheet need to be modified to assure the correct time to apply the entire procedure is provided. An alternative would be to provide an instruction sheet with each record sheet.

In designing the record sheets, it was decided that the input parameters (part 7 of the record sheet) should not be listed in an order so as to guide the user through the procedure, nor should they be listed alphabetical in a way that might confuse the user. It was decided to list all parameters for each procedure on its record sheet whether needed or not in the specific application in some reasonable order and consistently among procedures. The user would have to select those listed parameters applicable to the test watershed. The test results showed that this listing of parameters was confusing.

2. Resource Packages

Three potential problems with the resource packages that could affect procedure performance were recognized early in the test. One problem was the varying age and scales of the available topographic maps. While most of the maps were prepared after 1950, some of the 15-minute quadrangles were prepared prior to 1950. For some of the very small watersheds, the 15-minute quadrangles with 20-foot contours were not adequate for determining some of the necessary watershed characteristics, particularly for TR-55 Graph and Charts, TR-20, and HEC-1.

A second potential problem was the varying age of the aerial photos and indexes provided the tester to assess the "current conditions" of the test watersheds. It is conceivable that the photos did not portray the watershed conditions that prevailed during the majority of the period of the gage record. To reduce resource package costs, the number of aerial photos and topographic maps needed for the larger watersheds were reduced by providing only index sheets and large-scale maps.

A third potential problem was that only a few published soil maps covered whole or portions of the test watersheds. SCS personnel in state or local offices were asked to interpret and sketch available soils information on maps or provide lists of SCS hydrologic soil groups by percent of area.

The test was believed not significantly affected by these problems because for each watershed all testers received the same materials. These materials were the most current and readily available and were identical to those that would be available to practicing hydrologists. However, in practice, more hydrologists would make a field visit to compensate for inadequate data especially for small watersheds and important projects.

3. Sites

In the initial selection of test sites, the major concern was meeting the selection criteria (Table V-2), providing regional geographic variation, and achieving a good distribution of drainage areas within the site size classifications defined earlier. The test site locations were plotted on a map by site size classification within each region to ensure that the latter two criteria were met.

In the preparation of the resource packages for the pilot test, Work Group members roughly outlined the watershed boundaries on maps to ensure coverage of the smaller watersheds with soils data and aerial photos and topographic map coverage for the large watersheds. Visual inspection of the watersheds for significant man-made effects caused some watersheds to be eliminated and substitutes selected for the test. It is virtually impossible to find enough suitable watersheds without any man-made effects. The watersheds used in the pilot test are considered representative of ungaged sites where flood-frequency estimates are required. It was assumed that the watershed conditions shown on the maps and aerial photographs were typical of the period of peak flow record. In the Northwest, the selection criteria of having long records resulted in the majority of test sites being located in mountainous national forest areas. A more diversified sampling is desirable.

The annual peak data at the pilot test stations were briefly reviewed for quality by the Work Group. In addition, hydrologists knowledgeable about the flood hydrology of the watersheds were asked to comment on the suitability of these stations for the pilot test. Two sites were eliminated in this review process. At a few sites a time analysis of the annual peak data was made to check if man-made or natural changes had affected the peak discharge frequency relationships. These sites did not indicate any time trends and it was assumed that the records at the other sites were time stationary. In the nationwide test, a more comprehensive review of time stationarity would be advisable. It would also be desirable to look at individual records and watershed conditions more extensively at the time of site selection.

4. Testers

The tester site assignments were made as testers were identified. Thus, it was not possible to design the test to identify the effects of experience upon conclusions. This requires prior knowledge of the testers and their experience. Future tests should be designed to evaluate the effect of experience upon conclusions.

5. Quality Control

A number of mathematical and other errors in procedure application were to be expected and were identified. A process is needed to identify these errors during collection of test results and have them corrected. To prevent biasing results, a distinction between errors and simple differences in opinion must be clearly made. Experience with the pilot test indicated that this screening should be done at the point of data collection.

6. Management

The pilot test was designed and conducted by a committee whose members had significant additional responsibilities. Although the various tasks were assigned to separate subcommittees, this placed an extreme burden on a few individuals. Further, it was difficult to provide the detailed review and coordination that a test of this size requires. Further testing should be managed and conducted by persons who can devote full time to the effort.

B. Testers' Comments on Test

Testers were encouraged to provide comments about problems encountered in applying procedures or suggestions for conducting the nationwide test. Comments received were not extensive. Only about 10 percent of the submitted record sheets contained substantial comments. Of these, approximately 50 percent of the comments provided detail concerning the application of the procedure to the site by the tester. No attempt was made to summarize these site-specific comments. These included such items as how parameters were measured, what assumptions were made, what options were used, and a more detailed explanation of time required to apply procedures.

The other 50 percent of the comments discussed problems encountered in application of the procedures. These included problems inherent in the procedure itself, problems introduced by materials supplied or materials not supplied by the Work Group, and problems associated with the application of procedures to the individual sites. A few of these discussions included suggestions for improving the procedure or improving the approach for conducting the nationwide test. A summary of the comments received on problems encountered and suggestions for improvement is provided in Appendix 4 by procedures.

Several general conclusions can be drawn from the testers' comments. In general, procedures are not well designed for use by individuals inexperienced with them, with the possible exception of the USGS State Equations. Because many testers in the pilot test were asked to use procedures for which they had no past experience, they were more prone to confusion and error, especially with the more complex modeling procedures.

Some of the procedures were tested on some watersheds for which they were not applicable. Although this was by design of the Work Group, it was not stated and caused problems and confusion for some testers.

The lack of adequate rain, flood, and field data to calibrate the more complex modeling procedures with resulting inadequate testing was identified by most respondents. Respondents, in general, believed that a much better job could be done in a more real situation.

Simple items such as formulating example problems, size of maps and figures, quality of printing, and editorial errors were the major source of confusion and error in procedure use.

Clarity and consistency of definitions and straightforward examples are vital to accurate procedure usage.

VIII. PILOT TEST DATA ANALYSES AND RESULTS

This section describes the analyses of the pilot test data and results including: (1) design and data limitations; (2) data analyses and results; and (3) other pilot test benefits.

When presenting the results of the analyses, procedures are referred to by number rather than name. The numbering code is identified in Tables V-1 and V-6. The reasons for not identifying procedures by name are to achieve objectivity and to emphasize the limitations of the pilot test results. Further, the results are compared in three broad groupings which are based upon the similar processes used to make the estimates and different testing problems. These are: (1) those procedures based on regression analysis of flood peaks (Categories 1 and 3, procedures 1, 2, and 5); (2) those procedures based upon the rainfall-runoff process using non-complex (simple) watershed models and the assumption that the discharge frequency is equal to the rainfall frequency used in the computation (Categories 5 and 6, procedures 3, 6, 7, and 8); and (3) those procedures based upon the rainfall-runoff process using complex computer watershed models and the assumption that the discharge frequency is equal to the rainfall frequency used in the computation (Category 6, procedures 9 and 10). These groupings are supported by the analyses and facilitate subsequent discussion about the nationwide testing needed to develop a comprehensive national guide for peak flow frequency estimates.

In all, 1,784 procedure applications were made as shown in Table V-6. Of these 54 were made without resource packages to evaluate the need for resource packages in a nationwide test. Of the 1,730 remaining applications, the 140 Snowmelt procedure applications and 75 applications of the Reich procedure in the Northwest were excluded from the analysis because of the lack of applicability and testing problems. Deletion of the Snowmelt procedure left two watersheds in the Northwest with only one applicable procedure. As a result, these ten applications (sites 99 and 100) were excluded. Thus, the ANOVA and MANOVA statistical analyses are based upon 1,505 procedure applications.

Four procedures (260 applications) were applied to watershed sites and locations outside the range of intended application. These are: 90 Fletcher procedure applications on watersheds greater than 50 square miles; 40 Reich procedure applications on Midwest watersheds greater than 10 square miles; 65 rational formula applications on watersheds greater than 3 square miles; and 65 TR-55 Graph procedure applications on watersheds greater than 10 square miles. The purpose of these applications was to evaluate procedure performance beyond the range of applicability. The graphical comparisons are based on the 1,245 remaining applications.

A. Limitations of Test Design and Data Base

It is important to recognize the limitations of the pilot test so that conclusions on procedure performance are not drawn from it. The major pilot test objective was to develop the information needed to design a cost-effective nationwide test. This is the first step in the effort to develop an objective, authoritative testing of the performance of different procedures for computing peak flow frequencies for ungaged watersheds under field conditions. The major limitations of the pilot test are as follows:

Regions--The test was limited to two regions--the northwest and midwest United States. Although certain categories or procedures might be expected to perform in a similar manner in other parts of the country, this was not tested and should not be assumed without confirmation.

Site Data--All procedure applications were made assuming no site data were available for calibrating procedures. This is particularly significant for the TR-20 and HEC-1 procedures in Category 6. It is recommended that the watershed models inherent in these procedures be calibrated to site data. If such data were not available, these procedures would not be used unless the study purposes dictated otherwise. In that case an effort would be made to calibrate the model by regional analysis. Some regional data were supplied for some HEC-1 applications.

Tester Experience--The size of the test and completion schedule were such that it was necessary to use persons unfamiliar with the procedure and the region to do much of the testing. As shown in Table VIII-1, although 78 percent of the evaluated procedure applications were by persons with more than 2 years experience, only 4 percent were by persons very familiar with the region of application, and only 8 percent were by persons who had frequently used the procedure. The record sheets did not specifically require the tester to identify the years of experience developing peak flow frequency estimates for ungaged sites as opposed to other experience. Therefore, the data on experience may be misleading.

This lack of experience with procedures and regions is considered most important for the rational formula, TR-55 Charts, TR-55 Graph, TR-20, and HEC-1. These procedures require judgments based upon experience with the procedure and generally a field visit to evaluate watershed conditions. Only 10 percent of testers applying these procedures frequently used them, and field inspections were made by only 8 percent of the testers applying these procedures.

Table VIII-1 treats each item of the tester's background separately. The various combinations of tester background and their effects on accuracy and time to apply are given in Appendix 7.

Table VIII-1

TESTER BACKGROUND INFORMATION

		Categories 1, 3 Procedures			Categories 5, 6 Procedures				Category 6 Procedures		
		State Eq.	Fletcher	Index Flood	Reich	Rational Formula	TR-55 Charts	TR-55 Graph	TR-20	HEC-1	Average
Summary of Tester's Hydrologic Experience (Percent)											
Testers Hydrologic Experience:	0-2 Years	22	24	28	17	17	18	20	21	12	22
	2-5 Years	22	23	24	17	20	25	19	27	26	22
	5-10 Years	17	14	14	19	17	12	16	20	23	16
	10 + Years	39	39	34	47	46	45	45	32	39	40
Summary of Testers' Hydrologic Knowledge of the Region (Percent)											
Knowledge of Region:	No	68	70	71	63	65	69	63	68	68	68
	Somewhat	27	27	24	32	32	29	33	26	27	28
	Very	5	3	5	5	3	2	4	6	5	4
Summary of Testers' Frequency of Procedure Use (Percent)											
Frequency of Use:	Never	40	80	57	92	55	58	59	68	60	62
	Occasionally	38	19	39	8	39	37	29	23	34	30
	Frequently	22	1	4	0	6	5	12	9	6	8
Summary of Field Inspections (Percent)											
Made Field Inspection:	No	94	94	93	93	94	97	91	82	84	92
	Yes	6	6	7	7	6	3	9	18	16	8

Based on 1505 applications.

Regression Procedures--The regression procedures of Categories 1 and 3 were tested on some of the same gage sites that were used in their development. This would not affect the reproducibility but could affect bias. To properly test regression procedures, they should be tested against stations not used in their development. An analysis of the effects of this is contained in section VIII.B.3.c and Appendix 8 for the Ohio and Illinois State Equations.

Data Base - The pilot test data base was not corrected for computational errors or censored for anomalous parameter values and results because it was not possible to identify these in all of the procedures. Attempts were made, however, to eliminate keypunch errors.

This report describes many of the potential problems associated with the quality of the data base that were related to design, management, and execution of the pilot test. Some analyses were conducted to evaluate how the quality of the data base affected Work Group conclusions. These analyses provide further insight into the development of a better data base for the proposed nationwide test.

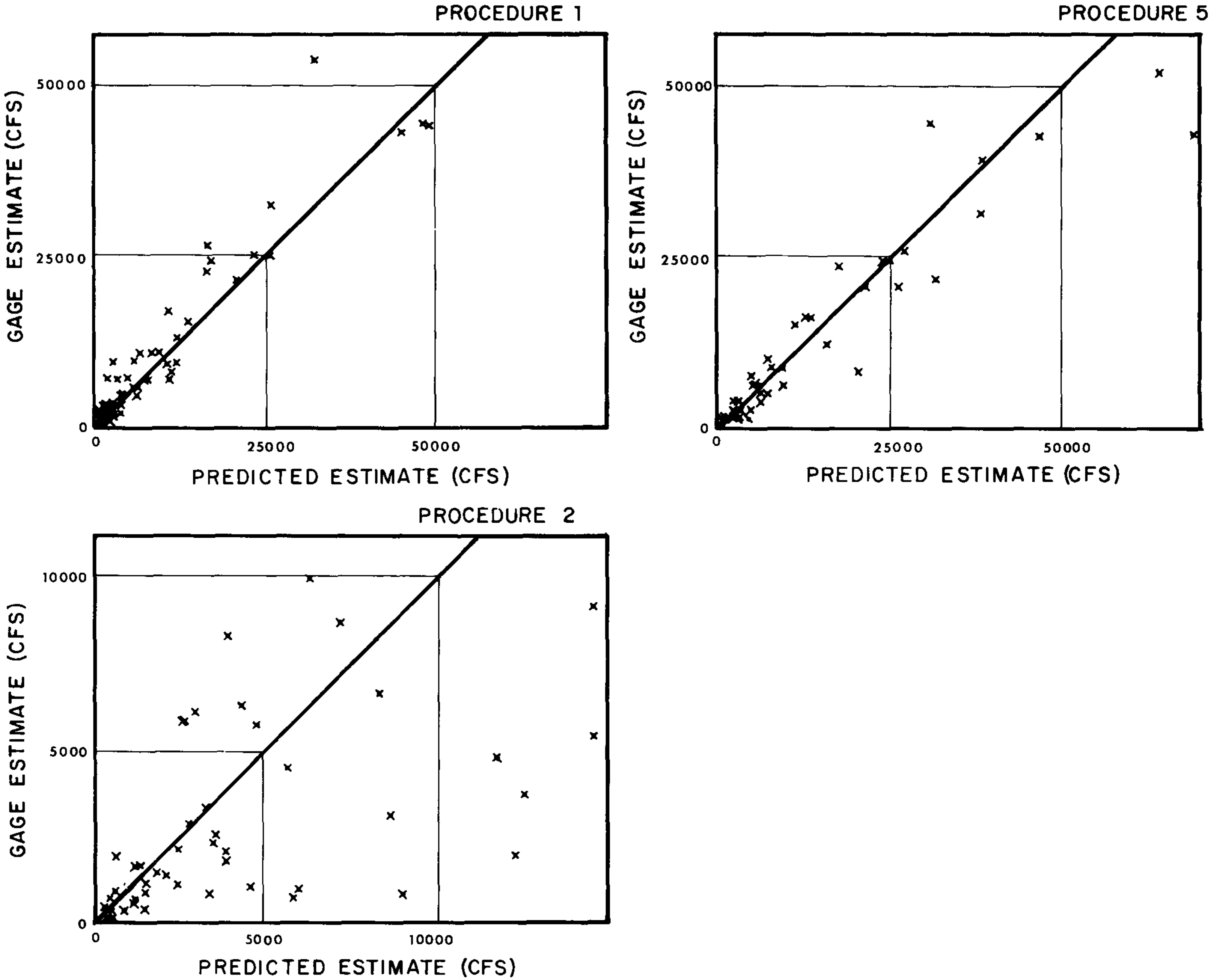
B. Data Analyses and Results

1. Procedure Effects

a. Nonstatistical Comparisons

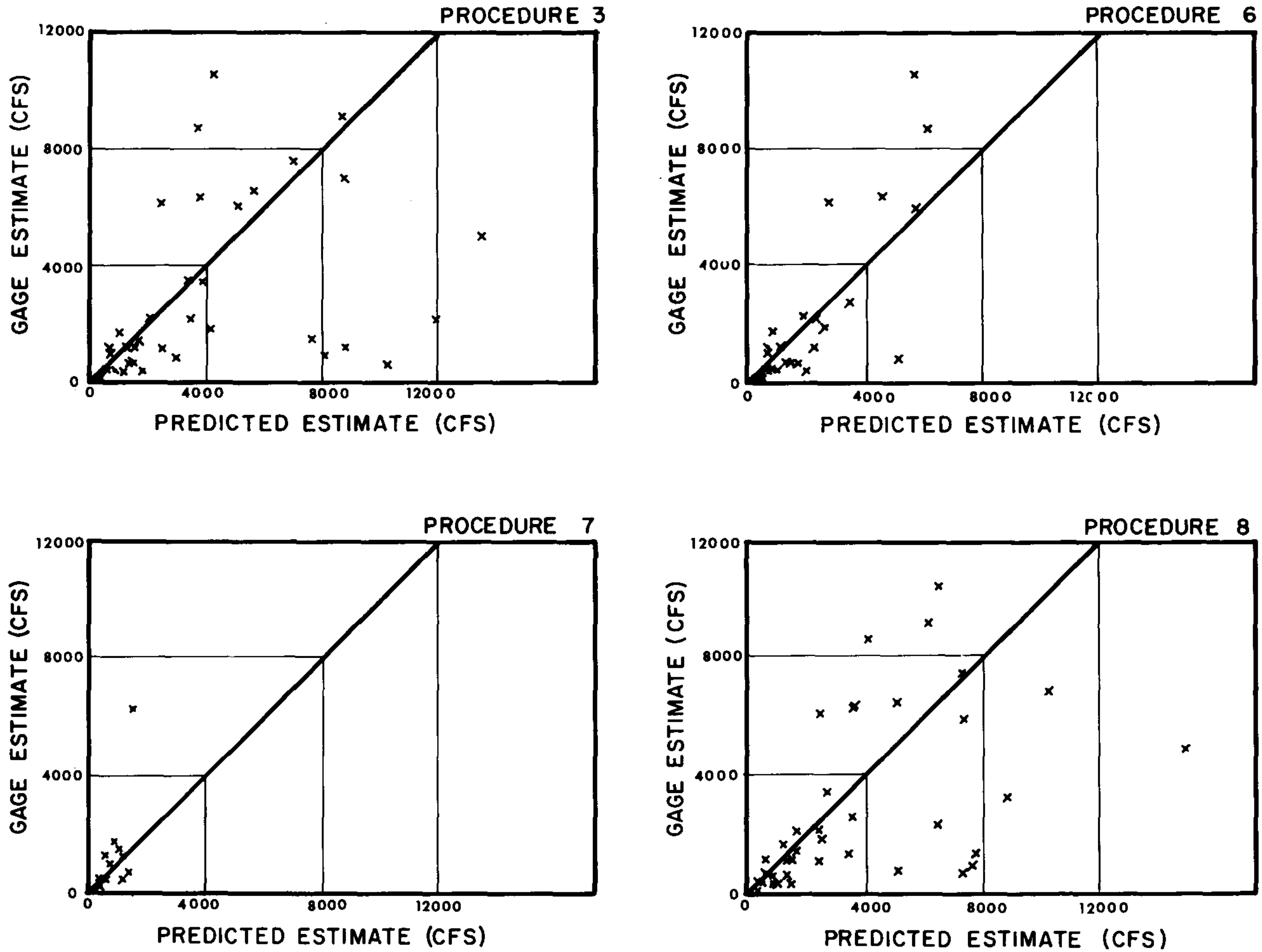
Comparisons between procedures were made using a variety of nonstatistical techniques. Graphical comparisons are extremely helpful in initially analyzing the data. Figures VIII-1 through VIII-3 are scatter plots of the watershed means of the predicted estimates versus gage estimates for the 1-percent-chance flood for each of the nine procedures used in the final analyses. These plots imply that the procedures used in the pilot test performed differently.

Figures VIII-4 to VIII-6 are box plots which display the pilot test data in a manner permitting a simple graphical comparison of procedure performance for the three exceedance probabilities investigated. Each box plot shows the distribution of individual estimates for a given procedure expressed as a percent deviation from the gage estimate. The height of each box defines the 25th and 75th percentiles. The median and mean are shown by solid and dashed lines, respectively. The 10th and 90th percentiles and the minimum and maximum values are shown by lines. The width of each box is a function of the sample size and the sample size is given inside the box.



PREDICTED VERSUS GAGE ESTIMATE
1% CHANCE FLOOD
CATEGORIES 1 and 3

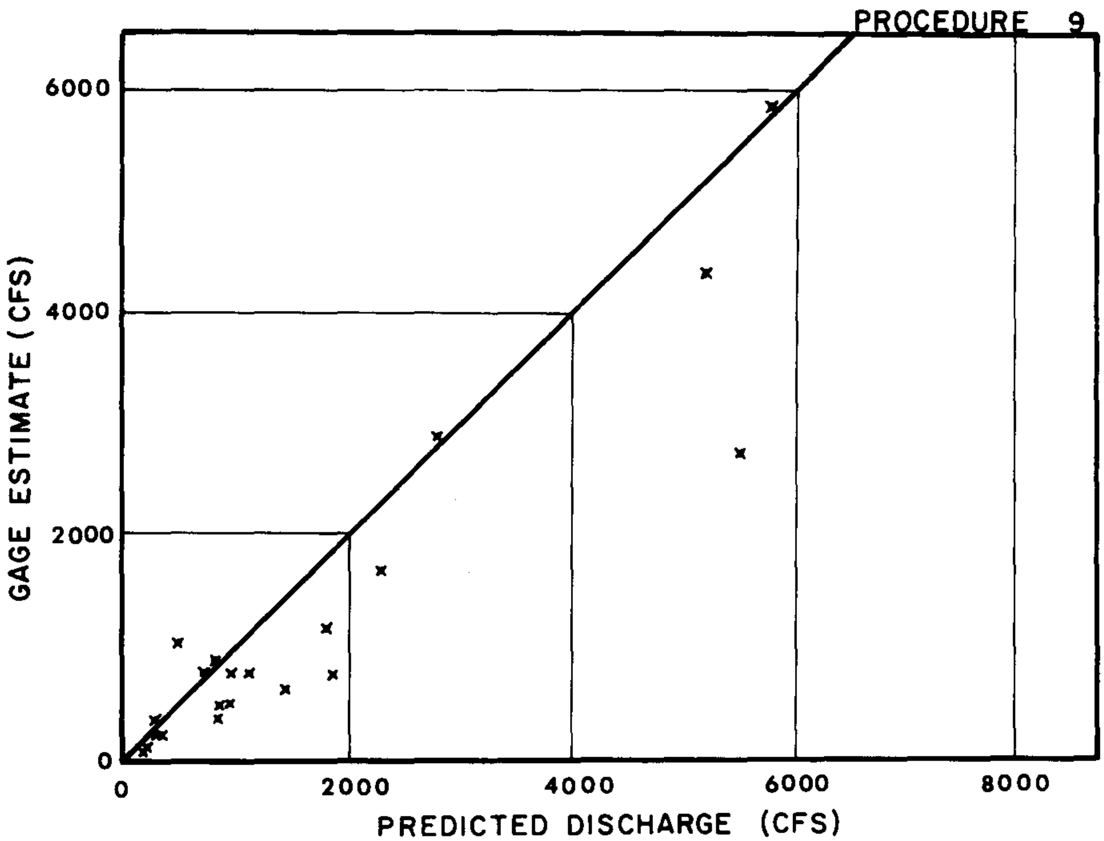
FIGURE VIII-1

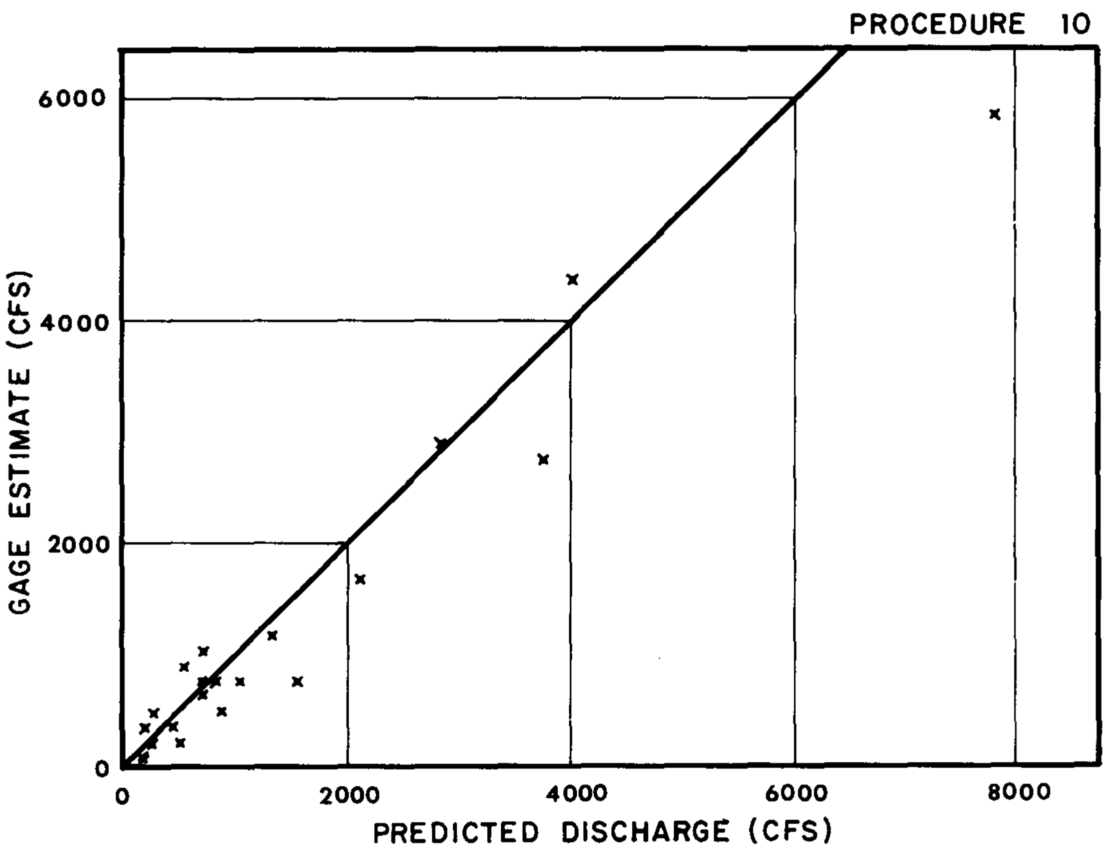


PREDICTED VERSUS GAGE ESTIMATE
1% CHANCE FLOOD
CATEGORIES 5 and 6

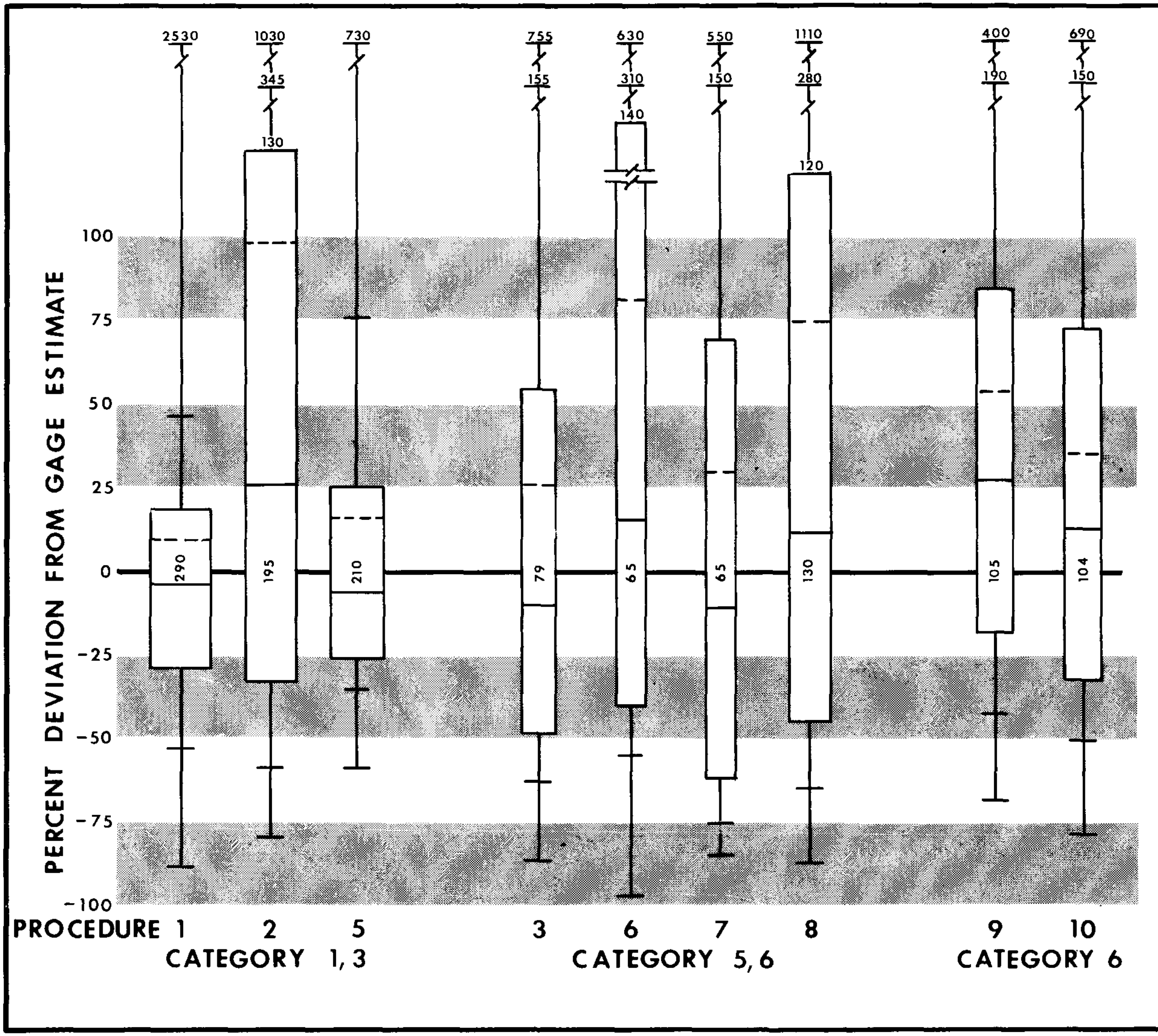
FIGURE VIII-2

FIGURE VIII - 3





PREDICTED VERSUS GAGE ESTIMATE
1% CHANCE FLOOD
CATEGORY 6



TOTAL ANALYSIS
1% FLOOD

FIGURE VIII – 4

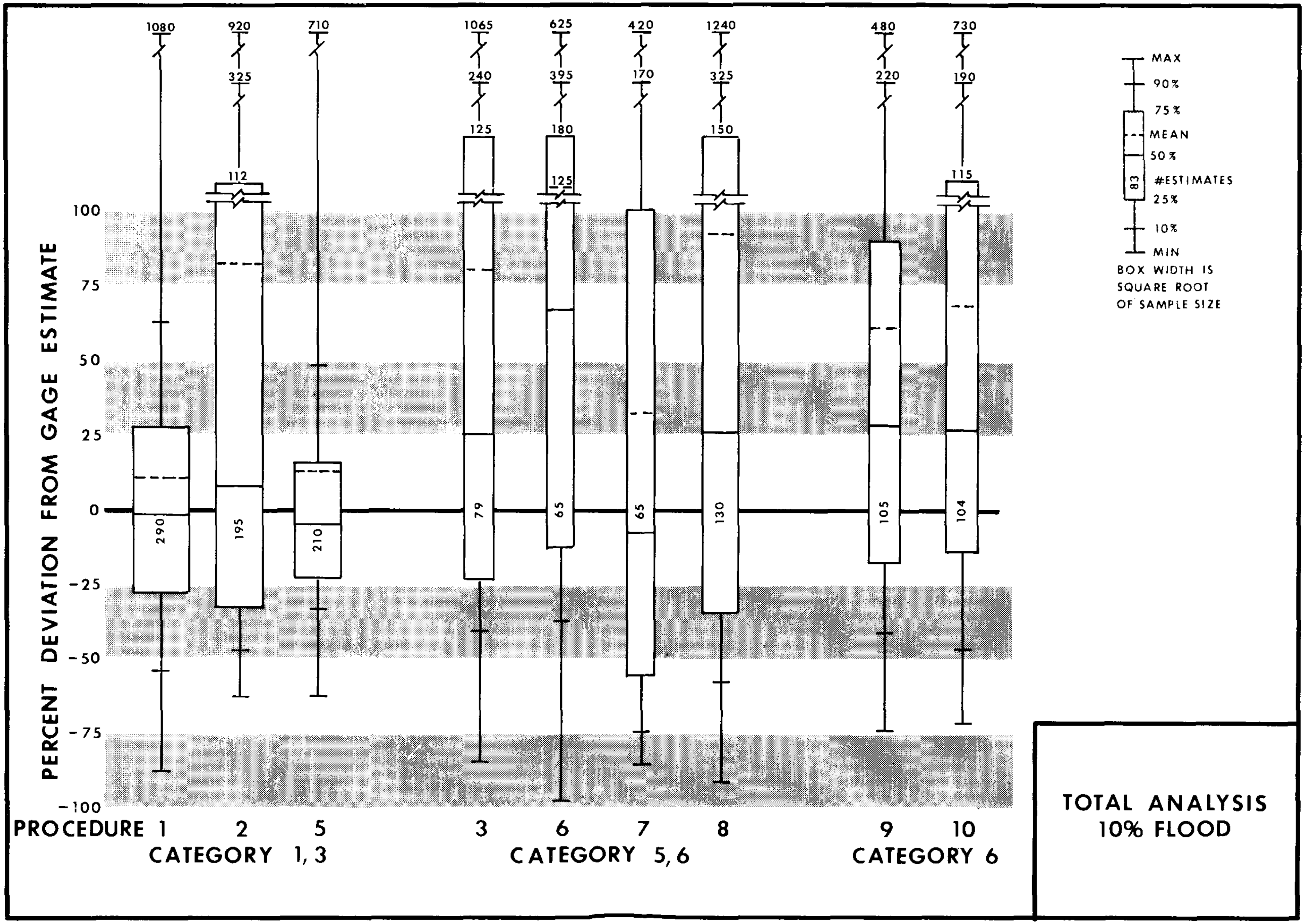
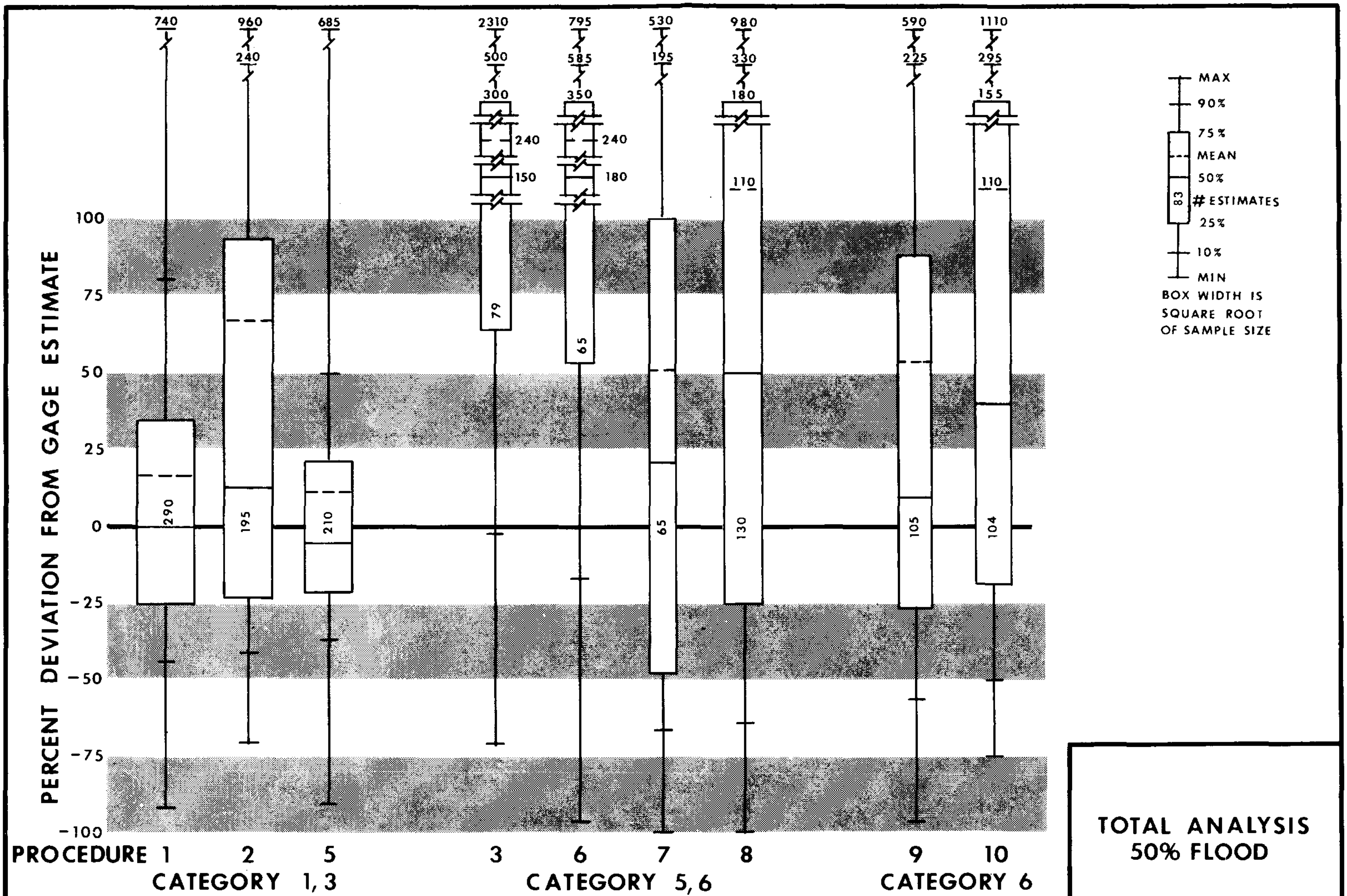


FIGURE VIII — 5



TOTAL ANALYSIS
50% FLOOD

FIGURE VIII – 6

These plots indicate that for the pilot test there were differences in procedure performance and that these differences were similar for each exceedance probability. They imply that one is more likely to obtain an answer which is close to the gage estimate using procedures 1 and 5. They also imply that the greatest variation in procedure performance within the grouping of categories was within the regression based procedures (Categories 1 and 3). Both other groupings performed somewhat similiarly in the test.

Are there differences in procedure performance when evaluated by the criterion variables bias, reproducibility, and time to apply? Figure VIII-7 shows the variability in bias for the 1-percent-chance flood estimates. Bias is the difference between the mean of estimates for a watershed and the gage estimate expressed as a fraction of the gage estimate. Thus, it is an average watershed value in contrast to the previous plots that compare individual estimates. In general, the variations and relationships based on bias are the same as for individual estimates except that procedure 10 of Category 6 compares more favorably with procedures 1 and 5.

Figure VIII-8 shows the variability in reproducibility for the 1-percent-chance flood estimates. Reproducibility is the ability of different people to get the same answer at a site using a particular procedure. It is the standard deviation of the estimates for a watershed, standardized by dividing by the square root of the gage estimate. In general, the relationships between procedure performance based on reproducibility are similar to those based on the total data except that procedure 3 compares more favorably with procedures 1 and 5.

The time to apply the procedures is displayed in Figure VIII-9. As expected, there is a distinct difference in the times required to obtain results using the simple estimating procedures 1 through 8 and the more complex watershed modeling procedures 9 and 10. Testers averaged about 3 hours to obtain an estimate using procedures 1 through 8 and about 30 hours using procedures 9 and 10. Times to apply procedures 1 through 8 increased with increasing drainage area.

b. Statistical Comparisons

The nonstatistical analyses of the previous section imply that there are probably differences between

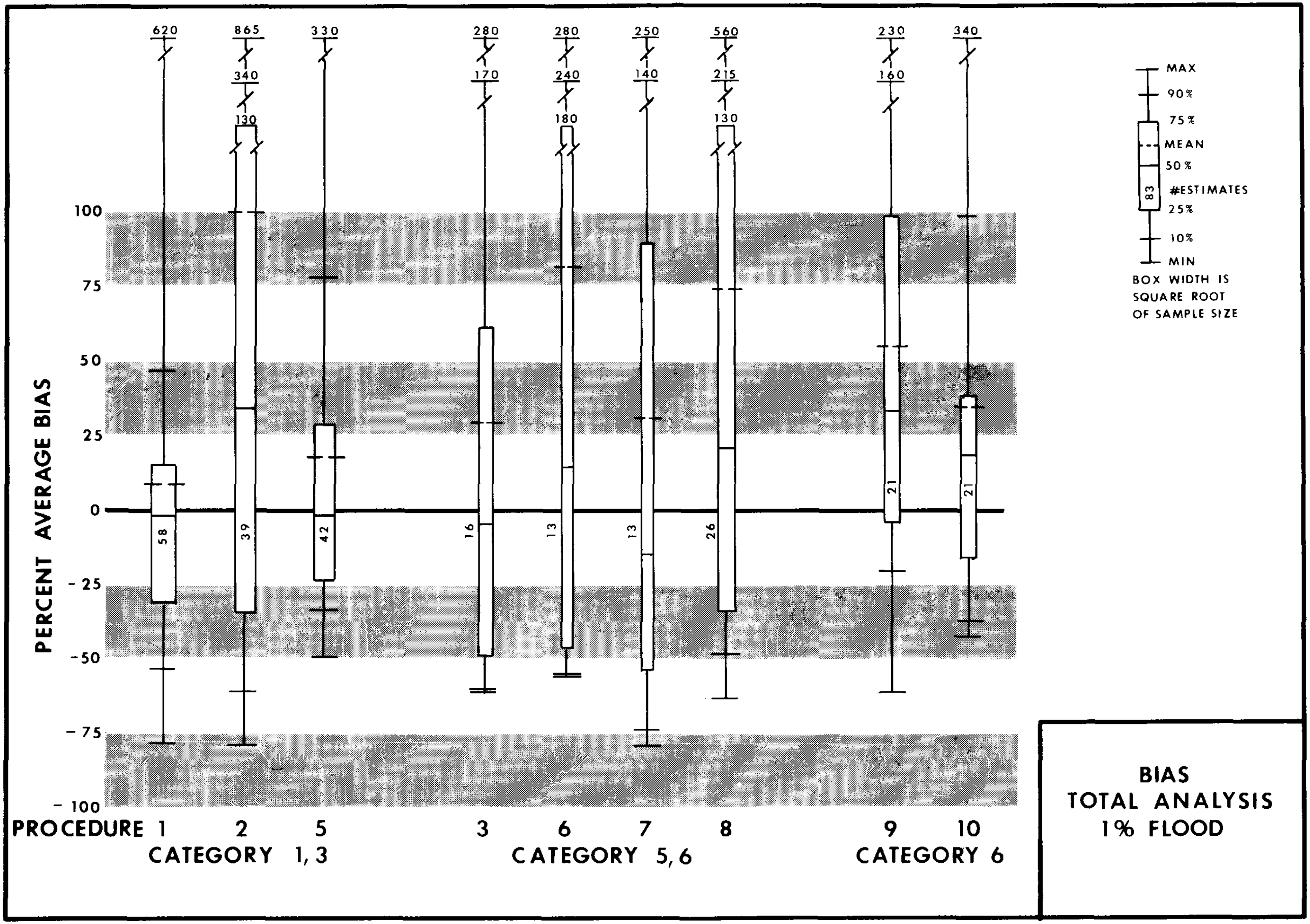
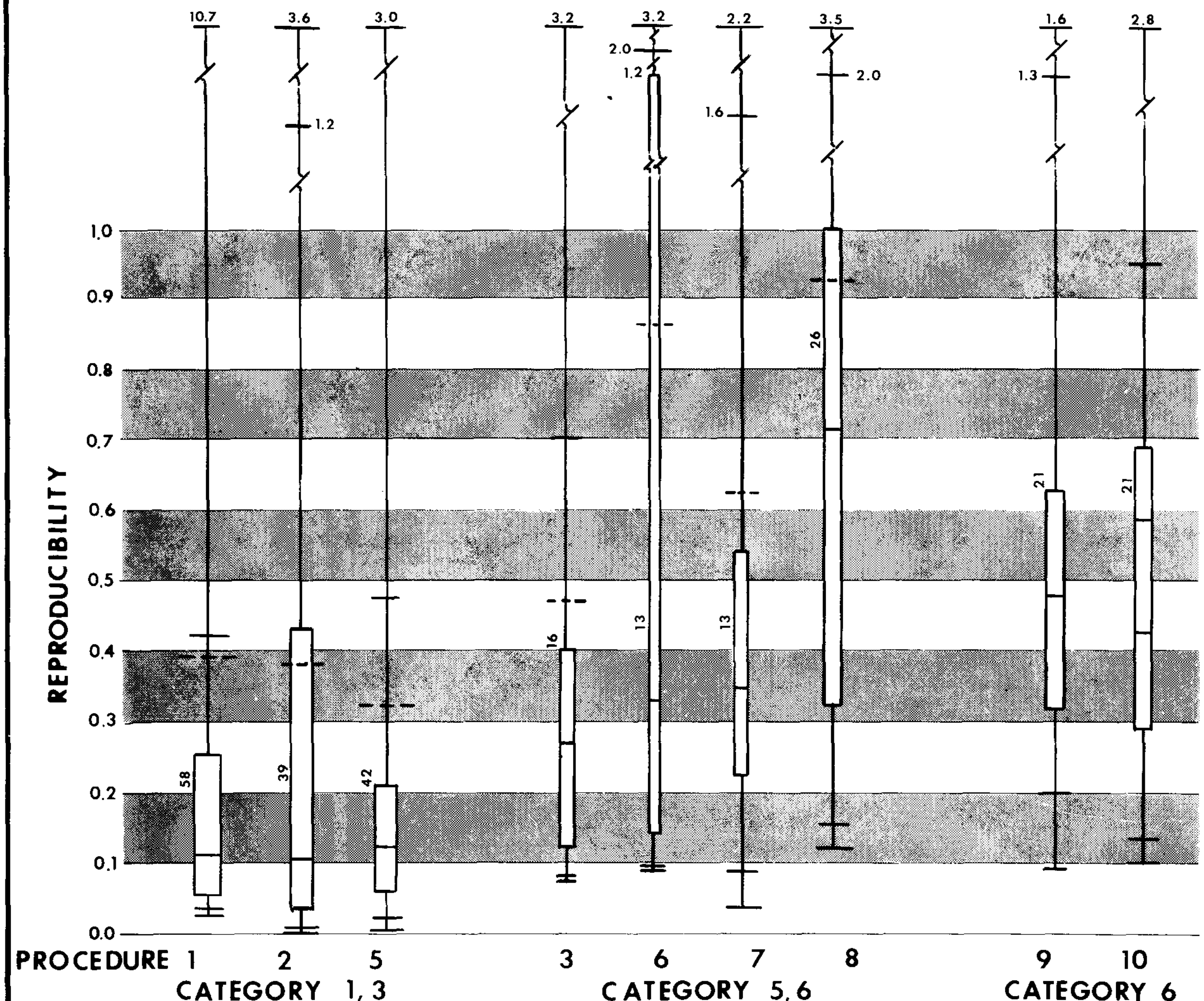
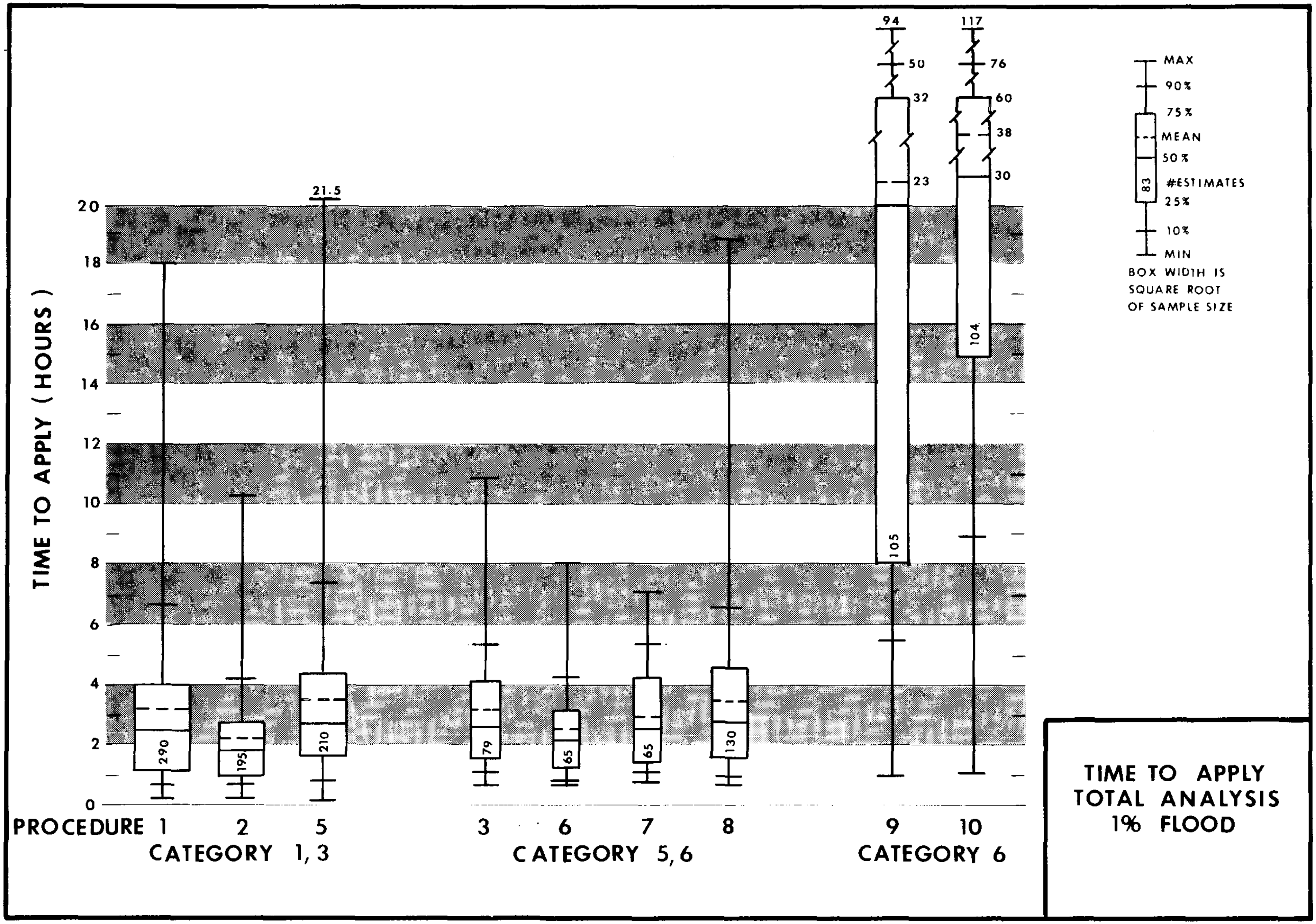


FIGURE VIII – 7



REPRODUCIBILITY
TOTAL ANALYSIS
1% FLOOD

FIGURE VIII - 8



TIME TO APPLY
TOTAL ANALYSIS
1% FLOOD

FIGURE VIII – 9

procedures with respect to the chosen criterion variables. In the pilot test, ANOVA and MANOVA techniques were used to determine whether or not these observed differences are statistically significant and to demonstrate an objective means to discriminate among the procedures on the basis of the criteria of accuracy, reproducibility, and time to apply. This section summarizes the findings. The details of the ANOVA analysis are explained in Appendix 5.

The ANOVA shows that there are statistically significant differences between procedures with respect to bias, transformed reproducibility, and time to apply using a significance level of 5 percent for both the Midwest and Northwest regions. These differences are initially identified by considering the factor "procedures" only, thereby averaging across the levels of the other design factors of exceedance probability, site size, and watershed within site size. The procedures may be classified into groups such that procedures within a group do not differ statistically with respect to a criterion variable, but the groups of procedures are statistically different. There may be some overlap in group membership because the multiple comparisons process considers only pairs of means.

The ANOVA analysis suggest groups of procedures as follows:

Midwest:

Bias	1,5,7,10	Lowest bias group
	9	
	2,8	
	6	
	3	Highest bias group
Transformed Reproducibility	2,5	Lowest transformed reproducibility group
	1	
	7,9	
	6,10,9	
	3	
	8	Highest transformed reproducibility group
Time to Apply	6,7,2,1,5,3,8	Lowest time to apply group
	9	
	10	Highest time to apply group

Northwest:

Bias	1,5	Lowest bias group
	1,9	
	2,7,9	
	10	
	8	
	6	Highest bias group
Transformed Reproducibility	2	Lowest transformed reproducibility group
	5	
	1	
	9	
	10,7	
	8,6	Highest transformed reproducibility group
Time to Apply	2,6,1,7,8,5	Lowest time to apply group
	9	
	10	Highest time to apply group

These groupings are based on Duncan's multiple range tests shown in Appendix 5 (Tables A5-4, A5-10, and A5-13 for the Midwest and Tables A5-17, A5-23, and A5-26 for the Northwest).

The ANOVA also indicates that interactions involving procedures and site sizes, and procedures and exceedance probabilities are statistically significant. What do those significant interactions imply? A two-factor interaction represents the failure of one factor to produce the same effect when the levels of the second factor are changed. These interactions are illustrated using pilot test data for the criterion variable bias in the Midwest.

Consider the procedure-site size interaction. This interaction is significant, implying that the effect of procedures on bias in the Midwest depends on which site size is under consideration. The graph in Figure VIII-10 plots Midwest bias versus site size for procedures 1 and 10. Note that the lines in this figure are not parallel, implying that the effect on bias of changing from procedure 1 to procedure 10 depends upon which site size is involved.

As a second example, consider the procedure-exceedance probability interaction. Figure VIII-11 shows a plot of Midwest bias versus exceedance probability for procedures 2 and 3. Once again, the lines are not parallel. This implies that the effect on bias of changing from procedure 2 to procedure 3 depends upon which exceedance probability is used. Further details

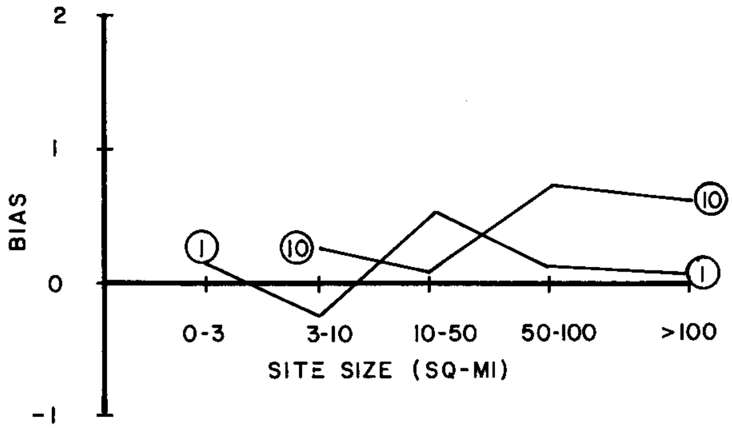


FIGURE VIII-10 PROCEDURE-SITE SIZE INTERACTION

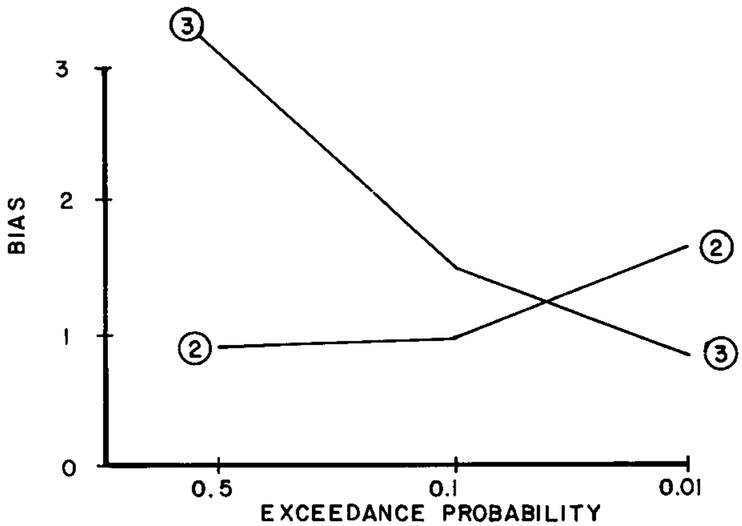


FIGURE VIII-11 PROCEDURE-EXCEEDANCE PROBABILITY INTERACTION of the analysis of these interactions for each criterion variable and region are in Appendix 5.

Why do those significant interaction effects occur? They may indicate the presence of real effects. That is, there may be some aspect of the design or implementation of a procedure that causes its performance to depend on such factors as the site size or the exceedance probability. On the other hand, these interactions may be a result of one or more of the following factors: (1) ANOVA (and MANOVA) analyses are sensitive to the presence of outlier or "wild" values and significant interactions may be due to erratic data in some of the cells; (2) the significant interactions may result because the level of significance ($\alpha = 0.05$) is not appropriate to identify meaningful hydrologic differences; and (3) the significant interactions may be due to two or three of the procedures. The ANOVA analysis is measuring the average effect of the design factors across all the procedures and a few procedures may influence the significance of certain interactions. For example, in the Northwest region procedures 6 and 10 are causing the procedure-exceedance probability to be significant for both bias and transformed reproducibility (see Figures A5-7 and A5-9). The Northwest analysis was rerun without procedures 6 and 10 and the procedure-exceedance probability interaction was not significant.

The MANOVA shows that procedures can be grouped such that all the procedures within a group are not significantly different, but all groups of procedures are significantly different.

Procedures with similar characteristics were initially classified into eight categories by the Work Group. Procedures from four of the eight categories were included in the pilot test. The box plots show that some of the procedures introduced a significant amount of variation into a category while other procedures that were in different categories had similar values of the three criterion variables. This suggested that other procedure combinations should be investigated.

Three MANOVA/DISCRIM analyses were made using different procedure combinations by region. In these analyses, differences were measured across groups rather than individual procedures. The following three alternative procedure combinations systems were examined.

Group	Original Classification	Combination 1	Combination 2	Combination 3
1	1,2	1,2	1,2,5	1,2
2	5	5	3,6	5
3	3,6	3,6,8	7,8	3,6,8
4	7,8,9,10	7,9,10	9,10	7
5				9,10

These alternatives will now be referred to as groups so that the groups are not confused with the eight categories in the classification system of the Work Group.

A MANOVA/DISCRIM analysis was performed on the criterion variables for the group separation of Combination 1. The statistics are given in Table VIII-2 and a decision table is given in Table VIII-3. The results indicate that the groups differ except for groups 1 and 2, both of which include regression techniques; thus a difference between groups 1 and 2 of Combination 1 was not expected.

Because of the results of the Combination 1 analysis, procedures 1, 2, and 5 were grouped together in Combination 2. Also, because procedures 7 and 8 are based on similar hydrologic characteristics, they were used to form a single group. The statistics of Table VIII-4 and decision table of Table VIII-5 indicate that all groups show significant differences.

Combination 3 differs from Combination 1 in that procedure 7 is separated from procedures 9 and 10. The statistics of Table VIII-6 and the decision table of Table VIII-7 indicate that several groups are not significantly different; specifically in the Midwest, group 1 does not differ from 2 and group 2 does not differ from group 4. In the Northwest, group 1 does not differ from either 2 or 4 and groups 2 and 4 do not differ from each other.

Table VIII-2

STATISTICS FOR CRITERION VALUE COMPARISON BY GROUP: COMBINATION 1

Group	Procedures
1	1, 2
2	5
3	3, 6, 8
4	7, 9, 10

Region	Group	Sample Size	Bias Mean	Bias Std Dev	Reproducibility Mean	Reproducibility Std Dev	Time to Apply Mean	Time to Apply Std Dev
Midwest	1	76	0.47	1.28	0.18	0.33	2.96	1.90
	2	26	0.16	0.74	0.16	0.37	3.17	1.78
	3	64	2.39	3.64	1.53	2.15	3.47	1.76
	4	32	0.55	0.70	0.74	0.47	25.33	18.38
	Total --		1.07	2.25	0.71	1.26	6.77	7.54
Northwest	1	39	0.31	0.90	0.37	0.53	3.14	2.05
	2	16	0.05	0.43	0.38	0.52	4.43	3.07
	3	25	2.82	3.24	2.56	2.94	3.96	1.14
	4	23	1.07	1.72	1.30	1.25	22.96	14.42
	Total --		1.05	1.88	1.11	1.61	7.96	7.04

Table VIII-3

DECISION TABLE FOR COMPARISON BY GROUP: COMBINATION 1

Group	Procedures
1	1, 2
2	5
3	3, 6, 8
4	7, 9, 10

Region	Group Differs from Group	1	2	3	4
Midwest	1	--	No	Yes	Yes
	2		--	Yes	Yes
	3			--	Yes
	4				--
		1	2	3	4
Northwest	1	--	No	Yes	Yes
	2		--	Yes	Yes
	3			--	Yes
	4				--

Table VIII-4

STATISTICS FOR CRITERION VALUE COMPARISON BY GROUP: COMBINATION 2

Group	Procedures
1	1, 2, 5
2	3, 6
3	7, 8
4	9, 10

			Bias		Reproducibility		Time to Apply	
Region	Group	Sample Size	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Midwest	1	102	0.39	1.17	0.18	0.34	3.01	1.86
	2	40	2.99	4.18	1.67	2.54	3.11	1.35
	3	32	1.15	2.01	1.19	1.15	3.68	2.02
	4	24	0.59	0.61	0.70	0.38	32.96	14.59
	Total --		1.07	2.22	0.71	1.26	6.77	5.30
Northwest	1	55	0.24	0.80	0.37	0.52	3.51	2.43
	2	10	4.99	3.55	3.27	2.76	3.51	0.88
	3	20	1.18	1.83	1.79	2.69	4.18	1.20
	4	18	1.19	1.91	1.41	1.37	28.19	11.50
	Total --		1.05	1.66	1.11	1.60	7.96	5.15

Table VIII-5

DECISION TABLE FOR COMPARISON BY GROUP: COMBINATION 2

Region	Group Differs from Group	1	2	3	4
Midwest	1	--	Yes(2)	Yes(2,3)	Yes(1,2)
	2		--	Yes(3)	Yes(1,2)
	3			--	Yes(1,3)
	4				--
		1	2	3	4
Northwest	1	--	Yes(2)	Yes(3)	Yes(1,2)
	2		--	Yes(2)	Yes(1,2)
	3			--	Yes(1,3)
	4				--

Note: Numbers in parentheses show the discriminant function on which a significant difference between one group of procedures and another was found. For example, group 1 is significantly different from group 2 in the Midwest and the second discriminant function detected this difference.

Table VIII-6

STATISTICS FOR CRITERION VALUE COMPARISON BY GROUP: COMBINATION 3

Group	Procedures
1	1, 2
2	5
3	3, 6, 8
4	7
5	9, 10

			Bias		Reproducibility		Time to Apply	
Region	Group	Sample Size	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Midwest	1	76	0.47	1.28	0.18	0.33	2.96	1.90
	2	26	0.16	0.74	0.16	0.37	3.17	1.78
	3	64	2.39	3.64	1.53	2.15	3.47	1.76
	4	8	0.44	0.95	0.86	0.70	2.46	0.31
	5	24	0.59	0.61	0.70	0.38	32.96	14.59
Northwest	1	39	0.31	0.90	0.37	0.53	3.14	2.05
	2	16	0.05	0.43	0.38	0.52	4.43	3.07
	3	25	2.82	3.24	2.56	2.94	3.96	1.14
	4	5	0.64	0.70	0.91	0.52	3.96	1.22
	5	18	1.19	1.91	1.41	1.37	28.19	11.56

Table VIII-7

DECISION TABLE FOR COMPARISON BY GROUP: COMBINATION 3

Group	Procedures
1	1, 2
2	5
3	3, 6, 8
4	7
5	9, 10

Region	Group Differs from Group	1	2	3	4	5
Midwest	1	--	No	Yes	Yes	Yes
	2		--	Yes	No	Yes
	3			--	Yes	Yes
	4				--	Yes
	5					--
		1	2	3	4	5
Northwest	1	--	No	Yes	No	Yes
	2		--	Yes	No	Yes
	3			--	Yes	Yes
	4				--	Yes
	5					--

In a nationwide test, it is recommended that the analyses proceed in steps from nonstatistical analyses to more complex statistical analyses. It should include a sufficient number of different analyses to assure sound conclusions. The box plots used in the pilot test were found to best illustrate potential trends, tendencies, and differences in procedure performance. This information helps to focus the statistical analyses on significant problems and provides a means of communication with persons not immediately familiar with statistical techniques. The various statistical analyses used in the pilot test were complementary and were all found to provide useful insights about procedure performance. The analyses should at least include these statistical techniques.

2. Effects of Other Design Factors

When developing the experimental design for the pilot test, it was believed that procedure performance might vary with watershed (site) size, exceedance probability, region, and category of procedure. The test was designed to permit evaluation of these potential variations. Also, it was of interest to evaluate the effects of the application of the procedure beyond its intended range, the variation in gage estimate, the unbalanced nature of the experimental design, the use of average watershed values rather than individual values of bias, and the method of standardization. The effects of these experimental design factors upon conclusions are summarized in the following paragraphs.

a. Watershed Size

The variation in the procedure performance by category and site size is illustrated by the box plots of Figures VIII-12 to VIII-14. They show variations in the 1-percent-chance flood estimate for all procedures and site size classifications. The variations in the 1-percent-chance flood for bias, reproducibility, and time to apply are shown in Appendix 6. They graphically illustrate why a site size effect and, to some extent, a procedure-site size interaction were detected in the ANOVA analysis.

The mean and standard deviation of each criterion variable was computed using the watersheds within five drainage area classes: 0-3, 3-10, 10-50, 50-100, and greater than 100 square miles. The values were computed for each procedure and each region. The bias, reproducibility, and time to apply values for each exceedance probability are shown in Appendix 6.

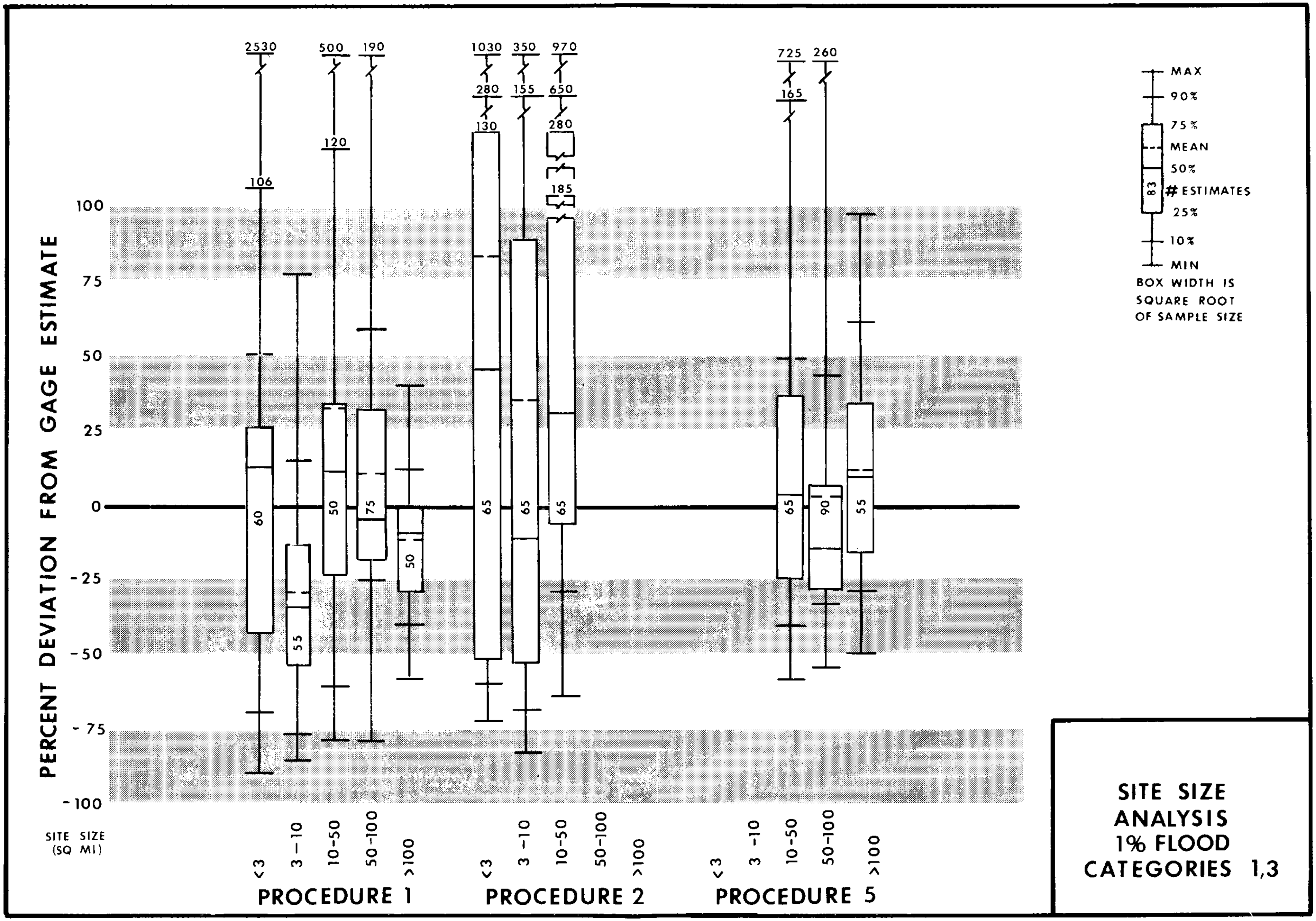


FIGURE VIII-12

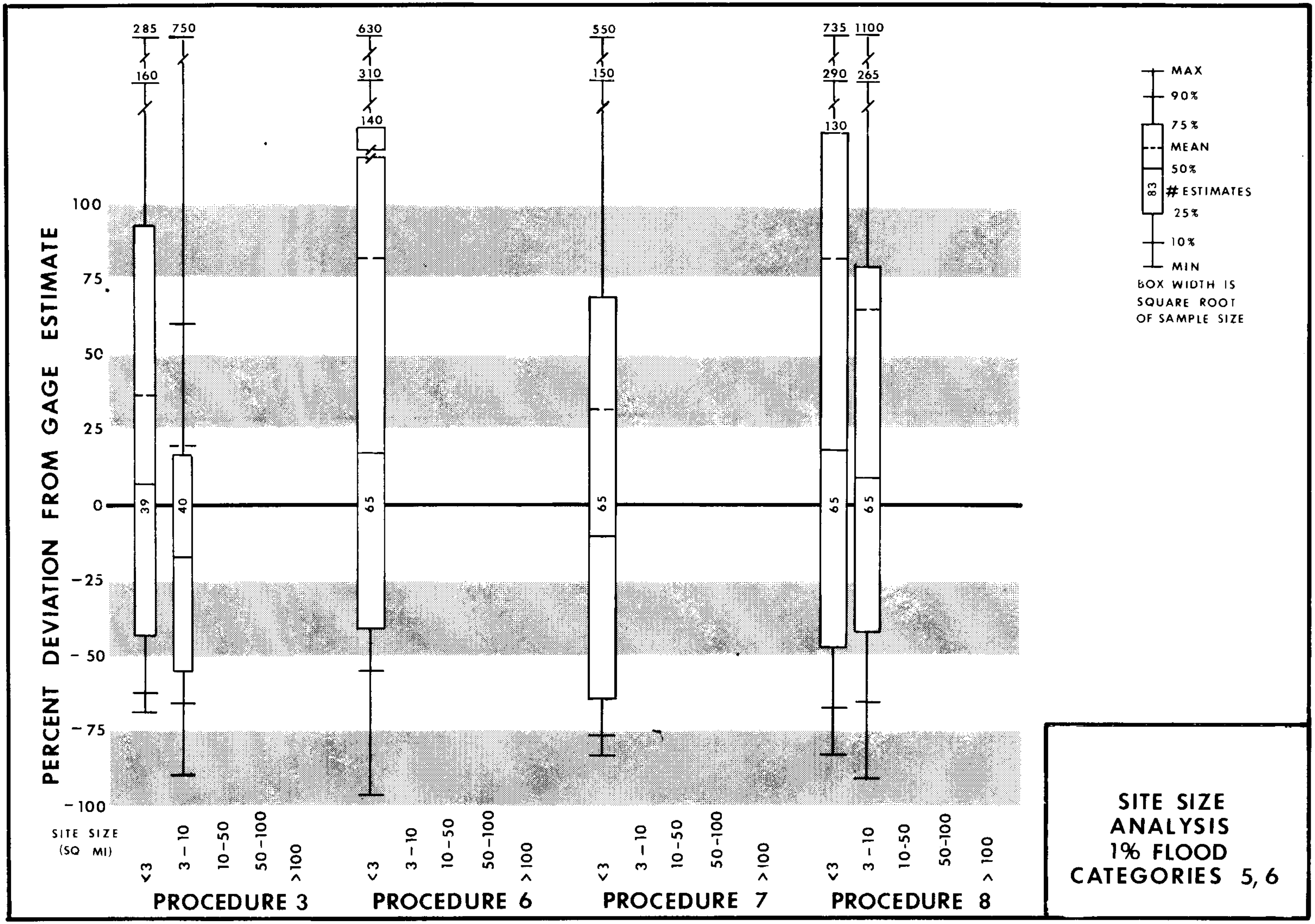
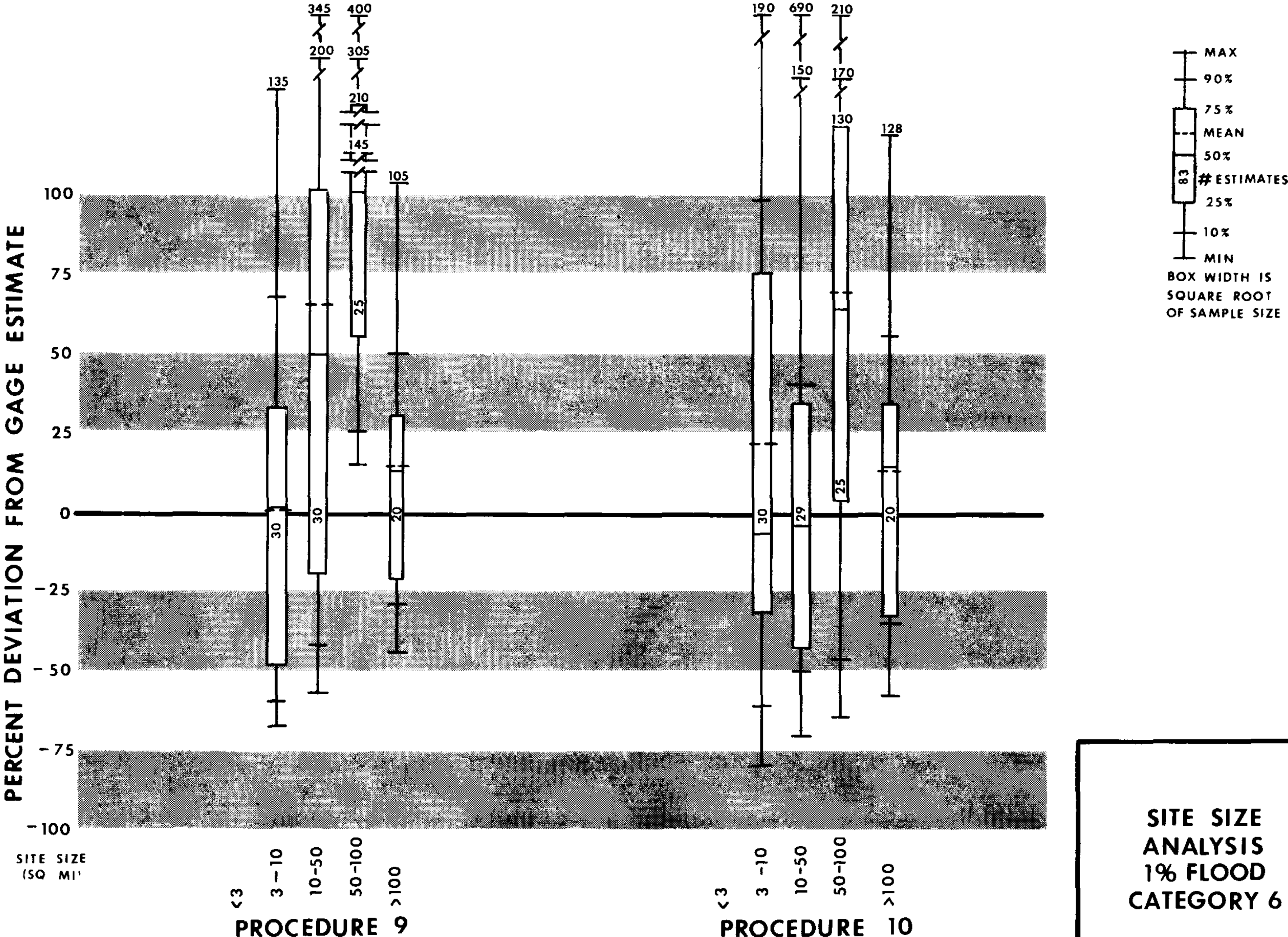


FIGURE VIII – 13



SITE SIZE ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE VIII – 14

Even though the ANOVA analysis detected a site size effect, it is difficult to detect a site size trend from a visual inspection of this data using the bias and reproducibility indexes. For example, procedure 1 in the Midwest shows consistently small values of bias and reproducibility in all drainage area classes except in the 10- to 50-square-mile class. There is no reason to believe that procedure 1 gives biased estimates in this class so this anomaly must be attributed to sampling variation. This is evidenced by the standard deviations, and thus the standard errors of the means, which are quite large for this drainage area class. It is also possible that those procedures that have been tested outside the range for which they are appropriate would show poorer statistics. This is true for procedures 3, 6, and 8 because the largest bias occurs in the largest drainage area class. In fact, on inspection of Table A6-1, procedures 3, 6, and 8 do exhibit a trend in bias for the different site sizes. These procedures are probably causing the significant procedure-site size interaction for bias in the ANOVA analysis for the Midwest (see also Figure A5-1).

The time to apply criterion shows a trend that should be expected. Specifically, the mean increases as drainage area increases. The standard deviations also show a direct trend. These trends appear to be physically significant. Their statistical significance was not examined using MANOVA.

In order to investigate the effect of site size, two additional ANOVA analyses were made grouping the data into two and three site size classifications. Changing the number of site size classifications from five to three to two did not significantly affect the conclusions.

For a nationwide test, it is recommended that at least three site size groupings be used. There is some evidence in the pilot test that three groupings produce results that are comparable with those obtained using five groupings.

b. Exceedance Probability

Peak flow estimates were made for three exceedance probabilities: 0.01, 0.10, and 0.50. The variation in procedure performance by category and exceedance probability is illustrated by the box plots of Figures VIII-4 to VIII-6. These plots illustrate, to some extent, why the main effect of exceedance probability and the procedure-exceedance probability interaction were significant in the ANOVA analysis.

From a hydrologic standpoint it is expected that the three exceedance probabilities used in the pilot test would be correlated. To examine if this correlation was significant, the correlation coefficients were determined for the three criteria and the three exceedance probabilities. The correlation matrix for each procedure is given in Appendix 6. With few exceptions the correlations of both the bias and reproducibility across exceedance probabilities are very high, with most values over 0.8. The implications of this are: (1) The bias and reproducibility indexes could be averaged across the three exceedance probabilities without a loss of information and (2) the results for each analysis will lead to similar conclusions. A MANOVA analysis for each exceedance probability was performed separately.

ANOVA analyses were conducted both on all exceedance probabilities simultaneously and on each exceedance probability separately. The conclusions did not differ except that the ranking of the procedures changed slightly depending upon the selected exceedance probability. This is a reflection of the procedure-exceedance probability interaction. As noted earlier, the significant procedure-exceedance probability interaction for both bias and transformed reproducibility in the Northwest is caused by procedures 6 and 10. An inspection of Table A6-1 does in fact indicate a trend in bias and reproducibility with exceedance probability for procedures 6 and 10 for the Northwest.

The observations in the ANOVA analysis where all three exceedance probabilities are simultaneously considered are correlated. However, any difficulties caused by this correlation should show up in the residual analyses associated with the ANOVA. These residual analyses, as discussed in Appendix 5, did not indicate a problem with correlated data.

For a nationwide test, it is recommended that peak flow estimates be made for at least two exceedance probabilities: 0.01 and 0.10. Although the pilot test indicates no major differences in conclusions for the different exceedance probabilities, at least two values should be tested to verify that the procedure-exceedance probability interaction is not significant and that conclusions do not differ across exceedance probabilities. The additional costs for a second exceedance probability are trivial.

c. Regional Differences

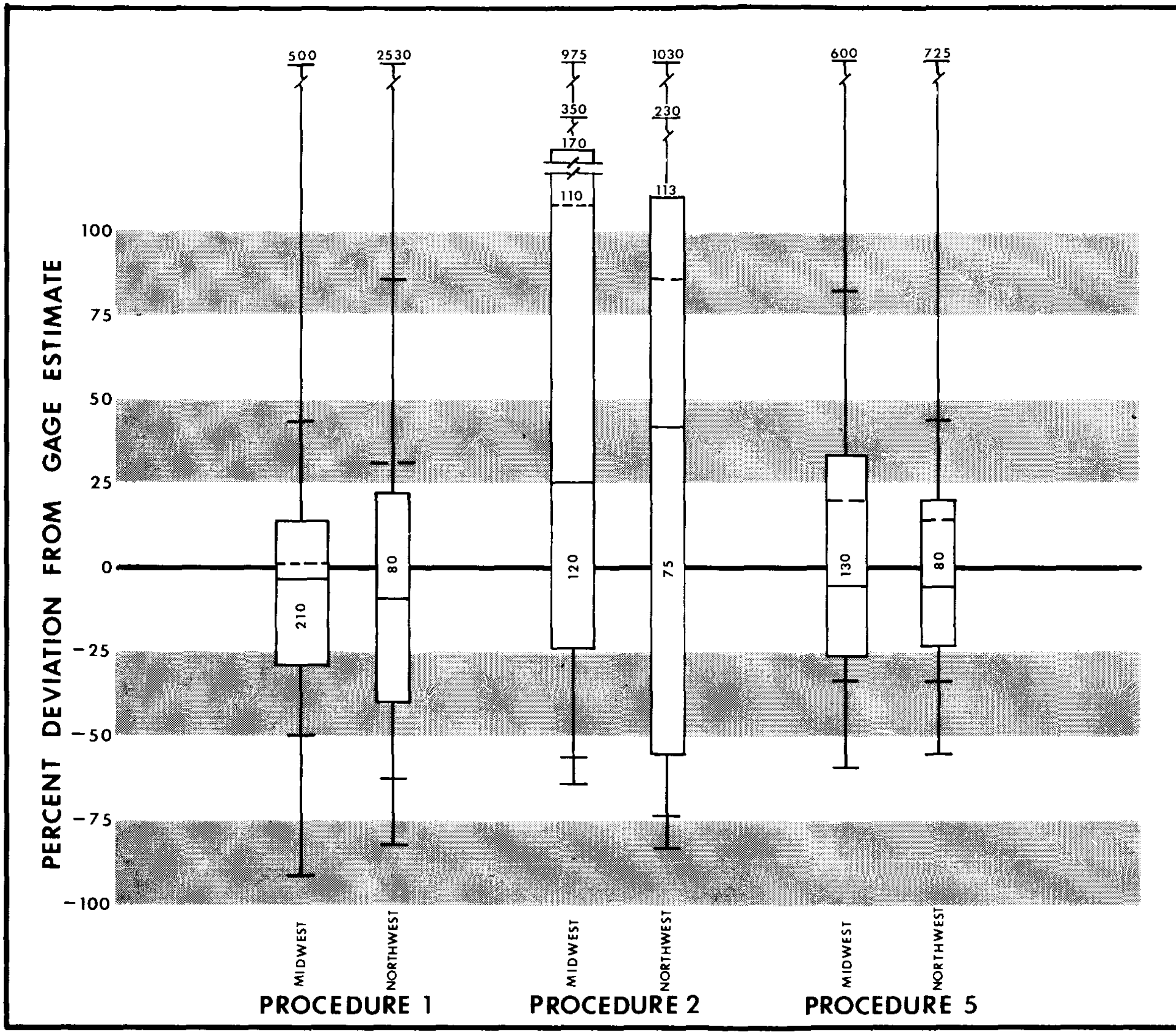
Pilot test data were collected in the Midwest and Northwest regions of the United States. The variation in procedure performance by category and region is illustrated by the box plots of Figures VIII-15 to VIII-17. They show variations in the 1-percent-chance flood estimates for all procedures in both regions. The variations in the 1-percent-chance flood for bias, reproducibility, and time to apply for both regions are shown in Appendix 6.

The box plots indicate only a slight tendency toward regional differences. For example, the bias for procedures 7 and 8 (Figure A6-11), the bias for procedures 9 and 10 (Figure A6-12), the reproducibility for procedure 2 (Figure A6-13), and the reproducibility for procedures 6, 7, and 8 (Figure A6-14) suggest regional differences. Care should be exercised in interpreting these plots as some of them are based on small samples.

Major differences across regions should not be expected because the procedures are usually regionalized. For example, regression equations are usually fitted to data from the region in which they are applied. Similarly, the TR-20 procedure uses different precipitation distributions (i.e., types IA and II) in different locations and regional curve number tables are available. Such factors should eliminate many of the differences across regions.

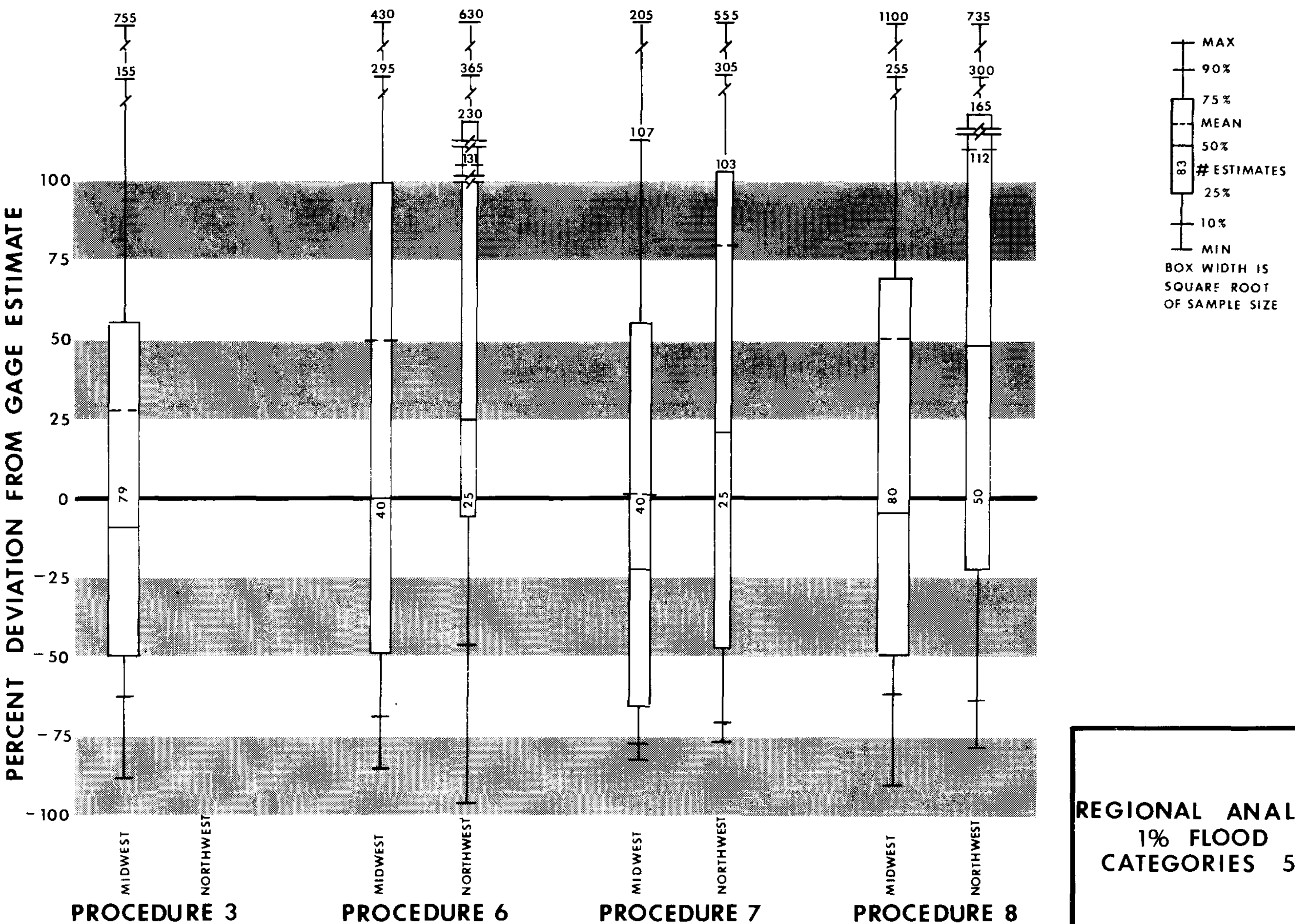
The ANOVA analysis was performed for the Midwest and Northwest regions separately. The conclusions were essentially the same for both regions. In the MANOVA analysis there were also no significant differences in the conclusions across regions.

Although the analyses indicate only slight regional differences in procedure performance, a regional analysis should be continued in a nationwide test for at least some procedures. This is believed necessary to add credibility to a nationwide test considering the different hydrologic characteristics of the different regions of the country. Furthermore, a region-by-region analysis simplifies the data analysis as the resulting regional analysis will permit testing of procedures that are only applicable to a given region without making the test design more unbalanced.



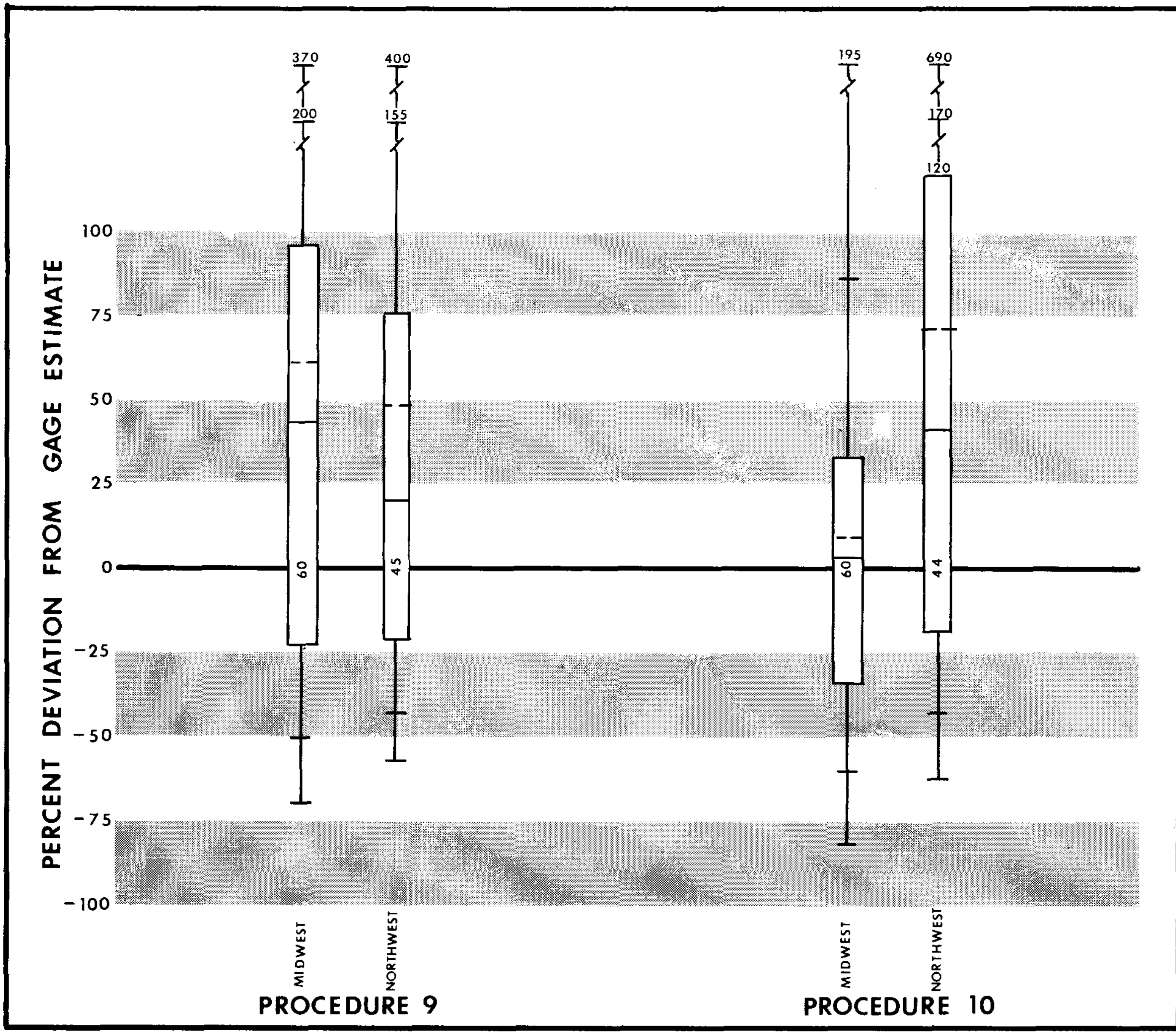
REGIONAL ANALYSIS
1% FLOOD
CATEGORIES 1,3

FIGURE VIII-15



REGIONAL ANALYSIS
1% FLOOD
CATEGORIES 5,6

FIGURE VIII-16



REGIONAL ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE VIII -17

d. Procedure Use Beyond Design Range of Applicability

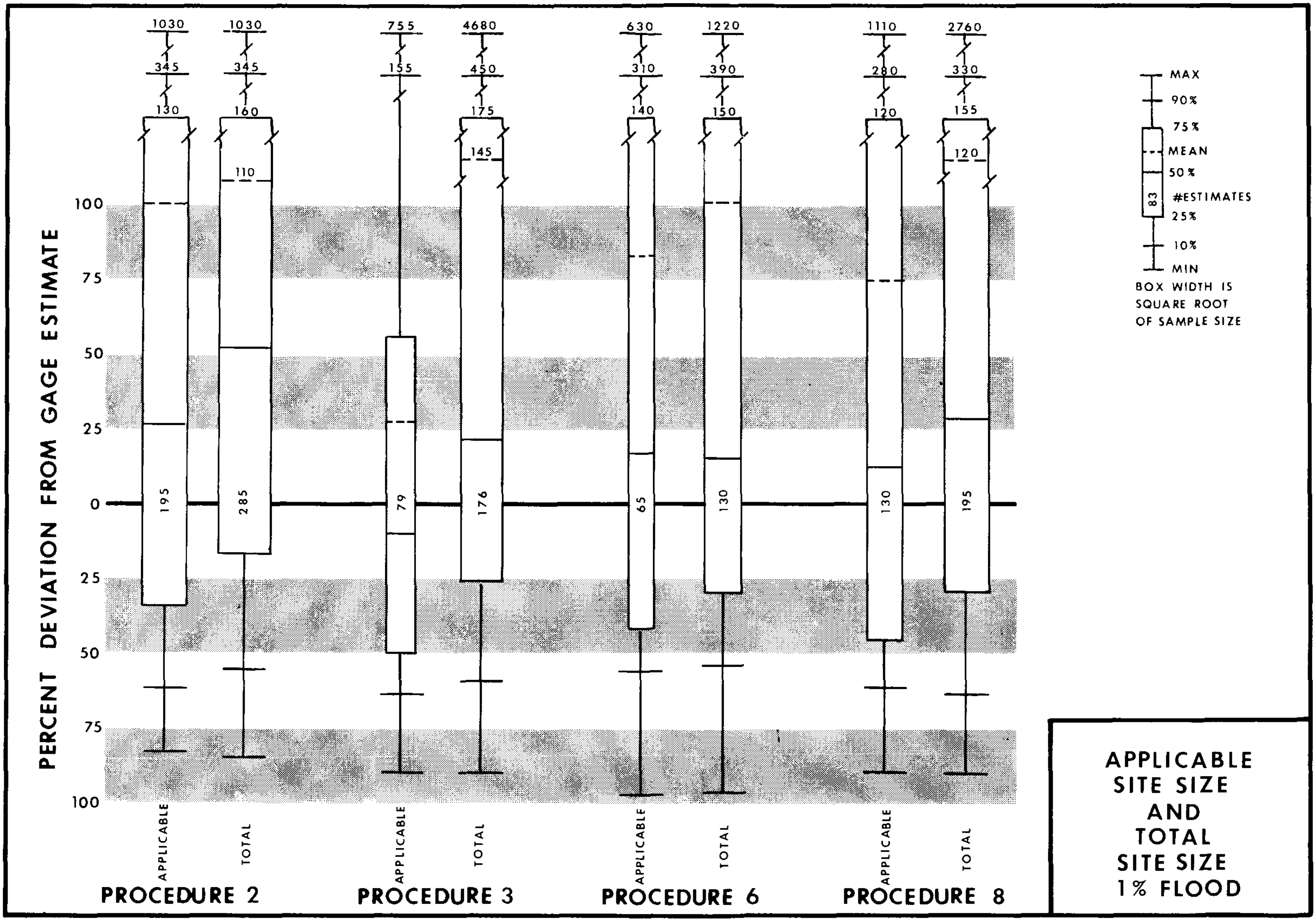
Procedures 2, 3, 6, and 8 were tested one site size grouping beyond the range of drainage areas suggested for their application. The applicable drainage area sizes for a given procedure are: (1) procedure 2, 0-50 square miles; (2) procedure 3, 0-10 square miles; (3) procedure 6, 0-3 square miles; and (4) procedure 8, 0-10 square miles. The variation in procedure performance using all test data and only applicable site size test data is illustrated by the box plots of Figure VIII-18. They show variations in the 1-percent-chance flood for the above procedures.

The MANOVA/DISCRIM analysis was also performed separately on the applicable test data set. For the Midwest region, the means and standard deviations of the criterion variables for procedures 3, 6, and 8 decreased significantly. For procedure 2 the bias and reproducibility means and standard deviations increased while the statistics for the time to apply criterion decreased; however, the changes for procedure 2 were not significant.

For the Northwest region the effect was less significant except for procedure 6, which showed significant decreases. For procedure 2 the mean bias decreased, but the reproducibility increased; however, there were insignificant changes in the standard deviations. Again the time to apply index always decreased. For the Northwest region, there were no changes in the decisions; that is, those procedures that were identified as being significantly different with all of the data were also identified as being significantly different when the watershed size was limited on procedures 2, 6, and 8.

An ANOVA analysis was performed on the applicable test data set. Analyzing procedures only within their range of applicability did not alter the conclusions from the ANOVA analysis of the total test data set.

In a nationwide test, it is recommended that procedures be restricted to their design ranges. Extending the procedures beyond their intended range did not materially affect the conclusions, but it would add substantially to the cost of a nationwide test.



APPLICABLE SITE SIZE AND TOTAL SITE SIZE 1% FLOOD

FIGURE VIII-18

e. Gage Estimate

The potential variation in conclusions resulting from adoption of a different gage estimate was examined. Gage estimates were computed using five different probability distributions including the adopted log-Pearson Type III distribution. Further, different fitting methods were used for three of the distributions giving eight values of the gage estimate. Three sets of gage estimates for each watershed were selected for the variation analysis. One set consisted of the largest value of the eight peak discharge estimates; the second set consisted of the smallest of the eight peak discharge estimates; and the third set consisted of the expected probability adjustments to the adopted gage estimates as described in WRC Bulletin 17A. Appendix 2, Table A2-2, and Table A2-3 give the different gage estimates and an analysis of their variation.

Using the extreme values of the gage estimates, MANOVA analyses were made for each of the three exceedance probabilities. In summary, the relative rankings of the procedures did not change. The means and standard deviations for both the bias and reproducibility values were smaller when the "high" gage estimate values were used. This is expected because the gage estimate values are used in the denominator.

ANOVA analyses were made using the high-gage estimates, the low-gage estimates, and the expected probability estimates. The results did not differ substantially from the log-Pearson Type III estimates and the conclusions were not altered.

In a nationwide test, it is recommended that the log-Pearson Type III distribution, with applications as described in the then current WRC Bulletin 17, be adopted to compute the gage estimate.

f. Unbalanced Test Design

In the pilot test, all procedures were not applicable to all watershed sizes. This resulted in an unbalanced design because not all procedures could be compared through all size ranges nor could all procedures be used in both regions. To determine if this had an effect on the conclusions, balanced subsets of the data were made. Balanced subsets were developed by performing the ANOVA analysis over restricted ranges of area sizes or by restricting the analysis to those procedures that covered all area sizes. Each subset indicated that conclusions were not affected by the unbalanced design layout.

In a nationwide test, it is recommended that the test design be as balanced as possible to make the test easier to manage and provide more comparable results. This should be accomplished by selecting regions, site sizes, and procedures such that procedures are applicable to the maximum number of sites.

g. Individual Versus Average Watershed Bias

An ANOVA analysis was made using individual bias values. Analyzing individual bias values did not produce different conclusions from those produced by analyzing average watershed values of bias. In a nationwide test, it is recommended that average watershed values of bias, as defined in section V, be used unless the tester effect is evaluated.

h. Standardization

In an attempt to remove the effect of the watershed size on the criterion variables, the bias and reproducibility indexes included the gage estimates in the denominator. This transformation did not entirely remove the trend of the watershed size in the values of these two indexes. In most cases, the mean values of bias and reproducibility decrease as either the exceedance probability or discharge increase; that is, the mean bias for the 1-percent-chance flood is smaller than the mean bias for the 50-percent-chance flood value. Additional consideration should be given to standardization of the criterion variables in a nationwide test.

i. Sample Size and Design Sensitivity

The sample sizes used in the pilot test are large enough to detect a difference in average bias between procedures of 30 percent. If the difference in average bias is less than 30 percent, this difference between procedures would probably not be detected.

The sample sizes for a nationwide test will depend on the region and hydrologic and statistical levels of significance. Recommendations for sample sizes for a nationwide test are included in section IX.

3. Data Quality Effects

a. Computational Errors

USGS State Equations, Fletcher's procedure, and the rational formula can be checked rather simply for computational errors, as there is a unique, direct solution for each set of parameters. These procedures were computerized and solved using input parameters provided by the tester. The results were compared with those provided by the tester. Where there was a difference of 10 percent or more, it was considered a computational error. An incorrectly applied regional equation was also considered a computational error.

Nine percent (or 27) of 290 applications of the USGS State Equations were in error. Eleven percent (or 31) of the 285 applications of Fletcher's procedure were in error. In 19 of the 31 error cases, the tester obtained the correct values of the 50- and 10-percent-chance flood discharge but forgot to raise the 10-percent-chance flood to the 1.029 power to obtain the 1-percent-chance estimate. Seven percent (or nine) of the 130 applications of the rational formula were in error.

For the USGS State Equations, Fletcher's procedure, and the rational formula, the computational errors did not affect the bias criterion significantly when averaged across all testers. The effect on the bias criterion from these computational errors was less than 4 percent for each of the percent-chance floods. This assumes that the testers who did not make computational errors were within a few percent of the correct answer (i.e., they correctly computed the watershed characteristics) and assumes no keypunch errors.

The physically based hydrologic processes are harder to check because they require tester judgment in their application. The problems associated with testing these procedures were subjectively evaluated by a person knowledgeable with the procedures. This evaluation of the 1-percent-chance peak discharge estimates was based upon a detailed examination of 65 applications of TR-55 Charts and 195 applications of TR-55 Graph.

To evaluate testing effects, input parameters given on the test record sheets were used to reconstruct the testers' peak estimates. Two types of errors were identified: mathematical errors and improper use of the procedure. A result was classified as a mathematical error if the tester estimate could not be reconstructed within about 5 percent. Those estimates found to be in error were further examined to determine the source of the error. In a large number of cases, it was possible to identify that errors resulted from an improper application of the shape factor or not converting rainfall to runoff. These procedural errors are attributed to either the documentation of the procedure or the design of the record sheet. The record sheet may have introduced errors because the record sheets were designed to record all possible adjustment parameters that might have been used in either of the computations. The conclusions from this analysis are shown in Table VIII-8.

Table VIII-8

TR-55 CHARTS AND GRAPH ERROR ANALYSIS

Problem	Procedure (percent) TR-55 Charts	TR-55 Graph
Procedures applied correctly	45	73
Shape factor applied incorrectly	22	5
Rainfall not converted to runoff	13	8
Multiple, mathematical, or other procedural errors	20	14

The other procedures, Reich, USGS Index Flood Equations, TR-20, and HEC-1, were not checked for computational errors. The Work Group lacked the resources to analyze the more complex and variable input of the graphically based Reich and Index Flood Equations and of the TR-20 and HEC-1 computer programs. As a result, it was not possible to correct the entire data set and not appropriate to correct only parts of the data set.

Preliminary statistical analyses of the data base described in Appendix 5 showed no significant difference in conclusions for the purpose of the pilot test with or without the inclusion of the extreme values identified as computational errors. Therefore, the incorrect data were not removed from the test data base.

In a nationwide test, it is recommended that adequate quality control be maintained during the data collection stage. Record sheets need to be designed so computations can be checked. Formal, systematic procedures need to be set up to evaluate the data and correct mathematical errors. This should be done as data are collected or as close to the point of data collection as possible.

b. Tester Experience

A graphical summary of the testers' background information obtained in the pilot test is given in Figure VIII-19. The summary treats each variable in the testers' background separately. It shows that while most testers had more than two years' experience,

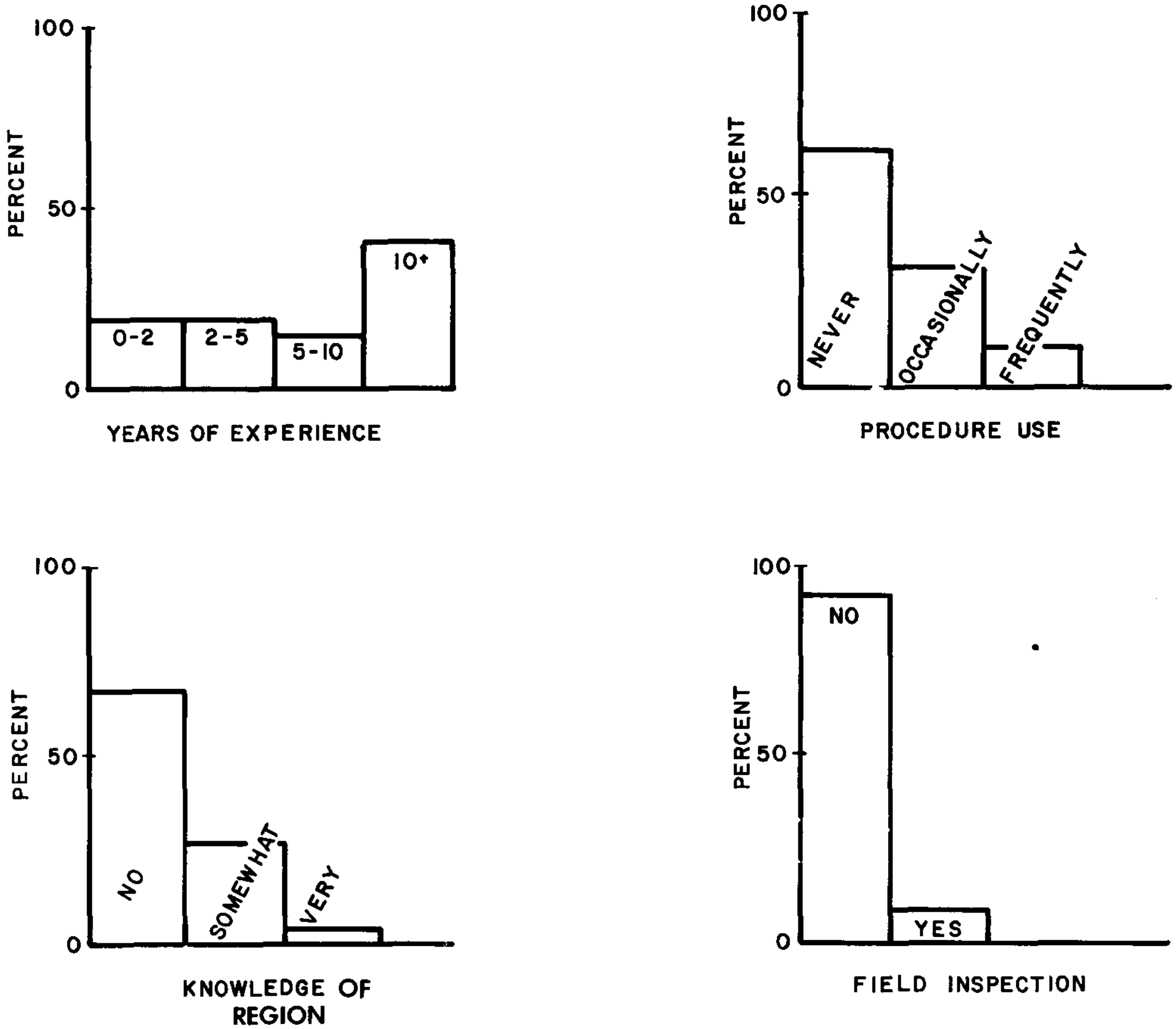


FIGURE VIII - 19 SUMMARY OF TESTER INFORMATION only a small percentage frequently used the procedure tested, were knowledgeable of the region, or made a site visit. This could influence the proper application of the pilot test procedures. This imbalance is further shown in Figure VIII-20 which illustrates the significant combinations of the testers' background.

A summary of the effects of the tester information on accuracy and time to apply is given in Appendix 7. The following general trends were exhibited:

1. As the hydrologic experience level increased, the accuracy generally decreased as illustrated by the mean accuracy values in Tables A7-1 and A7-2 for the various procedures and experience levels.

2. The time to apply the procedure was not generally influenced by the testers' level of experience as illustrated by the mean time to apply values in Table A7-1 and A7-2 for the various procedures and experience levels.

3. As the frequency of procedure use increased, generally the accuracy increased and the time to apply decreased as exhibited by the means in Table A7-3.

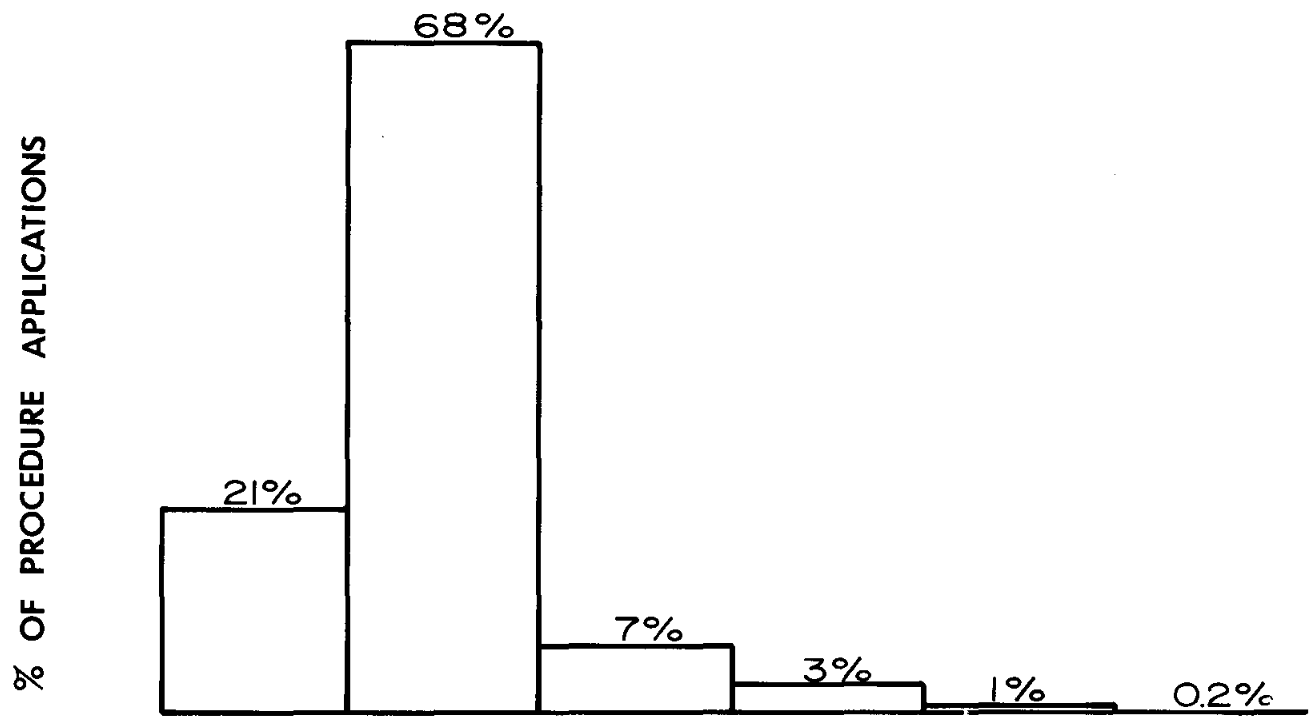
4. Field inspection generally increased the time to apply the procedures as exhibited by the mean time to apply values in Table A7-4.

5. For the SCS procedures, a field inspection increased the accuracy as shown in Table A7-4 by the mean accuracy values.

The decrease in accuracy with an increase in experience level was contrary to expectation. It may have occurred because: (1) The recorded experience did not adequately reflect the level of technical hydrologic experience or (2) the more experienced testers took the test too lightly.

A nationwide test should be designed to examine the effect of tester skill on the results. The inexperienced testers' results in the pilot test may have added noise to the data and made it harder to interpret. It is not clear whether observed differences among procedures are really due to procedures or due to testers (or some combination of the two). Because these two sources of variation are so intimately related, it may never be possible to separate their effects. The experience question needs to be revised

FIGURE VIII - 20
TESTER INFORMATION



TESTER BACKGROUND						
YEARS EXPERIENCE	LESS THAN 2	MORE THAN 2				
FREQUENCY OF PROCEDURE USE	OCCASIONALLY OR NEVER	OCCASIONALLY OR NEVER	FREQUENT	OCCASIONALLY OR NEVER	FREQUENT	FREQUENT
KNOW REGION	NO & SOME	NO & SOME	NO & SOME	VERY	VERY	VERY
FIELD INSPECTION	NO	NO	NO	NO	NO	YES

to be useful in making site assignments in a nationwide test so the experience level will not have a significant impact on the statistical analyses.

c. Regression Equations With and Without Test Stations

USGS State Equations, Fletcher's procedure, and USGS Index Flood Equations were tested against gaging stations that were used to develop the regression models. Thus, for the bias criterion variable, these procedures are more an examination of the fit of a procedure to that particular test station data rather than a measure of the procedure's predictive ability. The other two criterion variables, reproducibility and time to apply, are not compared with the gage estimate. In order to assess the predictive ability of these procedures, the following analyses were performed: (1) The regression equations for two USGS State Equations were recomputed without the pilot test stations and (2) the pilot test stations for one state were evaluated to see if they were a representative sample for the entire state.

The regression equations for Illinois and Ohio were recomputed without the watersheds used in the pilot test. These new equations were then used to estimate the 50-, 10-, and 1-percent-chance flood peaks using watershed characteristics supplied by the testers. The comparison of discharge estimates from the recomputed equations with the original equations is given in Appendix 8 along with a more detailed description of this analysis. For Illinois and Ohio, the inclusion or exclusion of the pilot test stations in developing the equations did not affect the bias criterion variable. The discharge estimates changed by less than 9 percent for all watersheds.

The regression equations for all the procedures were not recomputed because the necessary data were not readily available. It is possible that the results for Illinois and Ohio can be generalized to all regression-type procedures. The number of pilot test sites in any given state or region represents a small percentage of the total stations used to develop the equations and this should not have a significant influence on the equation's predictive ability.

An analysis was also made of the six pilot test sites in Indiana to determine if they were representative of all gaging stations in the state. The absolute value of the bias criterion was computed for the six sites in the pilot test using the regression and gage estimates provided in USGS Circular No. 710 (Davis, 1974). These values were compared to the absolute value of the bias criterion for all stations used to develop the USGS Indiana State Equations. The results are summarized in Appendix 8.

The average absolute value of bias for the six pilot test sites in Indiana is nearly equal to the average absolute value of bias for all stations in Indiana that were used to develop the regression equations (Davis, 1974). That is, they appear to be representative of the total sample of Indiana stations. In addition, the absolute values of the bias criterion computed using data from Davis (1974) agree fairly well with absolute bias criterion used in the pilot test.

In a nationwide test, it is recommended that the test sites be different than those used to develop the procedures being tested. This may require recomputing the regression equations. However, recomputing the regression equations may not be practical or necessary. How strictly the recommendation is adhered to depends upon: (1) the percentage of gaging stations used to develop the regression equations in a region or state that are test stations; (2) the watershed and/or climatic characteristics of a test site that were used in the regression equation development as compared to the other sites included in the regression analysis; and (3) the comparability of the station record length used to develop the regression equations and used in the nationwide test.

d. Procedure Application Without Resource Packages

Three testers applied procedures to two watersheds in the Midwest and two testers applied procedures to one watershed in the Northwest without being supplied resource packages. The results of these testers were compared to results obtained from the five testers at the same watershed who had resource packages. A t-test on the means and an ANOVA analysis of these data were performed and produced inconclusive results. The mean values and sums of squares for accuracy and time to apply are given in Tables VIII-9 and VIII-10, respectively. The availability of a resource package appears to have very little effect on bias, reproducibility, and time to apply for all procedures tested except TR-20 and HEC-1. For these more complex procedures, the effect of the availability of the resource package was to increase accuracy and time to apply.

For a nationwide test, it is recommended that no resource packages be provided. This should enable a nationwide test to be performed similar to conditions encountered in practice.

Table VIII-9

RESOURCE PACKAGE - ACCURACY

		No Resource Package			Resource Package			
Procedure	Watershed	Mean	S^2	n	Mean	S^2	n	t
State Eq.	41	0.1580	0.0039	3	0.2414	0.0092	5	-1.4000
	35	-0.1366	0.0369	3	-0.1779	0.0020	5	0.3665
	85	-0.6000	0.0009	2	-0.5356	0.0123	5	-1.1881
Fletcher	41	1.2773	1.0188	3	1.3653	1.2923	5	-0.1338
	35	0.1106	0.0266	3	0.2400	0.0012	5	-1.3562
	85	0.6818	0.0008	2	1.1006	0.0140	5	-2.4808
Reich	41	8.6880	13.9615	3	-0.0759	0.7539	3	3.9981
	35	1.2293	0.4154	3	0.6570	0.3134	5	1.2760
Index Flood	41	0.0681	1.2173	3	-0.5111	0.0148	5	0.9059
Rational	35	-0.1592	0.3783	3	0.6532	0.2782	5	-1.9057
	85	1.2828	0.0046	2	2.5930	3.2290	5	-1.6275
TR-55 Graph	41	1.7727	0.3584	3	2.0650	6.8350	5	-0.2397
	35	0.4519	0.3371	3	-0.1199	0.0728	5	1.0641
TR-20	41	1.7327	0.2780	3	1.2360	2.6250	5	0.6320
	35	0.0931	0.1061	3	-0.1370	0.1518	5	0.8975
HEC-1	41	1.9496	3.6850	3	-0.4034	0.0880	5	2.1082
	35	1.0760	4.0740	3	-0.1197	0.4554	5	0.1070

Note: The critical t-statistic values for given significant levels and six degrees of freedom are:

$t_{0.90,6} = 1.440$
$t_{0.95,6} = 1.943$
$t_{0.975,6} = 2.447$
$t_{0.99,6} = 3.143$

Table VIII-10

RESOURCE PACKAGE - TIME TO APPLY

		No Resource Package			Resource Package			
Procedure	Watershed	Mean	S^2	n	Mean	S^2	n	t
State Eq.	41	3.93	0.81	3	2.96	2.06	5	1.173
	35	3.00	1.00	3	3.86	11.54	5	-0.418
	85	1.60	0.32	2	2.24	1.58	5	-0.927
Fletcher	41	3.23	2.96	3	2.64	0.97	5	0.544
	35	3.17	1.58	3	3.80	12.80	5	-0.360
	85	1.90	0.72	2	2.06	0.75	5	-0.224
Reich	41	4.00	1.75	3	4.23	4.48	5	-0.189
	35	3.33	2.33	3	5.02	16.03	5	-0.847
Index Flood	41	4.66	1.08	3	2.10	1.93	5	2.913
Rational	35	4.20	1.57	3	3.90	13.30	5	0.168
	85	2.15	0.25	2	4.33	.37	5	-4.930
TR-55 Graph	41	6.80	6.69	3	4.18	5.11	5	1.453
	35	6.30	6.90	3	8.28	15.86	5	-0.962
TR-20	41	25.50	144.00	3	192.40	272.80	5	-16.480
	35	24.67	737.00	3	9.86	34.14	5	0.055
HEC-1	41	25.00	675.00	3	38.74	784.32	5	-0.703
	35	31.33	680.30	3	41.80	673.70	5	-0.550

C. Other Benefits from Pilot Test

The Work Group limited the test to procedures currently in use or available from Federal agencies or in the published literature. Thus the pilot test and the proposed nationwide test are designed to evaluate existing procedures and not to develop new or improved procedures. The information gained from the pilot test and that to be gained from the proposed nationwide test, however, provides basic information needed to develop improved procedures.

When evaluating procedures, it is useful to differentiate between the technical merit and practical application of a procedure. From the standpoint of writing a national guide, it is the performance of a procedure in practice that is important. To develop improved procedures it is helpful to consider both aspects independently.

The following discussion highlights some of insights gained from the pilot test that relate to developing improved procedures including: (1) the input parameter variability; (2) the technical understanding of procedures; (3) the practical application of procedures; and (4) the value of trying different procedures. Also included are questions that need to be addressed in a nationwide test.

1. Input Parameter Variability Analysis

All input parameters except those for TR-20 and HEC-1 (93 in all) were analyzed to determine their measurement variability. It was expected that this analysis would: (1) explain some of the variability in the 50-, 10-, and 1-percent-chance flow estimates; (2) identify where variations were introduced through the design of the record sheets and the use of inexperienced testers; and (3) identify the types of parameters that need attention in developing improved procedures. Details on the input parameter variability analysis are in Appendix 9.

It was not possible to analyze the variability of the actual parameter values because some parameters were site size dependent. For example, the variability of a sample of five replicates each for both a 3 and a 100 square mile watershed would be high (standard deviation of 51) even if there was no variability within each watershed.

The coefficient of variation (standard deviation divided by mean) was selected for parameter comparison because it was simple and dimensionless. A coefficient of variation based on the five replicates was calculated for each parameter on each watershed. A large coefficient of variation indicated that there was much difference between tester estimates of a parameter on a watershed while a small coefficient of variation indicated that there was little difference. Figure VIII-21 illustrates this.

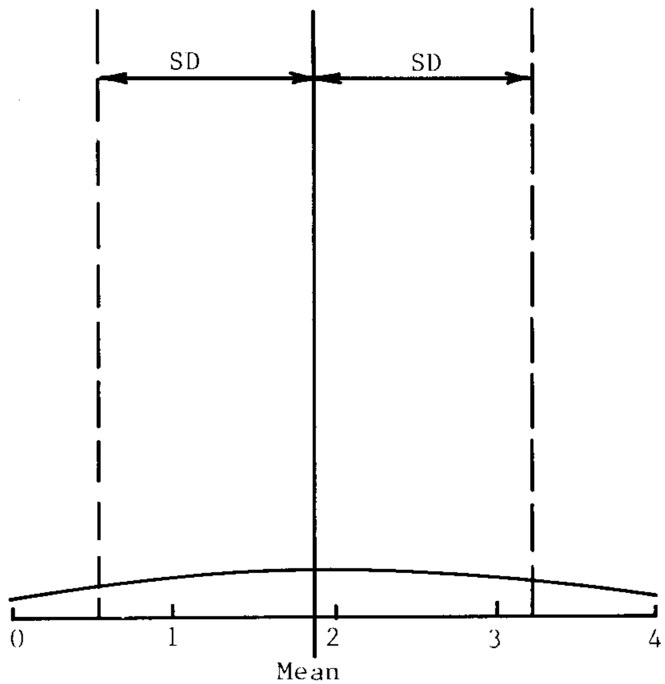
Some input parameters were common to more than one procedure. These similarly named parameters were grouped together to determine if differences existed in the same parameter across different procedures. It was expected that differences in variability could be related to the different definitions of the same parameter provided in the documentation. However, differences could have also resulted from other factors, including sampling variability.

Some procedures used adjustment factors when a parameter exceeded a given value. These adjustment factors were grouped separately because an analysis of their variability should consider: (1) the percentage of the testers who correctly identified the applicability of the adjustment factor to the watershed and (2) given the watersheds on which the adjustment factor was applicable, the variability of the adjustment factor.

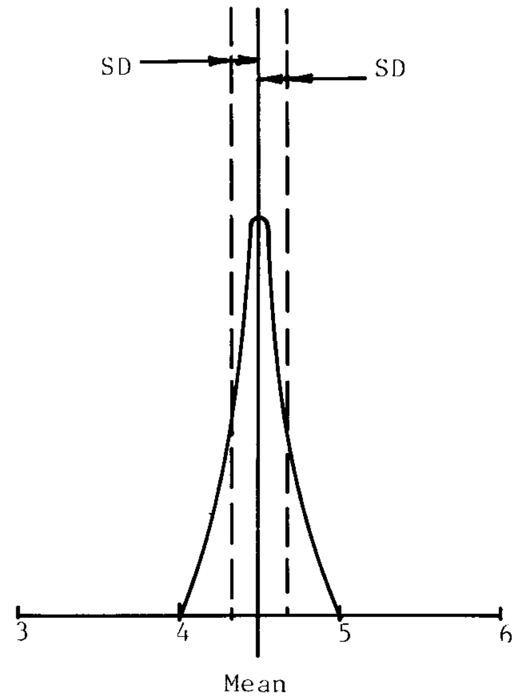
Mean = 1.88
Standard Deviation (SD) = 1.34
Coefficient of Variation = 0.71

Mean = 4.50
Standard Deviation (SD) = 0.16
Coefficient of Variation = 0.04

$$\text{Coefficient of Variation} = \frac{\text{Standard Deviation}}{\text{Mean}}$$



Large Coefficient of Variation
High Variability



Small Coefficient of Variation
Low Variability

ILLUSTRATION OF COEFFICIENT OF VARIATION

FIGURE VIII - 21

To simplify the variability analysis, the parameters were grouped according to the skill and judgment that were necessary to estimate the parameter. The resulting four parameter groups were: (1) those that were read directly from a map, graph, or table; (2) those that were measured from a topographic map; (3) those that required direct tester knowledge and judgment; and (4) those that were a combination of other parameters.

The relative variability of the groups of parameters, from least to most, was: (1) parameters read from a map, graph, or table; (2) parameters measured from a topographic map; (3) parameters that were a combination of other parameters; and (4) parameters that required direct test knowledge and judgment.

Seven of the eight parameters that were read from a map, graph, or table; five of the nine parameters that were measured from a topographic map; and one of the five parameters that was a combination of other parameters were input to regression procedures (Categories 1 and 3). One of the nine parameters that were measured from a topographic map; both parameters that required direct tester knowledge and judgment; and four of the five parameters that were a combination of other parameters were input to rain-runoff procedures (Categories 5 and 6). The remaining parameters were input to both regression and rain-runoff procedures. It appeared then that input parameters for regression procedures (Categories 1 and 3) were less variable than input parameters for rain-runoff procedures (Categories 5 and 6).

The absolute effect of the parameter variability on the peak flow estimates needs to be defined by a sensitivity analysis. For example, a highly variable parameter may have little effect on the peak flow estimate while a less variable parameter may have a large effect on the peak flow estimate. In that case, the less variable parameter would be more crucial to the flow estimate variability.

Many factors contributed to parameter variability. Some of these factors were: (1) the parameter description in the procedure documentation; (2) the skills required to determine the parameter; (3) the judgment required to determine the parameter; and (4) the physical basis of the parameter. It was impossible to know which factor or factors caused problems.

Generally, as the required level of skill and judgment to determine a parameter increased, parameter variability increased. Also, as a parameter became less physically based, reasonability checks broke down and variability increased. For example, testers may have recorded parameter values beyond the minimum or maximum without realizing their error. Therefore, a simple, straightforward, familiar, and physically significant parameter may introduce less variability into a flow estimate. If a more abstract parameter is necessary, a detailed definition including minimums, maximums, and typical values may decrease parameter variability.

2. Technical Understanding of Procedures

The pilot test demonstrated that if different hydrologists using the same procedure are to obtain the same flow-frequency estimates, the procedure parameters need to be clearly defined. In addition, the parameters need to be defined in a manner such that different hydrologists are likely to obtain the same value. The reproducibility of regression procedures which results from their generally low input parameter variabilities illustrates this.

The input parameter variability analysis identified four groups of parameters; their identification was based on the skill and judgment necessary to estimate the parameter. Even within the group of parameters that are simply read from a map, one parameter has significant variability. This shows that, even with simple parameters, a detailed definition and good location map are necessary to assure reproducibility. Even then, sites located near boundaries on maps could have high parameter variability.

It is no surprise that those procedures with generally higher input parameter variability showed the greatest variation in flow-frequency estimates. These high variability parameters, such as time of concentration and land use factor, also require the most tester judgment. Because of the small number of testers experienced with the procedure, no analysis of input parameter variability as related to tester experience and knowledge was made.

Regression procedures are developed for an assumed homogeneous region. The pilot test did not directly examine what effect the region size has on the regression procedures. Three regression procedures were included in the pilot test. The Index Flood procedures assumed the United States could be divided into 20 homogeneous regions. The Fletcher procedure assumed 24 and the USGS State Equations assumed at least one for every state. Because the USGS State Equations and Index Flood procedures had less variable flow-frequency estimates than the Fletcher procedure, it is not clear if smaller, more homogeneous regions improve regression relationships.

Procedures in Categories 5 and 6 are based on the assumption that the frequency of the rainfall used in the computation is equal or proportional to the flood frequency. Many of these procedures do not claim that a flood peak of a given frequency is estimated but rather that a flood peak from a storm of a given frequency is estimated. The pilot test did not address this important question.

3. Application of Procedures

The pilot test, although limited in application to the Midwest and Northwest regions, demonstrated that peak flow frequency estimates made on natural streams in a region unfamiliar to the hydrologist are more likely to be correct if a regression procedure (Category 1 or 3) is used. The test also demonstrated that care must be taken in the selection of the procedure as performance can vary significantly within a category. For example, the regression procedures, in general, have low bias and reproducibility values. Within these categories though, the Fletcher procedure is more biased than either the USGS State Equations or Index Flood procedures.

A problem with some procedures is that the data necessary to determine input parameters are not always readily available. In the pilot test, detailed soils, land-use, and hydraulic information was not readily available to most testers. In developing procedures for universal application, it is important to use only parameters that can be obtained by others.

4. Value of Trying Different Procedures

A side benefit for those who participated in the pilot test was the introduction to a variety of techniques for making flow-frequency estimates. The understanding gained by applying the variety of procedures hopefully will increase understanding of the estimating problem.

IX. CONCLUSION--RECOMMENDED NATIONWIDE TEST

A. Objectives

There are many techniques used by practicing hydrologists and engineers to develop peak flood flow frequency values at ungaged locations and wide differences of opinion as to which technique defines the peak flood flow frequencies cost-effectively in a particular situation. In spite of the evident need, no comprehensive evaluation of the many available techniques has been made.

Results of the pilot test demonstrate that there are significant differences in the performance of procedures in terms of accuracy, reproducibility, and time to apply. However, a nationwide test is needed to provide an authoritative basis for procedure selection to recommend for a national guide. The pilot test provides the information necessary to design a nationwide test; thus the objectives of the pilot test have been met.

Following are the major issues identified as needing testing to provide an authoritative basis for a national guide.

1. Nationwide evaluation of the performance of procedures in Categories 1 through 5 and the simple procedures in Category 6, including the effect of user experience and site visit upon results achieved with Categories 5 and 6 procedures.

2. Evaluation of procedures for and benefits from incorporating site historic information and/or short site records into the analysis made using the procedures in Categories 1 through 5 and the simple procedures of Category 6.

3. Evaluation of the performance of Category 6 complex watershed modeling procedures when calibrated to site data and regional information.

4. Evaluation of Categories 7 and 8 procedures.

The following sections outline the proposed scope of a recommended nationwide test including experimental design, costs, suggested management and organization to conduct the test, and benefits. Because of the magnitude of the task, the proposed testing is divided into a series of small subunits, each designed to answer specific questions. For each subunit, different levels of funding are proposed. The subunits individually produce information to assist users in procedure selection and application. Collectively they provide the information needed for a comprehensive national guide. It is proposed that testing proceed in small increments depending upon priorities and the availability of funds and manpower.

B. Experimental Design

There are a number of common elements in the experimental design for testing the four major issues that have been identified. Recommendations for these common elements based upon conclusions from the pilot test are described in this section. Recommendations regarding quality control and analysis are also discussed.

1. Sample Size

The recommended sample size is a function of the level of hydrologic significance at which it is desired to discriminate, the level of statistical significance (alpha level) selected, and the variance of procedure bias over a region. The desired level of hydrologic significance is achieved by specifying the width of the confidence interval desired for the difference in mean bias for any two procedures. The sample size formula is:

$$\bar{n} = \frac{2\, C_{\alpha}^{2}\, \sigma^{2}}{d^{2}}$$

where d is the desired half-width accuracy of the confidence interval, σ^2 is the variance of bias for any procedure, C_{α} is a factor from a normal table for a given value of α (1.96 for a 95 percent confidence limit), and $\bar{n}$ is the sample size. Once d, σ^2, and C_{α} are assumed, the appropriate sample size can be computed. Table IX-1 gives the sample sizes for the nationwide test based on various values of σ^2 and d for $\alpha = 0.05$.

Several assumptions were required to use Table IX-1 to determine the sample sizes for a nationwide test. These assumptions, which were used to estimate the number of watersheds in Table IX-3, are discussed in the following paragraphs.

A difference (d) in bias of 20 percent is proposed as being hydrologically significant for purposes of a nationwide test. The proposed alpha level (α) of 0.05 results in a C_{α} value appropriate for detecting a difference (d) between a specific pair of means and not all possible combinations. To detect a difference (d) between any one of the possible pairs of means, a larger value of C_{α} (and consequently a larger $\bar{n}$) is required. The relationship between hydrologic significance (d) and statistical significance (α) was not determined for the pilot test data.

Table IX-1

SAMPLE SIZES FOR NATIONWIDE TEST

Alpha Level=0.05

σ^2	d	$\bar{n}$
0.8	0.10	615
0.6	0.10	461
0.4	0.10	307
0.2	0.10	154
0.8	0.15	273
0.6	0.15	205
0.4	0.15	137
0.2	0.15	68
0.8	0.20	154
0.6	0.20	115
0.4	0.20	77
0.2	0.20	38
0.8	0.25	98
0.6	0.25	74
0.4	0.25	49
0.2	0.25	25
0.8	0.30	68
0.6	0.30	51
0.4	0.30	34
0.2	0.30	17
0.8	0.40	38
0.6	0.40	29
0.4	0.40	19
0.2	0.40	10
0.8	0.50	25
0.6	0.50	18
0.4	0.50	12
0.2	0.50	6

From the pilot test data, values of σ^2 on the order of 0.40 were typical for the two regions. Therefore, a value of 0.60 was assumed as a maximum in designing a nationwide test. If the variance of bias should exceed 0.60, a larger sample size than that in Table IX-3 would be required to achieve the same level of discrimination.

In the pilot test, the relationship between the average number of watersheds on which a procedure was tested and the total number of watersheds in the region was a factor of 2. Because of the unbalanced nature of the pilot test, it was necessary to have twice as many watersheds to obtain the required number of bias estimates. It is recommended that a nationwide test be more balanced; thus no multiplicative factor was assumed in estimating the number of watersheds in Table IX-3.

The number of watersheds in Table IX-3 is also based on the assumption that there is only one bias value per watershed and not three values for each exceedance probability. This is probably a reasonable assumption because the bias values for each exceedance probability are highly correlated.

The number of watersheds recommended per region in Table IX-3 are based on these assumptions. For this reason, they should not be regarded as absolute values but only as the best estimates possible at this time for designing a nationwide test.

2. Site Selection

The guide is to be nationwide in application. Thus it would be desirable that test sites be located in all 50 states and Puerto Rico and in all major watersheds. This, however, is not practical and not necessary to evaluate the difference in procedure performance in the various categories. The pilot test indicated that there were no major regional differences in relative procedure performance. However, the analysis was simplified by grouping sites by regions in which the same procedures applied. Further, most hydrologists normally identify different climatic and physiographic regions of the country in their analyses.

It is recommended that testing be done by regions. The regions should be selected to demonstrate expected procedure performance under a variety of climatic and hydrologic conditions and to achieve as balanced a test design as possible. A balanced design is achieved by selecting regions, watershed sizes, and procedures such that procedures are applicable to a maximum number of sites. Watershed sizes should form at least three size groupings covering the range from less than 1 to about 500 square miles.

3. Criteria

The criteria of accuracy, reproducibility, and practicality (time and costs to apply) are recommended for use in evaluating procedure performance. The criterion variables defined in section V, average watershed bias, reproducibility, and time to apply, are recommended for analysis. For the statistical analyses, the transformed reproducibility should be used. It is recommended that the gage estimate used to evaluate accuracy be computed by the log-Pearson Type III distribution with application as described in the then current version of WRC Bulletin 17.

The uncertainty in the gage estimate can be accounted for by using the standard errors of the flood discharges for the 0.01 and 0.10 exceedance probabilities. Hardison (1971) illustrates that this standard error is a function of both record length and the variability of annual peak discharges at the gage site. For a nationwide test, it is recommended that the procedure estimate be expressed as the number of standard errors from the gage estimate for each exceedance probability. Using this approach, the reliability of the gage estimate can be incorporated into the accuracy (or bias) criterion for a given watershed. Given the same procedure estimate for a long record-low variability and a short record-high variability site, the accuracy criterion will be better for the former site due to the increased reliability of the gage estimate.

4. Applications

No less than five replications of each procedure at a site should be made. This is the minimum number needed to evaluate reproducibility. It is recommended that peak flow estimates be made for at least two exceedance probabilities: 0.01 and 0.10.

5. Quality Control

The quality of the tester estimates can be affected by the resource and procedure information provided and the methods used to collect and record the results.

It is recommended that no resource packages be provided so that procedure performance will be evaluated as nearly as practical under conditions encountered in practice. However, there should be a place where testers who are testing sites outside their regions can request resource materials. Procedure packages are necessary to standardize the procedure application. Published procedure descriptions should be used whenever possible. Any necessary supplemental descriptions should be carefully reviewed and pretested for clarity. Record sheets should simply list the parameters necessary for the application of each procedure and have space to describe the resource materials used. Questions regarding tester experience are needed, but those used in the pilot test should be revised as previously discussed.

It is not possible to conduct a test of the proposed magnitude of a nationwide test without encountering computational or recording errors. To reduce those introduced by the tester, it is recommended that record sheets be reviewed and computations checked when submitted to identify obvious errors. The review should carefully distinguish between errors and differences in judgment.

6. Analysis

It is recommended that the analysis proceed in steps from nonstatistical analyses to more complex statistical analyses. It should include a sufficient number of different analyses to assure sound conclusions. The box plots used in the pilot test were found to best illustrate potential trends, tendencies, and differences in procedure performance. This information helps to focus the statistical analyses on significant problems and provides a means of communication with persons not intimately familiar with statistical techniques. The various statistical analyses used in the pilot test were complementary and were all found to provide useful insights about procedure performance. The analyses should at least include these statistical techniques.

C. <u>Procedures in Categories 1 Through 5 and Simple Procedures in Category 6</u>

1. Procedures to Test

It is recommended that selection of specific procedures for testing be made when developing the detailed design of the test. Recommended procedure selection criteria include: (1) frequency of use; (2) documentation; (3) representativeness of a category; and (4) size of region for which the procedure is applicable. Specific procedures to be considered for testing should include those listed in Table IX-2 and those suggested by the profession which fall within the selection criteria. Applications should be limited to the procedure design range. The recommendations of section VIII.B.3.c regarding testing of regression procedures on sites used to develop the procedures should be followed.

Table IX-2

PROCEDURES CONSIDERED FOR NATIONAL TESTING

(Publication numbers from the literature review by McCuen et al., 1977)

Category

1. Statistical Estimation of Q_p
   - Regression on basin characteristics (USGS State Equation example (23))
   - Regression on channel characteristics (USGS example (183))
   - Potter (155)
   - Publication 11
   - Q related (62)

2. Statistical Estimation by Moments
   - Corps of Engineers (221)
   - Water and Power Resource Service

3. Index Flood Estimation
   - USGS Index Flood method (209)
   - Publication 165

4. Estimation by Transfer
   - USGS method for transferring upstream and downstream

5. Empirical Equations
   - Rational (with C values as determined by local practice)
   - Chow (28)
   - Hewlett (86)
   - Reich (162)
   - Cypress Creek (194)

6. Single Storm Event
   - SCS (192) (TR-20)
   - SCS (198) (TR-55)
   - Corps of Engineers (HEC-1)
   - Colorado Urban Hydrograph

2. Testers and Test Application

It is recommended that testers be identified according to their experience with the procedure and region of testing. For those procedures requiring judgments based upon experience, test applications should be by testers experienced in these procedures except as required to evaluate differences in procedure performance for experienced and inexperienced testers.

3. Reconciling Estimates with Site Data

In practice, a hydrologist will often have some information about flooding at a site such as floodmarks or a discharge estimate for floods known to be the largest in some time period. A testing of the procedures used and the benefits from incorporating such data in the analysis is recommended.

For this testing, it is proposed to provide the same historic flood data as will be provided in testing the effects of calibration on Category 6 procedures at a selected subset of sites. It is proposed to specify one or more methods to adjust the tested procedure results for site specific data. As an additional method, each tester would be asked to use their favorite method if different and describe the method.

4. Testing Program

The testing program will of necessity be based both upon technical considerations and resource constraints including manpower. In general, test costs will vary directly with the number of site applications. There are certain parameters such as drainage area which are common to all procedures. Thus, by having one tester evaluate a number of procedures at the same site, the cost per application can be reduced. Costs will also vary depending upon how much information is included in the procedure package provided each tester. For costing a proposed program of testing, a site application was estimated to require 3.5 hours at a cost of $110 per application (1980 dollars). Costs to manage the test and analyze the data would be in addition to this cost.

Because of money and manpower constraints, testing is expected to proceed in small increments. To assure that the increments efficiently contribute to the final product, an overall program of testing is identified. The variables of the overall program are: (1) the hydrologic significance level which determines the number of watersheds per region; (2) the number of regions; (3) the number of replicates; (4) the number of procedures per region; and (5) the testing to identify the effects of tester experience and calibration to site data.

Table IX-3 shows one possible overall testing program. Three levels of testing are identified from a minimum that would permit credible discrimination between procedures (discrimination at a 30 percent hydrologic significance level) to the proposed full level of testing (discrimination at a 20 percent hydrologic significance level). It is proposed to limit testing in the conterminous United States to four or five regions. For the 30, 25, and 20 percent significance levels, testing of 50, 75, and 100

Table IX-3

NATIONWIDE TEST - TESTING COSTS
1980 Dollars

Categories 1 through 6 (Excluding Complex Modeling) Procedures

Assumptions	Minimum	Intermediate	Recommended	
Significance level	30%	25%	20%	
No. Watersheds per region	50	75	100	
No. Replicates per region	5	5	5	
No. Procedures per region	10	10	10	
No. Site Applications	2500	3750	5000	
Cost ($1000)	$275	$412	$550	at $110/application
No. Regions	4	4	5	
Total Cost ($1000)	$1100	$1700	$2800	(rounded)
Hawaii				
Significance level	50%	50%	50%	
Regions	1	1	1	
No. Watersheds	20	20	20	
No. Replicates	5	5	5	
No. Procedures	4	4	4	
No. Site Applications	400	400	400	
Cost ($1000)	$45	$45	$45	at $110/application (rounded)
Alaska				
Significance level	60%	60%	60%	
Regions	1	1	1	
No. Watersheds	10	10	10	
No. Replicates	5	5	5	
No. Procedures	4	4	4	
No. Site Applications	200	200	200	
Cost ($1000)	$25	$25	$25	at $110/application (rounded)
Puerto Rico				
Significance level	65%	65%	65%	
Regions	1	1	1	
No. Watersheds	8	8	8	
No. Replicates	5	5	5	
No. Procedures	4	4	4	
No. Site Applications	160	160	160	
Cost ($1000)	$20	$20	$20	at $110/application (rounded)

Table IX-3 (Continued)

NATIONWIDE TEST - TESTING COSTS
1980 Dollars

Categories 1 through 6 (Excluding Complex Modeling) Procedures-
Adjustments to Site Data

Assumptions	Minimum	Intermediate	Recommended	
Significance level	30%	30%	30%	
Regions	Nationwide	Nationwide	Nationwide	
No. Watersheds	50	50	50	
No. Replicates	5	5	5	
No. Procedures	10	10	10	
No. Site Applications	2500	2500	2500	
Cost ($1000)	$280	$280	$280	at $110/application (rounded)

Complex Model (TR-20/HEC-1) Category 6 Procedures - Calibrated

Significance level	40%	35%	30%	
Regions	Nationwide	Nationwide	Nationwide	
No. Watersheds	30	40	50	
No. Replicates	5	5	5	
No. Procedures	2	2	2	
No. Site Applications	300	400	500	
Cost ($1000)	$1700	$2200	$2800	at $5500/application (rounded)

Category 7/8 Modeling Procedures - Calibrated

Significance level	45%	45%	45%	
Regions	Nationwide	Nationwide	Nationwide	
No. Watersheds	25	25	25	
No. Replicates				
-Calibration Period	1	2	2	Each tester different period
-Model	1	1	2	
-Tester	5	5	5	
No. Procedures	1	1	1	
No. Site Applications	125	250	500	
Cost ($1000)	$1100	$2200	$4400	at $8,800/application

Total Costs ($1000)

Testing Subtotal	$4300	$6500	$10400	(rounded)
Administration[1]	$1250	$1250	$ 1250	
Grand Total--($1000)	$5500	$7700	$11600	(rounded)

[1]Assume five-year program with 100,000 to plan, 300,000 for reports (3 + Final), 150,000 a year for the executive director and staff to conduct the test, and 100,000 for computer support.

sites, respectively, per region is required. Testing of procedures in Hawaii, Alaska, and Puerto Rico, each considered a separate region, is proposed at a lesser level of hydrologic significance. Testing in Puerto Rico is limited by the availability of stream gage information.

In testing methods to incorporate site data in the flow-frequency estimate, it is proposed to limit testing to those sites where testing of Category 6 procedures is planned. For this testing, it is proposed to treat the Nation as one region using a 30- to 50-site subset of all the sites identified for testing in the conterminous United States.

Smaller testing increments than outlined in Table IX-3 can be obtained by testing one region at a time and to a lesser extent by testing fewer than ten procedures within a region. Testing methods to incorporate site data in the frequency determination could be done for more sites in one region rather than a few sites in several regions. The scope of the testing must be carefully established so as to minimize the loss in credibility of the total test.

D. Category 6 Watershed Modeling Procedures Calibrated to Site and/or Regional Data

1. Procedures to Test

It is proposed to test, in a calibrated mode, the HEC-1 and TR-20 procedures which were evaluated in the pilot test in an uncalibrated mode.

2. Data for Calibration

It is proposed to provide the following site data for calibration: (1) two or three peak discharges (one of which is the maximum of record) with corresponding dates and evaluations of how they were determined and the accuracy of the estimates; (2) information about historic record length and the rank of the given flood discharges within that record; and (3) all available rainfall records in the watershed for the storms which produced these flood peaks.

It is also proposed to provide any peak discharges or available high water marks upstream or downstream for the same floods as provided at the site. Stream and rainfall gage records within the site watershed or adjacent watersheds for the period of record would also be provided.

3. Site Selection

Because application of these procedures is costly and significant regional differences are not anticipated, it is proposed to test these procedures only in a calibrated mode, treating the Nation as one region. A 30- to 50-site subset of those identified for the testing described in section IX.C would be used. The sites would be selected to permit conclusions to be made about the performance of these procedures relative to those in Categories 1 through 5 and the simple procedures of Category 6.

4. Testers and Test Applications

It is proposed that only persons experienced with the procedures be used as testers. If a sufficient number of experienced testers cannot be found, others would be trained as needed. However, formal training alone is not considered an adequate substitute for experience. It will be necessary to consider the impact of using inexperienced testers on test results.

5. Testing Program

Testing the watershed modeling procedures in a calibrated mode is expensive and requires testers experienced with the procedures. Because of these constraints a minimum program of testing is proposed. Total testing costs will vary directly with the number of sites and procedures tested and the number of replicates. Each site application is estimated to require about four man-weeks effort and a total cost of about $5,500 (1980 dollars). Table IX-3 shows one possible overall testing program. Three levels of testing are identified from an estimated minimum of 30 sites that would permit credible discrimination between procedures at a 40 percent hydrologic significance level to a maximum of 50 sites to discriminate at the 30 percent level.

A program of testing would need to proceed in small increments based upon available funds and manpower. One approach would be to test increments of, say, five sites each until sufficient information is gained to evaluate the performance of these procedures relative to the more easily applied procedures.

E. Procedures in Categories 7 and 8

1. Procedures and Application

Testing of these procedures is extremely expensive. However, because they are the most hydrologically sophisticated when calibrated to a gaged record at a location, they offer a potential for being the most accurate.

To limit costs, it is proposed to test procedures in only one of these two categories. The major difference in the categories is the use of continuous versus discrete modeling of the rain-runoff process (the determination of precipitation excess, P_e). The difference from the standpoint of test design is a tradeoff between increased computer and calibration cost for continuous simulation versus a possible improved accruacy in estimation of P_e.

To further hold costs down, it is proposed to avoid testing "models." The question to be tested is: Given an adequate "model" calibrated to site data, is the flood-frequency curve generated using that model and rainfall either observed in the basin, observed in a similar climatic region, or statistically generated more or less accurate or otherwise different from results obtained using other procedures?

Depending on funds available, elements (variables) which could be tested, in order of significance, include:

a. Tester differences

   Provide the same consecutive 5-year site gage record (selected randomly) for calibration to each of five testers. Use rainfall observed in the watershed or similar climatic region for the modeling and calibration.

b. Calibration period effects

   1. Provide each tester with: (1) 5 years of record for calibration which contain some large peak flows and (2) 5 years of record for calibration which contain no out-of-bank peak flows.

   2. An alternative is to provide each tester with five sets of 5 years of gage records for calibration. This would provide a 5 by 5 matrix that could be analyzed for significant differences. This alternative could possibly be investigated using a smaller subset of data. This alternative was not included in the cost estimate.

c. Rainfall assumptions

   Repeat test described under (a) with statistically generated rainfall. This alternative was not costed.

d. Model effects

Repeat test described under (a) with a different model.

2. Site Selection

Testing would be limited to a 25-site subset of the sites used to test Category 6 watershed modeling procedures calibrated to site data.

3. Testers

It is proposed that only persons experienced with the selected watershed model be used as testers. If a sufficient number of experienced testers cannot be found, others would be trained as needed. However, formal training alone is not considered an adequate substitute for experience. It will be necessary to consider the impact of using inexperienced testers on test results.

4. Testing Program

Testing of a Category 7 or 8 procedure is estimated to cost about $8,800 (1980 dollars) per site application. Economies could be achieved by efficiently structuring testing so that each tester evaluates the effects of the calibration period and alternate rain assumptions. Table IX-3 provides costs for three possible levels of testing. They proceed from a minimum of five applications of one procedure for a common 5-year period at 25 sites, to an intermediate level of testing the effect of calibration periods, to a maximum level of testing two models as well as different calibration periods.

A program of testing would proceed in small increments based upon available funds and manpower. One approach would be to further subdivide the proposed minimum level into increments of five sites. The results would be appraised after each increment and testing would proceed only as more authoritative conclusions were needed.

F. Total Testing Program

The magnitude of the total testing program that is outlined is such that it must proceed in small increments. This results from both the costs and the need for experienced testers. The increments can be arranged in order of priority. It is recommended that the regions and sites for testing be selected at the start of the program to assure a common base for procedure performance evaluations and a more cost-effective testing program. Total costs for the program outlined vary from a minimum of $5,500,000 to a maximum of $11,600,000 (1980 dollars).

G. Management and Organization

Because of the magnitude of the task, conducting the proposed test even in small increments will require the full-time effort of an executive director who is knowledgeable in the fields of hydrology and statistical analysis. To achieve the goal set by Congress and the Water Resource Council (WRC) of a nationally acceptable guide, overall direction should remain under the WRC Hydrology Committee. This is an inter-agency committee whose members represent the Federal agencies which are responsible for the Federal programs which require flood flow frequency estimates. The Hydrology Committee in turn may want to continue the practice of assigning the immediate direction of the study to a subcommittee or Work Group composed of specialists in flood-frequency analysis from those agencies most directly involved in flow-frequency determinations. Non-Federal agencies, commercial consultants, and the academic community should be involved in designing and conducting the test as much as practical. The objective is to assure participation in the test by all those affected both as persons making estimates and managers of programs affected by flood-frequency estimates.

Responsibilities of the executive director would include:

1. Planning the test including recommendations on: procedures to test and test sites; methods for collecting and recording test data; identification of testers; data management and necessary computer software; and processes and staffing needs to conduct the test.

2. Conducting the test including: preparing and distributing test materials to testers; coordinating with testers to assure each understands the test, has the appropriate materials, and completes the test on schedule; collecting and quality control of test results; and validating and preparing the data for analysis.

3. Directing or overseeing the test analyses including data tabulation and summaries, graphical presentations, and statistical analyses.

4. Drafting reports of study results and a User's Guide of Peak Flow Frequency Determinations for Ungaged Watersheds.

5. Hiring and supervising staff and consultants as necessary to perform the various tasks.

6. Participating in and keeping records of Work Group meetings, documenting the study, and handling correspondence associated with the study.

Participation by non-Federal agencies, commercial consultants, and the academic community would be provided through participation in the testing and opportunities to review and comment upon proposed testing, testing results, and the proposed guidelines.

H. Benefits

The Federal Government spends an estimated $10 million annually on flood-frequency estimates at ungaged sites. These estimates are used to design structures and make land-use decisions involving billions of dollars.

The national guidelines, when developed, will provide more consistent hydrologic analyses needed for effective priority setting for national land-use management programs and the design of small projects. It will enhance the opportunity for equitable treatment of individuals, particularly in land-use management programs at the Federal, state, and local levels. It will simplify coordination between regulatory agencies. It will improve the efficiency of hydrologic assessments. The results of the analyses will focus hydrologic research needs on those areas required to improve the accuracy and reproducibility of peak flow frequency estimates.

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APPENDIX 1

PROCEDURE DESCRIPTIONS

This appendix contains a brief description of the procedures that were tested. These are not the descriptions provided to the testers. The actual procedure references are given in Table V-1. The procedure numbering code used in the statistical analyses described in section VIII is shown in parentheses.

USGS STATE EQUATIONS (1)

OHIO

Formula

$$Q_T = a\ A^b\ Sl^c\ St^d\ E^e\ P^f$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs

a, b, c, d, e, f = regression constant and coefficients

A = drainage area, square miles

Sl = main-channel slope, feet/mile

St = percentage of the drainage area occupied by lakes, ponds, and swamps, percent plus 1.0

E = average basin elevation index, thousands of feet above mean sea level

P = average annual precipitation, inches minus 27.0

The State is divided into five hydrologic regions. The parameters, constants, and coefficients vary with each region. There are separate formulas for each region to determine Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}.

Note: Procedures are also provided for transferring flood-frequency estimates upstream or downstream for sites whose drainage areas are within 1/2 to 2 times that of a gaging station on the same stream.

Basis

Regression analyses on flood-frequency curves were derived from records of 10 or more years collected at 215 gaging stations located on natural flow streams. The frequency curves were estimated using the log-Pearson Type III distribution (WRC Bulletin 17A) and annual peak data through 1975.

Applicable Watersheds

Size - Watersheds ranging in size from 0.01 to 7,400 square miles.

Conditions - Watersheds not significantly affected by man-made regulation, diversion, or urbanization, and watersheds which are not heavily forested.

Parameter Determination

Region - Selected from a figure given in report.

A - Measured from a 7-1/2-minute topographic quadrangle map or taken from Ohio Department of Natural Resources Report 12A (provided in report).

Sl - Stream length is measured from a map following prescribed procedures; elevations at 10 and 85 percent points are read from map; Sl is the difference in elevation in feet divided by the length in miles between the 10 and 85 percent points.

St - Measured from map and expressed as a percentage of the total area.

E - Elevations of the 10 and 85 percent points are read from a map; E is the average elevation of these two points.

P - Determined from an isohyetal map published by the Ohio Department of Natural Resources (map provided in the report).

Accuracy

Standard errors of estimate range from 26 to 41 percent; median value is about 30 percent.

INDIANA

Formula

$$Q_T = a\ A^b\ S^c\ L^d\ P_i^{\ e}\ R^f\ D^g\ R_c^{\ h}$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs

a, b, c, d, e, f, g, h = regression constant and coefficients

A = drainage area, square miles

S = channel slope, feet/mile

L = channel length, miles

P_i = precipitation index, inches

R = watershed relief, feet

D = drainage density, miles/miles squared

R_c = soil runoff coefficient

Four sets of formulas are provided: one for watersheds less than 100 square miles (model 2) and one for watersheds greater than 200 square miles (model 1). For watersheds between 100 and 200 square miles, Q_T is computed by the following equation:

$$Q_T = \left(\frac{A-100}{100} \right) Q_t \text{ model 1} + \left(\frac{200-A}{100} \right) Q_t \text{ model 2}$$

Model 3 is based on drainage area (A) and precipitation index (P_i) for all size watersheds but is not recommended for use. Model 4 was developed for the Wabash and White Rivers and is based on drainage area (A), channel slope (S), and channel length (L). The parameters, constants, and coefficients vary with each model. There are separate formulas for each model to determine Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}.

Basis

Regression analyses on flood-frequency curves were derived from records of 10 or more years collected at 149 gaging stations located on natural flow streams. The frequency curves were estimated using the log-Pearson Type III distribution (WRC Bulletin 15) and annual peak data through 1971.

Applicable Watersheds

Size - Watersheds draining at least 15 square miles.

Conditions - Watersheds not significantly affected by man-made regulation, diversion, or urbanization.

Parameter Determination

A - Measured from a USGS 7-1/2-minute series topographic map.

S - Stream length is measured from a map following prescribed procedures; elevations at 10 and 85 percent points are read from map; S is the difference in elevation in feet divided by the length in miles between the 10 and 85 percent points.

L - Measured from a USGS 7-1/2-minute series topographic map with dividers spaced at 0.1 mile.

P_i - Determined from an isohyetal map given in report based on data from the National Weather Service.

R - Measured from USGS 7-1/2-minutes series topographic map.

D - Measured from county drainage maps with dividers spaced at 0.25 mile.

R_c - Determined from a map given in report based on data from Purdue University and U.S. Soil Conservation Service.

Accuracy

Standard errors of estimate range from 9 to 63 percent; median value is about 30 percent.

ILLINOIS

Formula

$$Q_T = a\ A^b\ S^c\ (I-2.5)^d\ Af$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs

a, b, c, d = regression constant and coefficients

A = drainage area, square miles

S = main-channel slope, feet/mile

I = maximum 24-hour rainfall expected to be exceeded on an average once every 2 years, inches

Af = areal factor

The areal factor is defined on a map for four different regions. There are separate formulas to determine Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, and Q_{500}.

Note: Procedures are also provided for transferring flood-frequency estimates upstream or downstream.

Basis

Regression analyses on flood-frequency curves were derived from records of 10 or more years collected at 303 gaging stations located on natural flow streams. The frequency curves were estimated using the log-Pearson Type III distribution (WRC Bulletin 17) and annual peak data through 1975. In addition, synthetic estimates of the T-year flood discharges developed from a rainfall-runoff model were also used at 54 small-stream sites.

Applicable Watersheds

Size - Watersheds ranging in size from 0.02 to 10,000 square miles.

Conditions - Watersheds not significantly affected by natural or reservoir storage; channel changes; diversions; urbanization; and unusual hydrogeologic or morphologic conditions such as in karst terrane, bluff-floodplain combinations (streams that traverse the bluff and adjacent floodplain of major rivers), and other unusual conditions that affect flood flow.

Parameter Determination

A - Measured on USGS topographic maps.

S - Stream length is measured from a map following prescribed procedures; elevations at 10 and 85 percent points are read from map; S is the difference in elevation in feet divided by the length in miles between the 10 and 85 percent points.

I - Determined from the isohyetal maps in USWB TP 40 (maps provided in the report).

Af - Determined from a map given in the report.

Accuracy

Standard errors of estimate range from 34 to 47 percent; median value is about 39 percent.

MISSOURI

Formula

$$Q_T = a\, A^{bA^{c}} S^{d}$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs

a, b, c, d = regression constant and coefficients

A = drainage area, square miles

S = main-channel slope, feet/mile

There are separate formulas to determine Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}.

Basis

Regression analyses on flood-frequency curves were derived from records collected at 152 gaging stations on natural flow streams. The frequency curves were estimated using the log-Pearson Type III distribution (WRC Bulletin 15).

Applicable Watersheds

Size - Watersheds ranging in size from 0.1 to 14,000 square miles excluding the main stems of the Mississippi and Missouri Rivers.

Conditions - Watersheds where man-made changes have not appreciably changed the flow regime.

Parameter Determination

A - Measured on the best available topographic maps.

S - Stream length is measured from a map following prescribed procedures; elevations at 10 and 85 percent points are read from map; S is the difference in elevation in feet divided by the length in miles between 10 and 85 percent points.

Accuracy

Standard errors of estimate range from 34 to 39 percent; median value is 35 percent.

WASHINGTON

Formula

$$Q_T = a\ A^b\ P^c\ F^d$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs

a, b, c, d = regression constant and coefficients

A = drainage area, square miles

P = annual precipitation, inches

F = forest cover, percent (plus .01) of the total drainage

The State is divided into 12 hydrologic regions as shown on a map in the report. The parameters and coefficients vary with each region. There are separate formulas for each region to determine Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}. Only the four westernmost regions have formulas for estimating Q_2.

Basis

Regression analyses on flood-frequency curves were derived from records of 10 or more years collected at 450 gaging stations on natural flow streams. The frequency curves were estimated using the log-Pearson Type III distribution (WRC Bulletin 15) and annual peak data through 1973.

Applicable Watersheds

Size - Watersheds ranging in size from 0.15 to 3,550 square miles.

Conditions - Watersheds not significantly affected by man-made regulation, diversion, or urbanization.

Parameter Determination

A - Measured from the best available topographic maps.

P - Determined by the grid method from an isohyetal map prepared by the U.S. Weather Bureau (map provided in the report).

F - Determined by the grid method from a topographic map.

Accuracy

Standard errors of estimate in western Washington range from 25 to 61 percent; median value is about 38 percent. Standard errors of estimate in eastern Washington range from 42 to 129 percent; median value is about 60 percent.

MONTANA

Formula

$$Q_T = a\ A^b\ S^c\ P^d\ F$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs

a, b, c, d = regression constant and coefficients

A = drainage area, square miles

S = main-channel slope, feet/mile

P = mean-annual precipitation, inches

F = areal factor

The areal factor is defined for seven hydrologic regions and within each region may vary with recurrence interval. The same parameters and regression coefficients are used for each region with the areal factor the only parameter varying. There are separate formulas to determine Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}.

Note: Procedures are also provided for transferring flood-frequency estimates upstream or downstream using the drainage area ratio raised to the 0.6 power. Ungaged sites should have drainage areas between 1/2 and 2 times the gaging station drainage area.

Basis

Regression analyses on flood-frequency curves were derived from records of 6 years or more collected at 442 gaging stations located on natural flow streams. The frequency curves were estimated using the log-Pearson Type III distribution (WRC Bulletin 15 using a regional skew of -0.15).

Applicable Watersheds

Size - Watersheds ranging in size from 0.1 to about 2,600 square miles.

Conditions - Applicable to watersheds where the flood flows are virtually unaffected by urbanization, regulation, or diversion and for watersheds where a substantial part of the flow originates within Montana.

Parameter Determination

A - Measured from the largest scale topographic maps available.

S - Stream length is measured from a map following prescribed procedures; elevations at 10 and 85 percent points are read from map; S is the difference in elevation in feet divided by the length in miles between the 10 and 85 percent points.

P - Determined from an isohyetal map compiled from unpublished maps prepared by the Soil Conservation Service and National Weather Service in cooperation with the Montana Department of Natural Resources (map provided in the report).

F - Determined from a table and map provided in the report.

Accuracy

Standard errors of estimate range from 61 to 150 percent; median value is about 77 percent.

FLETCHER PROCEDURE (2)

Formula

$\hat{q}_{10} = a\ A^x\ R^y\ DH^z\ SC$

where: $\hat{q}_{10}$ = peak discharge for the 10-year recurrence interval, cfs

a, x, y, z = regression constant and coefficients

A = drainage area, square miles

R = iso-erodent factor - mean annual rainfall kinetic energy times the annual maximum 30-minute rainfall intensity

DH = difference in elevation of the main channel between the most distant point on the watershed boundary and the design point, feet.

SC = storage correction multiplication factor when the surface water storage exceeds 4 percent.

There are 24 hydrophysiographic zones (Z) in the United States and Puerto Rico as shown in Figure B-27. The coefficient and exponents vary with each region. To determine other flood peak frequencies:

$$Q_2 = 0.41\hat{q}_{10}$$
$$Q_{10} = 1.26\hat{q}_{10}^{\ 1.018}$$
$$Q_{50} = 1.56\hat{q}_{10}^{\ 1.023}$$
$$Q_{100} = 1.64\hat{q}_{10}^{\ 1.029}$$

Basis

Regression analyses on flood-frequency curves were derived from peak flow records of mostly 20 or more years collected at over 500 gaging stations located on natural flow streams. Annual peak flow data were through 1968. The frequency analysis was made by fitting a four parameter polynomial to the data.

Applicable Watersheds

Size - Watersheds with areas less than 50 square miles but may be used in areas up to 100 square miles.

Conditions - Watersheds are rural.

Parameter Determination

A - Measured from a topographic map

R - Read from map in Figure C-27

DH - Elevations read from map

S - Measured from map, divided by total area, and multiplied by 100. A storage correction multiplication factor (SC) is read from a figure.

Z - Selected from map in Figure B-27

Accuracy

Standard errors of estimate vary from 15 to 42 percent for 10-year runoff peak; median value is 28 percent.

REICH PROCEDURE (3)

Formula

$Q = q_{csm} \times A$

$$q_{csm} = 1.14 \frac{[484(0.1315 - 0.5792S + 0.1902B + 0.4261P_{30})]}{0.6B + 15}$$

where: A = drainage area, square miles

B = basin characteristics, Tc as defined by Figure 1, hours

S = infiltration capacity, in/hour

P_{30} = maximum 30-minute rainfall for desired return period, inches

Note: The design charts, Figure 2, were used in the pilot test to determine q_{csm}.

Adjustments:

antecedent precipitation index--Estimates in regions where 4 inches of rain are likely to fall during the five days preceding the storm should be increased by 20 percent.

late-peaking storm--Estimates in regions where the highest peaks are generally caused by storms which have their highest intensities after considerable rain has already fallen--or where additional precaution is desirable--should be increased by 50 percent.

combination--where both factors apply--safety factor is 1.8.

Basis

Simplified rain-runoff relationships. First, mathematical simplifications for a single triangular hydrograph were considered as valid approximations to floods in general. Second, the resulting algebraic equations were coupled to an empirical expression for storm runoff, which had been derived from observations of 47 floods. Third, a typical mass curve was assumed to relate the rainfall at any time after the commencement of the storm to the maximum 30-minute rain, P_{30m}. Fourth, equations which resulted from the above reasoning were evaluated for about 12,000 combinations of values for their five variables. Fifth, the resulting array of 12,000 values of peak rate of runoff was studied in an attempt to eliminate any unimportant variables and to find relationships between the remaining influences. Finally, an overall adjustment was made to these theoretical predictions in terms of 83 observed flood peaks. The discharge frequency is assumed equal to the rain frequency used in the computation.

Applicable Watersheds

Size - Watersheds ranging in size from 1/5 to 5 square miles.

Conditions - Watersheds are agricultural.

Parameter Determination

A - Measured from a topographic map

B - Read from nomograph, Figure 1, depending upon:

ℓ - the length of the longest collector in the stream system (continued out to the divide).

H - the fall in feet from the top of the watershed to the site (not including waterfalls and gully heads).

S - Computed using soil factor (f) times cover factor (F).

f - soil factor computed from Table 1 using factors for soil texture and structure, permeability, internal drainage, erosion class, land capability, surface drainage, and slope.

F - cover factor obtained from Table 2 based on land use and cover condition.

P_{30} - Read from rainfall atlas map.

Accuracy

Not defined

USGS INDEX FLOOD PROCEDURES (5)

USGS REGION 3-A

Formula

$$Q_T = c\ A^x\ R_T$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs

c, x = regression constant and coefficient

A = drainage area, square miles

R_T = ratio of T-year flood discharge (Q_T) to mean annual flood discharge ($Q_{2.33}$).

The basin is divided into eight hydrologic areas for estimating the mean annual flood ($Q_{2.33}$). The basin is also divided into four flood regions for determining R_T. The regression constant and coefficient vary across the eight hydrologic areas. A graph is provided for determining R_T up to recurrence intervals of 50 years.

Basis

Regression analyses on flood-frequency curves were derived from records of 10 or more years collected at 409 gaging stations located on natural flow streams. The frequency curves were defined graphically using annual peak data through 1961 for recurrence intervals up to 50 years.

Applicable Watersheds

Size - No limits given on watershed size.

Conditions - Watersheds not significantly affected by man-made regulation, diversion, or urbanization.

Parameter Determination

Hydrologic area and flood-frequency region - Selected from map provided in report.

A - Measured from the best available topographic map.

R_T - Determined from a figure in the report.

Accuracy

Standard error of estimate not provided.

USGS REGION 5

Formula

No formulas provided. The peak discharge for the T-year recurrence interval (Q_T) is estimated graphically using drainage area (A) in square miles and the percentage of the drainage area in lakes (L). The basin is divided into 11 hydrologic areas for estimating the mean annual flood ($Q_{2.33}$) and four flood-frequency regions for estimating the ratio of $Q_T/Q_{2.33}$ (R_T).

Basis

Graphical regression analyses on flood-frequency curves were derived from records of 10 or more years collected at 383 gaging stations on natural flow streams. The frequency curves were defined graphically using annual peak data through 1961 for recurrence intervals up to 50 years.

Applicable Watersheds

Size - No limits given on watershed size.

Conditions - Watersheds not significantly affected by man-made regulation, diversion, or urbanization.

Parameter Determination

Hydrologic area and flood-frequency region - Selected from map provided in report.

A - Measured from the best available topographic map.

L - Measured from the best available map.

R_T - Determined from a figure given in the report.

Accuracy

Standard error of estimate not provided.

USGS REGION 6-B

Formula

No formulas provided. The peak discharge for the T-year recurrence interval (Q_T) is estimated graphically using drainage area (A) in square miles and mean basin altitude (E) in feet. The basin is divided into 21 hydrologic areas for estimating the mean annual flood ($Q_{2.33}$) and eight flood-frequency regions for estimating the ratio of $Q_T/Q_{2.33}$ (R_T).

Basis

Graphical regression analyses on flood-frequency curves were derived from records collected at 558 gaging stations on natural flow streams. The frequency curves were defined graphically using annual peak data through 1962 for recurrence intervals up to 50 years.

Applicable Watersheds

Size - No limits given on watershed size.

Conditions - Watersheds not significantly affected by man-made regulation, diversion, or urbanization.

Parameter Determination

Hydrologic area and flood-frequency region - Selected from map provided in report.

A - Measured from the best available topographic map.

E - Measured from the best available map.

R_T - Determined from a figure given in the report.

Accuracy

Standard error of estimate not provided.

USGS REGION 12

Formula

$$Q_T = a\, A^b\, R^c\, L^d\, G\, R_T$$

where Q_T = peak discharge of the T-year recurrence interval, cfs

a, b, c, d = regression constant and coefficients

A = drainage area, square miles

R = average runoff for period 1930-57, inches

L = area of lakes and ponds, percent of total drainage area plus 0.01

G = geographical factor

R_T = ratio of T-year flood discharge (Q_T) to mean annual flood discharge ($Q_{2.33}$)

Different formulas are provided for the Pacific Slope basins and the upper Columbia River basin. The area is divided into eight flood-frequency regions for determining R_T. A graph is provided for determining R_T up to recurrence intervals of 50 years.

Basis

Regression analyses on flood-frequency curves were based on annual peak data through 1957. The frequency curves were defined graphically for recurrence intervals up to 50 years.

Applicable Watersheds

Size - Formulas are applicable to watersheds larger than 0.1 square mile in the Pacific Slope basin and to any watershed larger than 20 square miles in the upper Columbia River basin.

Conditions - Watersheds not significantly affected by man-made regulation, diversion, or urbanization.

Parameter Determination

Flood-frequency region - Selected from map provided in the report.

A - Measured from the best available topographic map.

R - Determined from a figure provided in the report.

L - Measured on a topographic map using either a planimeter or a grid of squares of known size.

G - Determined from a figure provided in the report.

R_T - Determined from a figure provided in the report.

Accuracy

Standard error of estimate for the mean annual flood is about 24 percent in the Pacific Slope basin and 23 percent in the upper Columbia River basin.

USGS REGION 13

Formula

$$Q_T = a\ A^b\ P^c\ G\ R_T$$

where: Q_T = peak discharge of the T-year recurrence interval, cfs

a, b, c = regression constant and coefficients

A = drainage area, square miles

P = mean annual precipitation, inches

G = geographical factor

R_T = ratio of T-year flood discharge (Q_T) to mean annual flood discharge ($Q_{2.33}$).

The basin is divided into nine flood-frequency regions for estimating R_T. R_T is also a function of mean basin altitude within seven of the nine regions and can be estimated from graphs provided in the report for recurrence intervals up to 50 years.

Basis

Regression analyses on flood-frequency curves were derived from records of 5 or more years collected at 295 gaging stations on natural flow streams. The frequency curves were defined graphically using annual peak data through 1957 for recurrence intervals up to 50 years.

Applicable Watersheds

Size - Watersheds between 10 and 5,000 square miles.

Conditions - Watersheds not significantly affected by regulation, diversion, or urbanization or where flow is significantly affected by springs.

Parameter Determination

Flood-frequency region - Selected from a map provided in the report.

A - Measured from the best available topographic map.

P - Determined from a map provided in the report.

G - Determined from a map provided in the report.

R_T - Determined from a figure provided in the report. Mean basin altitude, estimated from a topographic map, is also needed to estimate R_T.

Accuracy

The standard error of estimate of the mean annual flood is about 16 percent.

USGS REGION 14

Formula

$$Q_T = a\ A^b\ R^c\ L^d\ G\ R_T$$

where: Q_T = peak discharge for the T-year recurrence interval, cfs a, b, c, d = regression constant and coefficients

A = drainage area, square miles

R = average annual runoff, inches

L = area of lakes and ponds, percent of drainage area plus 0.01

G = geographic factor

R_T = ratio of T-year flood discharge (Q_T) to mean annual flood discharge ($Q_{2.33}$)

The basin is divided into eight flood-frequency regions for estimating R_T. A graph is provided for estimating R_T up to recurrence intervals of 50 years. The regression constant and coefficients are defined separately for the watersheds east and west of the Cascade Range.

Basis

Regression analyses on flood-frequency curves were derived from records of 5 or more years collected at natural flow streams. The frequency curves were defined graphically using annual peak data through 1957 for recurrence intervals up to 50 years.

Applicable Watersheds

Size - Watersheds larger than 0.5 square mile west of the Cascade Range and 10 square miles east of the Cascade Range.

Conditions - Watersheds not significantly affected by regulation, diversion, or urbanization.

Parameter Determination

Flood-frequency region - Selected from a map provided in the report.

A - Measured from the best available topographic map.

R - Determined from a map provided in the report.

L - Measured from a topographic map.

G - Determined from a map provided in the report.

R_T - Determined from a figure provided in the report.

Accuracy

The coefficient of determination for the mean annual flood is 0.92.

IDAHO

Formula

$$Q_{10} = a\ A^b\ F^c\ La^d\ N^e\ W^f$$

where: Q_{10} = peak discharge for the 10-year recurrence interval, cfs

a, b, c, d, e, f = regression constant and coefficients

A = drainage area, square miles

F = percentage of forest cover plus 1 percent

La = percentage of area of lakes and ponds in the basin plus 1 percent

N = latitude of centroid of basin in degrees minus 40 degrees

W = longitude of centroid of basin in degrees minus 110 degrees

The State is divided into eight hydrologic regions with the parameters, constants, and coefficients varying across the regions. For each region, the average ratio of Q_{25}/Q_{10} and Q_{50}/Q_{10} is given in a table enabling the user to estimate Q_{25} and Q_{50}.

Basis

Regression analyses on flood-frequency curves were derived from records of 10 or more years collected at 303 gaging stations on natural flow streams. The frequency curves were estimated using the log-Pearson Type III distribution (WRC Bulletin 15) and annual peak data through 1971.

Applicable Watersheds

Size - Watersheds ranging in size from 0.5 to 200 square miles.

Conditions - Formulas are not appropriate for urbanized areas, streams affected by regulation or diversion, unforested areas, streams with gaining or losing reaches, streams draining alluvial valleys and the Snake Plain, and intense thunderstorm areas.

Parameter Determination

Region - Selected from a map given in the report.

A - Measured from the best available topographic map.

F - Measured from U.S. Geological Survey 1:250,000 scale map using the grid method.

La - Measured from a U.S. Geological Survey 7-1/2- or 15-minute map using the grid method.

N - Measured from a U.S. Geological Survey 1:250,000 scale map.

W - Measured from a U.S. Geological Survey 1:250,000 scale map.

Accuracy

Standard errors of estimate of the 10-year flood discharge range from 41 to 61 percent across the eight regions; median value is about 55 percent.

RATIONAL FORMULA (6)

Formula

$Q = C\ i\ A$

where: C = coefficient of runoff representing the ratio of runoff to rainfall

i = intensity of rainfall for selected return period, inches/hour

A = drainage area, acres.

Basis

Simplified rain-runoff relationship--the formula takes advantage of the fact that 1 acre-in/hr nearly equals 1 cfs and assumes that for rainfall exceeding the time of concentration, the rate of runoff equals the rate of rainfall reduced by an appropriate factor. When computing a discharge of selected frequency, the discharge frequency is assumed equal to the rain (i) frequency.

Applicable Watersheds

Size - Watersheds with areas up to 3 square miles.

Conditions - Watersheds are natural or urban.

Parameter Determination

$$C = \sum_{j=1}^{j=n} LU_j\ C_j$$

C_j - Judgment requiring the selection of values from a table which gives proposed minimum and maximum values for various land uses, topography, and soil textures.

LU_j - Percentage of drainage area with coefficient of runoff C_j

$i = R/t_c$

R - Rain depth read from a rainfall atlas map for a storm of duration t_c

t_c - Time of concentration, hours (the time it takes runoff to flow from the farthest point in the drainage area to the design point)

Determination of t_c requires an estimate of the average velocity of overland flow. This can be obtained by judgment or use of a nomograph. Elements in the determination include:

L - Distance to farthest point in the watershed measured in feet from a map or survey.

N - A retardance or roughness coefficient selected by judgment depending upon the type of surface.

S - Average slope of watershed over length L. The necessary difference in elevation is determined from a map or survey.

In the pilot test, $t_c = 0.00013\ L^{0.77}/S^{0.385}$ was given as a method to compute t_c.

A - Measured from a map or by survey.

Accuracy

Not defined

TR-55 APPENDIX D - CHARTS (7)

Computation of peak discharge

$q = q_p \cdot Q \cdot SF \cdot$ Adjustment Factors from Appendix E.

where: q = peak discharge, cfs

q_p = peak discharge in cfs/inch of runoff for the watershed from Figure D-2

Q = runoff depth from Table 2-1, inches

SF = watershed slope interpolation factor from Table E-1

Adjustment Factors (if applicable):

PSF = ponding and swampy area factor from Table E-2, E-3, or E-4

WSF = watershed shape factor adjustment, the product of the equivalent peak discharge and the ratio of actual to equivalent drainage area.

Relationship

$q_p = f(P_{24II}, CN, A, S)$

where: P_{24II} = 24-hour storm rainfall, inches (Type II distribution assumed when developing basic relationships)

CN = curve number - a function of watershed soils, land use, and hydrologic conditions

A = drainage area, acres

S = average watershed slope, percent

PSF = f(PS, A, L, T)

where: PS = swampy and ponding areas, percent of drainage area

L = location in watershed

T = storm frequency, years

WSF = f(, w, EA, A, q_p)

where: = length of mainstream to farthest divide, feet

w = average width of watershed, feet.

EA = equivalent drainage area, acres.

Basis

Simplified rain-runoff relationship--peaks developed from flood hydrographs computed using a standard dimensionless unit hydrograph and 24-hour rainfall depths with a standard incremental time distribution for a range of watershed sizes, slopes, and runoff conditions. The watershed lag is related to the watershed size by a standard watershed shape. The discharge frequency is assumed equal to the rain frequency used in the computation.

Applicable Watersheds

Size - Watersheds with areas from 1 to 2000 acres (3.1 square miles).

Conditions - Watersheds are agricultural or urban if adjustments in Chapter 4 are used.

Parameter Determination

P_{24} - Read from rainfall atlas map

CN - Computed based upon hydrologic soils maps, land use, and hydrologic conditions

- Determine soils from soil survey
- Obtain hydrologic soil group from Table B-1
- Determine land use and hydrologic conditions from field inspection, aerial photo, or map
- Select soil cover complex CN from Table 2-2, compute weighted composite CN for watershed

A - Measured from a map or by survey

S - By inspection, from soil survey report, or from topographic map

PS - Measured from topographic map or aerial photograph

ℓ - Measured from map or by survey

w - Computed knowing area (A) and ℓ.

EA - Determine from Figure E-1

Accuracy

Not defined

Computation of peak discharge

$$q = q_p\ A\ Q$$

where: q = peak discharge, cfs

q_p = peak discharge in cubic feet per second per square mile (csm)/inch from Figure 5-2

A = drainage area, square miles

Q = runoff depth from Table 2-1, inches.

Relationship

$$q_p = f(P_{24II}, CN, t_c)$$

where: P_{24II} = 24-hour storm rainfall, inches (Type II distribution assumed when developing basic relationships)

CN = curve number - a function of watershed soils, land use, and hydrologic conditions

t_c = time of concentration, hours (time it takes runoff to travel from the hydrologically most distant point of the watershed to the point of reference)

Basis

Simplified rain-runoff relationship--peaks developed from flood hydrographs computed using a standard dimensionless unit hydrograph and 24-hour rainfall depths with standard incremental time distribution for a range of t_c. The discharge frequency is assumed equal to the rain frequency used in the computation.

Applicable Watersheds

Size - Watersheds with areas up to 20 square miles

Conditions - Runoff characteristics are uniform and valley routing is not required. Watersheds are agricultural or urban if impervious area adjustment in Chapter 3 is used.

Parameter Determination

P_{24} - Read from rainfall atlas map

CN - Computed based upon hydrologic soils maps, land use, and hydrologic conditions

- Determine soils from soil surveys

- Obtain hydrologic soil group from Table B-1

- Determine land use and hydrologic conditions from field inspection, aerial photo, or map

- Select soil cover complex CN from Table 2-2, compute weighted composite CN for watershed

t_c - Determined by computing travel time (T_t) based upon travel length (ℓ) and average flow velocity (V_{avg}) in feet per second.

ℓ - Measured from map or survey

V_{avg} (1) - Read from Figure 3-1

- Requires estimate of watercourse slope in percent and land use.

(2) - Computed using Manning's equation for bank full flow.

A--Measured from a map or by survey

Accuracy

Not defined

TR-20 PROCEDURE (9)

Purpose and Objectives:

The TR-20 program provides for hydrologic analyses of a watershed under present conditions and with various combinations of land cover/use and structural or channel modifications using single event storm rainfall-frequency data. The program computes surface runoff resulting from synthetic or natural rain storms, develops flood hydrographs, routes through stream channels and reservoirs, combines hydrographs with those from tributaries, and provides peaks and/or flood hydrographs, their time of occurrence, and water surface elevations at any desired cross section or structure.

Description:

TR-20 generates subarea surface runoff hydrographs from storm rainfall using a dimensionless unit hydrograph, drainage areas, times of concentration, and SCS runoff curve numbers. Standard control instructions to develop, route, add, store, divert, or divide hydrographs are established to convey floodwater from the headwaters to the watershed outlet. Reach routing is by a coefficient (convex) method with a typical cross section stage-discharge-area curve representing a reach. Reservoir routing is by the storage indication method.

Uniform rain depth and distribution are assumed over a subarea, groups of sequential subareas, or the whole watershed. Snowmelt runoff can be accounted for by baseflow or interflow hydrographs.

Input:

The program uses card input with fixed format. The required data are: sequential standard control instructions which include drainage area, time of concentration, and the SCS runoff curve number for each subarea; structure tables-elevation, discharge, and storage data; cross section tables-elevation, discharge, and endarea data or optional routing coefficients; reach lengths; main time increment; constant or triangular hydrograph base-flow; storm rainfall tables-depth, duration, distribution, and starting time data; and the soil moisture condition-wet, average or dry. The Standard Control and tabular information can be easily altered, inserted, or deleted for alternate runs. Hydrograph data can be read in directly and the dimensionless unit hydrograph can be easily changed by the user.

Output:

The program provides, in tabular form, peaks and flood hydrographs, their time of occurrence, and water surface elevations at any desired cross section or structure. Printed and punched output are user controlled. Summary tables are optional.

Operational Requirements and Restrictions:

a. One person can use the program with basic knowledge of watershed hydrology and hydraulics and a basic familiarity with computers and computer software.

b. At least one day of training is helpful to use the program plus several days additional if unfamiliar with SCS hydrologic techniques.

c. The program was written for the IBM 360/370 system in FORTRAN IV. Memory requirements are 212K Bytes and two temporary files.

d. In one continuous operation, the program can route through 99 reservoirs and 200 stream reaches with unlimited number of variations in each. It will process up to 9 rainfall distributions with unlimited number of routines based on variations in rainfall amounts, duration, and antecedent moisture condition. There are limitations of 600 Standard Control cards, a maximum number of constant time increments of 99 for each rainfall distribution, and 300 time increments (Δt's) for development of each hydrograph. The rainfall time increment must adequately define the intense portions of raifall and the main time increment must be small enough to sufficiently define the smallest subarea hydrograph.

e. Both the reach routing and reservoir routing techniques use the conservation of mass equation and a single-value rating curve as the conservation of momentum equation.

f. The areal distribution of a given frequency of rainfall may limit the program's use when discharge-frequency relationships are desired from the headwaters to the outlet of a large watershed. The typical range of application has been on watersheds ranging from 2 to 400 square miles with subareas from 0.1 to 20 square miles.

g. Users are encouraged to calibrate and verify the watershed model using stream gage data within or downstream of the watershed, supplemented by high water marks.

Form of Presentation:

Magnetic Tape 9- or 7-Track
Users Manual
Revised Standard input forms 1971-1973

THE HEC-1 FLOOD HYDROGRAPH PACKAGE (10)

History and Purpose:

HEC-1 is a mathematical watershed model containing several methods with which to simulate surface runoff and river/reservoir flow for flood events in river basins. The hydrologic model together with flood damage computations (also included in the model) provide a basis for evaluation of flood control projects. HEC-1 was developed by the Hydrologic Engineering Center (HEC), U.S. Army Corps of Engineers, in the late 1960's; an updated version of that program, dated January 1973, was used in these ungaged area flood-frequency studies. A new version of the model, with greatly expanded capabilities, was released in 1981 and is described here. The capabilities of the new HEC-1 Flood Hydrograph Package include: simulation of rainfall and/or snowmelt runoff from subbasins and flow through a stream network; simulation of flows in urban areas; hydrologic calculations for dam safety and dam failure studies; and economic calculations for planning flood control systems.

Description:

HEC-1 simulates a stream network using four components: (1) runoff from a subbasin; (2) hydrograph routing; (3) combining of hydrographs; and (4) flow diversion. Most complex, branching stream networks can be simulated with the model. Options for the watershed runoff calculation offer a variety of methods to input precipitation data; calculate interception/infiltration; and transform moisture excess into runoff. Precipitation may be described by a cumulative or incremental time series for one or more gages; weightings are specified for the gages in order to compute a basin average value. Probable maximum storms and other design-frequency storm distributions can be computed automatically by the program. Snowfall and snowmelt in several elevation zones within a subbasin are computed by either the degree day or energy budget method. Interception/infiltration computations may be made by any of the following methods: initial and uniform; Soil Conservation Service (SCS) curve number; HEC exponential; or Holtan's soil moisture accounting method. Rainfall and snowmelt excesses are transformed into direct surface runoff from a subbasin by a Clark, Snyder, SCS lag, or a given unit hydrograph or by the nonlinear kinematic wave land surface runoff method. Base flow is added to the direct surface runoff. The above methods may be used in any combination depending upon available data and user preferences.

Subbasin runoff is routed through the river basin network and combined with other subbasin runoff. Flood routing may be accomplished by the Muskingum, modified Puls, working R&D, level-pool reservoir, kinematic wave, or simplified average lag methods. The modified Puls storage routing may be performed with a given storage-outflow relationship or computed from user-specified channel geometry and hydraulic characteristics. The flow may be diverted from the main channel/reservoir at any point in the stream network. Diverted flows may be treated as a new link in the runoff network and reenter the system at virtually any point. Multistage pumping plants may also be used to divert flows. The number of subbasins and routing reaches is unlimited.

HEC-1 provides a powerful optimization technique for the estimation of some of the parameters when gaged precipitation and runoff data are available. By using this technique and regionalizing the results, rainfall-runoff parameters for ungaged areas can also be estimated. The parameter optimization option has the capability to automatically determine a set of unit hydrograph and loss rate parameters that "best" reconstitute an observed runoff hydrograph for a subbasin. Flood routing parameters for certain hydrologic techniques may also be optimized. The "best" reconstitution is considered to be that which minimizes the weighted squared difference between the observed hydrograph and the computed hydrograph.

Flow in urban areas can be simulated using kinematic wave routing of rainfall excess along a path which includes overland flow elements, collector channels, and a main channel to a subbasin outlet. Flow from overland flow elements contributes laterally to a collector channel. The initial collector channel may feed into another collector channel or directly to the main channel where it is then distributed as lateral inflow along the length of the main channel or lumped at either end of the reach. Flow from an upstream basin may be routed through the main channel simultaneously with lateral flow from the collectors. The overland flow/collector channel system may be used for a detailed simulation on a street-by-street basis or as representative subsystems within a subbasin.

A special level-pool reservoir routing routine is included in HEC-1 for simulating flow through a dam and spillway, over the top of the dam, or through a dam breach. This can be used in conjunction with other stream network modeling capabilities to determine potential hazards from dam overtopping or failure. The model has been frequently used in the U.S. National Non-Federal Dam Safety Inspection Program.

In addition to its hydrologic capabilities, HEC-1 can be used for economic evaluation of flood hazards and flood control systems. Expected annual flood damage is computed using the watershed model results together with flood-frequency and flood-damage data. Flood damage may be calculated for any locations in the river basin and for existing and alternative flood control projects. When combined with cost data for the projects and a systematic search procedure, the model can provide an estimte of the optimal size of the flood control projects based on net benefit criteria. This enables a planner to select the most desirable flood control scenario from a number of plans. Flood control projects which may be analyzed are detention reservoirs, channels, diversion, pumping plants, and levees.

Input/Output:

There are two general types of data for HEC-1: input control and river basin simulation data. The input control data specify the format of the river basin data as well as controlling certain diagnostic output. The river basin simulation data are all identified by a unique two-character alaphabetic code which serves two functions: it identifies the data to be read from the card and activates the various simulation options. The data may be input in a free or fixed format. A flow chart of the stream network simulation may be printed. Either English or metric units may be used. A large variety and degree of detail in the printer output are available from HEC-1. The output may be categorized in terms of input data feedback, intermediate simulation results, summary results, and error messages. The degree of detail of virtually all of the program output can be controlled by the user.

Computer Requirements and Support:

HEC-1 requires a FORTRAN IV compiler and up to 16 input/output scratch (tape, disk, etc.) files. The computer memory required on the CDC 7600 is 115,000 words and it requires approximately 7 seconds to compile. The program has been tested on several major computers and the machine dependent code removed whenever possible. A user's manual and programmer's supplement are available which describe the details of program usage, modifications necessary to run the program on different computer systems, and ways to reduce memory requirements. The HEC provides user support for HEC-1 and its other programs. User support consists of answering questions about application of the model and providing program updates.

APPENDIX 2

COMPUTATION OF GAGE ESTIMATES

The accuracy assessment of each procedure is based on a comparison of tester flood-frequency estimates with flood-frequency estimates determined from systematic stream gaging records of annual peaks at the test site. Development of the flood-frequency estimates based on the log-Pearson Type III distribution, use of mixed population analysis, and frequency estimates based on distributions other than the log-Pearson Type III are described in the following sections.

A. Introduction to Log-Pearson Type III Analysis

Methods described in U.S. Water Resources Council Bulletin 17A (1977) were generally followed to arrive at exceedance frequency estimates of annual flood peaks at each test site. Values obtained from these frequency estimates for the 50-, 10-, and 1-percent-chance floods were used for the primary accuracy assessment of each procedure and are referred to as the gage estimate. The gage estimates were developed in four stages: (1) review and editing of the data base; (2) identification of historic flood information and high outliers; (3) identification of low outliers; and (4) selection of generalized skew values. Departures from or interpretations of Bulletin 17A are described for each stage. A considerable amount of information was provided and certain special analyses were performed by experienced professionals familiar with the regional and site hydrology. Results of the analyses are summarized in Table A2-1. Table A2-1 lists the systematic record analysis, any additional analyses to include historic or outlier information, the adopted skew and discharge estimates (underlined), and any additional information collected for the analyses.

B. Data Base

The initial data base consisted of a systematic gaging record of annual flood peaks at each test site obtained from the USGS WATSTORE file. At some test sites the initial data base contained broken records, incomplete records, and/or historic information. An initial flood-frequency curve was computed for each test site based upon this data base. The initial flood-frequency curves and data base were reviewed by persons knowledgeable in flood-frequency analysis. Many of these persons were located near the test site and were familiar with the regional hydrology and the test sites. As a result of this review, additional information was obtained that was used in subsequent decisions concerning the data base. This additional data included historic information, generalized skew values, and questions concerning low outliers and mixed populations. This information is summarized in Table A2-1 under the heading of Additional Information. The agency initials follow the information provided by that agency. Other information under this column is from WATSTORE or developed in the analysis. Remarks in brackets are for information only and were not used in the analysis.

Table A2-1

PILOT TEST WATERSHED GAGE ESTIMATES[1]

	Systematic Record Analysis[2]						Additional Analyses[3]						Additional Information and Remarks [ ][4]
Pilot Test No.	N	Station Skew	Map Skew	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	Equivalent N	Equivalent Station Skew	Gen. Skew[5]	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	
21	27	-0.12	-0.4	201	551	1101	27	-0.12	-0.2	195	563	1249	[1957 is a high outlier but no historic information]
22	22	0.28	-0.4	21	41	65	22	0.28	-0.2	21	42	71	
23	20	-0.18	-0.4	258	558	946	20	-0.18	-0.2	252	268	1044	
24	28	-0.06	-0.35	257	691	1390	28	-0.06	-0.2	252	702	1520	
25	27	-0.61	-0.3	535	2033	5289	27	-0.61	-0.2	525	2062	5736	
26	40	-0.54	-0.1	118	288	565	--	----					
27	27	0.12	-0.35	36	78	134	27	0.12	-0.2	36	79	144	
28	21	-0.65	-0.35	277	562	924	21	-0.65	-0.2	276	569	989	
29	23	1.32	-0.4	165	381	676	23	1.32	-0.2	161	388	753	[1951 is a high outlier but no historic information (SCS)]
30	27	0.14	-0.3	724	2811	7491	27	0.14	-0.2	711	2852	8131	
31	26	-0.30	-0.35	1910	4792	9142	26	-0.30	-0.2	1874	4866	9963	
32	26	-0.69	-0.3	668	1399	2396	26	-0.69	-0.2	662	1410	2487	
33	27	-1.37	-0.4	282	1035	2492	26	0.28	-0.4	292	897	1942	1954 is a low outlier
							26	0.28	-0.2	292	881	2020	1954 is a low outlier
34	35	-0.40	-0.1	692	2053	4747	91	-0.17	-0.1	715	2186	5131	1935 highest since 1884 (USGS)
							90	0.35	-0.1	695	2144	5964	1935 (9020 cfs) highest since 1884 & 1954 is a low outlier
35	29	-0.45	-0.2	403	975	1884	[6] 64	-0.59	-0.2	400	891	1543	1968 highest since 1913 (USGS&COE)
36	28	0.75	-0.35	1936	3089	5455	28	0.75	-0.2	1374	3127	5858	[1958 stage highest since 1881 or 1882]
37	23	-0.49	-0.3	1969	4557	8326	23	-0.49	-0.2	1946	4599	8772	
38	28	-1.09	-0.35	1983	4796	8835	27	-0.74	-0.35	2148	4184	6657	1976 is a low outlier

Table A2-1 (Continued)

PILOT TEST WATERSHED GAGE ESTIMATES

Pilot Test No.	Systematic Record Analysis[2]						Additional Analyses[3]						Additional Information and Remarks [ ][4]
	N	Station Skew	Map Skew	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	N	Equivalent Station Skew	Gen. Skew[5]	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	
							28	-1.09	-0.2	1947	4868	9581	
							27	-0.74	-0.2	2148	4150	6774	1976 is a low outlier
39	28	-0.46	-0.4	200	484	886	28	-0.46	-0.2	195	494	988	
40	26	-0.21	-0.35	1458	2921	4759	26	-0.21	-0.2	1437	2955	5078	
41	28	0.37	-0.4	1015	1902	2946	68	0.18	-0.4	959	1796	2957	1958 highest since 1910
							28	0.37	-0.2	997	1929	3181	
							[6] 58	0.18	-0.2	952	1804	3051	1958 highest since 1910
42	26	-0.13	-0.35	1771	3856	6664	26	-0.13	-0.2	1742	3907	7167	
43	24	-0.53	-0.4	807	1456	2181	24	-0.53	-0.2	794	1476	2352	
44	30	-0.27	-0.1	800	1773	3301	--	----					
45	47	-0.53	-0.1	2438	4211	6320	47	-0.53	+0.2	2400	4259	6781	Ohio (COE) uses G = +0.2
46	38	0.57	-0.3	1154	2298	3901	38	0.57	-0.2	1145	2311	4036	[Ohio (COE) uses G = +0.7]
							38	0.57	+0.7	1069	2386	5422	
47	30	-0.46	-0.3	3662	7870	13601	103	-0.29	----	3719	8136	12426	1913 highest since 1875 (USGS)
							102	0.20	----	3658	8004	15916	1913 highest since 1875 & 1954 is a low outlier
							30	-0.46	-0.2	3626	7933	14222	
48	22	-1.38	-0.4	935	1832	2906	21	-0.54	-0.4	990	1635	2307	1964 is a low outlier
							22	-1.38	-0.2	917	1861	3167	
							21	-0.54	-0.2	990	1622	2349	1964 is a low outlier
49	40	-0.38	-0.4	2260	4880	8279	40	-0.38	-0.2	2221	4952	8958	
50	36	-0.39	-0.4	1699	4383	8394	35	0.17	-0.4	1642	4489	9195	1957 is a low outlier
							36	-0.39	-0.2	1660	4467	5309	

Table A2-1 (Continued)

PILOT TEST WATERSHED GAGE ESTIMATES

	Systematic Record Analysis[2]						Additional Analyses[3]						Additional Information and Remarks [ ][4]
Pilot Test No.	N	Station Skew	Map Skew	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	Equivalent N	Equivalent Station Skew	Gen. Skew[5]	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	
							35	0.17	-0.2	1642	4426	9483	1957 is a low outlier [1975 is below gage base]
51	38	-0.68	-0.4	5712	12640	21503	38	-0.68	-0.2	5604	12846	23417	
52	39	-1.25	-0.35	2590	5607	9231	38	-0.32	-0.35	2634	5195	8378	1938 is a low outlier
							38	-0.32	-0.2	2634	5159	8505	1938 is a low outlier
53	41	-0.92	-0.4	3965	9413	16481	38	-0.18	-0.4	4141	8686	14601	1961, 1968 & 1977 are low outliers
							41	-0.92	-0.2	3887	9583	18031	
							38	-0.18	-0.2	4141	8602	14913	1961, 1968 & 1977 are low outliers
54	27	0.74	-0.3	4291	11916	25054	27	0.74	-0.2	4232	12043	26642	
55	55	-0.71	-0.35	12127	27024	45644	54	-0.35	-0.35	12193	26251	44978	1934 is a low outlier
							55	-0.71	-0.2	12000	27282	47848	
							54	-0.35	-0.2	12193	26098	45547	1934 is a low outlier
56	50	-0.59	-0.4	8989	22646	41763	50	-0.59	-0.2	8830	23003	45261	
57	69	-0.32	-0.4	5181	11417	19861	69	-0.32	-0.2	5134	11504	20699	
58	39	-1.13	-0.4	9471	20255	32928	38	-0.45	-0.4	9694	18862	29708	1941 is a low outlier
							102	-0.33	----	9935	20076	33078	1941 is a low outlier & 1913 highest since 1875 (COE)
							39	-1.13	-0.2	9300	20593	35751	
							38	-0.45	-0.2	9694	18690	30301	1941 is a low outlier [1957 highest since 1913. 1913 (36,000 cfs), 1927 (24,000 cfs), and 1937 (8,770 cfs) are historic peaks]
59	61	0.36	0.0	12578	22663	37818	103	0.49	----	12436	23721	44271	1907 highest since 1873

Table A2-1 (Continued)

PILOT TEST WATERSHED GAGE ESTIMATES[1]

Pilot Test No.	Systematic Record Analysis[2] N	Station Skew	Map Skew	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	Additional Analyses[3] N	Equivalent Station Skew	Gen. Skew[5]	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	Additional Information and Remarks [ ][4]
							61	0.36	+0.7	12245	22931	42418	[1964 highest since 1907 (50,000 cfs) (COE) 1964 higher than 1844 and 1873 Ohio (COE) uses G = +0.7 Flows have been modified sine 1952 by Tom Jenkins Lake, and by eight retarding basins constructed between 1955 and 1961 (COE)]
60	64	0.36	-0.3	7030	14624	26848	93	0.25	-0.3	6868	14332	27347	1913 highest since 1884 (USGS)
							172	0.12	----	6858	13857	25245	1913 highest since 1905 (COE)
							93	0.25	-0.2	6862	14338	27448	1913 highest since 1884 [Some regulation by Indian Lake. Storage does not significantly affect peaks (USGS)]
76	20	-0.27	-0.2	24	95	269	28	-0.32	-0.2	23	88	240	1955 highest since 1946 [Historic information reduced $Q_{.01}$ by 11%]
77	20	-1.51	-0.3	59	214	538	19	-0.17	-0.3	50	259	842	1968 is a low outlier
							[6] 53	-0.33	-0.3	48	202	569	1968 is a low outlier & 1966 highest since 1920 (USGS)
							54	-1.60	-0.3	54	184	369	1966 highest since 1920 (USGS) [1967 had no flow]
78	20	0.42	0.0	55	114	207	--	----					
79	22	-0.37	0.2	23	42	72	--	----					[1967, 1968, and 1977 are below gage base]
80	21	-0.44	0.2	174	220	271	--	----					
81	47	-0.02	0.0	87	153	244	--	----					
82	53	0.27	0.0	285	557	982							
83	20	0.08	-0.1	29	175	717	62	-0.41	-0.1	26	121	369	1957 highest since 1914
							60	0.59	-0.1	26	113	417	1970 & 1971 are low outliers & 1957 highest since 1914
84	25	2.54	0.6	181	698	2686	25	2.54	-0.15	203	656	1613	

Table A2-1 (Continued)

PILOT TEST WATERSHED GAGE ESTIMATES

Pilot Test No.	N	Station Skew	Map Skew	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	N	Equivalent Station Skew	Gen. Skew[5]	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	Additional Information and Remarks [ ][4]
	Systematic Record Analysis[2]						Additional Analyses[3]						
							83	3.27	-0.15	134	354	1685	1964 & 1975 highest since 1894 (USGS)
							83	3.27	0.6	133	349	1762	1964 & 1975 highest since 1894 [Montana uses G = 0.15]
85	22	0.15	0.0	94	236	501	--	----					
86	59	-0.03	0.1	2236	3887	6145	--	----					
87	50	0.78	0.2	317	490	738	--	----	[7] MPA	325	480	770	[Separation by calendar periods increases $Q_{.01}$ by 4% (COE)] [Groundwater storage has a serious dampening effect of peak flow (USGS) 1965 is a high outlier but no historic information (SCS)]
88	37	-0.34	-0.2	476	812	1206	--	----	MPA	470	800	1400	[Separation by calendar periods increases $Q_{.02}$ by 15% (COE)] [Slight variation below $Q_{.50}$ probability]
89	22	-0.47	-0.3	810	1203	1559	--	----					
90	33	-0.11	0.0	319	578	936	--	----					
91	62	0.80	0.0	524	999	1830	--	----	MPA	460	1000	2130	[Separation by calendar periods increases $Q_{.01}$ by 16% (COE) Slight variation below $Q_{.50}$ probability]
92	48	0.78	0.0	1352	2916	5777	--	----	MPA	1380	2950	6400	[Separation by calendar periods increases $Q_{.01}$ by 11% (COE)]
93	53	-0.49	-0.1	1579	2202	2814	--	----					[Regulation and diversion affect peak stages slightly (Minam Lake)]
94	36	-0.76	-0.2	195	423	742	--	----					
95	47	0.04	0.1	9531	16084	24984	--	----					
96	64	-0.47	0.0	11892	17388	23006	--	----	MPA	12000	17200	24800	[Separation by calendar periods increases $Q_{.01}$ by 8% (COE)] [Wenatchee Lake provides "natural drainage"]
97	47	-0.15	0.2	22966	36444	53865	--	----					

Table A2-1 (Continued)

PILOT TEST WATERSHED GAGE ESTIMATES

	Systematic Record Analysis[2]						Additional Analyses[3]						Additional Information and Remarks [ ][4]
Pilot Test No.	N	Station Skew	Map Skew	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	N	Equivalent Station Skew	Gen. Skew[5]	$Q_{.50}$	$Q_{.10}$	$Q_{.01}$	
98	59	-0.05	-0.3	15062	26139	39653	--	----					
99	66	-0.25	-0.2	6734	10409	14360	80	-0.18	-0.2	6775	10614	14901	1965 highest since 1896 (16,000 cfs) (USGS)
							106	-0.18	----	6822	11040	15206	1872 (22,700 cfs) & 1965 highest since 1871 (19,600 cfs)
							--	----	MPA	6800	10000	13400	[Separation by calendar periods decreases $Q_{.01}$ by 12% (COE)] [Floods of 1300-1700 cfs (since 1865) occurred in 1874, 1875, 1881, 1896, and 1897]
100	45	0.21	-0.1	5401	11019	19622	94	0.22	-0.1	5291	11097	21226	1906 (15,500 cfs) highest since 1883 (17,000 cfs)
107	29	0.22	-0.35	2873	8368	11224	29	0.22	-0.2	2828	6448	12407	
108	24	0.07	-0.2	1534	4332	9447	--	----					
126	26	0.58	0.3	1917	3038	4619	--	----					[1964 high outlier but no historic information (SCS)]
128	37	-0.51	-0.3	304	593	951	--	----					
129	58	0.20	0.0	3386	689	1122	--	----					[1974 is high outlier but no historic information (SCS)]

1. The adopted analysis is underlined for each station.

2. Systematic record analysis used map skew from Plate I in Bulletin 17A but used no historical information and no outliers were deleted.

3. Additional analyses include historic and outlier information as noted under "Additional Information."

4. Remarks in brackets are for information only and were not used in the analysis.

5. CE recommends using a generalized skew of -0.2 or more positive for watershed Nos. 21 to 60, 107, and 108.

6. Historic data not used because high peak appears representative of systematic record.

7. MPA--Mixed population analysis.

C. Historic Information and High Outliers

Historic information was used to define a period longer than the systematic record, during which the largest flood(s) recorded is known. The historic information was carefully reviewed for reliability. All reliable historic information concerning flood peaks outside the systematic record was used. Historic information concerning flood peaks within the systematic record was used only when the large floods in the systematic record departed from the trend of the rest of the data. These departures, called high outliers, were determined primarily by inspection of the frequency plot of the data. Test sites with historic information that did not have high outliers are specifically identified in Table A2-1. Historic information that was used is also summarized in this table. Methods described in Appendix 6 of Bulletin 17A were used to adjust the flood-frequency statistics for the historic flood information.

D. Low Outliers

The low outlier criteria of Bulletin 17A did not detect any low outliers at the test sites when Bulletin 17A map skew values were used. However, unusually low peaks were affecting the 50-, 10-, and 1-percent-chance flood peak estimates at several test sites. This was considered unreasonable. An unusually low annual maximum peak flow that results from very small storm runoff or is unrelated to storm runoff, such as may happen during drought periods, does not contain much useful information related to the probability of large flood events. Therefore, a systematic search was made to identify low peaks which were significantly affecting the frequency analysis. When one, two, or three low peaks departed from the trend of the remaining systematic data they were considered low outliers and deleted from the record. The frequency analysis was then completed using the remaining record and adjusted using the combination of probabilities method discussed in Appendix 4 of Bulletin 17A.

E. Generalized Skew

Adopting a generalized skew coefficient was the most difficult task in the flood-frequency analysis. Consideration was given to using the skew map accompanying Bulletin 17A. However, some modifications to this skew map were believed desirable for this analysis because the map was developed without adjustments for historic information or high outliers. The development of a frequency curve is best approached as a whole analysis. For example, selection of a generalized skew should consider the procedures used to adjust the statistics for high and low outliers.

Development of generalized skew criteria for the pilot test could have been a major effort and was not considered appropriate. Therefore, there were basically two choices remaining: (1) Use the Bulletin 17A skew map with the Bulletin 17A low outlier test, without adjustment for high outliers and historic information or (2) adjust the statistics and Bulletin 17A map skew values. The latter choice was believed to provide the greater accuracy; therefore, the skew map values were adjusted where rational adjustments could be established within the available resource constraints. These adjustments resulted in the average skew for the systematic record for the Midwest region shifting from -0.28 to -0.11. The shift in skew when low outliers are censored and historic information is used to adjust high peaks is illustrated in Table A2-1. The generalized skew, once established, was weighted with station skew as recommended by Bulletin 17A. Selection of generalized skew values for the Midwest and Northwest regions was made as follows.

Midwest Region. For the Midwest region, the Bulletin 17A skew map values were used except a lower bound of -0.2 was imposed. The rationale for this limit included: (1) The regional skew study for Indiana (U.S. Army Corps of Engineers, 1976), a State with topography typical of many of the test sites in the Midwest region, resulted in an adopted generalized skew of -0.2 for the State; (2) the average skew value for the systematic record for all Midwest test sites was -0.11 after adjusting for historic information and outliers; and (3) at any test site, the most negative skew map value was -0.4. A maximum departure of 0.2 (50 percent) is consistent with the accuracy of the map. It should be noted that the isopleth lines of the map may depart a few tenths from group averages. The standard deviation of station values about the isopleth line is about 0.55. Therefore, a minimum skew of -0.2 is well within the predictive capability of the skew map.

Northwest Region. For the Northwest region, Bulletin 17A skew map values were used with Bulletin 17A analyses except for one site. For test site 84 (USGS gage number 12356000), a regional skew value (-0.15) provided by the Montana District of the U.S. Geological Survey (USGS) was used. The mixed population analysis used skew values developed specifically for this purpose.

F. Mixed Population Analysis

Mixed population analyses were conducted at several test sites in the Northwest by Speers and Flightner of the U.S. Army Corps of Engineers North Pacific Division Office. Mixed populations result when annual peak flows for a watershed are caused by different meteorological events such as rain, snowmelt, rain on snow, or rain on ice cover. Results of the mixed population analyses are included in Table A2-1. Bulletin 17A and mixed population analyses produced results which differed at most by 17 percent for the 1-percent-chance flood peak. The differences between the two estimates were not large enough to affect the conclusions of the pilot test. Therefore, the Bulletin 17A analysis was adopted for all test sites.

G. Variation in Gage Estimates

While the log-Pearson Type III distribution and Water Resources Council Bulletin 17A procedures were used to establish the gage estimates, other distributions were used to establish a potential range in gage estimates. Distributions used in the comparison include: Gumbel 1 (G1); log normal (LN); 3-parameter log normal (3LN); log-Pearson Type III (LP III); and 2-parameter gamma (GM2). All of these were fitted using maximum likelihood estimation (MLE) of the statistics. The log-Pearson Type III was also fitted using method of moments estimation (MME). Table A2-2 shows the computed values from these methods as well as the gage estimate adopted for the three probability levels (0.50, 0.10, and 0.01). For some sites, the log normal estimates were computed without adjustments for outliers (column 4) and with adjustments for outliers (column 8) based on Grubbs (1950) work at the 5 percent significance level. This was also the case for the log-Pearson Type III estimates using the method of moments--column 7 without adjustments and column 10 with adjustments. As a result, column 8 or 10 is blank if it is the same value (±1 in the third significant digit) as column 4 or 7, respectively.

At each test site, maximum and minimum values were selected for each exceedance probability level from the alternate frequency distributions (columns 3 through 10). Questionable values (denoted in Table A2-2 with a question mark) were not included in the selection of the limits. The maximum and minimum values were compared to the adopted values. The range of variation (expressed in percent difference from the adopted value) is summarized in Table A2-3. The minimum and maximum values for each of the 70 gaging stations were identified and are displayed by percent difference groups.

Thus, while 90 to 99 percent of the maximum and minimum 10- and 50-percent-chance gage estimates fall within 25 percent of the potential range of values from the other frequency distributions, only 60 to 70 percent of the maximum and minimum 1-percent-chance gage estimates fall within the 25 percent range. Over half of the minimum and maximum values that contribute to the range of values are from Gumbel 1 (G1) and log normal (LN) distributions.

In addition, the expected probability adjustment to the log-Pearson Type III distribution was considered as an alternative. It was computed as described in WRC Bulletin 17A and is shown in Table A2-2.

Table A2-2

VARIATION IN GAGE ESTIMATE USING OTHER FREQUENCY DISTRIBUTIONS

Site No. (1)	Exceedance Probability	Gage Estimate (2)	G1 MLE (3)	LN MLE (4)	3LN MLE (5)	LP III MLE (6)	LP III MME (7)	LN MLE (8)	GM2 MLE (9)	LP III MME (10)	EXP PROB (11)
		Discharge - CFS									
21	.01	1249	833?	1420	1300	1310	1310	1400	1040		1460
	.10	563	497	575	559	560	568	570	571		596
	.50	195	227	190	194	192	193		216		195
22	.01	71	63	77	121?		86		65		80
	.10	42	40	43	47		43		42		44
	.50	21	21	21	18		20		22		21
23	.01	1044	831	1150	1090	1020	1060	1080	889		1220
	.10	568	518	577	568	558	569	556	550		601
	.50	252	266	247	251	252	252		265		252
24	.01	1520	1040	1710	1740	1610	1650	1660	[2]		1750
	.10	702	624	716	720	699	712	703	702		740
	.50	252	290	245	244	247	247		277		252
25	.01	5736	2720	6830?	5030	3540	4150	4950	3470	4120	6970
	.10	2062	1590	2120	1910	1840	1930	1780	1810		2110
	.50	525	680	505	551	581	565		601		525
26	.01	565	423	625	499	388?	469	547	444		620
	.10	288	259	293	274	269	278	272	270		298
	.50	118	129	116	123	130	123		125		118
27	.01	144	105	132	133	132	138	160	130	167	161
	.10	79	74	80	80	79	81		80		82
	.50	36	38	35	35	35	34		38		36
28	.01	989	851	1080?	697	[2]	810	951	817		1130
	.10	569	537	577	511	[2]	546	538	532		598
	.50	273	285	267	304	[2]	285		281		273
29	.01	753	627?	837?	1320?	1500?	1610?	489[3]?	423[3]	541[3]	870
	.10	388	378	395	432	407	409	281[3]	278[3]	287[3]	410
	.50	161	178	157	138	137	135	142[3]	149[3]	139[3]	161
30	.01	8131	4360?	9540	14900	11800	10700	8850	5900		9940
	.10	2852	2480	2930	3380	2960	2970	2810	2920		3070
	.50	711	976	686	603	648	668		856		711
31	.01	9963	7190	11200	11400		9400	[2]	7740		11500
	.10	4866	4350	4960	4990		4820	4603	4569		5120
	.50	1874	2080	1830	1820		1900		2000		1870
32	.01	2487	2090	2730?	1980		2000	[2]	2054		2780
	.10	1410	1310	1430	1310		1350	1336	1322		1470
	.50	662	693	648	708		695		684		662

Table A2-2 (Continued)

VARIATION IN GAGE ESTIMATE USING OTHER FREQUENCY DISTRIBUTIONS

		Discharge - CFS									
Site No. (1)	Exceedance Probability	Gage Estimate (2)	G1 MLE (3)	LN MLE (4)	3LN MLE (5)	LP III MLE (6)	LP III MME (7)	LN MLE (8)	GM2 MLE (9)	LP III MME (10)	EXP PROB (11)
33	.01	2020	1300?	3550	2010	1520	[2]	1980[4]	1500[4]	2080[4]	2369
	.10	881	769	1100	878	892	[2]	850[4]	849[4]	889[4]	933
	.50	292	340	261	295	309	[2]	302[4]	339[4]	304[4]	292
34	.01	5964	3780?[1]	6870?	6680?	6840?	7150?	7000	[2]		7100
	.10	2144	2200[1]	2510	2490	2480	2520	2530	2576		2260
	.50	695	932[1]	729	734	724	722		864		695
35	.01	1884	1430	2110	1760	1640	1660	1890	1530		2120
	.10	975	879	993	940	938	952	934	925		1020
	.50	403	438	393	413	413	415		426		403
36	.01	5858	4730?	6340	8510	9080	9080	6900	[2]	9050	6590
	.10	3127	2920	3170	3380	3240	3280	3320	3290		3260
	.50	1374	1460	1350	1240	1240	1240		1470		1370
37	.01	8772	6700	9730	8120	6390	7560	8590	7040		10100
	.10	4599	4140	4680	4430	4320	4470	4360	4321		4850
	.50	1946	2090	1900	1990	2100	2010		2050		1950
38	.01	6774	6820	10900?	6580	[2]	5920	[2]	[2]	6350[4]	7420
	.10	4150	4210	4970	4200	[2]	4340	4310[4]	4261[4]	4330[4]	4290
	.50	2148	2120	1890	2150	[2]	2170	2050[4]	2170[4]	2210[4]	2150
39	.01	988	728	1100	902		858	951	763	856	1120
	.10	494	443	503	474		481	462	458		517
	.50	195	215	190	202		202		207		195
40	.01	5078	4400	5540	5360	4500	5070	5200	4440		5650
	.10	2955	2780	3000	2970	2870	2950	2890	2863		3070
	.50	1437	1490	1410	1420	1470	1440		1490		1440
41	.01	3181	2820	3410	3600	3660	3940	3480	[2]		3490
	.10	1929	1820	1950	1970	1940	1980	1970	1950		1990
	.50	997	1020	982	968	961	950		1030		997
42	.01	7167	5730	7900	7390	7370	7410	7650	6289		8080
	.10	3907	3580	3970	3890	3880	3930	3800	3860		4080
	.50	1742	1850	1700	1730	1720	1730		1830		1740
43	.01	2352	2170	2540	2200	2050	2080	2370	2100		2600
	.10	1476	1410	1490	1440	1430	1440	1440	1420		1530
	.50	794	806	780	808	814	816		811		794

Table A2-2 (Continued)

VARIATION IN GAGE ESTIMATE USING OTHER FREQUENCY DISTRIBUTIONS

Site No. (1)	Exceedance Probability	Discharge - CFS Gage Estimate (2)	G1 MLE (3)	LN MLE (4)	3LN MLE (5)	LP III MLE (6)	LP III MME (7)	LN MLE (8)	GM2 MLE (9)	LP III MME (10)	EXP PROB (11)
44	.01	3301	2620	3480	3240	2820	3070	3230	2700		3690
	.10	1773	1640	1790	1750	1710	1750	1720	1700		1840
	.50	800	849	790	805	825	813		842		800
45	.01	6230	6270	6810	6020	6040	5720	6530	5900		6630
	.10	4211	4150	4260	4120	4150	4130	4160	4120		4280
	.50	2438	2450	2400	2470	2450	2490		2470		2440
46	.01	4036	3420?	4150	5390	5640	5210	4340	[2]		4380
	.10	2311	2180	2320	2450	2390	2380	2380	2350		2370
	.50	1145	1190	1140	1060	1060	1080		1200		1140
47	.01	15916	13600[1]	19900	19100	18700	19000	14400	12000	12700	18200
	.10	8004	8370[1]	9410	9310	9220	9350	7670	7590	7760	8390
	.50	3658	4150[1]	3760	3800	3790	3800	3540	3770	3720	3660
48	.01	2349	2700?	3450	2160	[2]	1960	2550[4]	2320[4]	2280[4]	2560
	.10	1622	1730	1890	1620	[2]	1650	1660[4]	1640[4]	1660[4]	1670
	.50	990	953	900	1010	[2]	1020	997[4]	1010[4]		990
49	.01	8958	7440	10100	8960	6440?	8350	[2]	7580		9700
	.10	4952	4620	5050	4890	4690	4890	4780	4730		5090
	.50	2221	2350	2160	2230	2430	2260		2310		2220
50	.01	9483	6430?	10700	9170	8820	8450	9610	[2]	8540	10600
	.10	4426	3890	4570	4350	4370	4390	4270	4250	4320	4600
	.50	1642	1850	1610	1670	1670	1700	1580	1760	1651	1640
51	.01	23417	18900	27100?	20400	15200	19100	[2]	19500		25500
	.10	12846	11700	13200	12100	11900	12300	12200	12100		13300
	.50	5604	5950	5420	5850	6350	5860		5810		5600
52	.01	8505	8090	12000?	8380	7950	[2]	9140[4]	7870[4]	8420[4]	9110
	.10	5159	5070	5880	5180	5310	[2]	5200[4]	5140[4]	5230[4]	5280
	.50	2634	2660	2440	2650	2640	[2]	2600[4]	2740[4]	2680[4]	2630
53	.01	14913	13800	22000?	14500	12600	13200	18100	14600		16000
	.10	8602	8450	9910	8650	8760	8900	8880	8800	8910	8820
	.50	4141	4190	3720	4140	4200	4170		4030		4140
54	.01	26642	19100?	29700	45300	53500	46500	33400	[2]	46300	31100
	.10	12043	11300	12300	13600	12900	12800	13100	13100		12700
	.50	4232	4930	4130	3650	3610	3730		4770		4230

Table A2-2 (Continued)

VARIATION IN GAGE ESTIMATE USING OTHER FREQUENCY DISTRIBUTIONS

Site No. (1)	Exceedance Probability	Gage Estimate (2)	Discharge - CFS G1 MLE (3)	LN MLE (4)	3LN MLE (5)	LP III MLE (6)	LP III MME (7)	LN MLE (8)	GM2 MLE (9)	LP III MME (10)	EXP PROB (11)
55	.01	45547	40700	59100?	44500	32400?	40900	[2]	[2]	45000[4]	48200
	.10	26098	25100	28300	25900	25500	26300	25900[4]	25600[4]	26400[4]	26600
	.50	12193	12600	11400	12300	13500	12400	11900[4]	12700[4]		12200
56	.01	45216	33600	55300?	42800	36000	38600	47100	37000	38400	48900
	.10	23003	20300	23800	21900	21800	22200	21800	21600		23600
	.50	8830	9730	8440	9050	9270	9150		9290		8830
57	.01	20699	17200	23700	21500	19200	20200	22100	18200		21700
	.10	11504	10700	11800	11400	11300	11500	11300	11200		11700
	.50	5134	5420	4980	5110	5220	5160		5350		5130
58	.01	33078	31800[1]	48400?	36400	33900	30300	38800[4]	32800[4]	36600[4]	35200
	.10	20076	19800[1]	23200	21100	21400	21100	21100[4]	20900[4]	21300[4]	20500
	.50	9935	10200[1]	9430	10100	10100	10500	9990[4]	10600[4]	10200[4]	9930
59	.01	44271	34400?[1]	39100	43300	45200	47300	40600	35800		47300
	.10	23721	22700[1]	23900	24300	24100	24400	24400	24100		24100
	.50	12436	13200[1]	13000	12700	12600	12500		13600		12400
60	.01	25245	21600[1]	26300	28700	29200	30600	22500[3]	19700[3]	22400[3]	26700
	.10	13857	13700[1]	14600	14900	14700	14900	13200[3]	13100[3]	13300[3]	14100
	.50	6858	7420[1]	7060	6900	6880	6820	6860[3]	7170[3]	6900[3]	6860
76	.01	240	133[1]	313	305	225	250	257	[2]	253	312
	.10	88	77[1]	97	96	90	93	86	87		96
	.50	23	32[1]	23	23	24	24		28		23
77	.01	842	385?	1000	1100	775	845		606	[2]	1140
	.10	259	215	263	270	266	255	242	271	260	290
	.50	50	75	48	47	49	49	43	60	66	50
78	.01	207	166	207	235	240	246		176		244
	.10	114	105	114	117	114	116		113		120
	.50	55	57	55	53	53	53		58		55
79	.01	72	68	78	68	56	67	93	75		82
	.10	42	44	46	45	44	45		45		44
	.50	23	25	24	25	26	25	19	21	22	23
80	.01	271	293?	264	249	247	249	260	255		286
	.10	220	227	219	217	216	217		217		224
	.50	174	173	175	177	177	177		176		174

Table A2-2 (Continued)

VARIATION IN GAGE ESTIMATE USING OTHER FREQUENCY DISTRIBUTIONS

Site No. (1)	Exceedance Probability	Gage Estimate (2)	Discharge - CFS G1 MLE (3)	LN MLE (4)	3LN MLE (5)	LP III MLE (6)	LP III MME (7)	LN MLE (8)	GM2 MLE (9)	LP III MME (10)	EXP PROB (11)
81	.01	244	224	244	241		243	242	217		258
	.10	153	149	153	153		153		151		156
	.50	87	88	87	87		87		90		87
82	.01	982	817	946	1020	1030	1050	963	[2]		1050
	.10	557	528	554	564	558	562	560	554		568
	.50	285	297	288	282	282	281		301		285
83	.01	417	318?[1]	797?	747?		866	913	[2]		608
	.10	113	173[1]	178	174		180	192	[2]		127
	.50	26	57[1]	28	29		28		[2]		26
84	.01	1685	1530?	1790?	3060?		[2]	348[3]	324[3]	353[3]	2600
	.10	354	843	668	668		[2]	241[3]	240[3]	244[3]	390
	.50	134	290	199	160		[2]	154[3]	157[3]	154[3]	134
85	.01	501	344	501	530	525	542	487	388		600
	.10	236	210	236	240	234	238	232	230		251
	.50	94	103	94	92	92	92		102		94
86	.01	6154	5650	6060	6010	5960	6010	6000	5430		6430
	.10	3887	3770	3880	3870	3860	3880	3860	3820		3940
	.50	2236	2270	2240	2250	2250	2250		2310		2240
87	.01	738	673	675	739	740	806	589[3]	563[3]	582[3]	804
	.10	490	478	485	492	487	493	445[3]	443[3]	446[3]	497
	.50	317	321	323	316	315	310	316[3]	320[3]	317[3]	317
88	.01	1206	1200	1300	1190	1190	1160	1260	1140		1280
	.10	812	800	821	803	805	806	807	799		828
	.50	476	477	469	479	476	481		483		476
89	.01	1599	1760	1720	1480	1340	1540	1660	1560		1700
	.10	1203	1230	1220	1180	1170	1190	1190	1185		1230
	.50	810	796	797	828	850	818		810		810
90	.01	936	849	940	942	856	905	911	815		1020
	.10	578	558	578	579	567	575	568	563		594
	.50	319	325	319	318	324	321		330		319
91	.01	1830	1410?	1600	2150	2320	2090	1690	1490		1950
	.10	999	930	983	1030	1010	1010	1010	1000		1020
	.50	524	546	540	499	457	508		563		524

Table A2-2 (Continued)

VARIATON IN GAGE ESTIMATE USING OTHER FREQUENCY DISTRIBUTIONS

Site No. (1)	Exceedance Probability	Gage Estimate (2)	Discharge - CFS G1 MLE (3)	LN MLE (4)	3LN MLE (5)	LP III MLE (6)	LP III MME (7)	LN MLE (8)	GM2 MLE (9)	LP III MME (10)	EXP PROB (11)
92	.01	5777	4240?	5230	7110	7880	7180	5620	4700	7160	6300
	.10	2916	2690	2880	3050	2980	2960	2990	2960		2990
	.50	1352	1440	1380	1270	1260	1290		1470		1350
93	.01	2814	3180	2960?	2700	2610	2680	2815[4]	2710[4]	2810[4]	2890
	.10	2202	2280	2220	2170	2170	2180	2180[4]	2170[4]	[4]	2220
	.50	1579	1550	1560	1600	1610	1600	1590[4]	1600[4]	1590[4]	1580
94	.01	742	631	848?	561	463?	594	[2]	623	591	805
	.10	423	395	433	384	387	404	401	396		436
	.50	195	205	190	213	223	205		201		195
95	.01	24844	23200	24400	25000	24500	24700	24100	22100		26400
	.10	16084	15700	16600	16100	16000	16100	15900	15800		16400
	.50	9531	9640	9580	9530	9550	9560		9840		9530
96	.01	23006	25500?	24300?	22100	21800	21800	23800	22500		23600
	.10	17388	17900	17500	17100	17200	17200	17300	17200		17500
	.50	11892	11700	11700	12000	12000	12000		11900		11900
97	.01	53865	52600	52500	51200	47300	50300	51500	48000		56600
	.10	36444	36200	36300	36100	35600	36100	35900	35700		37000
	.50	22966	23100	23100	23300	23600	23300		23600		23000
98	.01	39653	38800	42200	41900	41000	41400	41600	37400		41300
	.10	26139	25600	26400	26400	26200	26300	26200	25900		26500
	.50	15062	15100	14900	14900	14900	14900		15400		15100
99	.01	15206	16700[1]	17600	18500	18600	19200	13800[3]	13000[3]	12200[3]	
	.10	11040	11300[1]	11500	11700	11600	11700	9870[3]	9800[3]	9760[3]	
	.50	6822	6930[1]	6940	6780	6780	6740	6540[3]	6650[3]	6770[3]	
100	.01	21226	17300[1]	22300	25700	26300	24500		18800	24300	
	.10	11097	11200[1]	12100	12500	12300	12200		12200		
	.50	5291	5840[1]	5650	5440	5440	5530	5757	6100	5645	
107	.01	12047	9500	13200	13400	13600	14600	13500	[2]		13500
	.10	6448	5900	6540	6570	6490	6630	6620	6560		6710
	.50	2828	3010	2770	2760	2730	2710		3000		2830
108	.01	9447	6460?	10700	11400	10800	11200	10200	7680		11100
	.10	4332	3850	4420	4510	4350	4450	4300	4300		4600
	.50	1534	1750	1490	1460	1470	1480		1680		1530

Table A2-2 (Continued)

VARIATION IN GAGE ESTIMATE USING OTHER FREQUENCY DISTRIBUTIONS

Site No. (1)	Exceedance Probability	Gage Estimate (2)	G1 MLE (3)	LN MLE (4)	3LN MLE (5)	LP III MLE (6)	LP III MME (7)	LN MLE (8)	GM2 MLE (9)	LP III MME (10)	EXP PROB (11)
		Discharge - CFS									
126	.01	4619	4190	4290	4650	4650	4950	3560[3]	3400[3]	3490[3]	5060
	.10	3038	2940	3010	3050	3010	3060	2670[3]	2660[3]	2685[3]	3130
	.90	1917	1940	1950	1910	1910	1890	1880[3]	1900[3]	1900[3]	1920
128	.01	951	897	1090	883	699	883	1000	870	881	1020
	.10	593	571	607	572	564	584	579	573		607
	.50	304	310	294	312	332	309			309	304
129	.01	1122	1000	1090	1110	1120	1160	948[3]	868[3]	887[3]	1180
	.10	689	664	686	689	686	692	628[3]	623[3]	628[3]	699
	.50	386	395	388	387	385	383	379[3]	389[3]	387[3]	386

1. Historic adjustments were made using statistical censoring theory (column 3).

2. No value reported because the computed frequency curve (after censoring or adjustments) deviated substantially from the plotted data near one of the three exceedance probabilities (columns 6-10).

3. Adjustments for high outlier(s) were made (column 8-10).

4. Adjustments for low outlier(s) were made (column 8-10).

? Estimate judged unreasonable as it was beyond plus or minus one standard error of the estimate determined from the distribution subjectively judged to best fit the sample data.

Table A2-3

VARIATION IN GAGE ESTIMATE

(Percent of Number of Gage Estimates by Range of Percent Differences)

Percent Difference	$Q_{.50}$ Min.	$Q_{.50}$ Max.	$Q_{.10}$ Min.	$Q_{.10}$ Max.	$Q_{.01}$ Min.	$Q_{.01}$ Max.
0 to 10	-84%	+69%	-76%	+80%	-11%	+33%
11 to 25	-15%	+21%	-20%	+17%	-49%	+37%
26 to 50	- 1%	+ 7%	- 3%	0%	-36%	+17%
51 to 100	0%	0%	- 1%	+ 2%	- 4%	+10%
100 +	0%	+ 3%	0%	+ 1%	0%	+ 3%

APPENDIX 3
TEST RECORD SHEETS

FIGURE A3-1

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE *USGS ILLINOIS STATE EQUATION (XX)* ____ *(1-3)*
2. TEST SITE NUMBER ____ *(5-7)*
3. TESTER INFORMATION *(9-17)*
   Name ____
   Organization ____
   Address ____
   ____
   Phone No: ____ Date: ____
   Years of Hydrologic Experience
   1 ☐ 0-2 yrs *2* ☐ 2-5 yrs *3* ☐ 5-10 yrs *4* ☐ more than 10 yrs *(19)*
   How frequently do you use this type of procedure?
   1 ☐ never *2* ☐ occasionally *3* ☐ frequently *(20)*
   Are you knowledgeable about the hydrology of the region?
   1 ☐ no *2* ☐ somewhat *3* ☐ very *(21)*
   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)
   1 ☐ no *2* ☐ yes *(22)*
4. SITE LOCATION INFORMATION
   State Name ____ *(23-26)*
   Stream Name ____ *(27-34)*
   Longitude ____ *(35-41)*
   Latitude ____ *(42-47)*
5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)
   2 year peak flood (Q_2), cfs ____ *(48-54)*
   10 year peak flood (Q_{10}), cfs ____ *(55-61)*
   100 year peak flood (Q_{100}), cfs ____ *(62-69)*
6. RESOURCES USED
   Time to become familiar with the procedure (hrs) ____ *(70-72)*
   Time to apply the procedure (hrs) ____ *(73-76)*
   Cost, other than manpower, to apply the procedure (explain on back) ____ *(77-80)*
7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	____	*(18-23)*	____	*(24-26)*
AF, Regional factor	____	*(27-32)*	____	*(33-35)*
I, Rainfall intensity index (in)	____	*(36-41)*	____	*(42-44)*
S, Main channel slope (ft/mi)	____	*(45-50)*	____	*(51-53)*

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS ILLINOIS STATE EQUATION

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE _USGS MISSOURI STATE EQUATION (XX)_ (1-3)
2. TEST SITE NUMBER ________ (5-7)
3. TESTER INFORMATION (9-17)

   Name ________

   Organization ________

   Address ________

   ____

   Phone No: ________ Date: ________

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)
4. SITE LOCATION INFORMATION

   State Name ________ (23-26)

   Stream Name ________ (27-34)

   Longitude ________ (35-41)

   Latitude ________ (42-47)
5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ________ (48-54)

   10 year peak flood (Q_{10}), cfs ________ (55-61)

   100 year peak flood (Q_{100}), cfs ________ (62-69)
6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ________ (70-72)

   Time to apply the procedure (hrs) ________ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)
7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	________	(18-23)	________	(24-26)
SL, Main channel slope (ft/mi)	________	(27-32)	________	(33-35)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS MISSOURI STATE EQUATION

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE USGS OHIO STATE EQUATION (XX) ______ *(1-3)*
2. TEST SITE NUMBER ______ *(5-7)*
3. TESTER INFORMATION *(9-17)*

   Name ______

   Organization ______

   Address ______

   ______

   Phone No: ______ Date: ______

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs *2* ☐ 2-5 yrs *3* ☐ 5-10 yrs *4* ☐ more than 10 yrs *(19)*

   How frequently do you use this type of procedure?

   1 ☐ never *2* ☐ occasionally *3* ☐ frequently *(20)*

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no *2* ☐ somewhat *3* ☐ very *(21)*

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no *2* ☐ yes *(22)*
4. SITE LOCATION INFORMATION

   State Name ______ *(23-26)*

   Stream Name ______ *(27-34)*

   Longitude ______ *(35-41)*

   Latitude ______ *(42-47)*
5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______ *(48-54)*

   10 year peak flood (Q_{10}), cfs ______ *(55-61)*

   100 year peak flood (Q_{100}), cfs ______ *(62-69)*
6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ______ *(70-72)*

   Time to apply the procedure (hrs) ______ *(73-76)*

   Cost, other than manpower, to apply the procedure (explain on back) ______ *(77-80)*
7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	______	(18-23)	______	(24-26)
E, Average basin elevation index (ft. above mean sea level	______	(27-32)	______	(33-35)
P, Average annual precipitation (in)	______	(36-41)	______	(42-44)
SL, Main channel slope (ft/mi)	______	(45-50)	______	(51-53)
ST, Surface storage index (% of total drainage area)	______	(54-59)	______	(60-62)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS OHIO STATE EQUATION

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE *USGS MONTANA STATE EQUATION (XX)* ____ *(1-3)*
2. TEST SITE NUMBER ____ *(5-7)*
3. TESTER INFORMATION *(9-17)*

   Name ____

   Organization ____

   Address ____

   ____

   Phone No: ____ Date: ____

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs *2* ☐ 2-5 yrs *3* ☐ 5-10 yrs *4* ☐ more than 10 yrs *(19)*

   How frequently do you use this type of procedure?

   1 ☐ never *2* ☐ occasionally *3* ☐ frequently *(20)*

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no *2* ☐ somewhat *3* ☐ very *(21)*

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no *2* ☐ yes *(22)*

4. SITE LOCATION INFORMATION

   State Name ____ *(23-26)*

   Stream Name ____ *(27-34)*

   Longitude ____ *(35-41)*

   Latitude ____ *(42-47)*

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ____ *(48-54)*

   10 year peak flood (Q_{10}), cfs ____ *(55-61)*

   100 year peak flood (Q_{100}), cfs ____ *(62-69)*

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ____ *(70-72)*

   Time to apply the procedure (hrs) ____ *(73-76)*

   Cost, other than manpower, to apply the procedure (explain on back) ____ *(77-80)*

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	____	*(18-23)*	____	*(24-26)*
F, Area factor	____	*(27-32)*	____	*(33-35)*
P, Mean annual precipitation (in)	____	*(36-41)*	____	*(42-44)*
S, Channel slope (ft.mi)	____	*(45-50)*	____	*(51-53)*

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS MONTANA STATE EQUATION

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE *USGS WASHINGTON STATE EQUATION (XX)* ______ (1-3)
2. TEST SITE NUMBER ______ (5-7)
3. TESTER INFORMATION (9-17)

   Name ______

   Organization ______

   Address ______

   ______ ______

   Phone No: ______ Date: ______

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

   State Name ______ (23-26)

   Stream Name ______ (27-34)

   Longitude ______ (35-41)

   Latitude ______ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______ (48-54)

   10 year peak flood (Q_{10}), cfs ______ (55-61)

   100 year peak flood (Q_{100}), cfs ______ (62-69)

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ______ (70-72)

   Time to apply the procedure (hrs) ______ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	______	(18-23)	______	(24-26)
F, Forest cover (% of total drainage area)	______	(27-32)	______	(33-35)
P, Average annual precipitation (in)	______	(36-41)	______	(42-44)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS WASHINGTON STATE EQUATION

FIGURE A3-6

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE FLETCHER ____________________ (1-3)
2. TEST SITE NUMBER ____________ (5-7)
3. TESTER INFORMATION (9-17)

   Name ____________________

   Organization ____________________

   Address ____________________

   ____

   Phone No: ____________ Date: ____________

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

   State Name ____________________ (23-26)

   Stream Name ____________________ (27-34)

   Longitude ____________________ (35-41)

   Latitude ____________________ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ____________________ (48-54)

   10 year peak flood (Q_{10}), cfs ____________________ (55-61)

   100 year peak flood (Q_{100}), cfs ____________________ (62-69)

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) __________ (70-72)

   Time to apply the procedure (hrs) __________ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

A, Drainage area (mi^2)	______	(18-23)	______	(24-26)
DH, Difference in elevation (ft)	______	(27-32)	______	(33-35)
R, Iso-erodent factor	______	(36-41)	______	(42-44)
S, Surface water storage (% of total drainage area)	______	(45-50)	______	(51-53)
Z, Hydrophysiographic Zone	______	(54-59)	______	(60-62)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - FLETCHER

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE REICH (XX) ________ (1-3)
2. TEST SITE NUMBER ________ (5-7)
3. TESTER INFORMATION (9-17)

Name ________

Organization ________

Address ________

____

Phone No: ________ Date: ________

Years of Hydrologic Experience

1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

How frequently do you use this type of procedure?

1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

Are you knowledgeable about the hydrology of the region?

1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

State Name ________ (23-26)

Stream Name ________ (27-34)

Longitude ________ (35-41)

Latitude ________ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

2 year peak flood (Q_2), cfs ________ (48-54)

10 year peak flood (Q_{10}), cfs ________ (55-61)

100 year peak flood (Q_{100}), cfs ________ (62-69)

6. RESOURCES USED

Time to become familiar with the procedure (hrs) ________ (70-72)

Time to apply the procedure (hrs) ________ (73-76)

Cost, other than manpower, to apply the procedure (explain on back) ________ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Parameter	Value		Time (hrs.)	
B,	Time of concentration (hr)	________	(18-23)	________	(24-26)
F,	Cover factor	________	(27-32)	________	(33-35)
f,	Land use factor	________	(36-41)	________	(42-44)
H,	Channel fall (ft)	________	(45-50)	________	(51-53)
L,	Length of main channel (ft)	________	(54-59)	________	(60-62)
P_{30-2},	2 year 30 minute rainfall (in)	________	(63-68)	________	(69-71)
P_{30-10},	10 year 30 minute rainfall (in)	________	(72-76)	________	(77-80)
P_{30-100},	100 year 30 minute rainfall (in)	________	(18-23)	________	(24-26)
S,	Infiltration index	________	(27-32)	________	(33-35)
API,	Adjustment (%)	________	(36-38)	________	(39-41)
LPS,	Adjustment (%)	________	(42-45)	________	(46-48)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE USCE SNOWMELT ( ) ______ (1-3)
2. TEST SITE NUMBER ______ (5-7)
3. TESTER INFORMATION (9-17)

   Name ______

   Organization ______

   Address ______

   ______

   Phone No: ______ Date: ______

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

   State Name ______ (23-26)

   Stream Name ______ (27-34)

   Longitude ______ (35-41)

   Latitude ______ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______ (48-54)

   10 year peak flood (Q_{10}), cfs ______ (55-61)

   100 year peak flood (Q_{100}), cfs ______ (62-69)

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ______ (70-72)

   Time to apply the procedure (hrs) ______ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

Parameter	Value		Time (hrs.)	
A, Drainage area (mi^2)	______	(18-23)	______	(24-26)
C_1, 1-day runoff coefficient	______	(27-32)	______	(33-35)
K_1, 1-day frequency coefficient	______	(36-41)	______	(42-44)
W, Total water content of snowpack	______	(45-50)	______	(51-53)
Ratio 2 year 10 day runoff to Q_1	______	(54-59)	______	(60-62)
Ratio 10 year 10 day runoff to Q_1	______	(63-68)	______	(69-71)
Ratio 100 year 10 day runoff to Q_1	______	(72-76)	______	(77-80)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USCE SNOWMELT

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE *USGS ILLINOIS INDEX FLOOD* (xx) ______ *(1-3)*
2. TEST SITE NUMBER ______ *(5-7)*
3. TESTER INFORMATION *(9-17)*

   Name ______

   Organization ______

   Address ______

   ______

   Phone No: ______ Date: ______

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs *2* ☐ 2-5 yrs *3* ☐ 5-10 yrs *4* ☐ more than 10 yrs *(19)*

   How frequently do you use this type of procedure?

   1 ☐ never *2* ☐ occasionally *3* ☐ frequently *(20)*

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no *2* ☐ somewhat *3* ☐ very *(21)*

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no *2* ☐ yes *(22)*
4. SITE LOCATION INFORMATION

   State Name ______ *(23-26)*

   Stream Name ______ *(27-34)*

   Longitude ______ *(35-41)*

   Latitude ______ *(42-47)*
5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______ *(48-54)*

   10 year peak flood (Q_{10}), cfs ______ *(55-61)*

   100 year peak flood (Q_{100}), cfs ______ *(62-69)*
6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ______ *(70-72)*

   Time to apply the procedure (hrs) ______ *(73-76)*

   Cost, other than manpower, to apply the procedure (explain on back) ______ *(77-80)*
7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	______	(18-23)	______	(24-26)
L, Area of lakes and ponds (% of total drainage area)	______	(27-32)	______	(33-35)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS ILLINOIS INDEX FLOOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE USGS INDIANA INDEX FLOOD (XX) (1-3)
2. TEST SITE NUMBER ______ (5-7)
3. TESTER INFORMATION (9-17)

   Name ______

   Organization ______

   Address ______

   Phone No: ______ Date: ______

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

   State Name ______ (23-26)

   Stream Name ______ (27-34)

   Longitude ______ (35-41)

   Latitude ______ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______ (48-54)

   10 year peak flood (Q_{10}), cfs ______ (55-61)

   100 year peak flood (Q_{100}), cfs ______ (62-69)

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ______ (70-72)

   Time to apply the procedure (hrs) ______ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	______	(18-23)	______	(24-26)
L, Area of lakes and ponds (% of total drainage area)	______	(27-32)	______	(33-35)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS INDIANA INDEX FLOOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE USGS MISSOURI INDEX FLOOD (XX) ____ (1-3)
2. TEST SITE NUMBER ____ (5-7)
3. TESTER INFORMATION (9-17)

Name ____

Organization ____

Address ____

____

Phone No: ____ Date: ____

Years of Hydrologic Experience

1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

How frequently do you use this type of procedure?

1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

Are you knowledgeable about the hydrology of the region?

1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

State Name ____ (23-26)

Stream Name ____ (27-34)

Longitude ____ (35-41)

Latitude ____ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

2 year peak flood (Q_2), cfs ____ (48-54)

10 year peak flood (Q_{10}), cfs ____ (55-61)

100 year peak flood (Q_{100}), cfs ____ (62-69)

6. RESOURCES USED

Time to become familiar with the procedure (hrs) ____ (70-72)

Time to apply the procedure (hrs) ____ (73-76)

Cost, other than manpower, to apply the procedure (explain on back) ____ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	____	(18-23)	____	(24-26)
E, Mean basin elevation (ft)	____	(27-32)	____	(33-35)
Es, Elevation of the site (ft)	____	(36-41)	____	(42-44)
L, Length of basin (mi)	____	(45-50)	____	(51-53)
W, Width of basin (mi)	____	(54-59)	____	(60-62)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS MISSOURI INDEX FLOOD

FIGURE A3-12

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE USGS OHIO INDEX FLOOD (XX) ______ (1-3)
2. TEST SITE NUMBER ______ (5-7)
3. TESTER INFORMATION (9-17)

   Name ______

   Organization ______

   Address ______

   ______

   Phone No: ______ Date: ______

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs   2 ☐ 2-5 yrs   3 ☐ 5-10 yrs   4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never   2 ☐ occasionally   3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no   2 ☐ somewhat   3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no   2 ☐ yes (22)
4. SITE LOCATION INFORMATION

   State Name ______ (23-26)

   Stream Name ______ (27-34)

   Longitude ______ (35-41)

   Latitude ______ (42-47)
5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______ (48-54)

   10 year peak flood (Q_{10}), cfs ______ (55-61)

   100 year peak flood (Q_{100}), cfs ______ (62-69)
6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ______ (70-72)

   Time to apply the procedure (hrs) ______ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)
7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	______	(18-23)	______	(24-26)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS OHIO INDEX FLOOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE *USGS IDAHO INDEX FLOOD (XX)* (1-3)
2. TEST SITE NUMBER ____________ (5-7)
3. TESTER INFORMATION (9-17)

   Name ______________________

   Organization ______________________

   Address ______________________

   ____

   Phone No: ____________ Date: ____________

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs   2 ☐ 2-5 yrs   3 ☐ 5-10 yrs   4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never   2 ☐ occasionally   3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no   2 ☐ somewhat   3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no   2 ☐ yes (22)
4. SITE LOCATION INFORMATION

   State Name ______________________ (23-26)

   Stream Name ______________________ (27-34)

   Longitude ______________________ (35-41)

   Latitude ______________________ (42-47)
5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______________________ (48-54)

   10 year peak flood (Q_{10}), cfs ______________________ (55-61)

   100 year peak flood (Q_{100}), cfs ______________________ (62-69)
6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ________ (70-72)

   Time to apply the procedure (hrs) ________ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)
7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	________	(18-23)	________	(24-26)
F, Forest cover (% of total drainage area)	________	(27-32)	________	(33-35)
La, Area of lakes and ponds (% of total drainage area)	________	(36-41)	________	(42-44)
N, Latitude (decimal degrees minus 40)	________	(45-50)	________	(51-53)
W, Longitude (decimal degrees minus 110)	________	(54-59)	________	(60-62)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS IDAHO INDEX FLOOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE USGS MONTANA INDEX FLOOD (XX) ________ (1-3)
2. TEST SITE NUMBER ________ (5-7)
3. TESTER INFORMATION (9-17)

Name ________

Organization ________

Address ________

____

Phone No: ________ Date: ________

Years of Hydrologic Experience

1 ☐ 0-2 yrs *2* ☐ 2-5 yrs *3* ☐ 5-10 yrs *4* ☐ more than 10 yrs (19)

How frequently do you use this type of procedure?

1 ☐ never *2* ☐ occasionally *3* ☐ frequently (20)

Are you knowledgeable about the hydrology of the region?

1 ☐ no *2* ☐ somewhat *3* ☐ very (21)

Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

1 ☐ no *2* ☐ yes (22)

4. SITE LOCATION INFORMATION

State Name ________ (23-26)

Stream Name ________ (27-34)

Longitude ________ (35-41)

Latitude ________ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

2 year peak flood (Q_2), cfs ________ (48-54)

10 year peak flood (Q_{10}), cfs ________ (55-61)

100 year peak flood (Q_{100}), cfs ________ (62-69)

6. RESOURCES USED

Time to become familiar with the procedure (hrs) ________ (70-72)

Time to apply the procedure (hrs) ________ (73-76)

Cost, other than manpower, to apply the procedure (explain on back) ________ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	________	(18-23)	________	(24-26)
G, Geographic Factor	________	(27-32)	________	(33-35)
L, Area of lakes and ponds (% of total drainage area)	________	(36-41)	________	(42-44)
R, Average annual runoff (in)	________	(45-50)	________	(51-53)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS MONTANA INDEX FLOOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE _USGS OREGON INDEX FLOOD (xx)_ (1-3)
2. TEST SITE NUMBER ______ (5-7)
3. TESTER INFORMATION (9-17)

   Name ______

   Organization ______

   Address ______

   ______

   Phone No: ______ Date: ______

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)
4. SITE LOCATION INFORMATION

   State Name ______ (23-26)

   Stream Name ______ (27-34)

   Longitude ______ (35-41)

   Latitude ______ (42-47)
5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______ (48-54)

   10 year peak flood (Q_{10}), cfs ______ (55-61)

   100 year peak flood (Q_{100}), cfs ______ (62-69)
6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ______ (70-72)

   Time to apply the procedure (hrs) ______ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)
7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	______	(18-23)	______	(24-26)
E, Mean basin elevation (ft)	______	(27-32)	______	(33-35)
G, Geographic factor	______	(36-41)	______	(42-44)
L, Area of lakes and ponds (% of total drainage area)	______	(45-50)	______	(51-53)
P, Mean annual precipitation (in)	______	(54-59)	______	(60-62)
R, Average annual runoff (in)	______	(63-68)	______	(69-71)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS OREGON INDEX FLOOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE *USGS WASHINGTON INDEX FLOOD (xx)* (1-3)
2. TEST SITE NUMBER ____________ (5-7)
3. TESTER INFORMATION (9-17)

   Name ____________

   Organization ____________

   Address ____________

   ____

   Phone No: ____________ Date: ____________

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

   State Name ____________ (23-26)

   Stream Name ____________ (27-34)

   Longitude ____________ (35-41)

   Latitude ____________ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ____________ (48-54)

   10 year peak flood (Q_{10}), cfs ____________ (55-61)

   100 year peak flood (Q_{100}), cfs ____________ (62-69)

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ________ (70-72)

   Time to apply the procedure (hrs) ________ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

	Value		Time (hrs.)	
A, Drainage area (mi^2)	________	(18-23)	________	(24-26)
E, Mean basin elevation (ft)	________	(27-32)	________	(33-35)
G, Geographic factor	________	(36-41)	________	(42-44)
L, Area of lakes and ponds (% pf total drainage areas)	________	(45-50)	________	(51-53)
P, Mean annual precipitation (in)	________	(54-59)	________	(60-62)
R, Average annual runoff (in)	________	(63-68)	________	)69-71)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - USGS WASHINGTON INDEX FLOOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

PROCEDURE RATIONAL METHOD (xx) ________ *(1-3)*

TEST SITE NUMBER ________ *(5-7)*

TESTER INFORMATION *(9-17)*

Name ________

Organization ________

Address ________

____

Phone No: ________ Date: ________

Years of Hydrologic Experience

1 ☐ 0-2 yrs *2* ☐ 2-5 yrs *3* ☐ 5-10 yrs *4* ☐ more than 10 yrs *(19)*

How frequently do you use this type of procedure?

1 ☐ never *2* ☐ occasionally *3* ☐ frequently *(20)*

Are you knowledgeable about the hydrology of the region?

1 ☐ no *2* ☐ somewhat *3* ☐ very *(21)*

Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

1 ☐ no *2* ☐ yes *(22)*

SITE LOCATION INFORMATION

State Name ________ *(23-26)*

Stream Name ________ *(27-34)*

Longitude ________ *(35-41)*

Latitude ________ *(42-47)*

PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

2 year peak flood (Q_2), cfs ________ *(48-54)*

10 year peak flood (Q_{10}), cfs ________ *(55-61)*

100 year peak flood (Q_{100}), cfs ________ *(62-69)*

RESOURCES USED

Time to become familiar with the procedure (hrs) ________ *(70-72)*

Time to apply the procedure (hrs) ________ *(73-76)*

Cost, other than manpower, to apply the procedure (explain on back) ________ *(77-80)*

FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

		Value		Time (hrs)	
A,	Drainage area (acres)	________	(18-23)	________	(24-26)
C,	Runoff coefficient	________	(27-32)	________	(33-35)
I_2,	2-yr rainfall intensity (in/hr)	________	(36-41)	________	(42-44)
I_{10},	10-yr rainfall intensity (in/hr)	________	(45-50)	________	(51-53)
I_{100},	100-yr rainfall intensity (in/hr)	________	(54-59)	________	(60-62)
Tc,	Time of concentration (hr)	________	(63-68)	________	(69-71)

Please check box if you applied the rational method different from attached description and explain on back of record sheet ☐ (73)

PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET-RATIONAL METHOD

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE SCS TR-55 GRAPHICAL [Tc] ( ) ____ (1-3)
2. TEST SITE NUMBER ____ (5-7)
3. TESTER INFORMATION (9-17)

Name ____

Organization ____

Address ____

____

Phone No: ____ Date: ____

Years of Hydrologic Experience

1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

How frequently do you use this type of procedure?

1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

Are you knowledgeable about the hydrology of the region?

1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

State Name ____ (23-26)

Stream Name ____ (27-34)

Longitude ____ (35-41)

Latitude ____ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

2 year peak flood (Q_2), cfs ____ (48-54)

10 year peak flood (Q_{10}), cfs ____ (55-61)

100 year peak flood (Q_{100}), cfs ____ (62-69)

6. RESOURCES USED

Time to become familiar with the procedure (hrs) ____ (70-72)

Time to apply the procedure (hrs) ____ (73-76)

Cost, other than manpower, to apply the procedure (explain on back) ____ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

		Value		Time (hrs.)	
A,	Drainage area (mi^2)	____	(18-23)	____	(24-26)
CN,	Runoff curve number	____	(27-32)	____	(33-35)
P_{100},	100 year 24 hour rainfall (in)	____	(36-41)	____	(42-44)
P_{10},	10 year 24 hour rainfall (in)	____	(45-50)	____	(51-53)
P_2,	2 year 24 hour rainfall (in)	____	(54-59)	____	(60-62)
Tc,	Time of concentration (hr)	____	(63-68)	____	(69-71)
	Storm distribution 24 hour type	____	(72-76)	____	(77-80)
	Slope adjustment factor	____	(18-23)	____	(24-26)
	Shape adjustment factor	____	(27-32)	____	(33-35)
	Ponding and swampy adjustment factor	____	(36-41)	____	(42-44)
	Imperivious area adjustment factor	____	(45-50)	____	(51-53)
	Hydraulic length adjustment factor	____	(54-59)	____	(60-62)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - SCS TR-55 GRAPHICAL

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE *SCS TR-55 CHARTS (Appendix D & E) ( )* (1-3)
2. TEST SITE NUMBER ____________ (5-7)
3. TESTER INFORMATION (9-17)

   Name ______________________________

   Organization ______________________________

   Address ______________________________

   ____

   Phone No: ____________ Date: ____________

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

   State Name ______________________________ (23-26)

   Stream Name ______________________________ (27-34)

   Longitude ______________________________ (35-41)

   Latitude ______________________________ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ______________________________ (48-54)

   10 year peak flood (Q_{10}), cfs ______________________________ (55-61)

   100 year peak flood (Q_{100}), cfs ______________________________ (62-69)

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ________ (70-72)

   Time to apply the procedure (hrs) ________ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. FOR EACH PARAMETER LISTED, GIVE THE PARAMETER VALUE AND THE APPROXIMATE TIME IT TOOK YOU TO MEASURE THE PARAMETER

		Value		Time (hrs.)	
a,	Drainage area (acres)	________	(18-23)	________	(24-26)
CN,	Runoff curve number	________	(27-32)	________	(33-35)
P_{100},	100 year 24 hour rainfall (in)	________	(36-41)	________	(42-44)
P_{10},	10 year 24 hour rainfall (in)	________	(45-50)	________	(51-53)
P_2,	2 year 24 hour rainfall (in)	________	(54-59)	________	(60-62)
Y,	Average watershed slope (%)	________	(63-68)	________	(69-71)
	Storm distribution 24 hour type	________	(72-76)	________	(77-80)
	Slope adjustment factor	________	(18-23)	________	(24-26)
	Shape adjustment factor	________	(27-32)	________	(33-35)
	Ponding and swampy adjustment factor	________	(36-41)	________	(42-44)
	Imperivious area adjustment factor	________	(45-50)	________	(51-53)
	Hydraulic length adjustment factor	________	(54-59)	________	(60-62)

8. PLEASE GIVE US ON THE BACK OF THIS SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!!

PILOT TEST RECORD SHEET - SCS TR-55 CHARTS

WRC FLOOD FREQUENCY FOR UNGAGED WATERSHEDS PILOT TEST RECORD SHEET

1. PROCEDURE USCE HEC-1 (XX) ____________ (1-3)
2. TEST SITE NUMBER ____________ (5-7)
3. TESTER INFORMATION (9-17)

   Name ____________

   Organization ____________

   Address ____________

   ____

   Phone No: ____________ Date: ____________

   Years of Hydrologic Experience

   1 ☐ 0-2 yrs 2 ☐ 2-5 yrs 3 ☐ 5-10 yrs 4 ☐ more than 10 yrs (19)

   How frequently do you use this type of procedure?

   1 ☐ never 2 ☐ occasionally 3 ☐ frequently (20)

   Are you knowledgeable about the hydrology of the region?

   1 ☐ no 2 ☐ somewhat 3 ☐ very (21)

   Have you made a field inspection of the watershed? (if you field inspected the watershed, indicate on the back the type of data you collected)

   1 ☐ no 2 ☐ yes (22)

4. SITE LOCATION INFORMATION

   State Name ____________ (23-26)

   Stream Name ____________ (27-34)

   Longitude ____________ (35-41)

   Latitude ____________ ____________ (42-47)

5. PEAK FLOOD FLOW FREQUENCY ESTIMATES (annual peak series)

   2 year peak flood (Q_2), cfs ____________ (48-54)

   10 year peak flood (Q_{10}), cfs ____________ (55-61)

   100 year peak flood (Q_{100}), cfs ____________ (62-69)

6. RESOURCES USED

   Time to become familiar with the procedure (hrs) ____________ (70-72)

   Time to apply the procedure (hrs) ____________ (73-76)

   Cost, other than manpower, to apply the procedure (explain on back) ______ (77-80)

7. SUMMARY OF KEY COMPONENTS OF HEC-1

   Total drainage area at the test site (sq.mi.) ____________ (19-24)

   Type of unit hydrograph characteristics unit

   1 ☐ Clark 2 ☐ Snyder (25)

   Unit hydrograph duration (hrs) ____________ (26-27)

   If Clark's unit hydrograph was used, was time area curve determined for the test waterhsed and input to the computer? 1 ☐ yes 2 ☐ no (28)

   Type of rainfall frequency. 1 ☐ annual 2 ☐ seasonal rainfall (29)

(CONTINUED ON SECOND SHEET)

PILOT TEST RECORD SHEET - USCE HEC-1

7. SUMMARY OF KEY COMPONENTS OF HEC-1 (continued)

Was snowmelt runoff used? 1 ☐ Yes 2 ☐ No (30)

If snowmelt runoff was calculated what method was used?
1 ☐ degree day 2 ☐ energy budget (31)

How was rainfall excess (runoff) separated from rainfall?
1 ☐ initial and uniform loss 2 ☐ loss function (32)

Was the area subdivided? 1 ☐ Yes 2 ☐ No (33)

If the area was subdivided, into how many areas? ______________ (34-36)

If subareas were routed and combined, what routing method was used? (37-38)

1 ☐ Modified Puls 2 ☐ Muskingum 3 ☐ Working R and D
4 ☐ Straddle-Stagger 5 ☐ Tatum 6 ☐ Multiple Storage

Was the balanced hydrograph routine used? 1 ☐ Yes 2 ☐ No (39)

8. TIME ESTIMATES: Please provide the following information concerning the man hours and computer time required to conduct this test. Note that site and regional estimates are separated in a and b.

a. Give the approximate time to develop the test site data and watershed characteristics for:

Unit hydrographs (including time area)	(hrs)	______	(40-42)
Loss rates	(hrs)	______	(43-45)
Rainfall frequency depth, area, duration	(hrs)	______	(46-48)
Snowmelt runoff	(hrs)	______	(49-51)
Routing of flood hydrographs	(hrs)	______	(52-54)

b. Any time developing regional (general) relationships and equations should not be included in the above (items 8A). If regional relationships were developed specifically for this test, then tabulate the time required to develop these general equations. Otherwise, leave blank.

Unit hydrograph characteristics	(hrs)	______	(55-58)
Loss rate coefficients	(hrs)	______	(59-62)
Rainfall frequency	(hrs)	______	(63-66)
Snowmelt runoff coefficients	(hrs)	______	(67-70)
Routing coefficients	(hrs)	______	(71-74)

c. Provide a summary of your computer processing time.
Number of computer runs attempted including final ______________ (75-76)

Total central processing units (CPU) time (sec) ______ (77-79)

Computer type and location ______________________________ (80)

9. COMPUTER PRINTOUT: Provide as an attachment to this record sheet your final computer printout of the HEC-1 program. For the purpose of providing this computer printout give IPRT a value of 4 in field 9 of B card (Addendum 6 page 5 of 40) and if appropriate give JPRT a value of 4 in field 6 of K card (Addendum 6 page 18 of 40). Do not provide a more detailed printout unless requested to do so. Please retain this test in your file for one year to provide more complete information if requested.

10. PLEASE GIVE US ON THE BACK OF THESE RECORD SHEET ANY COMMENTS ABOUT PROBLEMS INCURRED IN APPLYING THE PROCEDURE OR SUGGESTIONS WHICH YOU THINK WILL BE HELPFUL IN CONDUCTING THE FINAL TEST.

THANK YOU FOR YOUR HELP!

PILOT TEST RECORD TEST SHEET - USCE HEC-1 (Continued)

APPENDIX 4

TESTER COMMENTS

About ten percent of the testers provided substantial comments of which about one-half or five percent discussed problems encountered in the testing. Following is a summary of these comments by procedures.

USGS State Equations

Some difficulties were encountered with the specific state publications as described in the following paragraphs.

Illinois. Several respondents experienced problems with map scale and contour intervals which made slope and stream distances and drainage areas difficult to compute for very small watersheds. One respondent suggested that the drainage area be supplied for small watersheds in future testing because the answer was sensitive to this parameter and a field check would otherwise be required. The measurement of the stream length parameter also apparently caused some difficulty when major streams forked. It was suggested that the accuracy of nomograph versus equation solutions be checked.

Indiana. The drainage density parameter required the use of county drainage maps which were not available to testers. It was suggested that such procedures be developed using readily available maps such as USGS quadrangles. The results obtained were said to be sensitive to the measurement of this parameter. The requirement to measure total stream length to the drainage divide also caused some confusion in this and other procedures where defined streams are not shown on the maps near the divide.

Ohio. The negative exponent of the basin elevation parameter was questioned, particularly when results were said to be sensitive to this parameter.

Washington. Many respondents found it difficult to use Plate 2 to obtain mean annual precipitation because the scale was too small in relation to the range in precipitation which was portrayed by the contours. This figure was reduced in size from the original by the Work Group for inclusion in the resource packages.

Missouri. Several respondents recommended that smaller scale maps be provided for measuring drainage area and slope on the larger watersheds.

Montana. Several respondents found the precipitation maps too cluttered to use in mountainous areas where precipitation varies rapidly. Larger scale maps are recommended.

Fletcher Procedure

The most frequent difficulty encountered by respondents in the application of the Fletcher procedure was the determination of the iso-erodent factor. Many respondents indicated difficulty in locating the basin on the maps due to their small scale. Most respondents perceived the result to be very sensitive to the iso-erodent factor and thus had difficulties on boundaries between zones. Several respondents recommended that procedures be developed for handling watersheds which include more than one zone. Some respondents found the iso-erodent parameter to be abstract, which bothered them.

Problems were also encountered with the difference in elevation factor (DH). Due to a printing problem, the sign of the exponent for DH in Table 1 was difficult to read. A wrong exponent was used in several cases. As with other procedures, many respondents experienced difficulty in defining the main channel and its terminus, which affected the channel length measurement. Several respondents also questioned the number of significant figures for constants and exponents which were provided in the tables.

The hydrophysiographic zone map of Indiana had latitude lines which were incorrect by +2 degrees. This caused confusion for a number of respondents. Many respondents also expressed a need for examples of application of the procedure.

Reich Procedure

The most comments from testers were about the Reich procedure. A large number of watersheds had parameter measurements which exceeded the nomographs provided in the publication. Figure 1 in Reich's report, used to determine the time of concentration, frequently had to be extended on the upper end. Many respondents also noted that Figure 1 provided by the Work Group was not consistent with the figure provided in the formal publication. Differences as large as 20 percent in time of concentration were obtained when the two different sources were used.

Figure 2 in Reich's report, used to determine discharge per square mile, likewise had to be extrapolated on both ends to obtain answers for 30-minute precipitation less than 1 inch or greater than 5 inches. Figure 2 was also found to have inadequate coverage of the time of concentration for a number of watersheds in the test. Several respondents also indicated that Figure 2 was too small to work with. Equations were recommended instead. As a result of these problems, many respondents concluded that this procedure was not applicable to the watersheds on which they were working and did not complete the test record sheets. This conclusion was common for watersheds in the Northwest region, particularly Washington and Idaho sites. When designing the test, it was recognized that the procedure was considered by the author to be inapplicable to the Northwest.

Most testers providing comments indicated that their evaluations of parameters used in this procedure were very subjective. This was particularly true for infiltration capacity when soils data were not supplied. Respondents also indicated a need to make field checks for a proper determination of cover factors. The need for more information to properly evaluate the use of the antecedent precipitation adjustment and late-peaking storms adjustment was expressed.

A number of respondents concluded that the procedure was so subjective and overrefined through the use of adjustments that wide variation in results could be expected. The procedure description which was provided by the Work Group was criticized as not adequately describing the procedure particularly with regard to parameter evaluation. Neither the procedure, nor the record sheets, indicated the necessity to multiply the result in cubic feet per second per square mile (CSM) by the drainage area to obtain the correct answer. This problem was pointed out by a number of respondents.

USCE Snowmelt Procedure

The most frequent comment provided by testers on this procedure was that it was inapplicable to the watersheds on which it was being tested. Many respondents found that the test watersheds were below the April 1 snowline elevation, which is the recommended minimum elevation for applicability. As a result, many of the results obtained were unreasonably low according to respondents. Many respondents felt that rainfall peaks had to be added to those obtained for snowmelt in order to obtain reasonable results. Several respondents also questioned the applicability of the procedure for estimating peak flows because the procedure produced average daily flows.

Most of the remaining comments involved criticism of the procedure description itself. Many respondents stated that the procedure description put together for the test was poorly written, vague, and confusing, with examples that were difficult to follow. A Work Group error on the record sheet, where 1-day runoff was referred to as 10-day runoff, also caused confusion.

USGS Index Flood Procedures

The comments on these procedures related primarily to the format of text and figures in the various reports as discussed below.

Illinois--Part 5 WSP-1678. Respondents found the graph for determining the ratio of T-year flood discharge to mean annual flood discharge (Figure 2) to be too small and lacking in detail for the values to be read to the desired precision.

Oregon--Part 14 WSP-1689. Respondents had difficulty determining the average annual runoff and geographic factor from the maps provided due to the small scale. Respondents also found the use of numbered parts, areas, regions, factors, and other items confusing and hard to follow. The record sheets also contained parameters that were not needed in several basins, which caused confusion.

Idaho Water Resources Investigations 7-73. Respondents indicated that this procedure was not applicable to at least one site because the drainage area greatly exceeded that recommended in the procedure. The publication also provides no recommended procedure for handling watersheds which are located in more than one region.

Rational Formula

Relatively few tester comments were received on the application of the rational formula. However, some respondents experienced difficulty with the definition of many of the parameters required by the particular description which was supplied. Several respondents stated that better definitions of drainage area, length, slope, and time of concentration were needed. Respondents were often confused as to whether to use values measured for the channel or watershed slope. Respondents expressed a need for rainfall-duration-frequency curves and soils reports which were not supplied. They also indicated that a good knowledge of the area was required to make this procedure work well.

SCS TR-55 Graph and Charts Procedures

Many respondents perceived these procedures to be sensitive to the time of concentration and runoff curve number parameters. They believed they could not adequately evaluate these parameters. The need for channel shape and depth information to determine channel velocities was frequently expressed. Likewise, the need for field checks to properly evaluate curve numbers was also indicated. Without this information, respondents found the procedures very subjective.

A number of respondents criticized the documentation of the procedures, stating that the manual was inexplicit and confusing, excessive in size, and contained extraneous information not needed to apply the procedures. A glossary of terms was recommended.

Respondents often found the shape and slope adjustment procedures confusing in applying the charts procedure. Average watershed slope was often confused with channel slope. The Work Group's inclusion of the slope and shape adjustment factors for consistency on the graphical procedure record sheet also generated confusion among the respondents because these adjustments did not apply.

Several respondents questioned the applicability of the graphical procedure to large watersheds because the ranges of tables and figures were exceeded. Also, the applicability of this procedure was questioned in areas of significant snowmelt contribution to peaks, such as in Idaho.

SCS TR-20 Procedure

Most respondents providing comments generally indicated that more data than were supplied in the resource packages were needed to obtain a good answer. In particular, the time of concentration, routing coefficients, and runoff curve numbers were parameters most frequently listed as difficult to evaluate. Respondents expressed a need for stream hydraulic data, including cross sections, as well as field checks to evaluate these parameters.

Some respondents suggested that a summary sensitivity analysis be provided for the TR-20 model so that impacts of variation in input variables would be known, particularly with regard to rainfall durations. It was also suggested that rainfall tables be made a part of the program to simplify application in a nationwide test. Familiarization time might also be reduced by simplifying instructions to address only the peak flow determination according to some testers.

HEC-1 Procedure

A large number of respondents were not satisfied with their application of the procedure, or their results, for a number of reasons. The complexity of the program was evident from the number of comments indicating that use of the procedure was time consuming and required considerable experience both with the procedure itself and the hydrologic region. Many respondents indicated that the two-day training session supplied by the U.S. Geological Survey was inadequate. The omission of the snowmelt routine in the training session was also criticized. It was recommended that the full training course materials be made available to all testers.

The adequacy of data to calibrate the model was the subject of numerous comments. Many respondents indicated that they had insufficient or inadequate data for proper calibration of the procedure. This was also true for respondents who were provided data by the Work Group. It was recommended that data be provided for a large number of gages in the area and that testers be allowed to choose the data used for calibration. Some repondents questioned the usefulness of calibration data provided for watersheds in the Northwest region because of the apparent presence of snowmelt runoff. Many respondents found the use of calibration data difficult because no basin characteristics were supplied for the corresponding watersheds. It was suggested that quadrangle maps be supplied in the resource packages for the watersheds to be calibrated. Several respondents objected to working with stage data supplied for the calibration watersheds because of the time required to convert to discharge hydrographs.

Several criticisms of the procedure were also made. Many respondents were uncomfortable with the amount of engineering judgment or subjectivity required to apply the procedure. Difficulty was experienced in obtaining consistent parameters for unit hydrographs and loss rate functions in optimization runs. Time of concentration was a particularly troublesome parameter. The development of proper rainfall distributions was found to be time consuming for some respondents. An improved edit routine was also recommended.

APPENDIX 5

STATISTICAL ANALYSIS OF THE PILOT TEST DATA USING ANALYSIS OF VARIANCE

The three criterion variables to be analyzed are bias, reproducibility, and time to apply. Because the experimental design consisted of applying different procedures for three exceedance probabilities to different watersheds grouped according to size, each criterion variable is potentially affected by four factors:

1. Procedure, P--the nine procedures described in section V-A-1.

2. Exceedance Probability, R--the three frequency levels of flood peaks: 50-, 10-, and 1-percent-chance floods.

3. Site Size, S--the five site sizes described in section V-A-2: 0-3, 3-10, 10-50, 50-100, and greater than 100 square miles.

4. Watershed, W(S)--watershed factor within each site size. Each watershed has its own unique effect on the criterion variables. Within each site size the watersheds are numbered sequentially.

The watershed factor is nested within site size because the levels of the watershed factor are different within each site size. Procedures, site sizes, and exceedance probabilities are arranged in a factorial layout; that is, each procedure is used for all three exceedance probabilities and, whenever possible, for each size site. However, not all procedures are applicable at all watersheds, and this creates an unbalanced design structure.

A convenient method of analysis for multifactor data such as this is the analysis of variance (ANOVA). This procedure will allow identification of significant factors (and their interactions) by individual criterion variable.

The analysis of variance models that describe the relationship between the criterion variables and the four factors above are:

$$B = P + R + S + W(S) + P*R + R*S + R*W(S) + P*S + P*W(S) + E \qquad (1)$$

$$RE = P + R + S + W(S) + P*R + R*S + R*W(S) + P*S + P*W(S) + E \qquad (2)$$

$$TA = P + S + W(S) + P*S + P*W(S) + E \qquad (3)$$

where B is the bias for watershed i, procedure k, and exceedance probability R; RE is the reproducibility for watershed i, procedure k, and exceedance probability R; TA is the time to apply for watershed i and procedure k; P, R, S, and W(S) are defined above; and E is an error term. Terms such as P*S represent interactions of the original factors. The P*S interaction represents the failure of the procedure factor to produce a constant effect from one site size to another. In equations (1) and (2), the error term E consists of higher-order interactions (three-factor) involving exceedance probability R, because the analysis is done on either average bias or reproducibility (that is, there is only one observation per cell). In equation (3), the analysis is performed using the raw time to apply scores, so that the error term is derived from replication rather than by combining higher-order effects.

The Statistical Analysis System (SAS) general linear models (GLM) routine was used to analyze the data. The type III sums of squares were used in the analysis of variance. These sums of squares were considered most appropriate for the unbalanced design used in the pilot test based on a study of the resulting estimable functions. Separate analyses were performed for the Northwest and Midwest regions. The statistical analyses are performed using the data set that includes the computational errors. Only data coding and transcription errors have been corrected.

Because reproducibility is defined as a standard deviation, the original reproducibility variable is not normally distributed. However, for moderately small samples of n = 5, say, the natural logarithm of the sample variance is approximately normally distributed. Therefore, the ANOVA analyses used the natural logarithm of the square of reproducibility called the transformed reproducibility. This provides closer agreement with the basic analysis of variance assumptions. The bias and time to apply variables were not transformed, as these criterion variables were assumed to be approximately normally distributed.

A. Midwest Region

1. Bias

The analysis of variance for average bias in the Midwest region is shown in Table A5-1. All main effects and interactions are statistically significant, except the exceedance probability-site size (R*S) interaction. That is, there are statistically significant effects of exceedance probability, procedure, site size, and watershed within site size on bias. Furthermore, there are interactions between procedures and exceedance probabilities, procedures and site sizes, procedures and watersheds, and exceedance probabilities and watersheds. The interactions involving procedures imply that the procedure effect is not constant across all exceedance probabilities, site sizes, and watersheds.

In order to draw specific conclusions about which procedures differ, the procedure-site size and procedure-exceedance probability interactions are analyzed using Duncan's multiple range test (Hines and Montgomery, 1980 or Montgomery, 1976). Table A5-2 shows the procedure-site size interaction. For small sites (10 square miles or less), procedures 1, 7, and 9 are equivalent and have the smallest bias. Procedures 3 and 6 have the largest bias regardless of site size. For site sizes of 10 to 50 square miles, procedure 10 has the smallest bias, although procedures 5

Table A5-1

ANALYSIS OF VARIANCE FOR BIAS
MIDWEST REGION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	CV
Model	297	1948.33187697	6.65003999	18.81	0.0001	0.949674	80.2463
Error	296	103.24700886	0.34880746		Std Dev		Mean
Corrected Total	593	2051.57888583			0.59059924		0.73598316

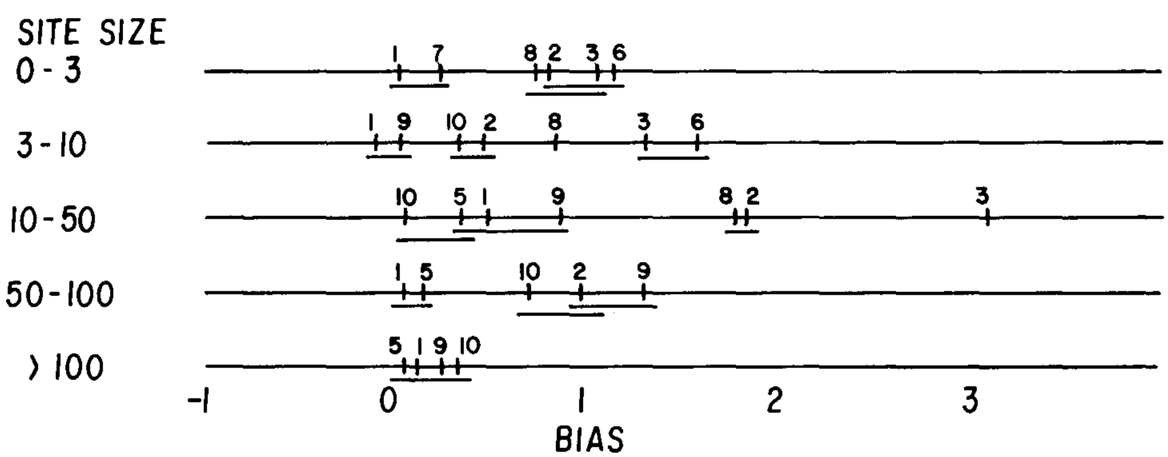
Source	DF	Type III SS	F Value	PR > F
R	2	30.01964248	43.03	0.0001
P	8	160.43461539	57.49	0.0001
S	4	69.08524156	49.52	0.0001
W(S)	37	1092.19139498	84.63	0.0001
R*P	16	74.17928489	13.29	0.0001
R*S	8	2.81781744	1.01	0.4285
R*W(S)	74	58.87687573	2.28	0.0001
P*S	16	29.30988586	5.25	0.0001
P*W(S)	132	345.41710303	7.50	0.0001

Table A5-2

DUNCAN'S MULTIPLE RANGE TEST--BIAS
PROCEDURE-SITE SIZE INTERACTION
MIDWEST REGION

Procedure	Site Size				
	0-3	3-10	10-50	50-100	>100
1	0.055 24	-0.169 24	0.478 24	0.070 30	0.034 24
2	0.764 24	0.459 24	1.766 24	0.923 30	
3	1.088 24	1.277 24	3.061 24		
5			0.362 24	0.114 30	0.016 24
6	1.182 24	1.604 24			
7	0.201 24				
8	0.713 24	0.820 24	1.725 24		
9		0.035 9	0.806 12	1.251 9	0.244 6
10		0.281 9	0.027 12	0.674 9	0.319 6

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.

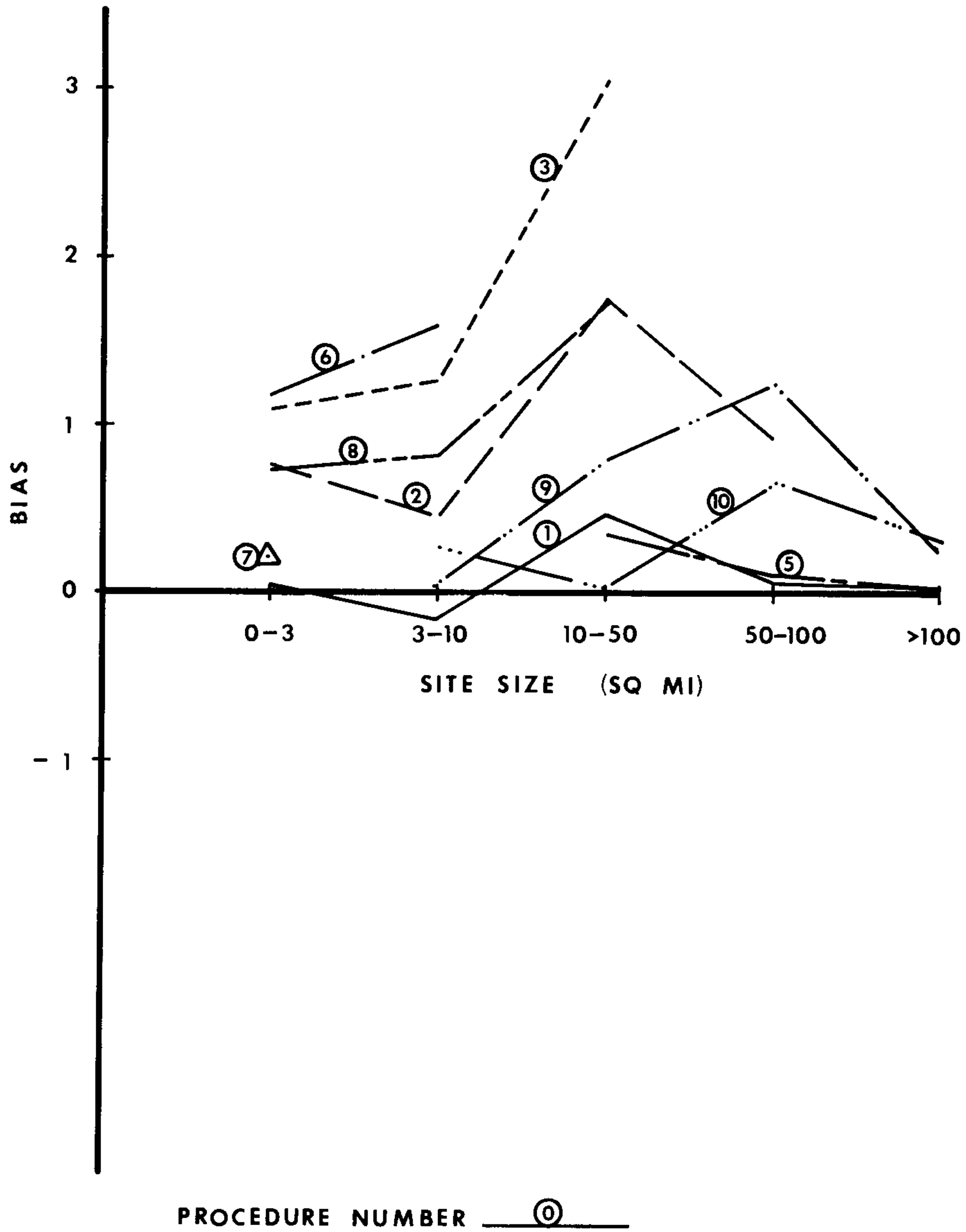


NOTE : Underlined procedures are not different at $\alpha = 0.05$

and 1 have reasonably small bias values. For site sizes of 50 to 100 square miles, procedures 1 and 5 have lower average bias than procedures 2, 9, and 10. For larger sites, above 100 square miles, procedures 1, 5, 9, and 10 produce equivalent values of bias. Figure A5-1 shows the cell means.

Table A5-3 shows the analysis of the procedure-exceedance probability interaction. Regardless of the choice of exceedance probability, procedures 1, 5, 7, and 10 produce the smallest average bias. For the 50-percent-chance flood level, procedures 2 and 9 are equivalent to procedures 7 and 10, while procedures 3, 6, and 8 exhibit significantly higher bias. At less frequent flood levels, procedures 3, 6, and 8 have lower bias values and are roughly comparable to procedures 2 and 9. Figure A5-2 shows the cell means.

The analysis of these interactions shows how the procedure effect for bias varies with the choice of site size and exceedance probability. It is also possible to investigate the procedure main effect averaged across the levels of the other factors. This information is useful in assessing the performance of procedures regardless of the site size or the exceedance probability selected. Table A5-4 shows the results of applying the Duncan's multiple range test to the main effect procedures. This analysis was used to draw the conclusions regarding procedures with respect to the bias criterion variable in the Midwest reported in section VIII-B.



BIAS

PROCEDURE —SITE SIZE INTERACTION

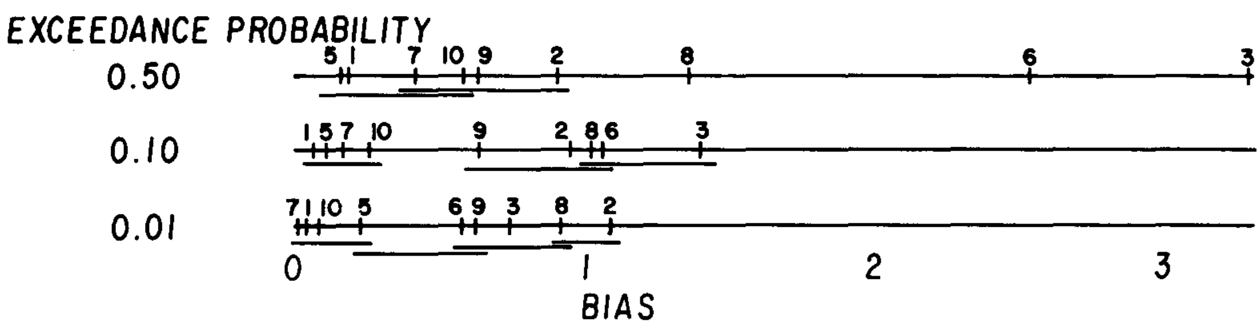
REGION —MIDWEST

Table A5-3

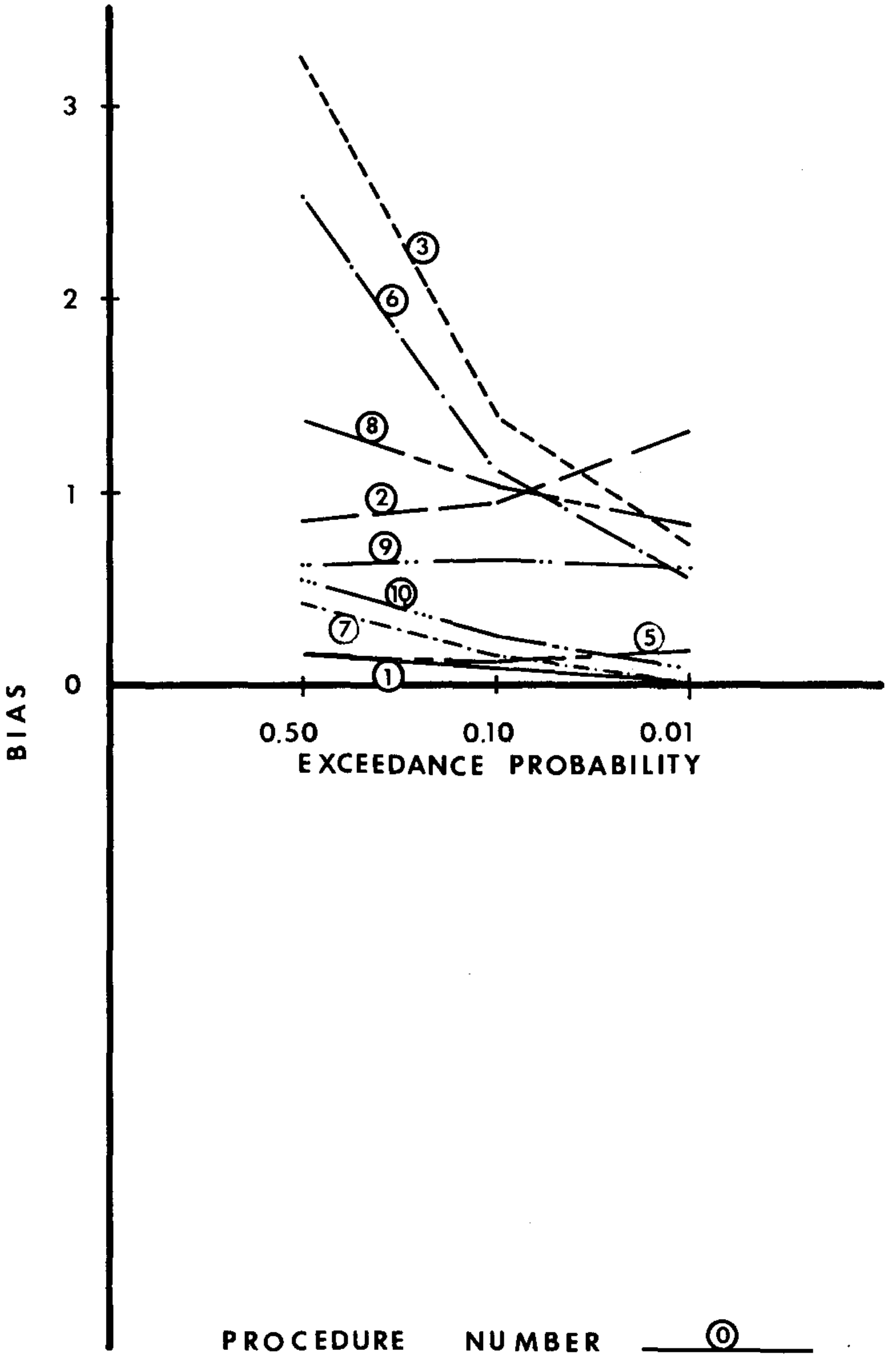
DUNCAN'S MULTIPLE RANGE TEST--BIAS
PROCEDURE-EXCEEDANCE PROBABILITY INTERACTION
MIDWEST REGION

Procedure	Exceedance Probability 0.50	0.10	0.01
1	0.166 42	0.093 42	0.017 42
2	0.847 34	0.946 34	1.132 34
3	3.296 24	1.400 24	0.730 24
5	0.164 26	0.123 26	0.194 26
6	2.512 16	1.105 16	0.562 16
7	0.438 8	0.159 8	0.005 8
8	1.391 24	1.040 24	0.826 24
9	0.628 12	0.648 12	0.617 12
10	0.560 12	0.253 12	0.090 12

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.



NOTE: Underlined procedures are not different at $\alpha = 0.05$



BIAS

PROCEDURE — EXCEEDANCE PROBABILITY INTERACTION

REGION — MIDWEST

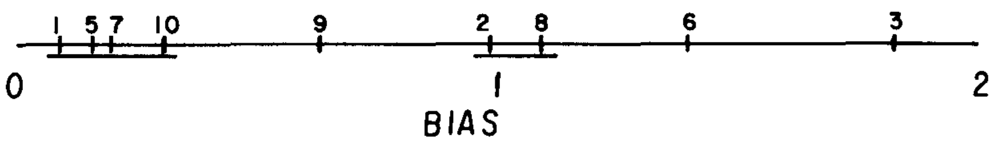
Table A5-4

DUNCAN'S MULTIPLE RANGE TEST--BIAS
PROCEDURE MAIN EFFECT
MIDWEST REGION

Alpha Level = 0.05 Df = 301 MS = 0.349115

Procedure	Grouping	Mean	N
3	A	1.808679	72
6	B	1.393343	48
8	C	1.085821	72
	C		
2	C	0.974681	102
9	D	0.630745	36
10	E	0.300875	36
	E		
7	E	0.200642	24
	E		
5	E	0.160328	78
	E		
1	E	0.092143	126

Note: Means with the same letter are not significantly different.



NOTE: Underlined procedures are not different at α = 0.05

2. Transformed Reproducibility

The analysis of variance for the transformed reproducibility is shown in Table A5-5. All main effects and interactions are significant. Table A5-6 shows the analysis of the procedure-site interaction. In general, procedures 1, 2, and 5 exhibit the smallest variability while the other procedures are uniformly more variable. At site sizes in excess of 10 square miles, procedures 9 and 10 exhibit larger values of transformed reproducibility, while at site sizes of 50 square miles or less, procedures 3, 6, 7, and 8 exhibit larger values of transformed reproducibility. A graph of the transformed reproducibility cell means is shown in Figure A5-3.

Table A5-7 shows the analysis of the procedure-exceedance probability interaction. Procedures 1, 2, and 5 have the lowest variability, although at the 50- and 10-percent-chance flood levels, procedure 1 has significantly higher variability than procedures 2 and 5. All other procedures, 3, 6, 7, 8, 9, and 10, have significantly higher transformed reproducibility values. A plot of the transformed reproducibility cell means is shown in Figure A5-4.

Because the transformed reproducibility is somewhat difficult to visualize, the original standard deviations by site size and exceedance probability are shown in Tables A5-8 and A5-9, respectively. The units of the standard deviation are cfs, while the units of the transformed reproducibility are $\ln(cfs)^2$.

The analysis of the main effect of procedures is shown in Table A5-10. This table was used to draw the conclusions regarding procedures with respect to the transformed reproducibility criterion variable in the Midwest reported in section VIII-B.

Table A5-5

ANALYSIS OF VARIANCE FOR TRANSFORMED REPRODUCIBILITY
MIDWEST REGION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	CV
Model	297	4601.19804562	15.49224931	38.08	0.0001	0.974497	21.0322
Error	296	120.41457438	0.40680599		Std Dev		Mean
Corrected Total	593	4721.61262000			0.63781345		-3.03256353

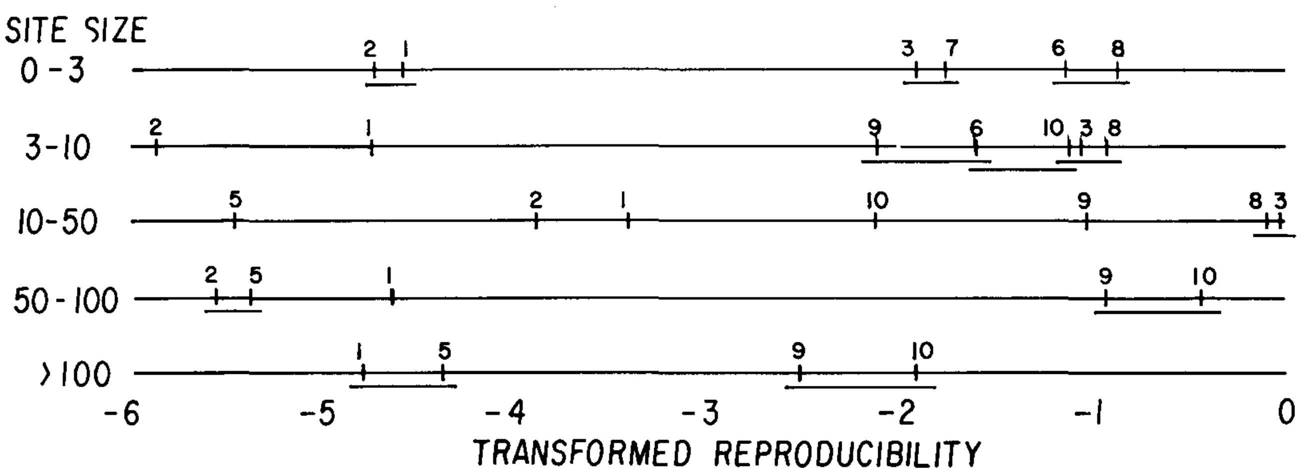
Source	DF	Type III SS	F Value	PR > F
R	2	33.37808616	41.02	0.0001
P	8	1554.46670807	477.64	0.0001
S	4	41.77366422	25.67	0.0001
W(S)	37	1253.49811662	83.28	0.0001
R*P	16	90.75421163	13.94	0.0001
R*S	8	14.49498688	4.45	0.0001
R*W(S)	74	78.38445841	2.60	0.0001
P*S	16	124.40228694	19.11	0.0001
P*W(S)	132	910.05269778	16.95	0.0001

Table A5-6

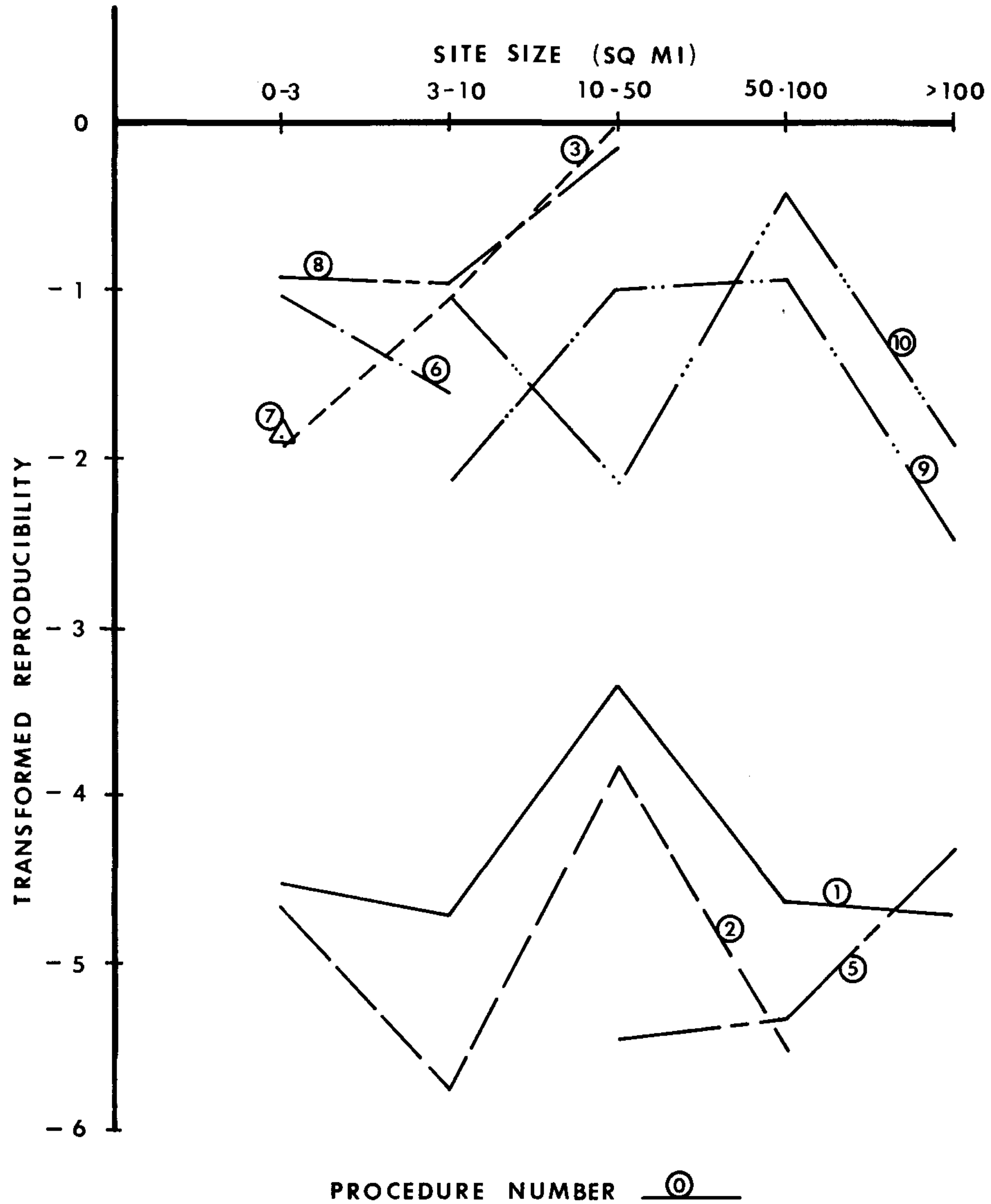
DUNCAN'S MULTIPLE RANGE TEST--TRANSFORMED REPRODUCIBILITY
PROCEDURE-SITE SIZE INTERACTION
MIDWEST REGION

Procedure	Site Size				
	0-3	3-10	10-50	50-100	>100
1	-4.515 24	-4.716 24	-3.362 24	-4.656 30	-4.713 24
2	-4.673 24	-5.776 24	-3.846 24	-5.547 30	
3	-1.933 24	-1.068 24	-0.000 24		
5			-5.467 24	-5.366 30	-4.354 24
6	-1.134 24	-1.613 24			
7	-1.871 24				
8	-0.927 24	-0.966 24	-0.161 24		
9		-2.133 9	-1.005 12	-0.955 9	-2.509 6
10		-1.132 9	-2.163 12	-0.437 9	-1.916 6

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.



NOTE: Underlined procedures are not different at $\alpha = 0.05$



TRANSFORMED REPRODUCIBILITY

PROCEDURE – SITE SIZE INTERACTION

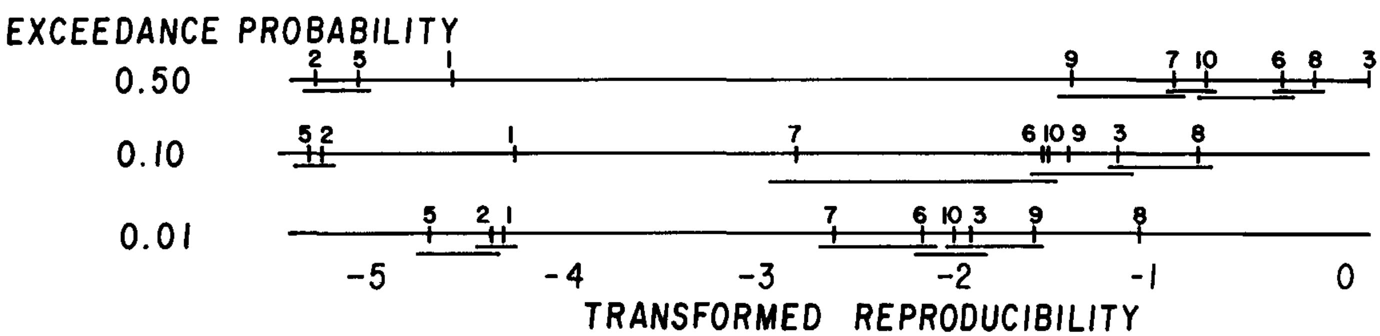
REGION – MIDWEST

Table A5-7

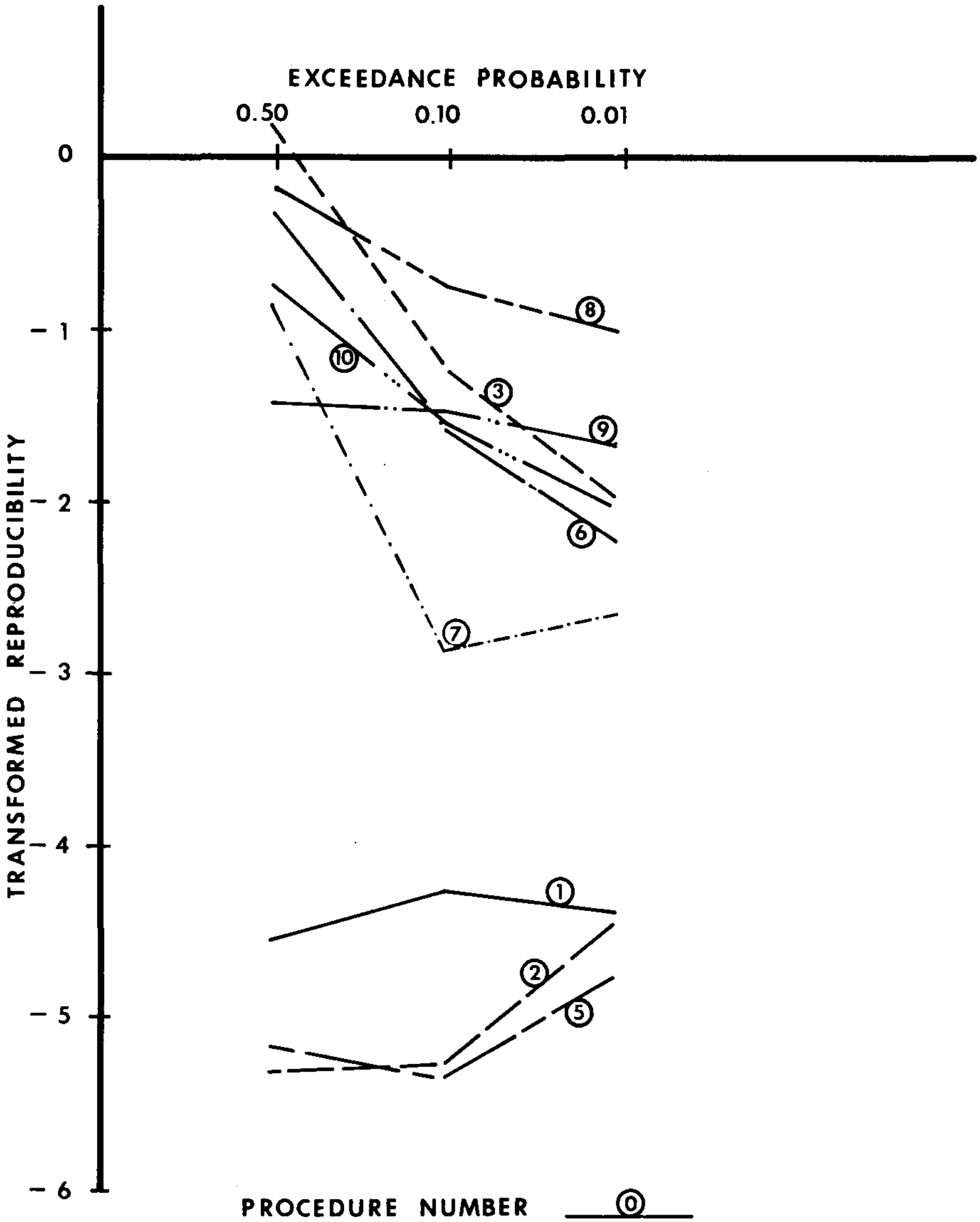
DUNCAN'S MULTIPLE RANGE TEST--TRANSFORMED REPRODUCIBILITY
PROCEDURE-EXCEEDANCE PROBABILITY INTERACTION
MIDWEST REGION

Procedure	Exceedance Probability 0.50	0.10	0.01
1	-4.559 42	-4.274 42	-4.382 42
2	-5.300 34	-5.272 34	-4.457 34
3	0.193 24	-1.218 24	-1.977 24
5	-5.155 26	-5.351 26	-4.752 26
6	-0.312 16	-1.579 16	-2.229 16
7	-0.877 8	-2.872 8	-2.663 8
8	-0.194 24	-0.750 24	-1.109 24
9	-1.433 12	-1.475 12	-1.668 12
10	-0.724 12	-1.543 12	-2.031 12

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.



NOTE: Underlined procedures are not different at $\alpha = 0.05$



TRANSFORMED REPRODUCIBILITY

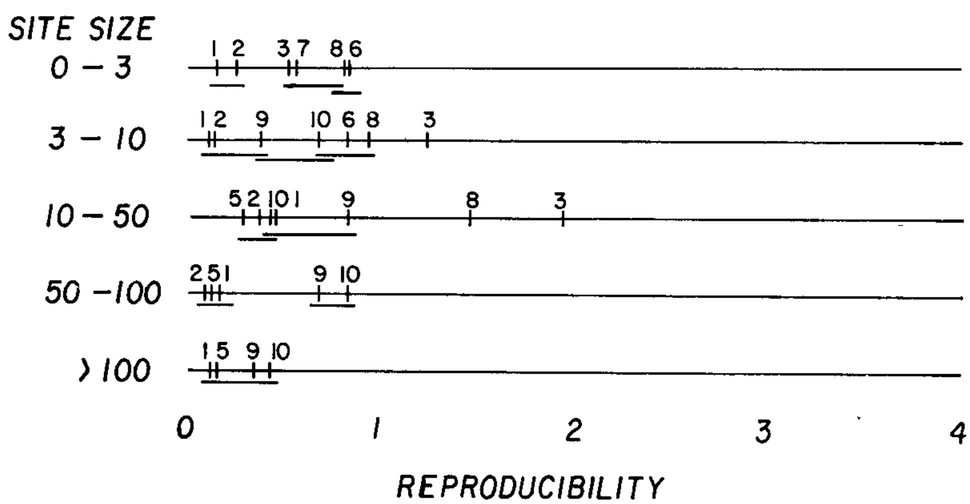
PROCEDURE — EXCEEDANCE PROBABILITY INTERACTION
REGION — MIDWEST

Table A5-8

DUNCAN'S MULTIPLE RANGE TEST--REPRODUCIBILITY
PROCEDURE-SITE SIZE INTERACTION
MIDWEST REGION

Procedure	Site Size				
	0-3	3-10	10-50	50-100	>100
1	0.150 24	0.119 24	0.472 24	0.149 30	0.110 24
2	0.248 24	0.141 24	0.378 24	0.097 30	
3	0.538 24	1.247 24	1.923 24		
5			0.294 24	0.109 30	0.150 24
6	0.831 24	0.827 24			
7	0.558 24				
8	0.812 24	0.930 24	1.470 24		
9		0.395 9	0.813 12	0.680 9	0.320 6
10		0.672 9	0.429 12	0.820 9	0.417 6

Note: Top number is cell mean.
Bottom number is number of observations used to compute value.



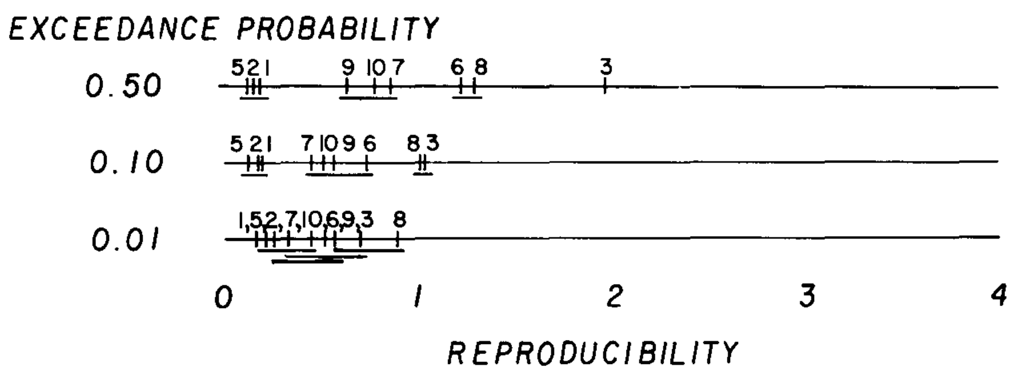
NOTE: Underlined procedures are not different at $\alpha = 0.05$

Table A5-9

DUNCAN'S MULTIPLE RANGE TEST--REPRODUCIBILITY PROCEDURE-EXCEEDANCE PROBABILITY INTERACTION MIDWEST REGION

Procedure	Exceedance Probability		
	0.50	0.10	0.01
1	0.193 42	0.203 42	0.197 42
2	0.173 34	0.188 34	0.266 34
3	1.981 24	1.025 24	0.702 24
5	0.163 26	0.156 26	0.217 26
6	1.227 16	0.728 16	0.533 16
7	0.861 8	0.469 8	0.344 8
8	1.300 24	1.023 24	0.889 24
9	0.616 12	0.585 12	0.578 12
10	0.786 12	0.530 12	0.441 12

Note: Top number is cell mean.
Bottom number is number of observations used to compute value.



NOTE: Underlined procedures are not different at $\alpha = 0.05$

Table A5-10

DUNCAN'S MULTIPLE RANGE TEST--TRANSFORMED REPRODUCIBILITY
PROCEDURE MAIN EFFECT
MIDWEST REGION

Alpha Level = 0.05 Df = 301 MS = 0.456381

Procedure	Grouping		Mean	N
8		A	-0.684428	72
3		B	-1.002191	72
6		C	-1.370992	48
		C		
10		C	-1.432370	36
		C		
9	D	C	-1.525400	36
	D			
7	D		-1.860729	24
1		E	-4.423633	126
2		F	-4.864161	102
		F		
5		F	-5.038658	78

Note: Means with the same letter are not significantly different.

NOTE: Underlined procedures are not different at $\alpha = 0.05$

3. Time to Apply

The analysis of variance for time to apply in the Midwest region is shown in Table A5-11. All main effects and interactions are statistically significant except the procedure-watershed (P*W(S)) interaction. An analysis of the procedure-site size interaction is shown in Table A5-12. At small sites, less than 3 square miles, all procedures, 1, 2, 3, 6, 7, and 8, have equivalent times to apply. If the site size varies from 3 to 50 square miles, procedures 1, 2, 3, 6, and 8 have equal times to apply; but procedures 9 and 10 exhibit significantly larger times to apply. Procedure 10 has a larger time to apply than procedure 9 at those sites. For larger sites, greater than 50 square miles, procedures 1, 2, and 5 are equivalent, with procedures 9 and 10 having significantly larger times to apply. At more than 100 square miles, procedures 9 and 10 have equivalent times to apply. A plot of the cell means is shown in Figure A5-5.

Table A5-13 shows an analysis of the main effect of procedures for the time to apply criterion variable in the Midwest. This table was used to draw the conclusions regarding procedures for time to apply in the Midwest reported in section VIII-B.

Table A5-11

ANALYSIS OF VARIANCE FOR TIME TO APPLY
MIDWEST REGION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	CV
Model	197	120872.98985436	613.56847642	9.02	0.0001	0.693246	121.060
Error	786	53485.12696667	68.04723533		Std Dev		Mean
Corrected Total	983	174358.11682104			8.24907482		6.78344512

Source	DF	Type III SS	F Value	PR > F
P	8	67924.54886534	124.77	0.0001
S	4	4387.80472657	16.12	0.0001
W(S)	37	4233.58286386	1.68	0.0075
P*S	16	4293.85283200	3.94	0.0001
P*W(S)	132	5439.78798310	0.61	0.9998

Table A5-12

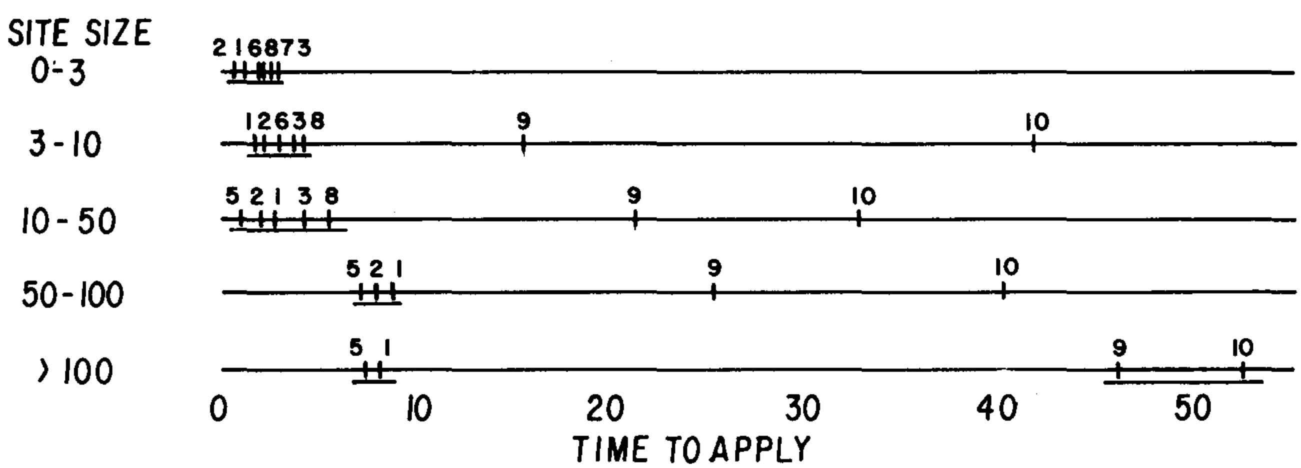
DUNCAN'S MULTIPLE RANGE TEST--TIME TO APPLY

PROCEDURE-SITE SIZE INTERACTION

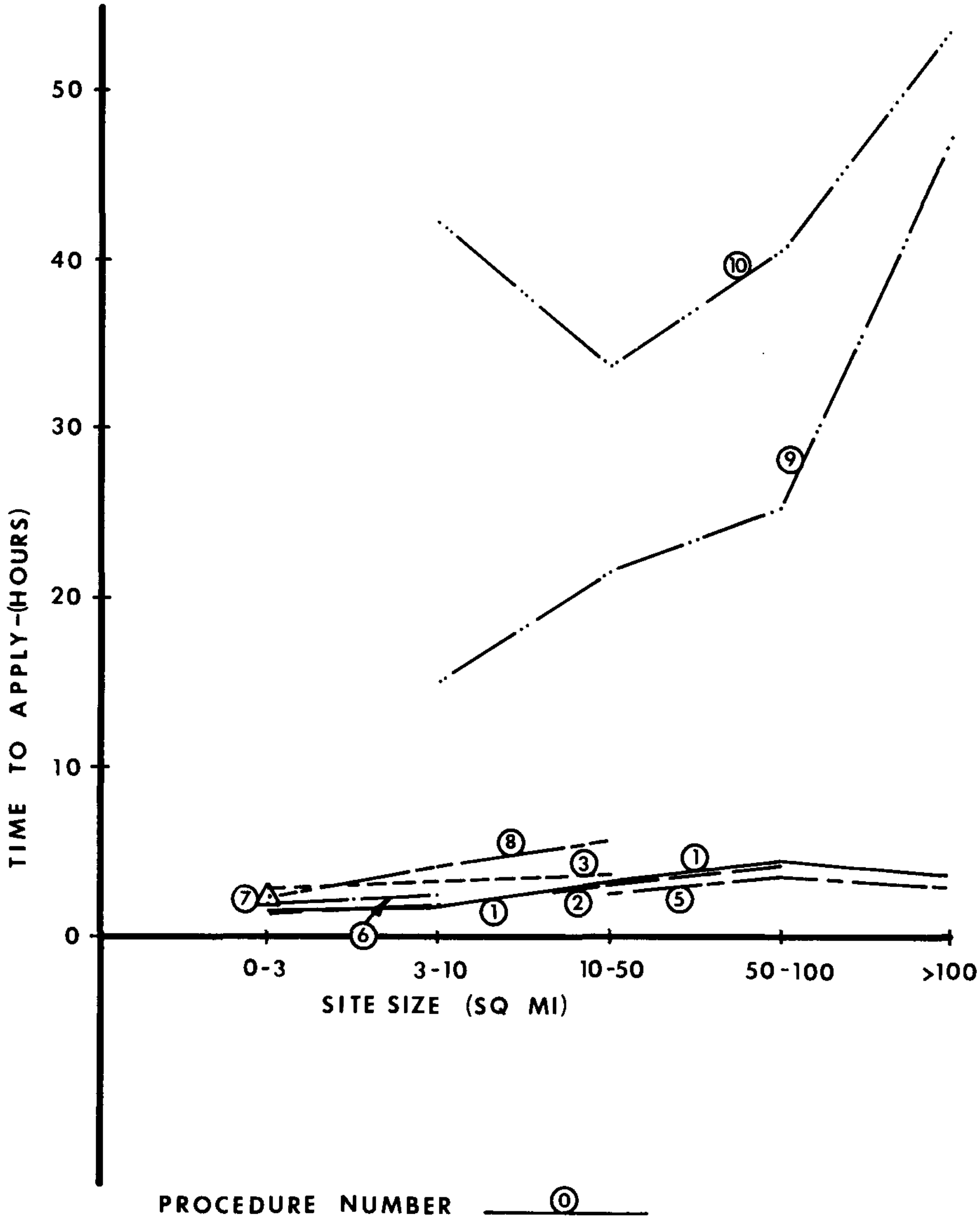
MIDWEST REGION

Procedure	Site Size				
	0-3	3-10	10-50	50-100	>100
1	1.522 40	1.835 40	3.309 40	4.628 50	3.771 40
2	1.315 40	1.950 40	3.102 40	4.419 50	
3	2.905 39	3.428 40	4.853 35		
5			2.656 40	3.592 50	3.146 40
6	1.915 40	2.473 40			
7	2.460 40				
8	2.260 40	4.231 40	5.753 40		
9		15.135 15	21.640 20	25.300 15	47.000 10
10		42.167 15	33.700 20	40.400 15	53.300 10

Note: Top number is cell mean.
Bottom number is number of observations used to compute means.



NOTE: Underlined procedures are not different at $\alpha = 0.05$



TIME TO APPLY

PROCEDURE—SITE SIZE INTERACTION

REGION —MIDWEST

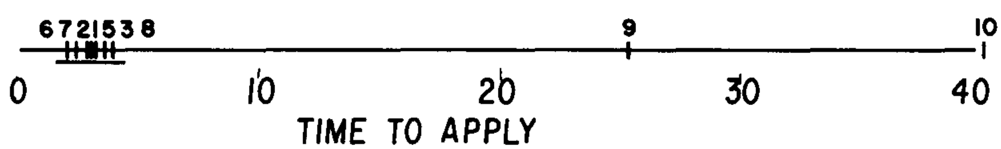
Table A5-13

DUNCAN'S MULTIPLE RANGE TEST--TIME TO APPLY
PROCEDURE MAIN EFFECT
MIDWEST REGION

Alpha Level = 0.05 Df = 786 MS = 68.0472

Procedure	Grouping	Mean	N
10	A	40.758333	60
9	B	25.155333	60
8	C	4.081167	120
	C		
3	C	3.686579	114
	C		
5	C	3.166846	130
	C		
1	C	3.089857	210
	C		
2	C	2.797824	170
	C		
7	C	2.459750	40
	C		
6	C	2.193750	80

Note: Means with the same letter are not significantly different.



NOTE: Underlined procedures are not different at $\alpha = 0.05$

B. Northwest Region

1. Bias

The analysis of variance for average bias in the Northwest region is shown in Table A5-14. All main effects and interactions are significant except the exceedance probability main effect. Because the procedure-site size and procedure-exceedance probability interactions are of major importance, they will be analyzed by the Duncan's multiple range test.

Table A5-15 presents the analysis of the procedure-site size interaction. For site sizes of 10 square miles or less, procedures 1, 2, 7, and 9 have the smallest average bias, while procedures 6, 8, and 10 exhibit significantly greater bias. For site sizes of 10 to 50 square miles, procedures 1 and 9 have the smallest average bias, followed by procedures 2 and 5, followed by procedures 8 and 10. For site sizes of 50 to 100 square miles, procedures 1 and 5 have smaller bias, with procedures 2, 9, and 10 producing a substantially larger bias. For site sizes greater than 100 square miles, procedures 1, 5, 9, and 10 perform equivalently. As site size increases, there is a general tendency for bias to decrease for procedures 1, 5, 9, and 10, while bias increases with site size for procedures 2, 6, and 8. However, procedures 2, 6, and 8 were designed for small watersheds and were extended beyond their range in this test. Procedure 1 produces consistently small average bias regardless of site size. Procedure 2 yields low bias for small size sites (10 square miles or less) but higher bias for larger sites. Procedure 5 yields low bias for larger sites (50 square miles or more). A graph of the cell means is shown in Figure A5-6.

Table A5-16 presents the analysis of the procedure-exceedance probability interaction. Procedures 1, 2, 5, 7, and 9 have small bias for the 50- and 10-percent-chance flood levels, while procedures 6, 8, and 10 have larger bias. At the 1-percent-chance flood level, procedures 1, 5, 7, 9, and 10 are equivalent, with procedures 6 and 8 having larger bias. A graph of the cell means is shown in Figure A5-7.

Table A5-17 shows the Duncan's multiple range test analysis of procedures for bias averaged across the levels of the other factors. This analysis was used to draw the conclusions reported in section VIII-B for procedures regarding bias in the Northwest.

Table A5-14

ANALYSIS OF VARIANCE FOR BIAS
NORTHWEST REGION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	CV
Model	168	975.32242361	5.80549062	14.82	0.0001	0.946760	66.3098
Error	140	54.84664220	0.39176173		Std Dev		Mean
Corrected Total	308	1030.16906581			0.62590872		0.94391586

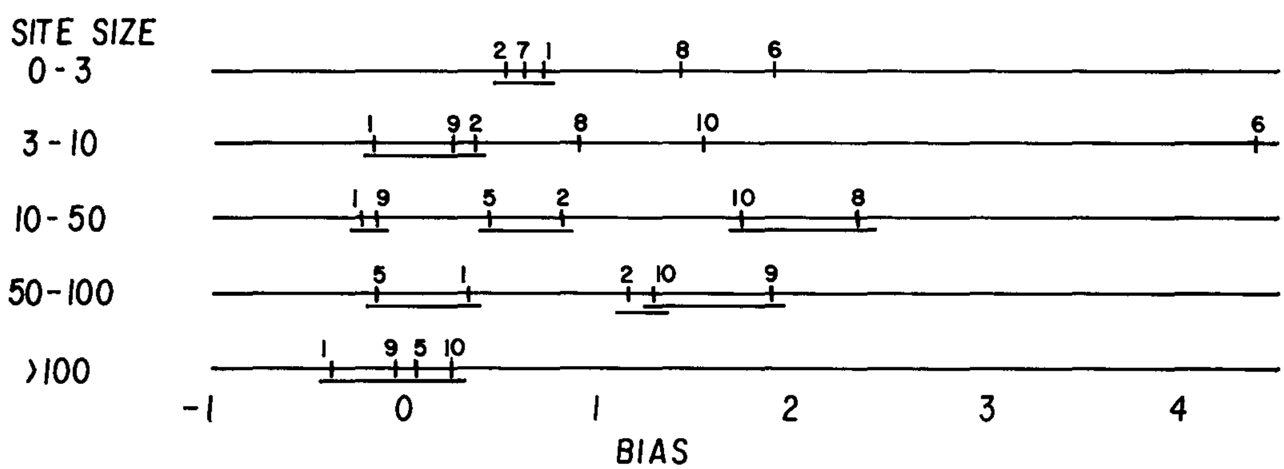
Source	DF	Type III SS	F Value	PR > F
R	2	0.92972923	1.19	0.3083
P	7	196.03262716	71.48	0.0001
S	4	26.64790024	17.01	0.0001
W(S)	21	286.43227896	34.82	0.0001
R*P	14	52.06976998	9.49	0.0001
R*S	8	9.30521061	2.97	0.0042
R*W(S)	42	52.43466742	3.19	0.0001
P*S	14	82.15629938	14.98	0.0001
P*W(S)	56	208.31903122	9.50	0.0001

Table A5-15

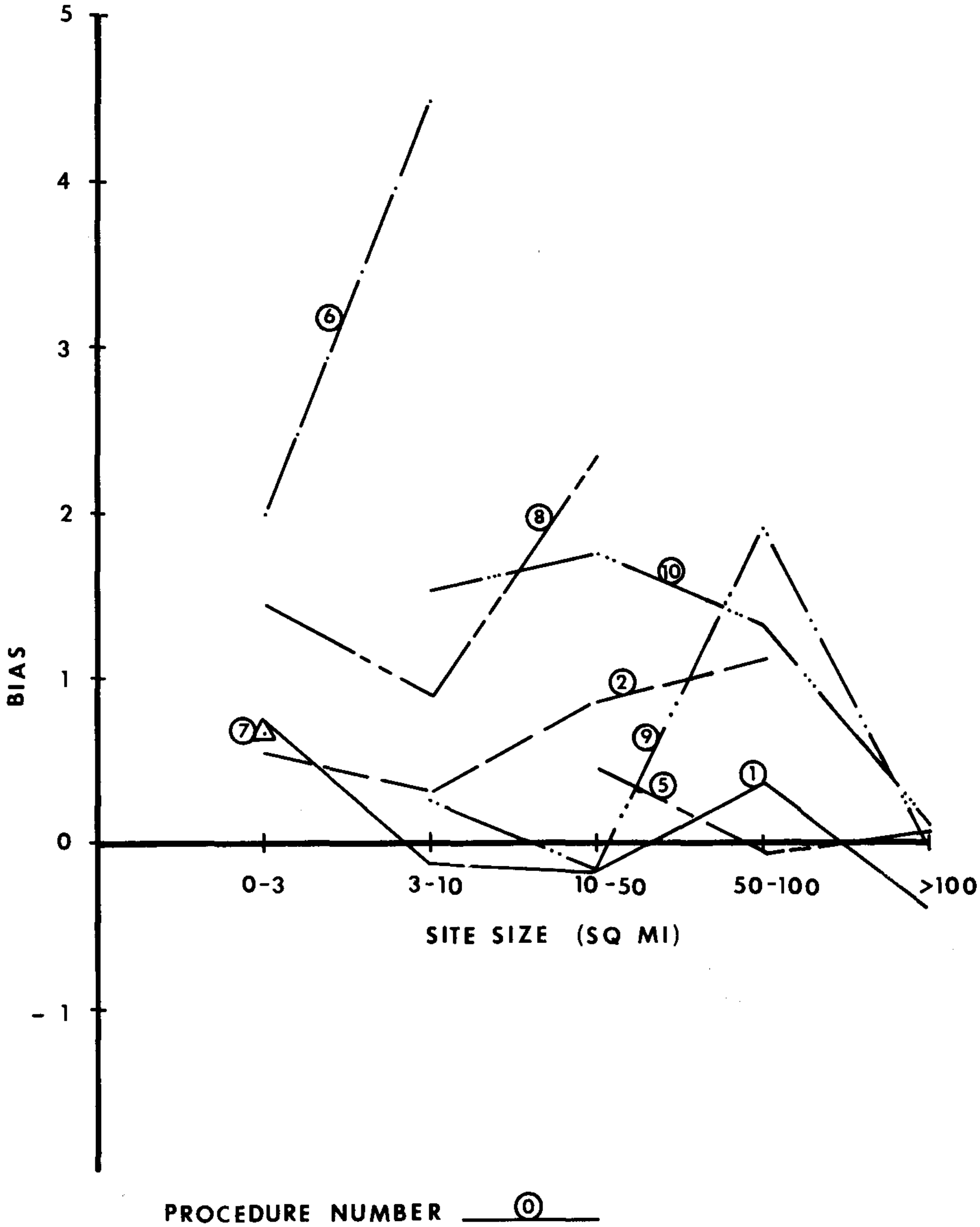
DUNCAN'S MULTIPLE RANGE TEST--BIAS
PROCEDURE-SITE SIZE INTERACTION
NORTHWEST REGION

Procedure	Site Size 0-3	3-10	10-50	50-100	>100
1	0.752 12	-0.139 9	-0.176 6	0.370 15	-0.397 6
2	0.563 15	0.314 15	0.850 15	1.117 24	
5			0.466 15	-0.072 24	0.084 9
6	1.984 15	4.478 15			
7	0.672 15				
8	1.441 15	0.899 15	2.332 15		
9		0.272 9	-0.146 6	1.915 6	-0.023 6
10		1.943 9	1.745 6	1.320 6	0.119 6

Note: Top number is cell mean.
Bottom number is number of observations used to compute means.



NOTE: Underlined procedures are not different at α = 0.05



BIAS

PROCEDURE— SITE SIZE INTERACTION

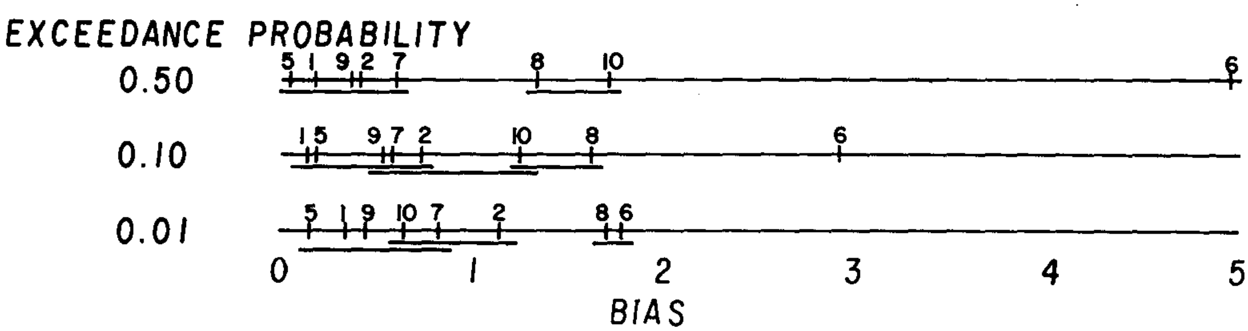
REGION — NORTHWEST

Table A5-16

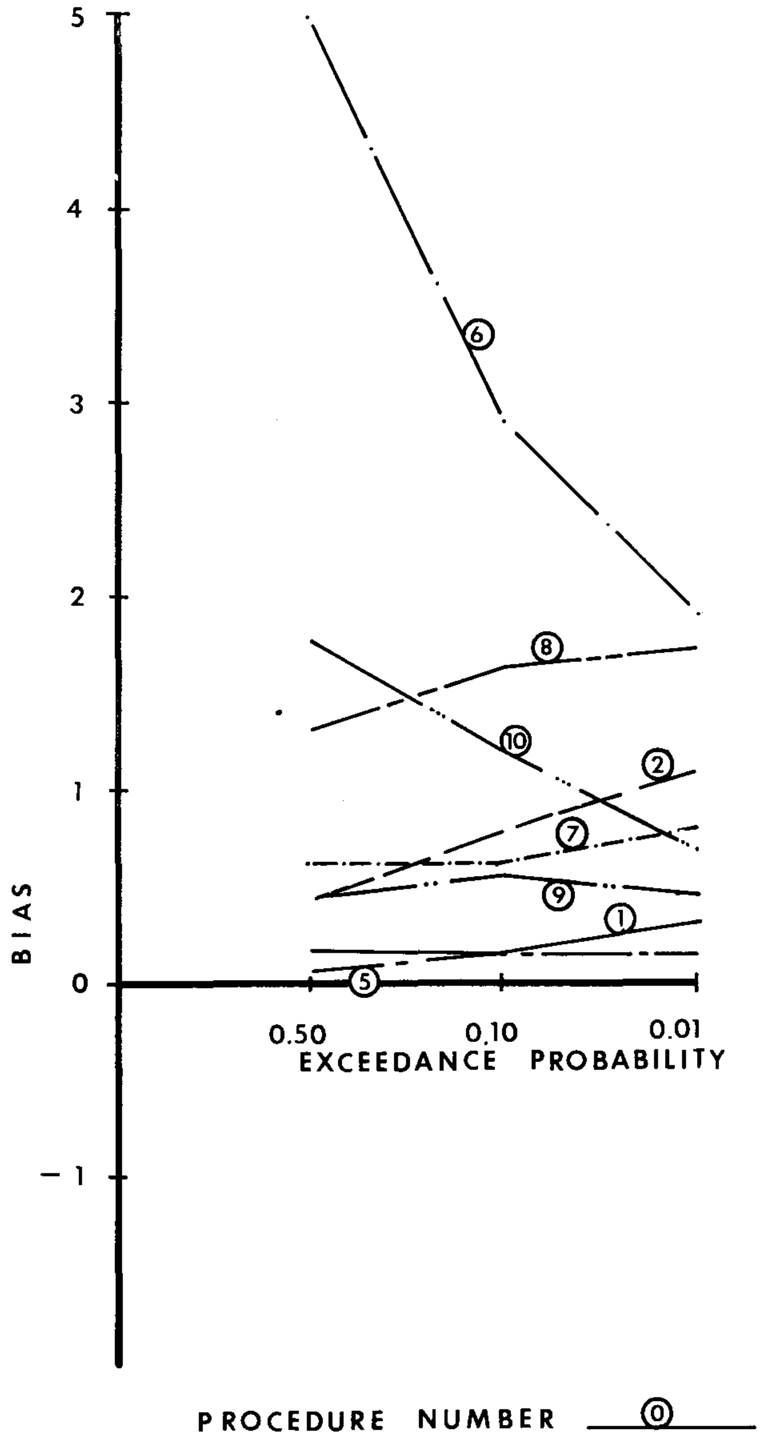
DUNCAN'S MULTIPLE RANGE TEST--BIAS
PROCEDURE-EXCEEDANCE PROBABILITY INTERACTION
NORTHWEST REGION

Procedure	Exceedance Probability		
	0.50	0.10	0.01
1	0.160 16	0.148 16	0.311 16
2	0.419 23	0.770 23	1.104 23
5	0.050 16	0.152 16	0.174 16
6	4.974 10	2.902 10	1.818 10
7	0.610 5	0.609 5	0.798 5
8	1.339 15	1.614 15	1.720 15
9	0.415 9	0.549 9	0.474 9
10	1.770 9	1.204 9	0.694 9

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.



NOTE: Underlined procedures are not different at $\alpha = 0.05$



BIAS

PROCEDURE — EXCEEDANCE PROBABILITY INTERACTION
REGION — NORTHWEST

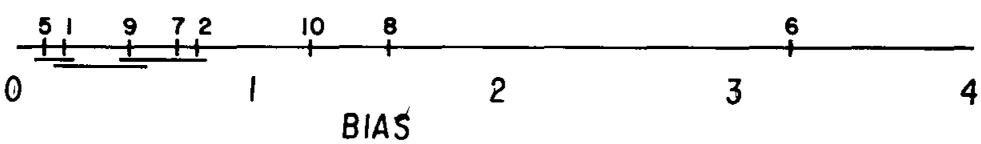
Table A5-17

<u>DUNCAN'S MULTIPLE RANGE TEST--BIAS</u>
<u>PROCEDURE MAIN EFFECT</u>
<u>NORTHWEST REGION</u>

Alpha Level = 0.05   Df = 140   MS = 0.39178

Procedure	Grouping		Mean	N
6		A	3.231125	30
8		B	1.557479	45
10		C	1.222707	27
2		D	0.764219	69
		D		
7		D	0.672152	15
		D		
9	E	D	0.478686	27
	E			
1	E	F	0.206031	48
		F		
5		F	0.125149	48

Note: Means with the same letter are not significantly different.



NOTE: Underlined procedures are not different at $\alpha = 0.05$

2. Transformed Reproducibility

The analysis of variance for the transformed reproducibility for the Northwest region is shown in Table A5-18. All the factors are statistically significant. An analysis of the procedure-site size interaction is shown in Table A5-19. Procedures 1, 2, and 5 consistently produce the lowest variability between testers. Procedures 6, 7, 8, 9, and 10 consistently yield higher values of variability. Figure A5-8 shows a plot of the transformed reproducibility cell means.

The procedure-exceedance probability interaction is shown in Table A5-20. Procedures 1, 2, and 5 again produce the lowest values of variability. Procedure 2 has lower transformed reproducibility values than procedures 1 and 5. All other procedures have higher values of transformed reproducibility. A plot of the transformed reproducibility cell means is shown in Figure A5-9.

Tables A5-21 and A5-22 show reproducibility, expressed as a standard deviation, by site size and by exceedance probability, respectively. Because the units of the standard deviation are cfs, they should be somewhat easier to interpret than the transformed reproducibility.

Table A5-23 shows the Duncan's multiple range test analysis of the main effect of procedures. This analysis was used to draw the conclusions for procedures regarding transformed reproducibility in the Northwest reported in section VIII-B.

Table A5-18

ANALYSIS OF VARIANCE FOR TRANSFORMED REPRODUCIBILITY
NORTHWEST REGION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	CV
Model	168	2412.71063273	14.36137281	39.46	0.0001	0.979320	34.2072
Error	140	50.94741421	0.36391010		Std Dev		Mean
Corrected Total	308	2463.65804694			0.60324962		-1.76351773

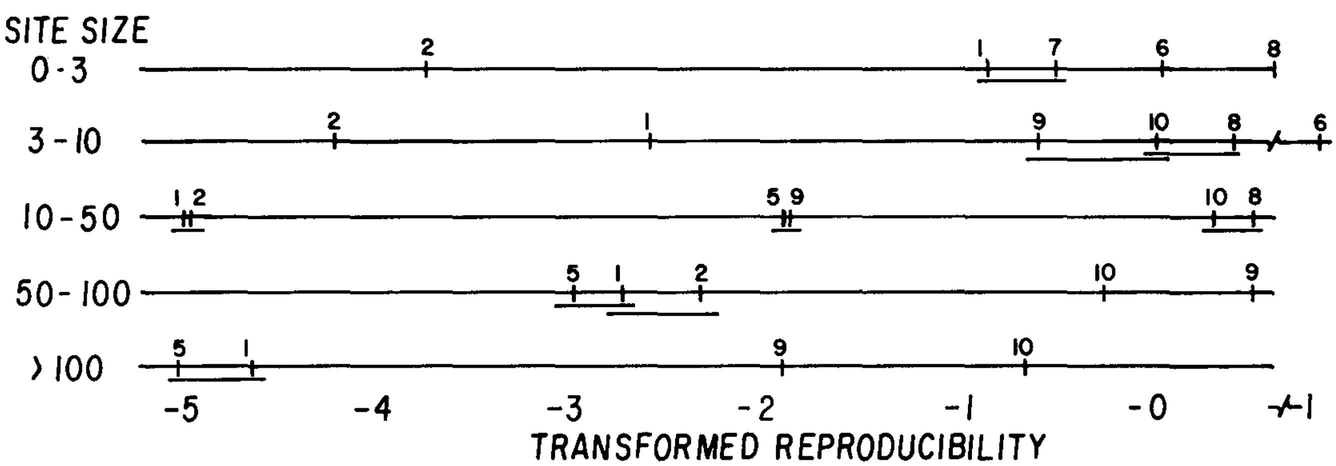
Source	DF	Type III SS	F Value	PR > F
R	2	3.89887221	5.36	0.0057
P	7	830.24328040	325.92	0.0001
S	4	95.21411633	65.41	0.0001
W(S)	21	562.96325151	73.67	0.0001
R*P	14	26.19805800	5.14	0.0001
R*S	9	14.16753257	4.87	0.0001
R*W(S)	42	62.90890128	4.12	0.0001
P*S	14	174.26445360	34.20	0.0001
P*W(S)	56	532.76145294	26.14	0.0001

Table A5-19

DUNCAN'S MULTIPLE RANGE TEST--TRANSFORMED REPRODUCIBILITY
PROCEDURE-SITE SIZE INTERACTION
NORTHWEST REGION

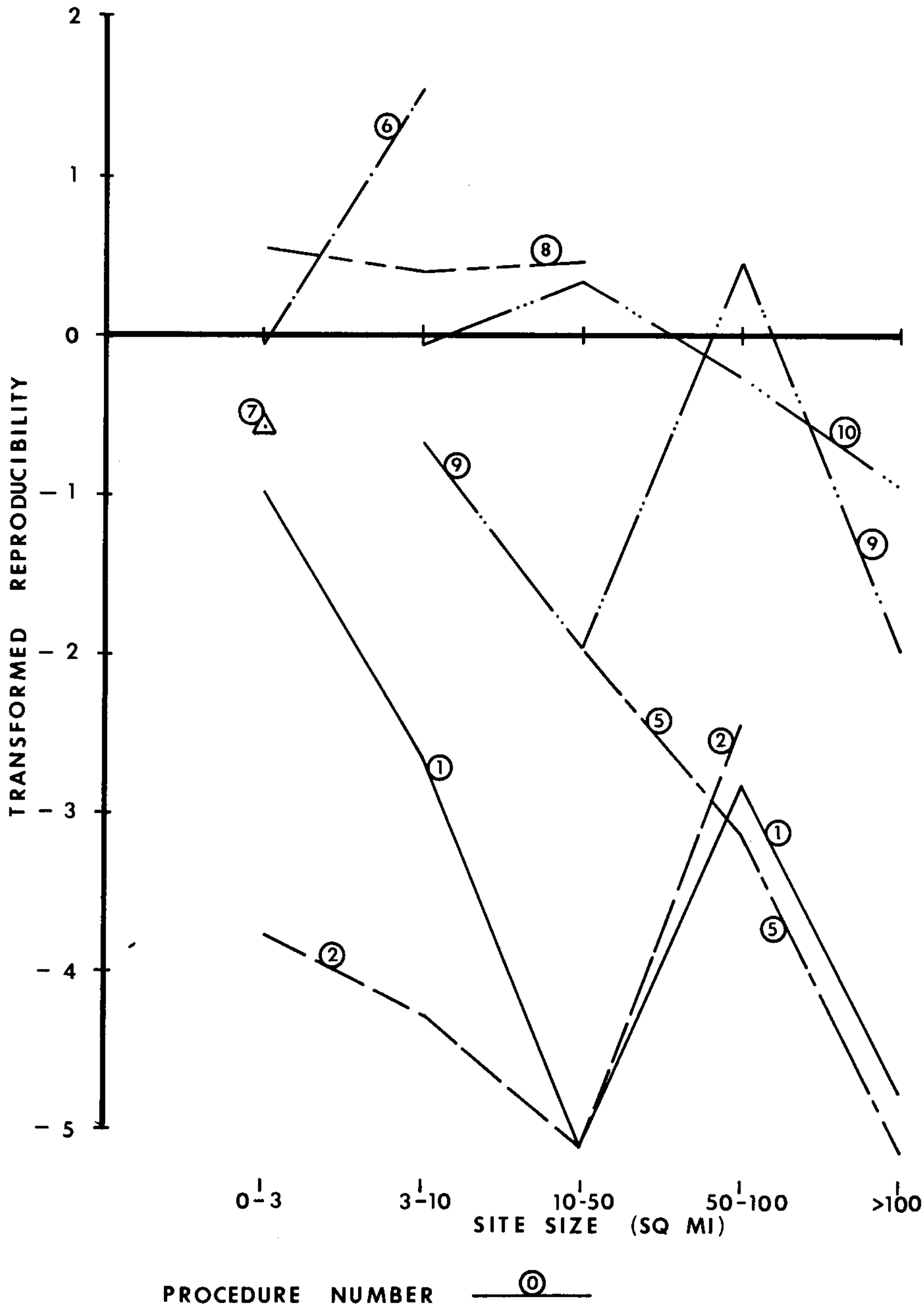
Procedure	Site Size				
	0-3	3-10	10-50	50-100	>100
1	-0.978 12	-2.640 9	-5.140 6	-2.821 15	-4.779 6
2	-3.782 15	-4.287 15	-5.106 15	-2.459 24	
5			-1.989 15	-3.137 24	-5.136 9
6	-0.053 15	1.527 15			
7	-0.594 15				
8	0.541 15	0.399 15	0.453 15		
9		-0.682 9	-1.985 6	0.440 6	-2.003 6
10		-0.070 9	0.321 6	-0.292 6	-0.971 6

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.



NOTE: Underlined procedures are not different at $\alpha = 0.05$

FIGURE A5 – 8



TRANSFORMED REPRODUCIBILITY

PROCEDURE – SITE SIZE INTERACTION

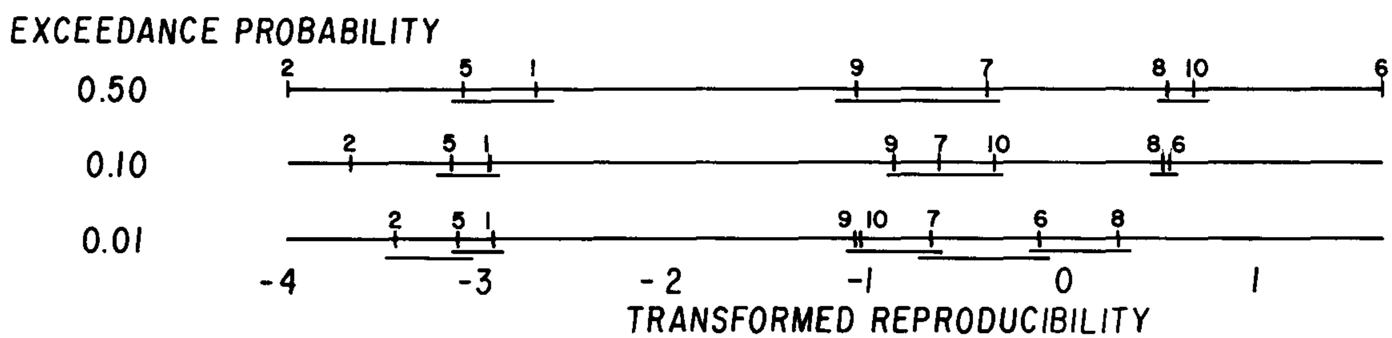
REGION – NORTHWEST

Table A5-20

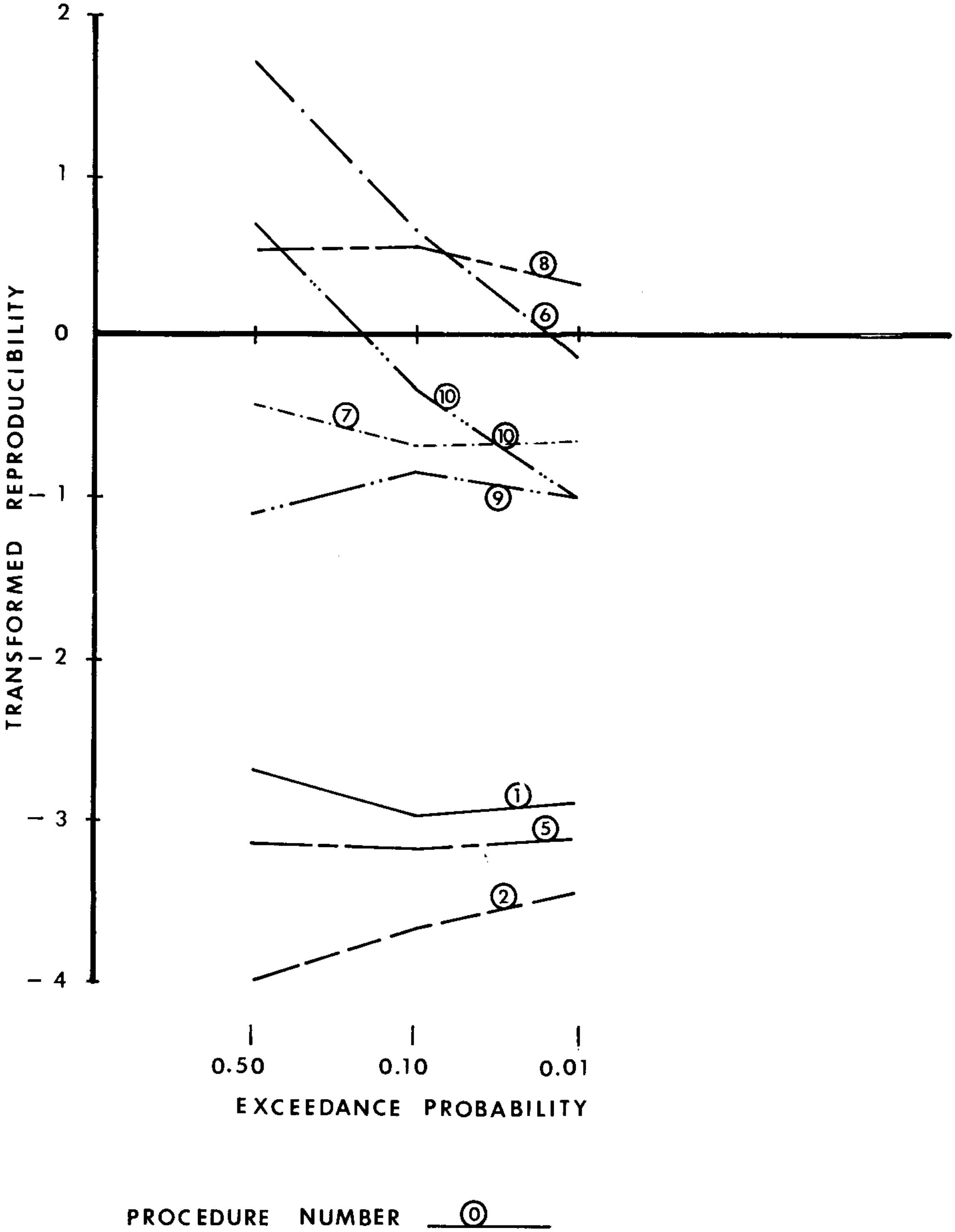
DUNCAN'S MULTIPLE RANGE TEST--TRANSFORMED REPRODUCIBILITY
PROCEDURE-EXCEEDANCE PROBABILITY INTERACTION
NORTHWEST REGION

Procedure	Exceedance Probability		
	0.50	0.10	0.01
1	-2.701 16	-2.982 16	-2.900 16
2	-4.003 23	-3.693 23	-3.462 23
5	-3.158 16	-3.186 16	-3.116 16
6	1.690 10	0.640 10	-0.119 10
7	-0.429 5	-0.694 5	-0.659 5
8	0.525 15	0.547 15	0.321 15
9	-1.107 9	-0.860 9	-1.080 9
10	0.694 9	-0.347 9	-1.046 9

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.



NOTE: Underlined procedures are not different at $\alpha = 0.05$



TRANSFORMED REPRODUCIBILITY

PROCEDURE—EXCEEDANCE PROBABILITY INTERACTION

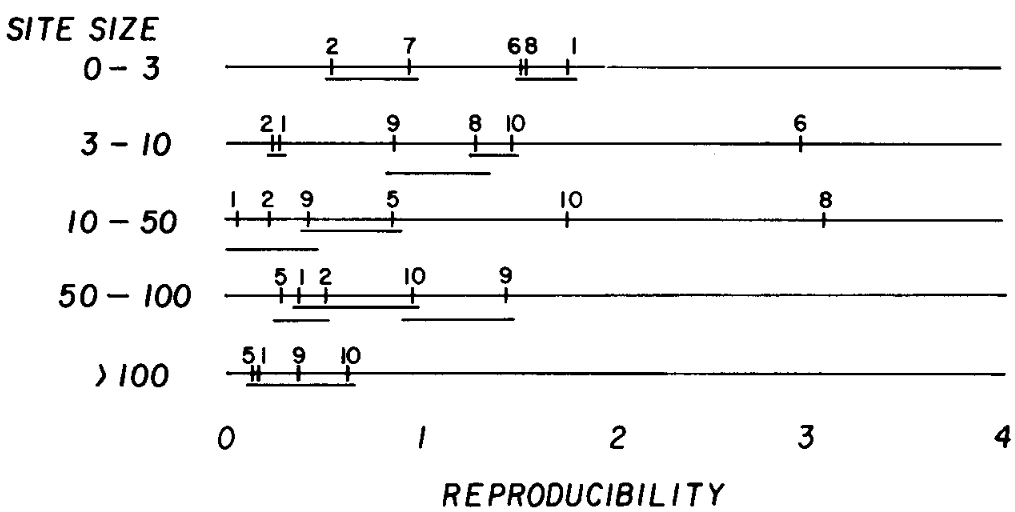
REGION —NORTHWEST

Table A5-21

DUNCAN'S MULTIPLE RANGE TEST--REPRODUCIBILITY
PROCEDURE-SITE SIZE INTERACTION
NORTHWEST REGION

Procedure	Site Size				
	0-3	3-10	10-50	50-100	>100
1	1.760 12	0.290 9	0.078 6	0.368 15	0.142 6
2	0.552 15	0.255 15	0.209 15	0.498 24	
5			0.883 15	0.298 24	0.133 9
6	1.532 15	2.964 15			
7	0.946 15				
8	1.545 15	1.303 15	3.094 15		
9		0.873 9	0.415 6	1.436 6	0.380 6
10		1.490 9	1.786 6	0.958 6	0.618 6

Note: Top number is cell mean.
Bottom number is number of observations used to compute value.



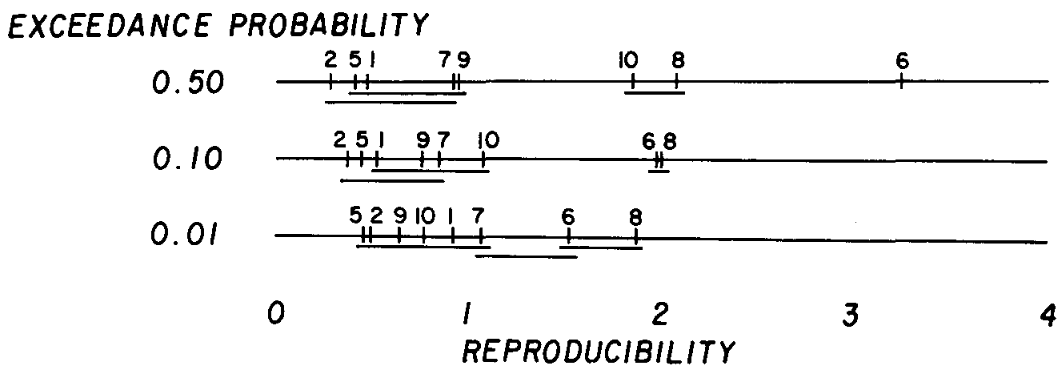
NOTE: Underlined procedures are not different at $\alpha = 0.05$

Table A5-22

DUNCAN'S MULTIPLE RANGE TEST--REPRODUCIBILITY
PROCEDURE-EXCEEDANCE PROBABILITY INTERACTION
NORTHWEST REGION

Procedure	Exceedance Probability		
	0.50	0.10	0.01
1	0.479 16	0.516 16	0.917 16
2	0.292 23	0.389 23	0.503 23
5	0.397 16	0.457 16	0.495 16
6	3.259 10	1.966 10	1.519 10
7	0.909 5	0.849 5	1.079 5
8	2.080 15	1.387 15	1.875 15
9	0.940 9	0.769 9	0.651 9
10	1.859 9	1.087 9	0.786 9

Note: Top number is cell mean.
Bottom number is number of observations used to compute value.



NOTE: Underlined procedures are not different at $\alpha = 0.05$

Table A5-23

DUNCAN'S MULTIPLE RANGE TEST--TRANSFORMED REPRODUCIBILITY
PROCEDURE MAIN EFFECT
NORTHWEST REGION

Alpha Level = 0.05 Df = 140 MS = 0.3849

Procedure	Grouping	Mean	N
6	A	0.737805	30
	A		
8	A	0.464336	45
10	B	-0.433446	27
	B		
7	B	-0.594162	15
9	C	-1.016072	27
1	D	-2.846951	48
5	E	-3.139942	48
2	F	-3.720659	69

Note: Means with the same letter are not signficantly different.

NOTE: Underlined procedures are not different at $\alpha = 0.05$

3. Time to Apply

Table A5-24 presents the analysis of variance for time to apply in the Northwest region. All main effects and interactions are statistically significant except the watershed main effect (W(S)) and the procedure-watershed (P*W(S)) interaction. An analysis of the procedure-site size interaction is given in Table A5-25. For small sites, procedures 1, 2, 6, 7, and 8 are equivalent and have the lowest times to apply. For site sizes of 3 to 50 square miles, procedures 9 and 10 have significantly higher times to apply. Furthermore, procedure 10 has a higher time to apply than procedure 9. At larger sites, above 50 square miles, procedures 1, 2, and 5 have the lowest times to apply and are equivalent, while procedures 9 and 10 continue to have higher times to apply. Above 100 square miles, procedures 9 and 10 have equivalent times to apply. A plot of the cell means is shown in Figure A5-10.

Table A5-26 summarizes the Duncan's multiple range test analysis of the main effect of procedures for the time to apply criterion variable in the Northwest. This analysis was used to draw the conclusions for procedures regarding time to apply in the Northwest reported in section VIII-B.

Table A5-24

ANALYSIS OF VARIANCE FOR TIME TO APPLY
NORTHWEST REGION

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	CV
Model	102	57524.77882039	563.96841981	6.65	0.0001	0.622561	116.2897
Error	411	34875.47008000	84.85515835		Std Dev		Mean
Corrected Total	513	92400.24890039			9.21168597		7.92132296

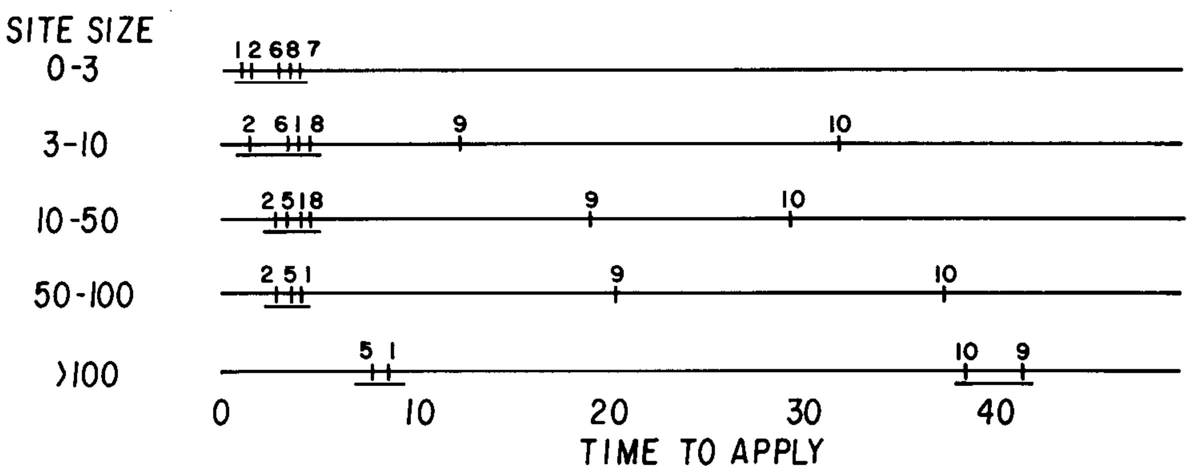
Source	DF	Type III SS	F Value	PR > F
P	7	29376.09860936	49.46	0.0001
S	4	3245.05486827	9.56	0.0001
W(S)	21	1409.22975732	0.79	0.7324
P*S	14	2461.27019878	2.07	0.0125
P*W(S)	56	1858.86603871	0.39	1.0000

Table A5-25

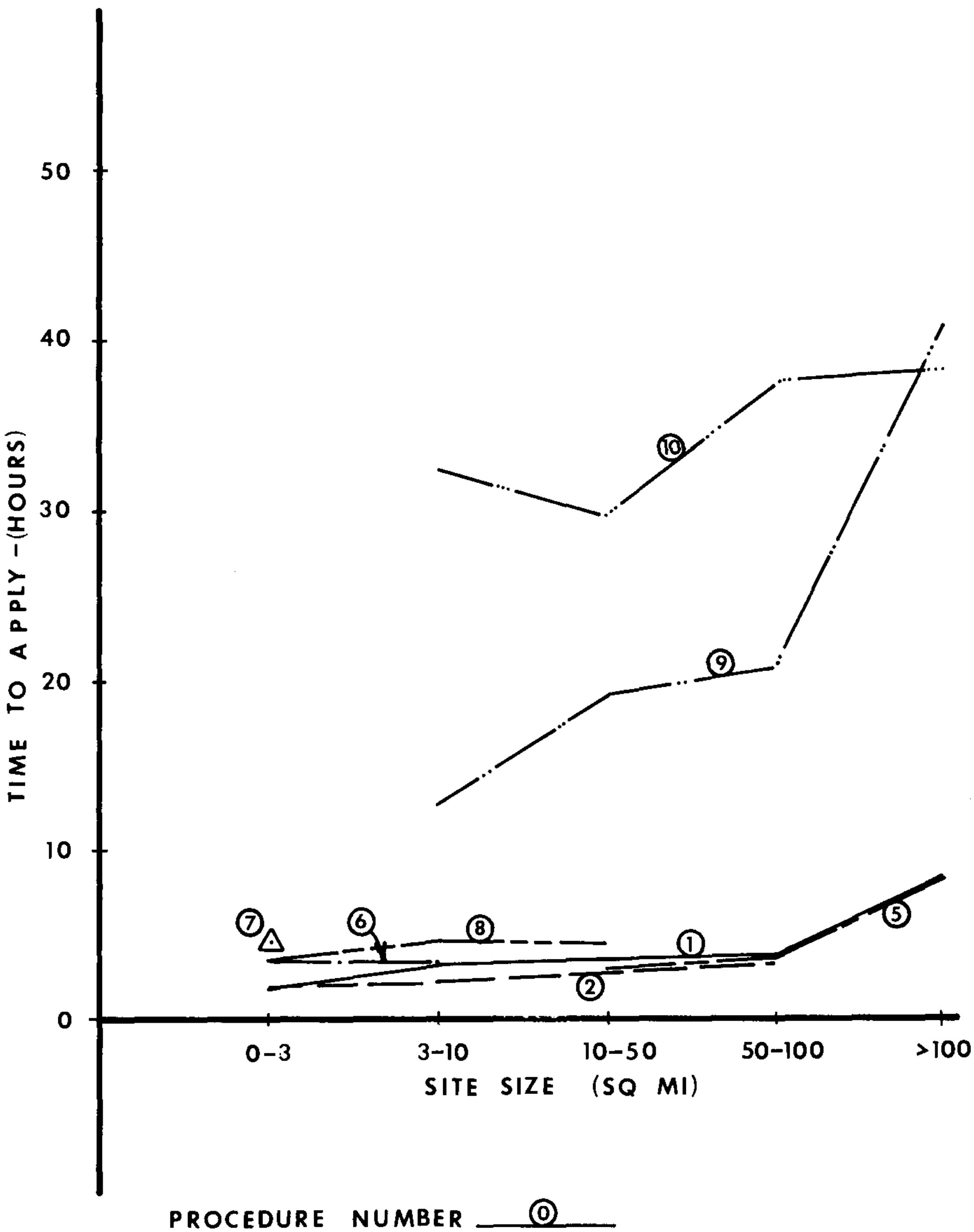
DUNCAN'S MULTIPLE RANGE TEST--TIME TO APPLY
PROCEDURE-SITE SIZE INTERACTION
NORTHWEST REGION

Procedure	Site Size 0-3	3-10	10-50	50-100	>100
1	1.820 20	3.127 15	3.695 10	3.910 25	8.580 10
2	1.846 25	2.170 25	2.954 25	3.355 40	
5			3.270 25	3.618 40	8.507 15
6	3.420 25	3.606 25			
7	3.956 25				
8	3.476 25	4.760 25	4.516 25		
9		12.567 15	19.060 10	20.750 10	41.500 10
10		32.380 15	29.444 9	37.550 10	38.410 10

Note: Top number is cell mean.
Bottom number is number of observations used to compute mean.



NOTE: Underlined procedures are not different at $\alpha = 0.05$



TIME TO APPLY

PROCEDURE-SITE SIZE INTERACTION

REGION - NORTHWEST

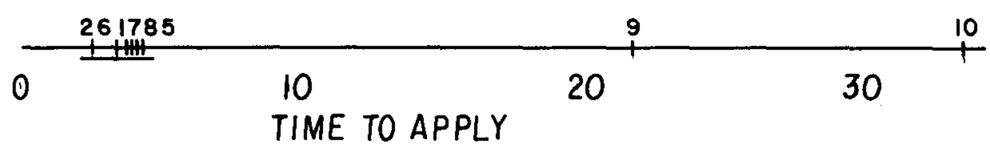
Table A5-26

DUNCAN'S MULTIPLE RANGE TEST--TIME TO APPLY
PROCEDURE MAIN EFFECT
NORTHWEST REGION

Alpha Level = 0.05   Df = 411   MS = 84.8552

Procedure	Grouping	Mean	N
10	A	34.325000	44
9	B	22.257778	45
5	C	4.425625	80
	C		
8	C	4.250667	75
	C		
7	C	3.956000	25
	C		
1	C	3.797500	80
	C		
6	C	3.513000	50
	C		
2	C	2.682261	115

Note: Means with the same letter are not significantly different.



NOTE: Underlined procedures are not different at $\alpha = 0.05$

C. General Comments on the Analysis

1. In general, procedures 1 and 5 perform well with respect to bias, reproducibility, and time to apply. These procedures are regression-based methods and the watersheds used in the pilot test were also among those used to build the regression models. This is particularly true for procedure 1. Thus, to some extent, the pilot test is an examination of the "fit" of these equations at these stations rather than their predictive ability. Thus, these methods could be expected to give somewhat better results with respect to bias than the other methods. To determine how these methods operate in a true predictive mode, they need to be applied on watersheds that were not used to build the model. Some preliminary analyses, discussed in section VIII-B and Appendix 8, indicate that the effect of removing those stations and refitting the regression model did not affect the conclusions. However, it is dangerous to generalize these conclusions. To some extent, the regression methods have had an advantage in the pilot test.

2. Procedures 3, 6, and 8 consistently yield poorer performance with respect to the response variables.

3. Procedures 2, 3, 6, and 8 were applied over a range of watershed sizes that included some that exceeded their designed range of applicability. Those watersheds that exceeded the range of applicability were eliminated from the data base and the analysis rerun to determine if this violation of assumptions critically affected results. No major changes in conclusions occurred as a result of this analysis.

4. The analysis was performed with unedited data. Only obvious data coding errors and keypunch or other transcription errors were corrected. The data set was also analyzed with a more extensive set of corrections made in which errors in using some of the procedures were identified and, when possible, corrected. This analysis did not change the conclusions from those obtained by analyzing the unedited data. In general, the residual mean squares were somewhat smaller and, consequently, it was somewhat easier to differentiate between procedures. Furthermore, the mean values of the responses changed, but their relative performance did not.

5. The sample sizes used in the pilot test are large enough to detect differences between procedures of approximately 30 percent with respect to bias. This measure of sensitivity is determined by calculating the length of the 95 percent (individual, not simultaneous) confidence interval on the difference in mean bias between any two procedures. The confidence interval formula is

$$\bar{X}_1 - \bar{X}_2 \pm 1.96\ \sigma_{\bar{X}_1 - \bar{X}_2}$$

where $\bar{X}_1$ and $\bar{X}_2$ are the average bias values for the two procedures, $\sigma_{\bar{X}_1 - \bar{X}_2}$ is the standard deviation of the difference in means, and 1.96 is the factor from the normal table providing 95 percent confidence. Now

$$\sigma^2_{\bar{X}_1 - \bar{X}_2} = \frac{2\sigma^2}{\bar{n}}$$

where σ^2 is the variance of the observed bias and $\bar{n}$ is the average sample size used in each procedure (number of watersheds). From the analysis of variance table for bias, a reasonable estimate of the variance is mean square error (MSE) in the Northwest region (the largest value), or

$$\sigma^2 = \text{MSE} \simeq 0.40$$

The value of MSE for the Midwest is only slightly smaller. Averaging across both exceedance probabilities and site sizes gives $\bar{n} \simeq 39$ for the Northwest (the smallest sample sizes). Therefore,

$$\sigma^2_{\bar{X}_1 - \bar{X}_2} = \frac{2\sigma^2}{\bar{n}} = \frac{2(0.4)}{39} = 0.02;\ \sigma_{\bar{X}_1 - \bar{X}_2} = 0.14$$

Consequently, 95 percent confidence intervals on the difference in average bias between any two procedures would be made with an accuracy of approximately

$$\pm 1.96\ \sigma_{\bar{X}_1 - \bar{X}_2} = \pm 1.96(0.14) = \pm 0.28$$

If the comparison is made by individual exceedance probability, then a 95 percent confidence interval on the difference in average bias between any two procedures would be ±0.50, or ±50 percent, approximately.

If confidence intervals are desired on the average bias of a single procedure, the accuracy of those confidence intervals is approximately ±20 percent across exceedance probabilities or ±30 percent by individual exceedance probability. Consequently, it seems that sample sizes in the pilot test are sufficient to detect large differences in procedures. However, it is not easy, based on the small sample sizes used, to detect small differences in procedures with respect to bias.

D. Model Adequacy

1. The underlying assumptions of the analysis of variance are not exactly satisfied (indeed they are never satisfied in any experiment). In particular, average bias is nearly but not exactly normally distributed. There is evidence that the distribution of bias is unimodal but somewhat skewed with heavier tails than the normal. However, the analysis of variance is relatively robust to the normality assumption; that is, the effect on the analysis is minor. Instead of testing at the 5 percent level, say, tests are probably at the 8 or 9 percent level. Thus test of hypotheses and confidence intervals should be considered approximate rather than exact.

performed in terms of the natural logarithm of square of the reproducibility. This is an approximate variance stabilizing transformation.

Plots of residuals versus fitted values and normal probability plots of the residuals were constructed and examined for the analysis of variance runs. These plots did not reveal any serious departures from normality. Furthermore, the equality of variance and independence assumptions are not seriously violated. There is reasonable evidence that the usual analysis of variance assumptions are approximately satisfied.

2. The effect of the number of site sizes used in the analysis was investigated. The data were analyzed using two site sizes (0 to 50 and greater than 50 square miles) and three site sizes (0 to 7, 7 to 70, and greater than 70 square miles). If the number of site sizes is reduced, the coefficient of determination (R^2) for the fitted model is reduced and interactions involving exceedance probability and site size and exceedance probability and watershed drop out of the model. No other significant effects or interactions are changed. Tables A5-27, A5-28, and A5-29 summarize the results of redefining the number of site sizes. While the site size main effect appears small in the alternative runs, site size is not negligible because the procedure-site size interaction is still active. There is some evidence that the R*S and R*W(S) interactions result from the narrow definitions of the range of site sizes with five classifications.

3. Unbalanced experimental designs such as the one analyzed here sometimes present difficulties in analysis and interpretation. For example, the hypotheses that are tested may be functions of the pattern of missing cells in the layout (Speed, Hocking, and Hackney, 1973). To determine whether the unbalanced nature of the pilot test has seriously affected the conclusions, two balanced subsets of the pilot test data were analyzed. The results are shown in Table A5-30.

   One balanced subset used only two procedures, 2 and 8. This is the largest subset of the Northwest data that has at least three site sizes. There is little difference in the conclusions between the balanced subset and the full unbalanced data set. Some interactions are missing in the transformed reproducibility analysis because the procedures that cause that interaction were deleted to form the balanced subset. A four-procedure balanced subset of the Midwest data was constructed and analyzed. There are no appreciable differences in conclusions between the balanced subset and the full unbalanced data set.

Table A5-27

ANALYSIS OF SITE SIZE CLASSIFICATION - BIAS

Region	Level	R	P	S	W(S)	R*P	R*S	R*W(S)	P*S	P*W(S)	R^2
NW	5		X	X	X	X	X	X	X	X	0.9468
MW	5	X	X	X	X	X		X	X	X	0.9497
NW	3		X	.15	X	X			.16	X	0.6829
MW	3		X		X	X			X		0.5325
NW	2		X		X	X			.11	X	0.5616
MW	2	X	X		X	X				X	0.3939

Note: X indicates statistical significance at at least the 0.10 level.

Table A5-28

ANALYSIS OF SITE SIZE CLASSIFICATION - TRANSFORMED REPRODUCIBILITY

Region	Level	R	P	S	W(S)	R*P	R*S	R*W(S)	P*S	P*W(S)	R^2
NW	5	X	X	X	X	X	X	X	X	X	0.9793
MW	5	X	X	X	X	X	X	X	X	X	0.9745
NW	3		X		X				X	X	0.7873
MW	3	X	X		X	X			X	X	0.7654
NW	2		X		X				X	X	0.7162
MW	2	X	X		X				.11	X	0.6662

Note: X indicates statistical significance at at least the 0.10 level.

Table A5-29

ANALYSIS OF SITE SIZE CLASSIFICATION - TIME TO APPLY

Region	Level	P	S	W(S)	P*S	P*W(S)	R^2
NW	5	X	X		X		0.6226
MW	5	X	X	X	X		0.6932
NW	3	X	X		X		0.5926
MW	3	X	X	X	X		0.6780
NW	2	X	X		X		0.5875
MW	2	X	X	X	X		0.6488

Note: X indicates statistical significance at at least the 0.10 level.

Table A5-30

BALANCED SUBSETS OF ORIGINAL DATA

	R	P	S	W(S)	R*P	R*S	R*W(S)	P*S	P*W(S)
Original Data--Unbalanced									
NW-Bias		X	X	X	X	X	X	X	X
NW-Trans Repro	X	X	X	X	X	X	X	X	X
MW-Bias	X	X	X	X	X		X	X	X
MW-Trans Repro	X	X	X	X	X	X	X	X	X
Balanced Data--Three Site Sizes									
Procedures 2 and 8-Northwest									
Bias	X	X	X	X		X	X	X	X
Trans Repro		X		X		X			X
Procedures 1, 2, 3, and 8-Midwest									
Bias	X	X		X	X			X	X
Trans Repro	X	X	X	X	X	X	X	X	X

Note: X indicates statistical significance at at least the 0.10 level.

4. Analyses were conducted by individual exceedance probability. The results of the analyses do not differ substantially from the results of the analysis with all exceedance probabilities considered simultaneously.

APPENDIX 6

SUPPLEMENTAL INFORMATION TO STATISTICAL ANALYSES

This appendix contains supplemental information concerning the effects of other design factors in the statistical analyses including:

1. box plots showing the variations in the 1-percent-chance flood for bias, reproducibility, and time to apply for all procedures and site size classifications (Figures A6-1 to A6-9);

2. the mean and standard deviation for bias, reproducibility, and time to apply using the watersheds within the five drainage area classifications (Table A6-1);

3. the correlation coefficients for bias, reproducibility, and time to apply for the three exceedance probabilities (Tables A6-2 and A6-3); and

4. box plots showing the variations in the 1-percent-chance flood for bias, reproducibility, and time to apply for all procedures in both regions (Figure A6-10 to A6-18).

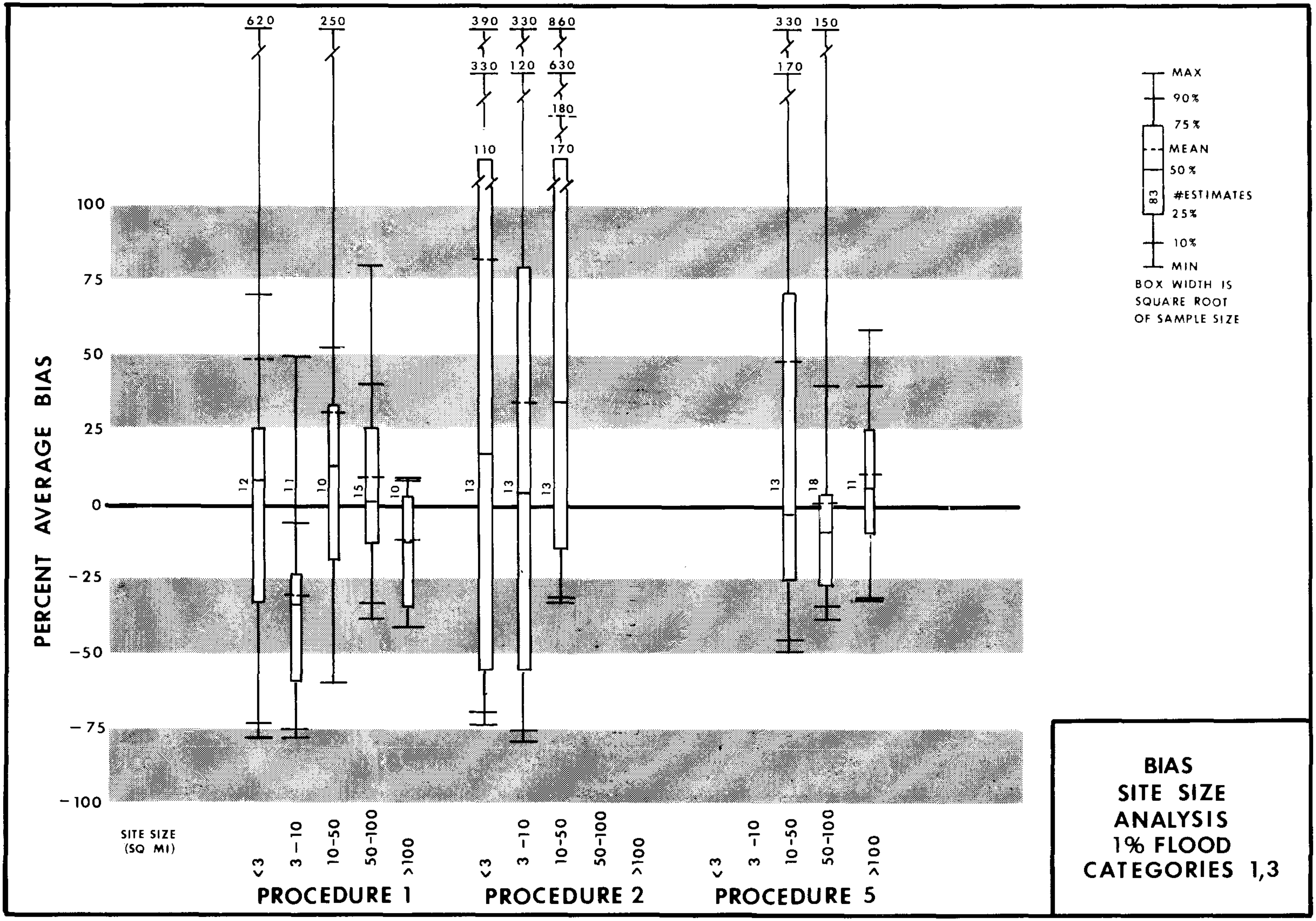

PERCENT AVERAGE BIAS
100
75
50
25
0
-25
-50
-75
-100
SITE SIZE (SQ MI)
<3
3-10
10-50
50-100
>100
PROCEDURE 1
PROCEDURE 2
PROCEDURE 5
620
250
390
330
860
330
120
630
180
110
170
330
150
170
12
11
10
15
10
13
13
13
13
18
11
MAX
90%
75%
MEAN
50%
83
#ESTIMATES
25%
10%
MIN
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE
BIAS
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORIES 1,3

FIGURE A6 – 1

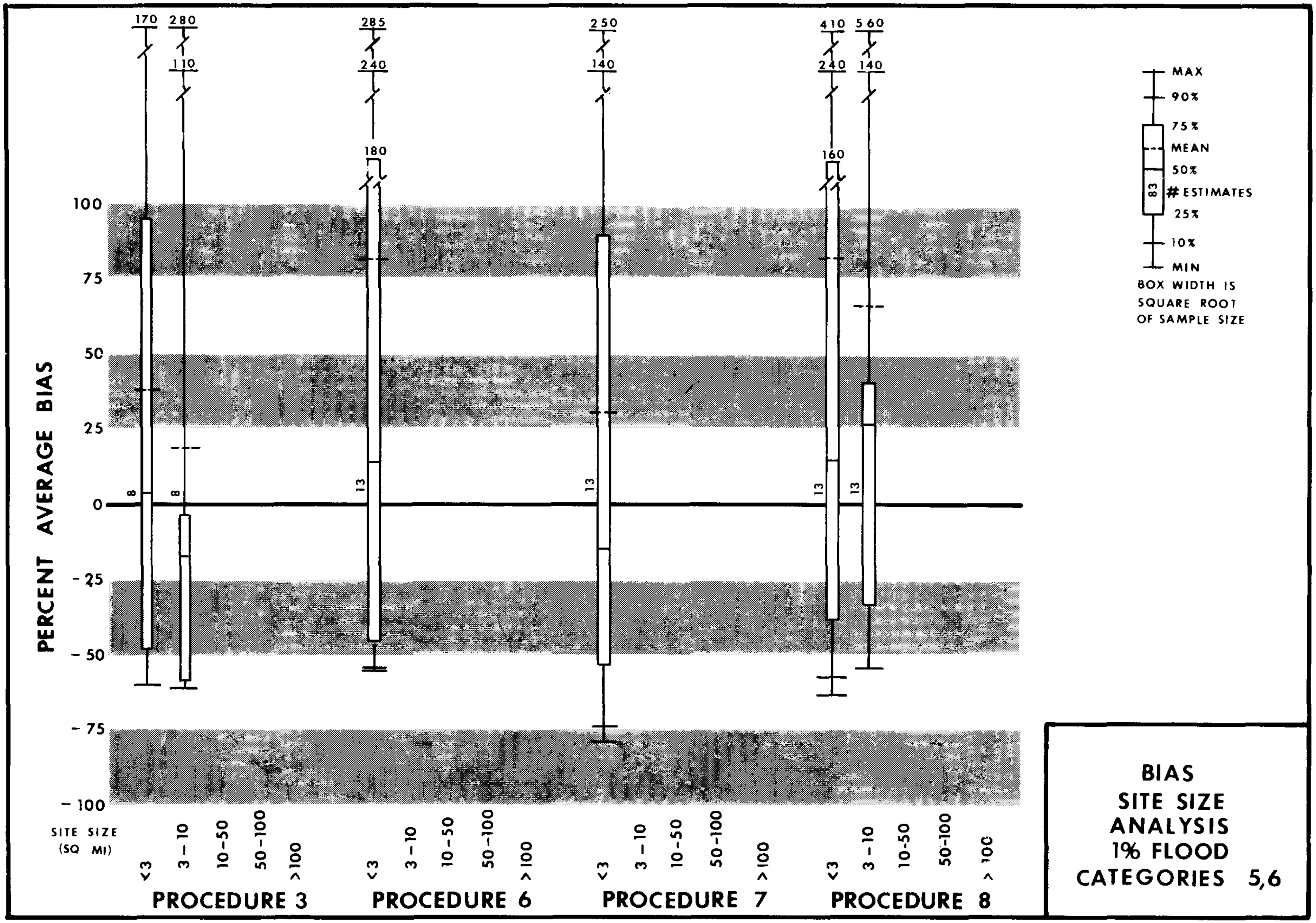

PERCENT AVERAGE BIAS
100
75
50
25
0
-25
-50
-75
-100
SITE SIZE (SQ MI)
<3
3-10
10-50
50-100
>100
PROCEDURE 3
PROCEDURE 6
PROCEDURE 7
PROCEDURE 8
170
280
110
285
240
180
250
140
410
560
240
140
160
8
8
13
13
13
13
MAX
90%
75%
MEAN
50%
ESTIMATES
25%
10%
MIN
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE
BIAS
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORIES 5,6

FIGURE A6 - 2

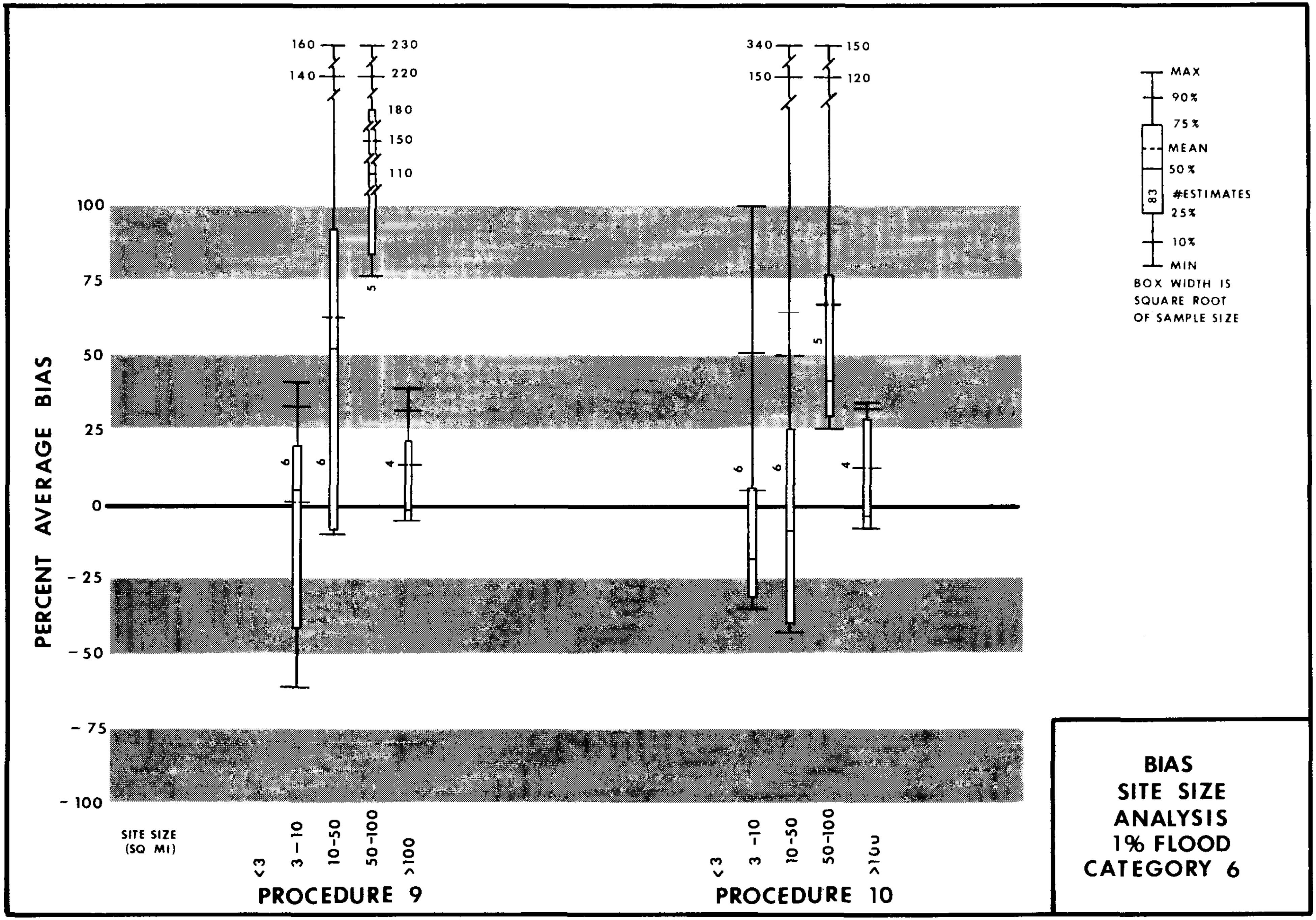

PERCENT AVERAGE BIAS
100
75
50
25
0
- 25
- 50
- 75
- 100
160
140
230
220
180
150
110
340
150
150
120
6
6
5
4
6
6
5
4
MAX
90%
75%
MEAN
50%
83
#ESTIMATES
25%
10%
MIN
BOX WIDTH IS
SQUARE ROOT
OF SAMPLE SIZE
SITE SIZE
(SQ MI)
<3
3 - 10
10-50
50-100
>100
PROCEDURE 9
<3
3 -10
10-50
50-100
>100
PROCEDURE 10
BIAS
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE A6 – 3

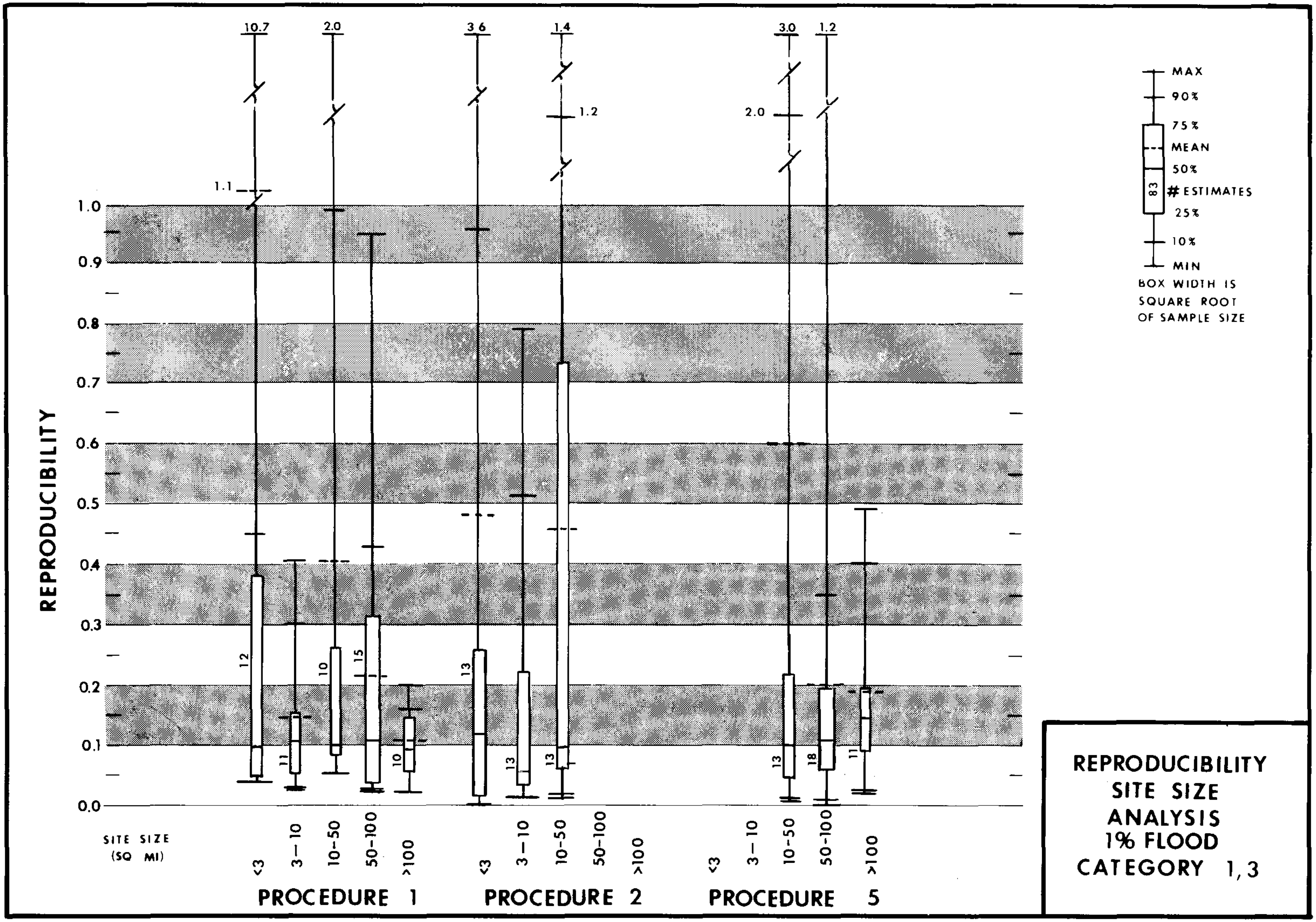
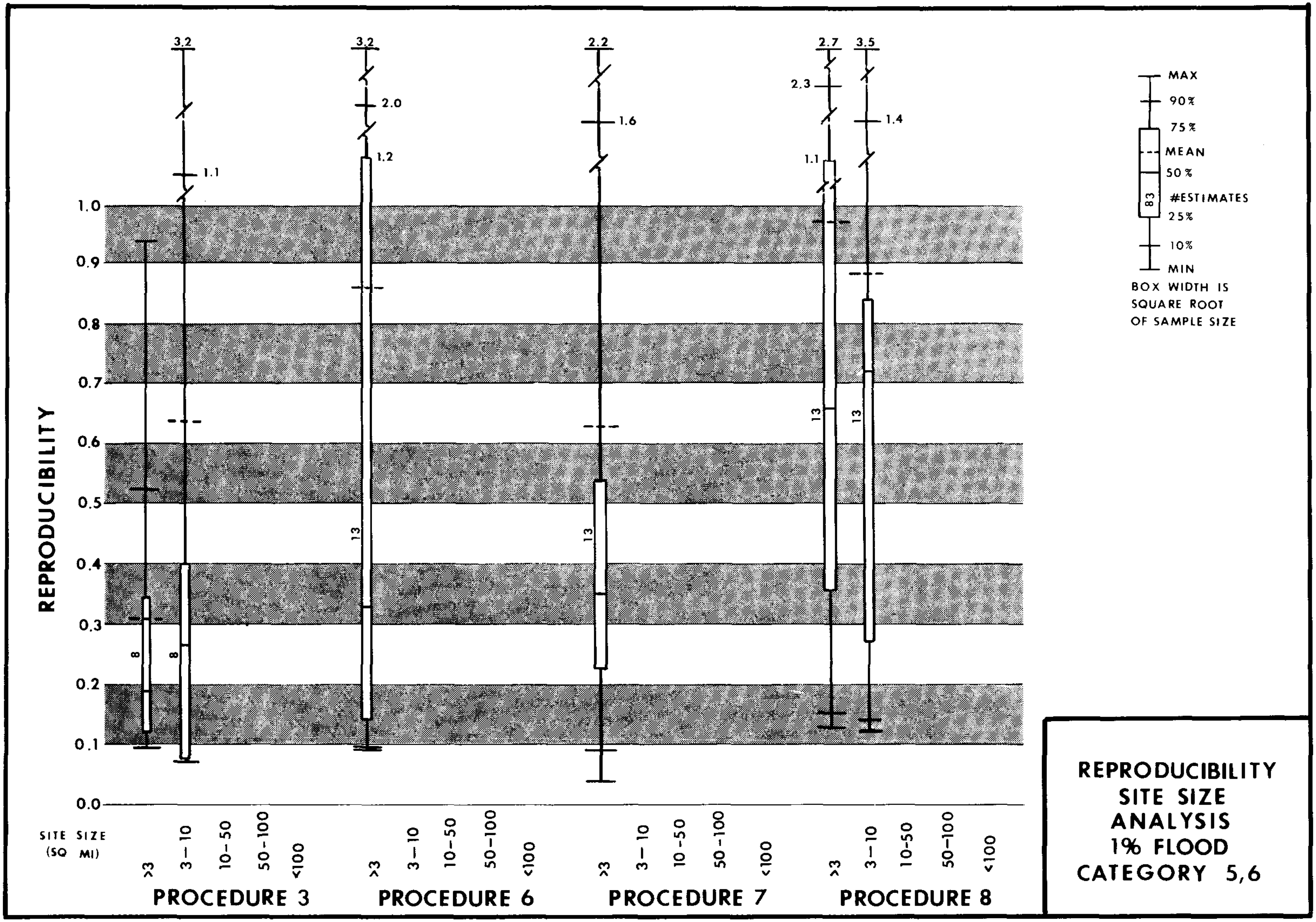
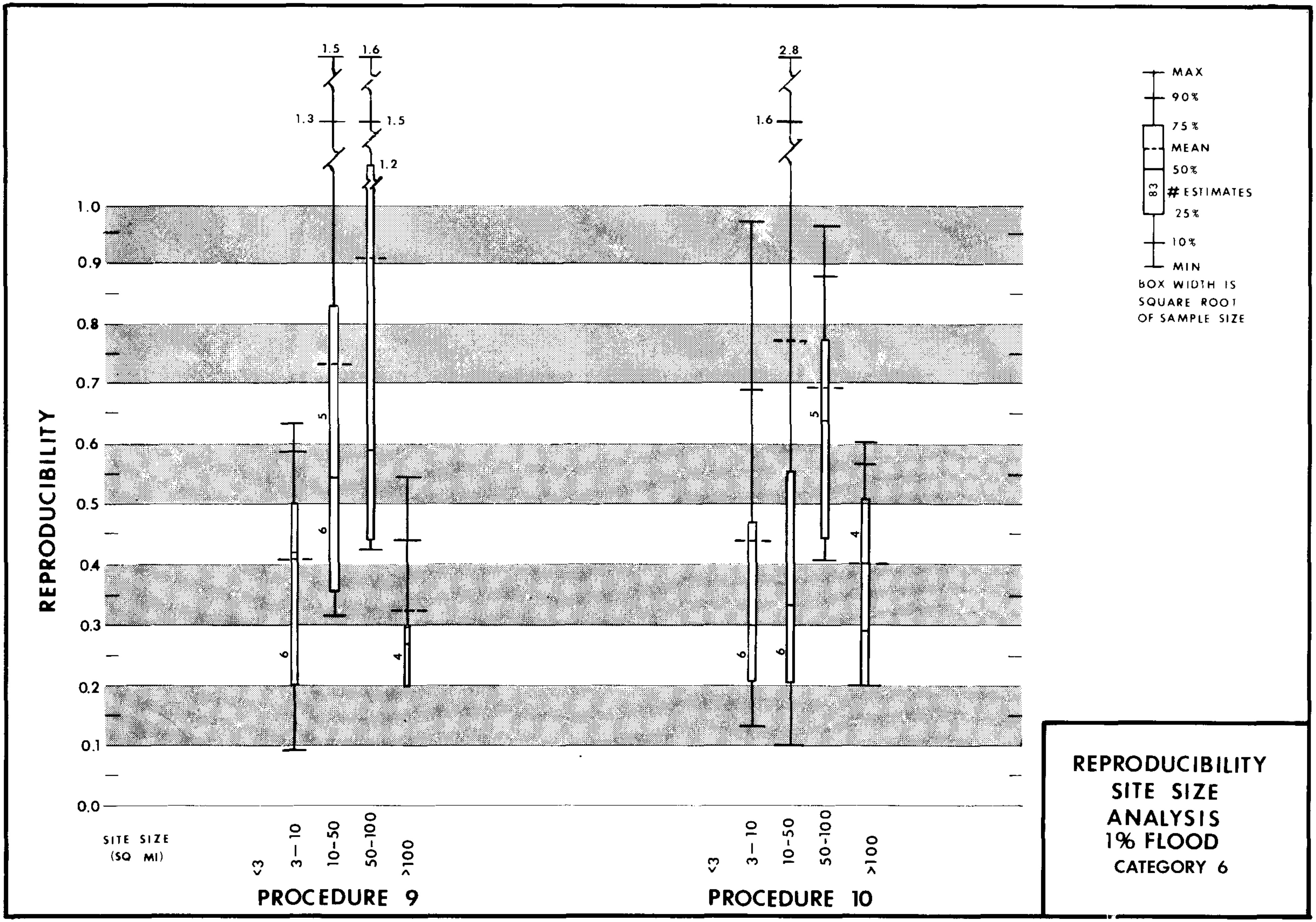

REPRODUCIBILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
10.7
2.0
3.6
1.4
3.0
1.2
1.1
1.2
2.0
12
11
10
15
10
13
13
13
13
18
11
MAX
90%
75%
MEAN
50%
83
ESTIMATES
25%
10%
MIN
BOX WIDTH IS
SQUARE ROOT
OF SAMPLE SIZE
SITE SIZE
(SQ MI)
<3
3—10
10–50
50–100
>100
<3
3—10
10–50
50–100
>100
<3
3—10
10–50
50–100
>100
PROCEDURE 1
PROCEDURE 2
PROCEDURE 5
REPRODUCIBILITY
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORY 1, 3

FIGURE A6 - 4



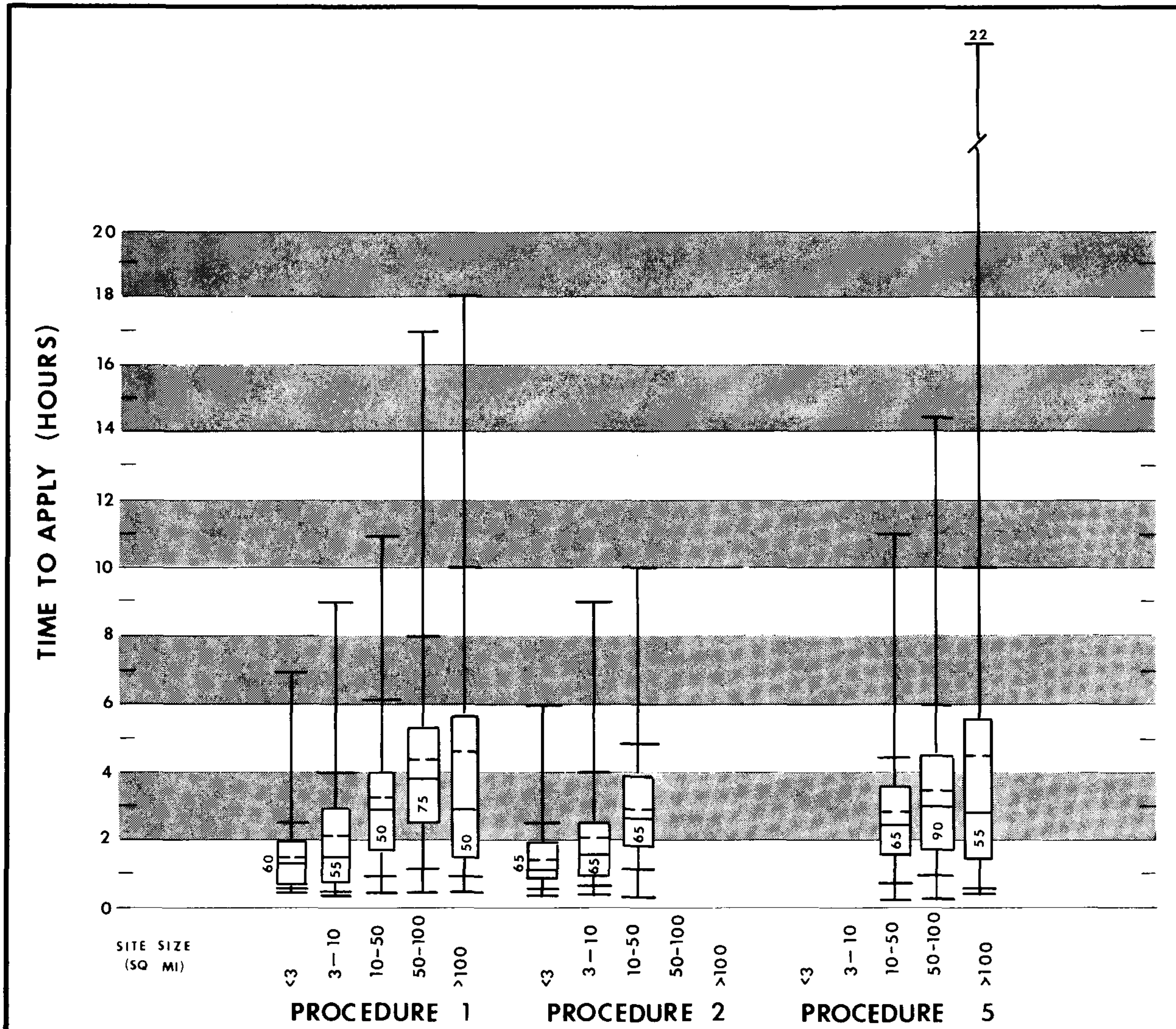
REPRODUCIBILITY
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORY 5,6

FIGURE A6-5



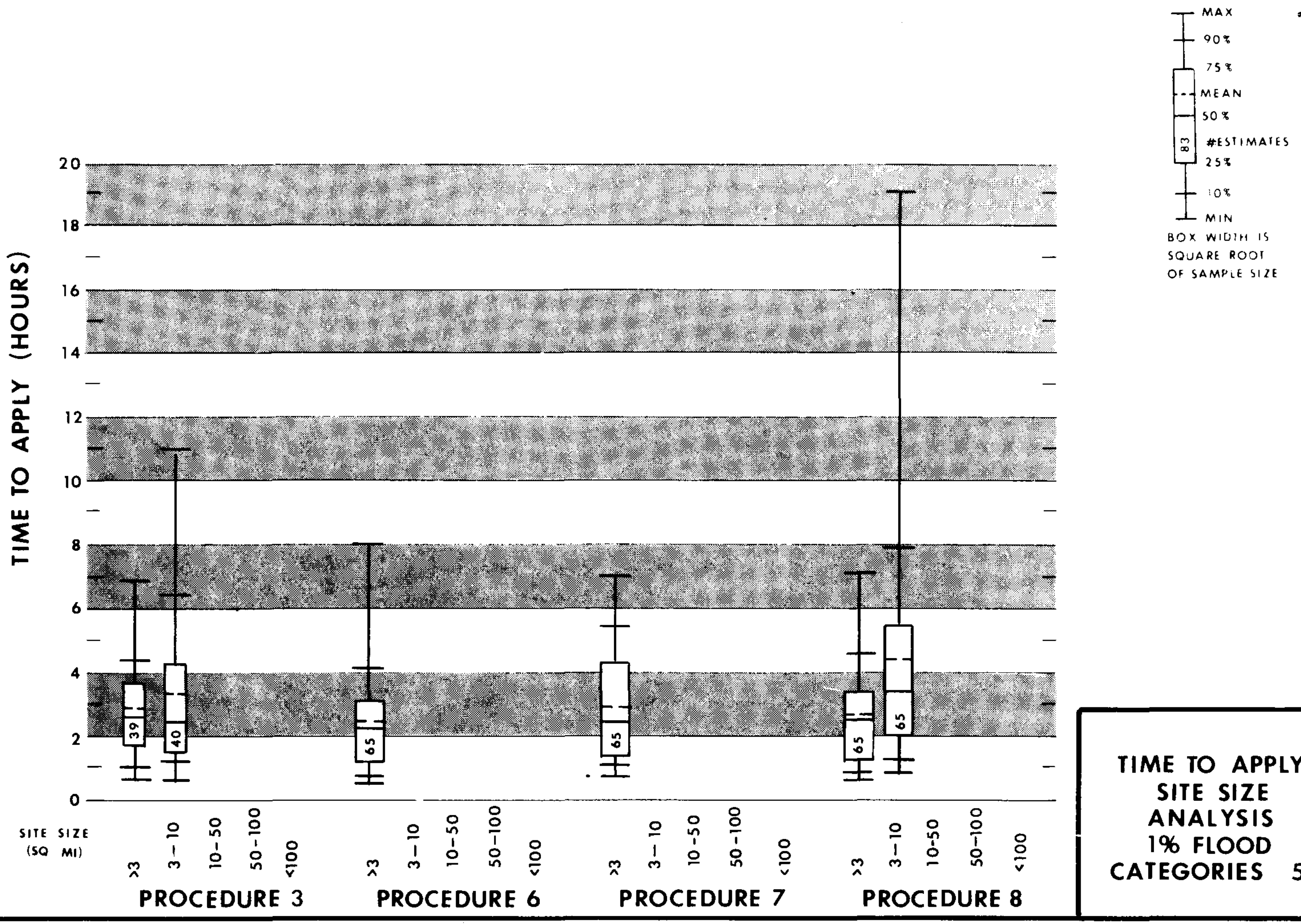
REPRODUCIBILITY
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE A6 - 6



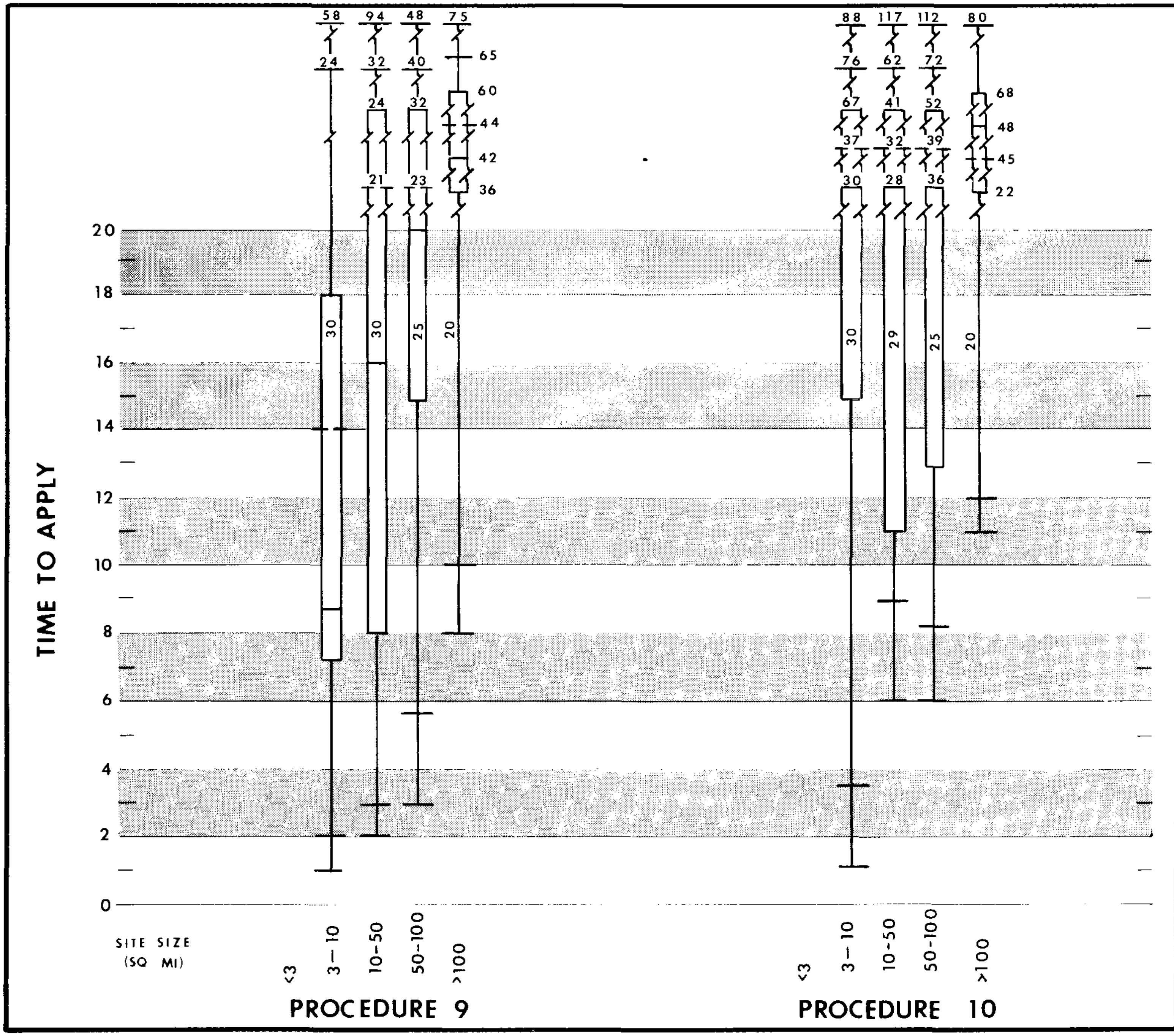
TIME TO APPLY
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORIES 1,3

FIGURE A6 – 7



TIME TO APPLY
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORIES 5, 6

FIGURE A6 – 8



TIME TO APPLY
SITE SIZE
ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE A6 - 9

Table A6-1

STATISTICS OF CRITERION VARIABLE VALUES VERSUS DRAINAGE AREA

Procedure	Drainage Area Range	Sample Size	Bias - Midwest					
			$Q_{0.50}$		$Q_{0.10}$		$Q_{0.01}$	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	0-3	8	.0917	.4746	.0603	.4839	.0124	.5182
	3-10	8	-.0571	.3739	-.1721	.3809	-.2788	.3811
	10-50	8	.5063	1.3386	.4869	1.0811	.4398	.8871
	50-100	10	.1601	.2805	.0683	.2465	-.0144	.2524
	100+	8	.1316	.2419	.0321	.1837	-.0632	.1727
2	0-3	8	.7077	1.1616	.7688	1.4136	.8150	1.5638
	3-10	8	.5395	1.2060	.4291	1.2073	.4074	1.2886
	10-50	8	1.5060	3.1433	1.7377	3.0241	2.0552	3.0880
	50-100	10	.6753	.5925	.8707	.6075	1.2327	.8128
3	0-3	8	2.0556	1.7384	.8236	1.1648	.3846	.9601
	3-10	8	2.8124	3.1840	.8246	1.5624	.1943	1.1334
	10-50	8	5.0801	7.3753	2.6058	3.8568	1.6099	2.6184
5	10-50	8	.3539	1.3071	.3184	1.2288	.4142	1.2476
	50-100	10	.1436	.3525	.0884	.3963	.1171	.5449
	100+	8	-.0008	.0832	-.0257	.1545	.0744	.2926
6	0-3	8	2.0634	1.9700	.9679	1.4300	.5151	1.2106
	3-10	8	2.9612	4.3605	1.2430	2.7480	.6094	2.0763
7	0-3	8	.4380	.9515	.1587	.8327	.0052	.6850
8	0-3	8	1.0374	1.2276	.6668	1.0609	.4312	.9593
	3-10	8	1.0683	1.8996	.8095	2.0467	.5829	2.0389
	10-50	8	2.0661	3.2103	1.7447	2.4995	1.4654	2.2446
9	3-10	3	.2282	.3142	.0177	.4620	-.1417	.5221
	10-50	4	.7472	1.0067	.8308	.8032	.8408	.7556
	50-100	3	1.0597	.3421	1.3135	.4302	1.3742	.8014
	100+	2	.3323	.2977	.2274	.0046	.1709	.3108
10	3-10	3	.8461	.7262	.1466	.3069	-.1494	.2881
	10-50	4	.1483	.4461	.0100	.4083	-.0772	.3828
	50-100	3	.8277	.6563	.6567	.4064	.5301	.3231
	100+	2	.5447	.3209	.2901	.0305	.1219	.2224

Table A6-1 (Continued)

STATISTICS OF CRITERION VARIABLE VALUES VERSUS DRAINAGE AREA

Procedure	Drainage Area Range	Sample Size	Reproducibility - Midwest					
			$Q_{0.50}$		$Q_{0.10}$		$Q_{0.01}$	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	0-3	8	.1546	.1356	.1538	.1402	.1428	.1507
	3-10	8	.1153	.0711	.1235	.0883	.1183	.0925
	10-50	8	.4416	.8498	.4893	.7501	.4854	.6826
	50-100	10	.1579	.1726	.1486	.1449	.1395	.1247
	100+	8	.1033	.0625	.1141	.0612	.1141	.0563
2	0-3	8	.2179	.2537	.2452	.3169	.2794	.3882
	3-10	8	.1486	.2593	.1308	.2093	.1427	.1819
	10-50	8	.2661	.3047	.3058	.3791	.5628	.5417
	50-100	10	.0813	.0849	.0930	.0955	.1171	.1186
3	0-3	8	.8730	.5546	.4271	.3704	.3148	.2764
	3-10	8	2.1264	2.9275	.9706	1.3884	.6426	1.0399
	10-50	8	2.8921	4.6305	1.6693	2.4429	1.1478	1.6504
5	10-50	8	.2875	.6647	.2682	.6023	.3277	.7411
	50-100	10	.0920	.0889	.0985	.0889	.1358	.1471
	100+	8	.1276	.0734	.1149	.0748	.2081	.1583
6	0-3	8	1.2020	.9037	.7185	.6877	.5730	.6230
	3-10	8	1.2522	1.3426	.7368	.9890	.4921	.6678
7	0-3	8	.8613	.6957	.4688	.3610	.3440	.2090
8	0-3	8	1.0130	.7555	.7741	.5558	.6493	.4609
	3-10	8	1.0141	.8852	.9810	1.2460	.7936	1.1035
	10-50	8	1.8729	1.8213	1.3133	1.2931	1.2244	1.2173
9	3-10	3	.5280	.1486	.3739	.1789	.2830	.1815
	10-50	4	.7947	.7011	.8145	.5882	.8311	.5716
	50-100	3	.6154	.1463	.6656	.3622	.7568	.5065
	100+	2	.3899	.3408	.3209	.1072	.2484	.0692
10	3-10	3	1.0980	.1010	.5582	.1665	.3589	.1975
	10-50	4	.5190	.4165	.3986	.3274	.3696	.2631
	50-100	3	.9292	.1241	.7789	.1711	.7502	.2094
	100+	2	.6305	.0168	.3744	.0394	.2450	.0657

Table A6-1 (Continued)

STATISTICS OF CRITERION VARIABLE VALUES VERSUS DRAINAGE AREA

Procedure	Drainage Area Range	Sample Size	Time to Apply - Midwest Mean	Time to Apply - Midwest Std Dev
1	0-3	40	1.5215	.2979
	3-10	40	1.8350	.9347
	10-50	40	3.3092	1.5979
	50-100	50	4.6282	2.1260
	100	40	3.7707	2.3199
2	0-3	40	1.3150	.1924
	3-10	40	1.9500	.9385
	10-50	40	3.1022	1.2116
	50-100	50	4.4188	2.0743
3	0-3	39	2.8931	.3701
	3-10	40	3.4280	.9749
	10-50	35	4.8271	1.5913
5	10-50	40	2.6562	1.2935
	50-100	50	3.5920	1.9241
	100+	40	3.1460	2.0824
6	0-3	40	1.9150	.2646
	3-10	40	2.4725	.8838
7	0-3	40	2.4597	.3139
8	0-3	40	2.2597	.4024
	3-10	40	4.2312	2.2571
	10-50	40	5.7525	1.8644
9	3-10	15	15.1347	4.5737
	10-50	20	21.6400	7.7495
	50-100	15	25.3000	6.7134
	100+	10	47.0000	12.1622
10	3-10	15	42.1667	3.2655
	10-50	20	33.7000	8.6603
	50-100	15	40.4000	19.4031
	100+	10	53.3000	12.3037

Table A6-1 (Continued)

STATISTICS OF CRITERION VARIABLE VALUES VERSUS DRAINAGE AREA

Procedure	Drainage Area Range	Sample Size	Bias - Northwest $Q_{0.50}$ Mean	$Q_{0.50}$ Std Dev	$Q_{0.10}$ Mean	$Q_{0.10}$ Std Dev	$Q_{0.01}$ Mean	$Q_{0.01}$ Std Dev
1	0-3	4	.3197	1.0481	.5178	1.5703	1.4198	3.1873
	3-10	3	-.0053	.5901	.0042	.6518	-.3903	.2423
	10-50	2	-.1459	.6754	-.1938	.6004	-.1914	.5819
	50-100	5	.4906	.8996	.3063	.5432	.3097	.3233
	100+	2	-.4179	.1493	-.4135	.1247	-.3584	.0809
2	0-3	5	.2989	.4006	.5343	1.0765	.8569	1.8940
	3-10	5	.3316	.6707	.3530	.7822	.2627	.9655
	10-50	5	.2154	1.4337	.8492	2.2965	1.4836	3.1678
	50-100	8	.6774	1.1438	1.1278	1.4399	1.5392	1.7561
5	10-50	5	.3033	.6995	.5104	.9728	.5826	.9483
	50-100	8	-.0677	.2227	-.0531	.1988	.0976	.2354
	100+	3	-.0623	.1068	.1004	.1077	.2134	.2151
6	0-3	5	2.9357	1.1745	1.7051	1.0869	1.3116	1.3392
	3-10	5	7.0521	4.0487	4.1212	2.2069	2.3240	2.4627
7	0-3	5	.6376	.7032	.6090	.9796	.7977	1.3214
8	0-3	5	1.4898	1.3191	1.4088	1.6209	1.4642	1.9317
	3-10	5	.9043	.6301	1.0608	.5617	.7865	.5702
	10-50	5	1.7028	3.5268	2.3842	3.4793	2.9061	3.5694
9	3-10	3	.1634	.8520	.5310	.5408	.1530	.1125
	10-50	2	-.5115	.0051	-.1507	.0859	.2244	.4556
	50-100	2	2.3130	1.1936	1.8551	.8035	1.5767	.6573
	100+	2	-.1559	.4246	-.0158	.2185	.1040	.1586
10	3-10	3	3.3885	2.6127	1.9564	1.4339	.5280	.6264
	10-50	2	1.8997	2.8384	1.6941	2.5245	1.6311	2.4445
	50-100	2	1.7163	1.8951	1.2909	1.1704	.9529	.7957
	100+	2	.1157	.1327	.0975	.2041	.1438	.2988

Table A6-1 (Continued)

STATISTICS OF CRITERION VARIABLE VALUES VERSUS DRAINAGE AREA

Procedure	Drainage Area Range	Sample Size	Reproducibility - Northwest					
			$Q_{0.50}$		$Q_{0.10}$		$Q_{0.01}$	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	0-3	4	1.0428	1.4137	1.3198	2.1006	2.9187	5.1796
	3-10	3	.3326	.1106	.3044	.1157	.2393	.1529
	10-50	2	.0771	.0145	.0760	.0052	.0812	.0041
	50-100	5	.4018	.2466	.3223	.2378	.3807	.3675
	100+	2	.1687	.1908	.1516	.1624	.1045	.0856
2	0-3	5	.3395	.4383	.5110	.9180	.8058	1.5560
	3-10	5	.2131	.1968	.2591	.2671	.2936	.3207
	10-50	5	.1322	.2241	.2054	.3534	.2901	.5023
	50-100	8	.4105	.3448	.5080	.4340	.5748	.5419
5	10-50	5	.6786	.8320	.9312	1.2187	1.0384	1.2788
	50-100	8	.3064	.2965	.2953	.3628	.2909	.3828
	100+	3	.0925	.0563	.0966	.0644	.1339	.1031
6	0-3	5	1.8246	1.2295	1.4301	1.2465	1.3403	1.2767
	3-10	5	4.7250	3.2269	2.5154	1.4460	1.6977	1.3321
7	0-3	5	.9051	.5211	.8488	.5590	1.0786	.9739
8	0-3	5	1.7336	.5892	1.4393	.8083	1.4794	1.1539
	3-10	5	1.5071	.7143	1.3942	.3858	1.0233	.2883
	10-50	5	3.0244	5.4930	3.1364	4.9876	3.1186	4.3291
9	3-10	3	1.2189	1.3235	.8913	.3158	.5375	.1043
	10-50	2	.2168	.1221	.4660	.1442	.5626	.0301
	50-100	2	1.8887	.8989	1.2668	1.0293	1.1532	.6793
	100+	2	.3274	.0499	.4052	.1322	.4086	.1881
10	3-10	3	2.8062	2.2400	1.1593	.9903	.5228	.3909
	10-50	2	2.0024	2.0910	1.7685	1.8771	1.5883	1.7147
	50-100	2	1.4853	.1797	.7871	.2674	.6023	.2723
	100+	2	.6874	.0434	.6062	.0160	.5616	.0635

Table A6-1 (Continued)

STATISTICS OF CRITERION VARIABLE VALUES VERSUS DRAINAGE AREA

Procedure	Drainage Area Range	Sample Size	Time to Apply - Northwest Mean	Time to Apply - Northwest Std Dev
1	0-3	20	1.8200	.6798
	3-10	15	3.1267	.8612
	10-50	10	3.6950	.9263
	50-100	25	3.9100	1.8534
	100+	10	8.5800	6.2225
2	0-3	25	1.8460	.5514
	3-10	25	2.1700	.9179
	10-50	25	2.9540	.5634
	50-100	40	3.3552	1.4365
5	10-50	25	3.2700	.5273
	50-100	40	3.6175	1.3752
	100+	15	8.5067	5.7078
6	0-3	25	3.4200	.6544
	3-10	25	3.6060	1.1358
7	0-3	25	3.9560	1.2154
8	0-3	25	3.4760	1.1850
	3-10	25	4.7600	1.5295
	10-50	25	4.5160	.6037
9	3-10	15	12.5667	4.7374
	10-50	10	19.0600	5.4589
	50-100	10	20.7500	3.8891
	100+	10	41.5000	8.3439
10	3-10	15	32.3800	11.8842
	10-50	9	29.0500	5.0205
	50-100	10	37.5500	.9192
	100+	10	38.4100	1.4001

Table A6-2

CORRELATION MATRICES FOR CRITERION VARIABLES: MIDWEST REGION

Procedure	Bias 0.5	Bias 0.1	Bias 0.01	Reproducibility 0.5	Reproducibility 0.1	Reproducibility 0.01	Time to Apply
1	1.000	.962	.880	.870	.850	.817	.146
	.962	1.000	.974	.831	.839	.827	.125
	.880	.974	1.000	.755	.785	.799	.120
	.870	.831	.755	1.000	.986	.954	.133
	.850	.839	.785	.986	1.000	.985	.134
	.817	.827	.799	.954	.985	1.000	.126
	.146	.125	.120	.133	.134	.126	1.000
2	1.000	.980	.936	.377	.328	.598	.064
	.980	1.000	.986	.399	.375	.650	.139
	.936	.986	1.000	.380	.373	.652	.222
	.377	.399	.380	1.000	.980	.873	-.128
	.328	.375	.373	.980	1.000	.899	-.096
	.598	.650	.652	.873	.899	1.000	.025
	.064	.139	.222	-.128	-.096	.025	1.000
3	1.000	.984	.957	.935	.928	.892	.266
	.984	1.000	.992	.901	.905	.868	.327
	.957	.992	1.000	.867	.876	.840	.358
	.935	.901	.867	1.000	.991	.981	.075
	.928	.905	.876	.991	1.000	.993	.106
	.892	.868	.840	.981	.993	1.000	.057
	.266	.327	.358	.075	.106	.057	1.000
5	1.000	.954	.875	.902	.905	.868	.091
	.954	1.000	.975	.876	.881	.835	.042
	.875	.975	1.000	.830	.836	.801	-.036
	.902	.876	.830	1.000	.997	.977	.107
	.905	.881	.836	.997	1.000	.969	.113
	.868	.835	.801	.977	.969	1.000	.080
	.091	.042	-.036	.107	.113	.080	1.000
6	1.000	.985	.959	.867	.872	.787	-.309
	.985	1.000	.993	.863	.892	.832	-.326
	.959	.993	1.000	.847	.894	.853	-.324
	.867	.863	.847	1.000	.966	.924	-.330
	.872	.892	.894	.966	1.000	.981	-.317
	.787	.832	.853	.924	.981	1.000	-.294
	-.309	-.326	-.324	-.330	-.317	-.294	1.000

Table A6-2 (Continued)

CORRELATION MATRICES FOR CRITERION VARIABLES: MIDWEST REGION

Procedure	Bias 0.5	Bias 0.1	Bias 0.01	Reproducibility 0.5	Reproducibility 0.1	Reproducibility 0.01	Time to Apply
7	1.000	.954	.872	.856	.751	.605	-.794
	.954	1.000	.968	.719	.672	.624	-.873
	.872	.968	1.000	.655	.679	.723	-.897
	.856	.719	.655	1.000	.940	.753	-.642
	.751	.672	.679	.940	1.000	.916	-.689
	.605	.624	.723	.753	.916	1.000	-.695
	-.794	-.873	-.897	-.642	-.689	-.695	1.000
8	1.000	.979	.961	.942	.924	.916	.127
	.979	1.000	.995	.918	.963	.962	.119
	.961	.995	1.000	.898	.959	.968	.143
	.942	.918	.898	1.000	.923	.906	.177
	.924	.963	.959	.923	1.000	.987	.032
	.916	.962	.968	.906	.987	1.000	.075
	.127	.119	.143	.177	.032	.075	1.000
9	1.000	.851	.714	.837	.734	.667	.234
	.851	1.000	.972	.686	.798	.843	.191
	.714	.972	1.000	.563	.765	.852	.174
	.837	.686	.563	1.000	.892	.785	.098
	.734	.798	.765	.892	1.000	.972	.053
	.667	.843	.852	.785	.972	1.000	.052
	.234	.191	.174	.098	.053	.052	1.000
10	1.000	.696	.392	.679	.234	.030	-.069
	.696	1.000	.919	.519	.529	.445	-.041
	.392	.919	1.000	.349	.588	.584	-.004
	.679	.519	.349	1.000	.733	.482	.178
	.234	.529	.588	.733	1.000	.938	.339
	.030	.445	.584	.482	.938	1.000	.295
	-.069	-.041	-.004	.178	.339	.295	1.000

Table A6-3

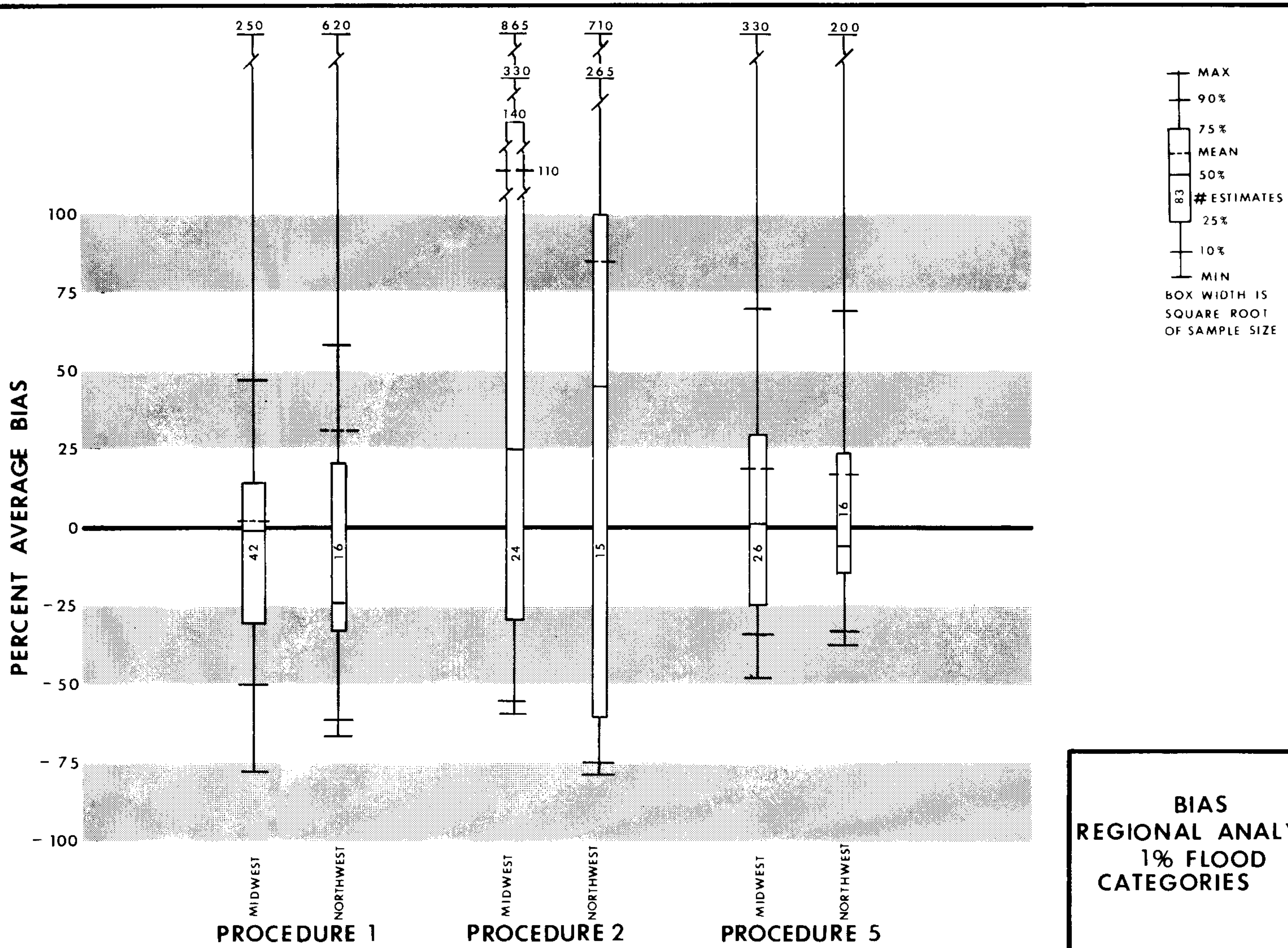
CORRELATION MATRICES FOR CRITERION VARIABLES: NORTHWEST REGION

Procedure	Bias			Reproducibility			Time to Apply
	0.5	0.1	0.01	0.5	0.1	0.01	
1	1.000	.910	.685	.657	.575	.537	-.280
	.910	1.000	.904	.885	.844	.818	-.253
	.685	.904	1.000	.978	.977	.975	-.217
	.657	.885	.978	1.000	.990	.978	-.242
	.575	.844	.977	.990	1.000	.996	-.206
	.537	.818	.975	.978	.996	1.000	-.197
	-.280	-.253	-.217	-.242	-.206	-.197	1.000
2	1.000	.940	.867	.490	.435	.327	-.022
	.940	1.000	.981	.569	.575	.495	-.026
	.867	.981	1.000	.606	.646	.592	-.001
	.490	.569	.606	1.000	.955	.887	.056
	.435	.575	.646	.955	1.000	.974	-.012
	.327	.495	.592	.887	.974	1.000	-.038
	-.022	-.026	-.001	.056	-.012	-.038	1.000
5	1.000	.963	.906	.884	.898	.893	-.069
	.963	1.000	.968	.915	.946	.943	-.048
	.906	.968	1.000	.899	.922	.931	-.001
	.884	.915	.899	1.000	.988	.986	-.103
	.898	.946	.922	.988	1.000	.998	-.113
	.893	.943	.931	.986	.998	1.000	-.090
	-.069	-.048	-.001	-.103	-.113	-.090	1.000
6	1.000	.755	.221	.943	.781	.339	.401
	.755	1.000	.777	.718	.794	.776	-.202
	.221	.777	1.000	.155	.419	.890	-.639
	.943	.718	.155	1.000	.858	.326	.361
	.781	.794	.419	.858	1.000	.686	.077
	.339	.776	.890	.326	.686	1.000	-.501
	.401	-.202	-.639	.361	.077	-.501	1.000
7	1.000	.688	.485	.049	.276	.140	-.433
	.688	1.000	.966	-.074	.802	.740	-.316
	.485	.966	1.000	-.137	.858	.872	-.298
	.049	-.074	-.137	1.000	.342	-.150	.551
	.276	.802	.858	.342	1.000	.800	.083
	.140	.740	.872	-.150	.800	1.000	-.401
	-.433	-.316	-.298	.551	.083	-.401	1.000
8	1.000	.950	.861	.918	.943	.932	.067
	.950	1.000	.957	.856	.935	.956	.157
	.861	.957	1.000	.781	.879	.949	.059
	.918	.856	.781	1.000	.975	.927	.164
	.943	.935	.879	.975	1.000	.978	.174
	.932	.956	.949	.927	.978	1.000	.100
	.067	.157	.059	.164	.174	.100	1.000

Table A6-3 (Continued)

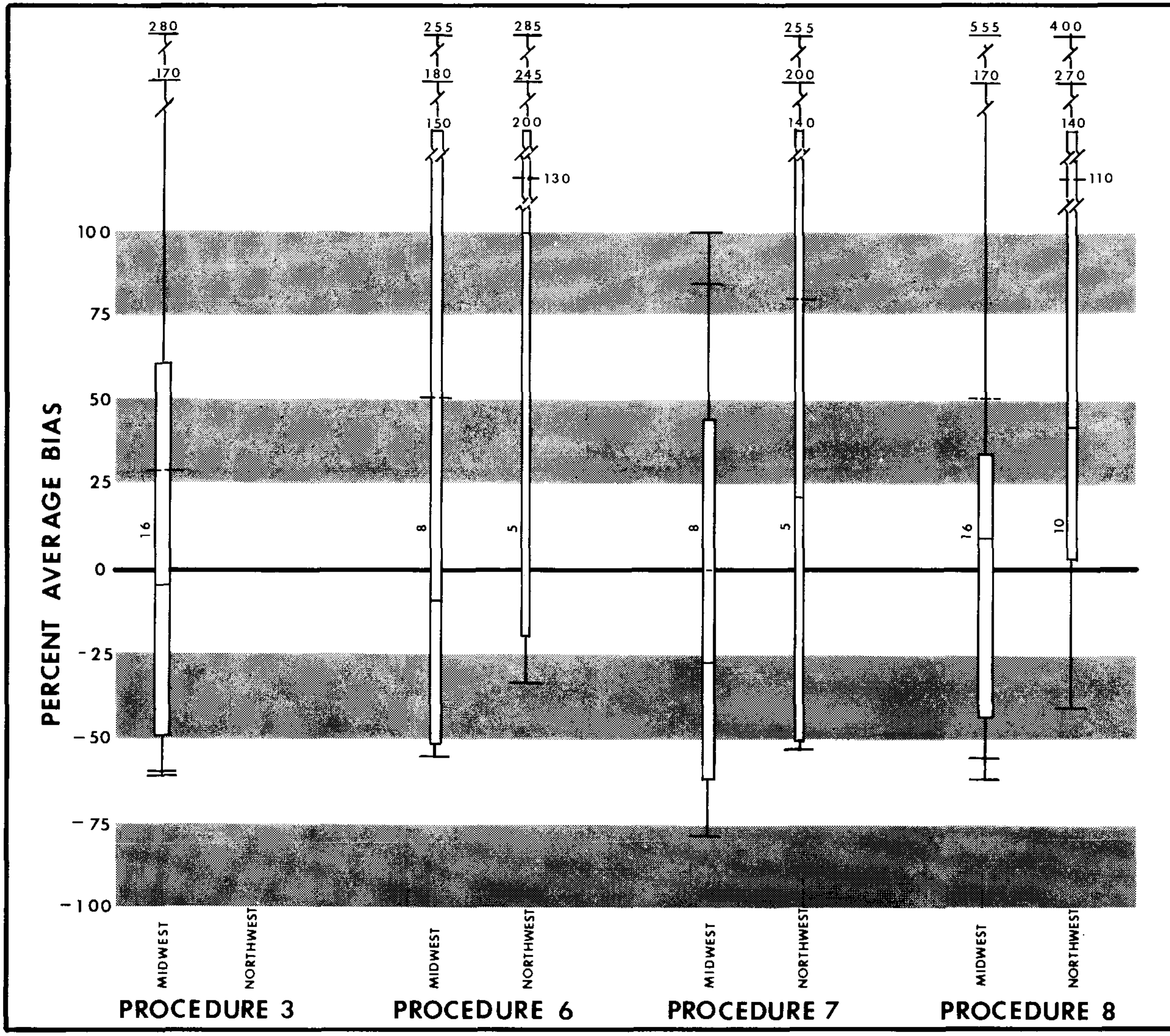
CORRELATION MATRICES FOR CRITERION VARIABLES: NORTHWEST REGION

Procedure	Bias			Reproducibility			Time to Apply
	0.5	0.1	0.01	0.5	0.1	0.01	
9	1.000	.983	.906	.646	.370	.469	-.212
	.983	1.000	.888	.677	.429	.479	-.309
	.906	.888	1.000	.405	.241	.490	-.203
	.646	.677	.405	1.000	.831	.683	-.302
	.370	.429	.241	.831	1.000	.891	-.242
	.469	.479	.490	.683	.891	1.000	-.154
	-.212	-.309	-.203	-.302	-.242	-.154	1.000
10	1.000	.960	.565	.941	.733	.436	-.091
	.960	1.000	.770	.916	.842	.641	-.153
	.565	.770	1.000	.564	.787	.866	-.155
	.941	.916	.564	1.000	.832	.542	.060
	.733	.842	.787	.832	1.000	.907	-.187
	.436	.641	.866	.542	.907	1.000	-.262
	-.091	-.153	-.155	.060	-.187	-.262	1.000



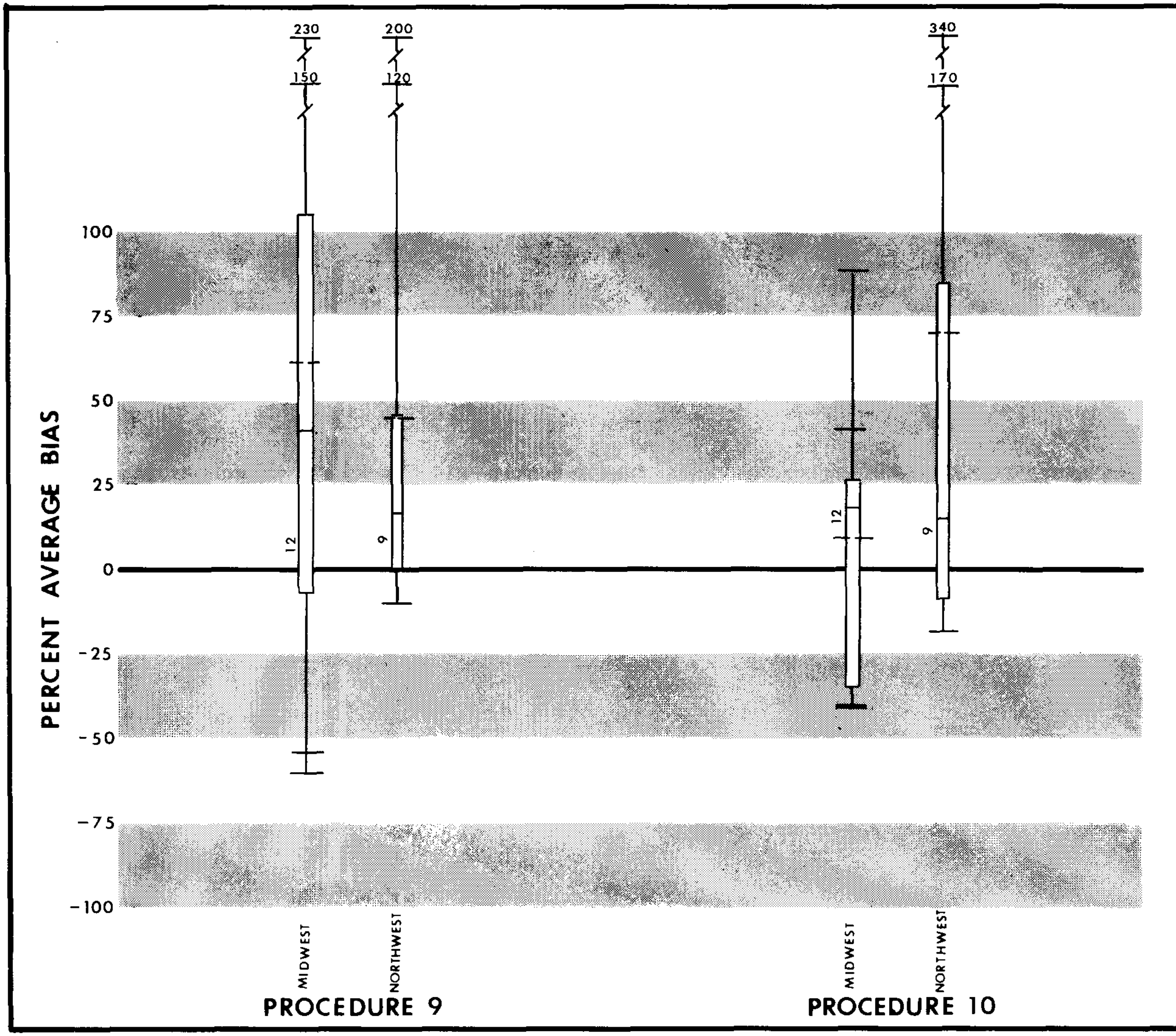
BIAS
REGIONAL ANALYSIS
1% FLOOD
CATEGORIES 1, 3

FIGURE A6 – 10



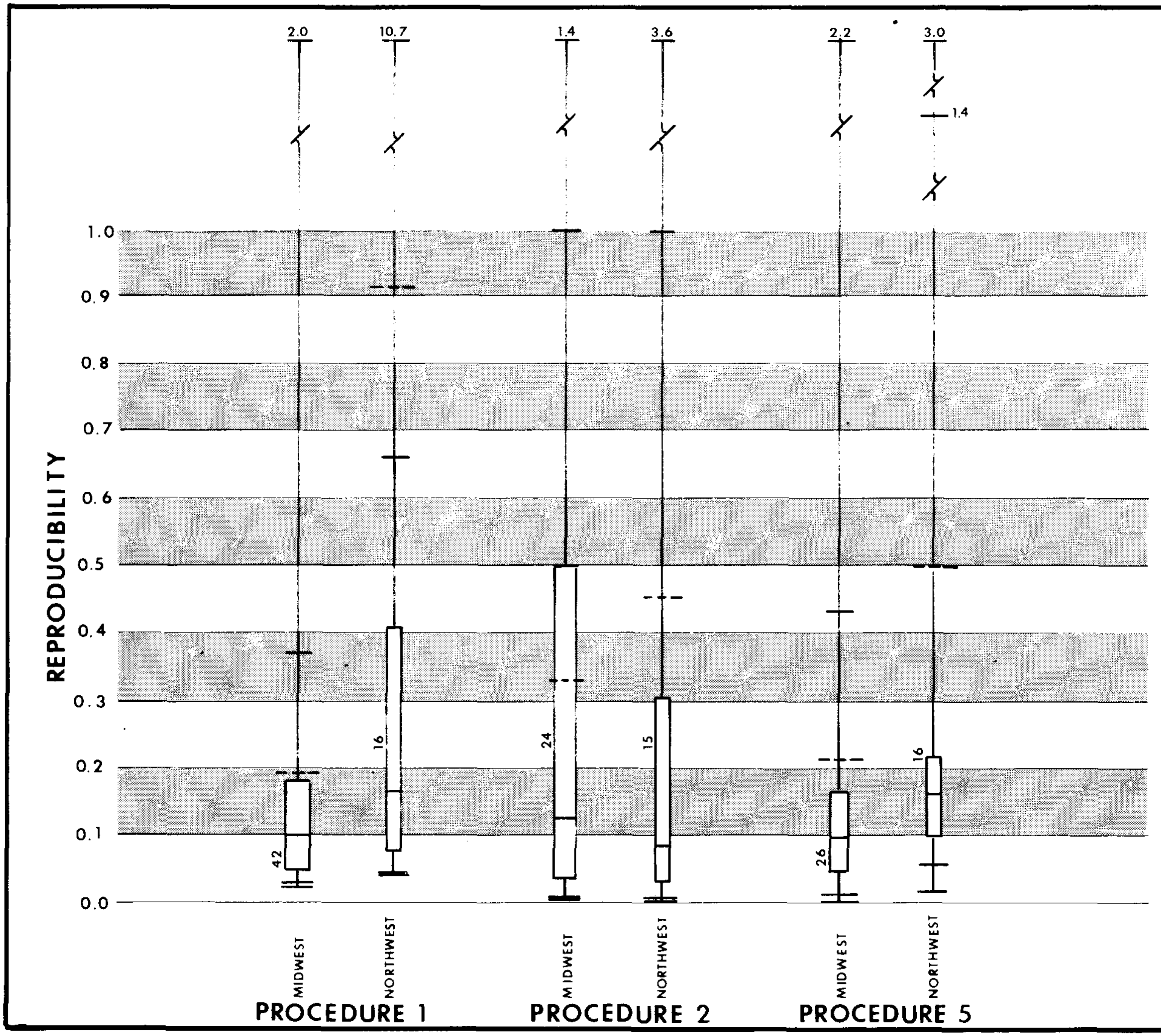
BIAS
REGIONAL ANALYSIS
1% FLOOD
CATEGORIES 5,6

FIGURE A6 – 11



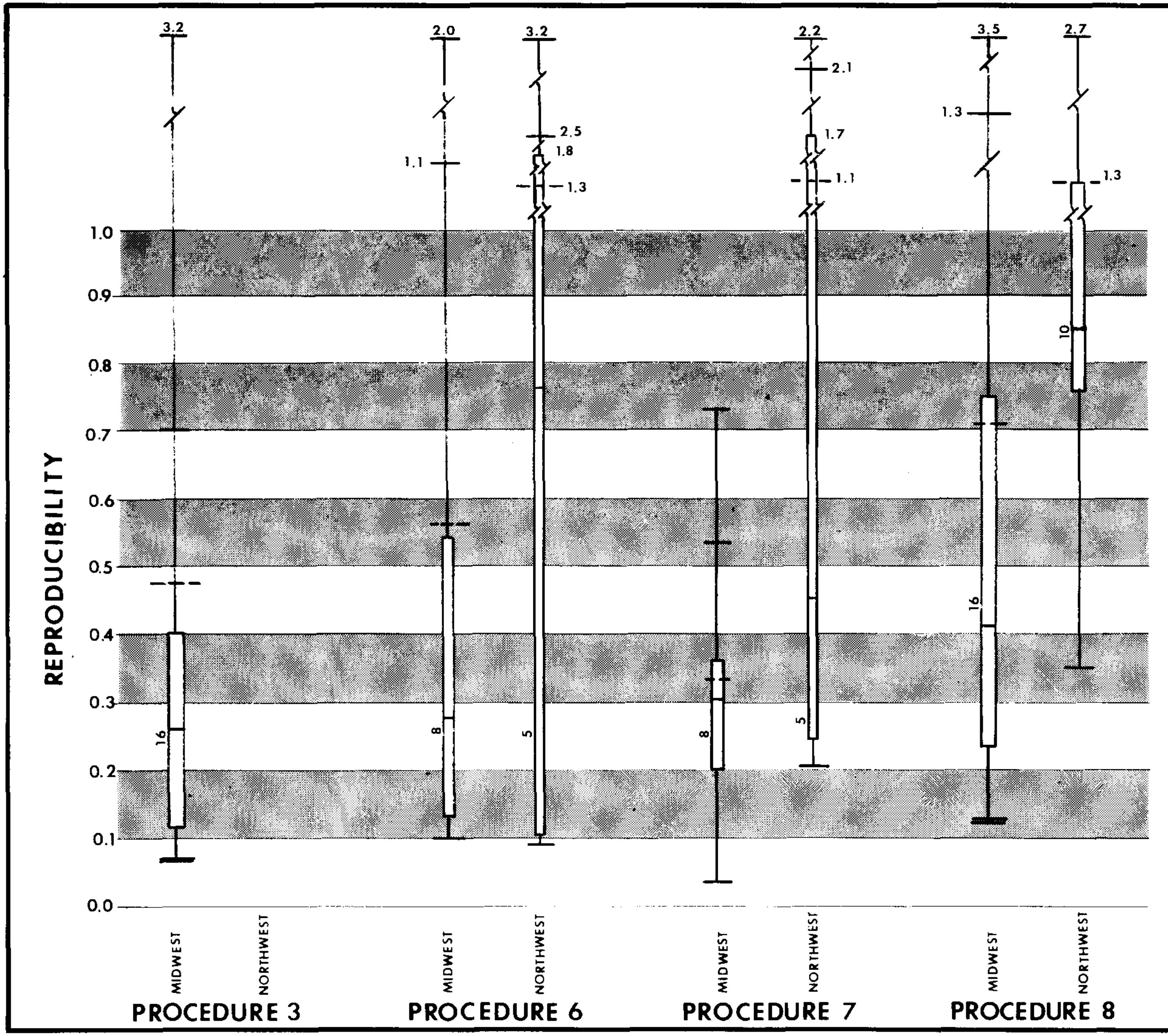
BIAS
REGIONAL ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE A6 – 12



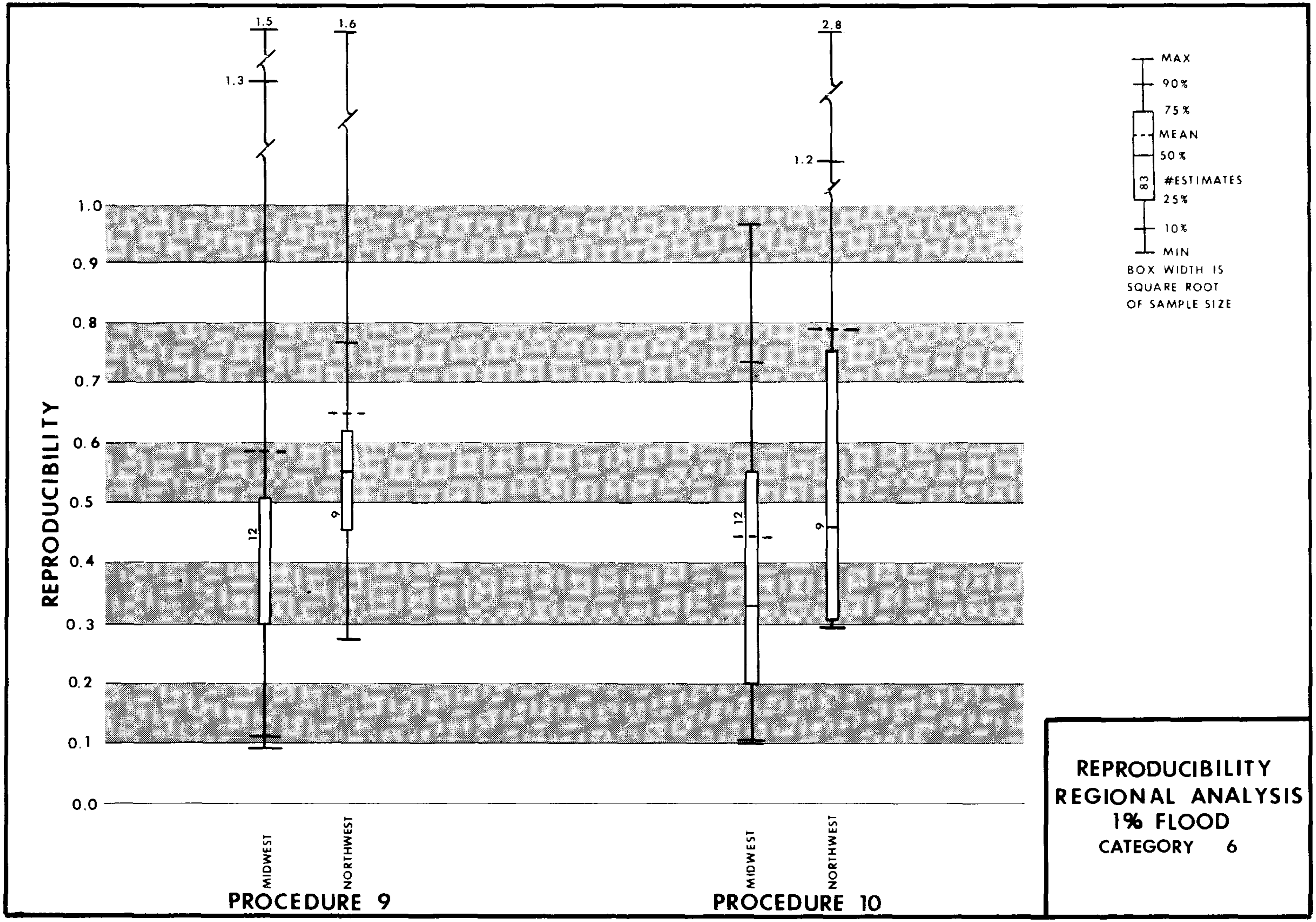
REPRODUCIBILITY REGIONAL ANALYSIS 1% FLOOD CATEGORY 1,3

FIGURE A6-13



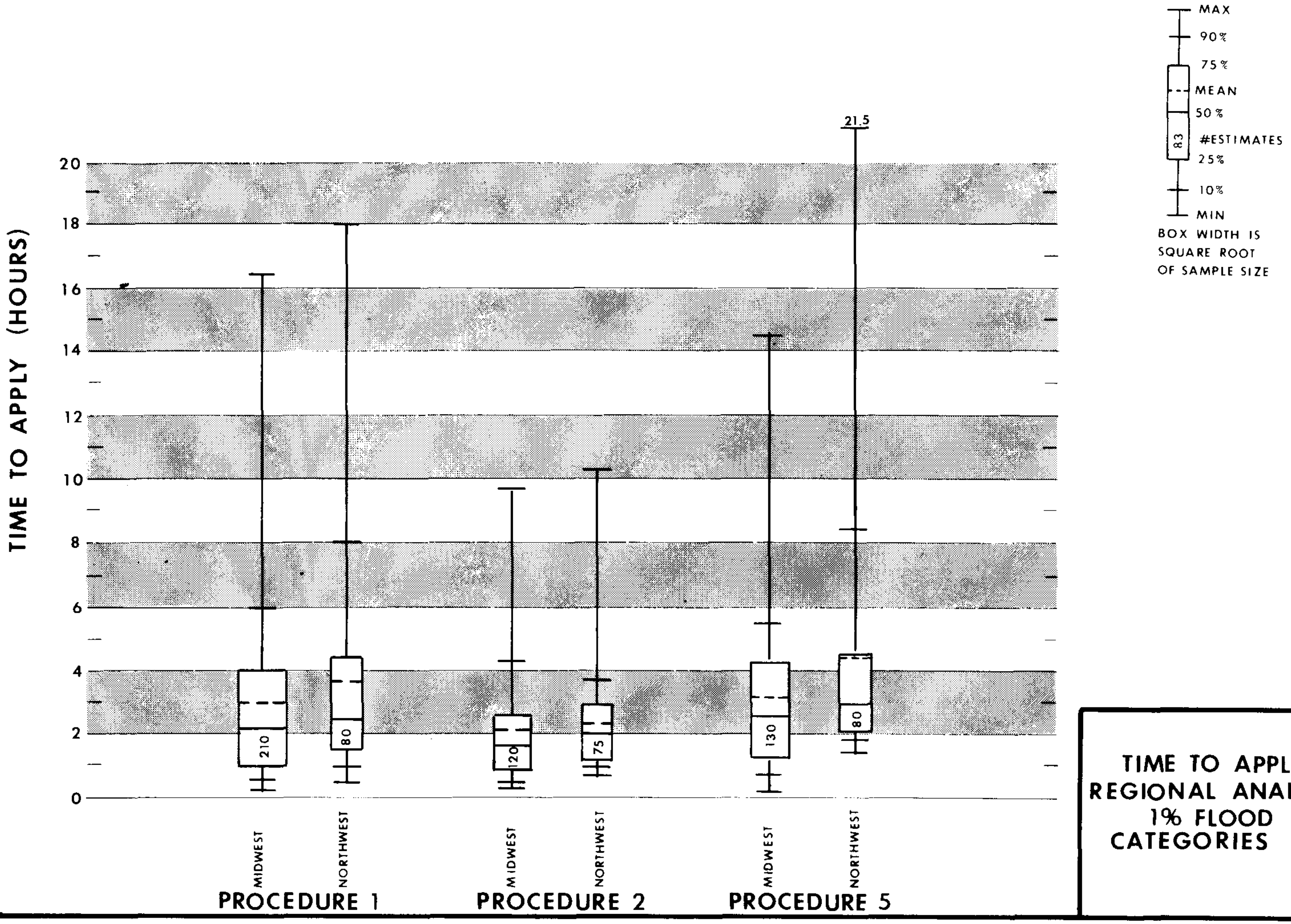
REPRODUCIBILITY
REGIONAL ANALYSIS
1% FLOOD
CATEGORY 5,6

FIGURE A6 - 14



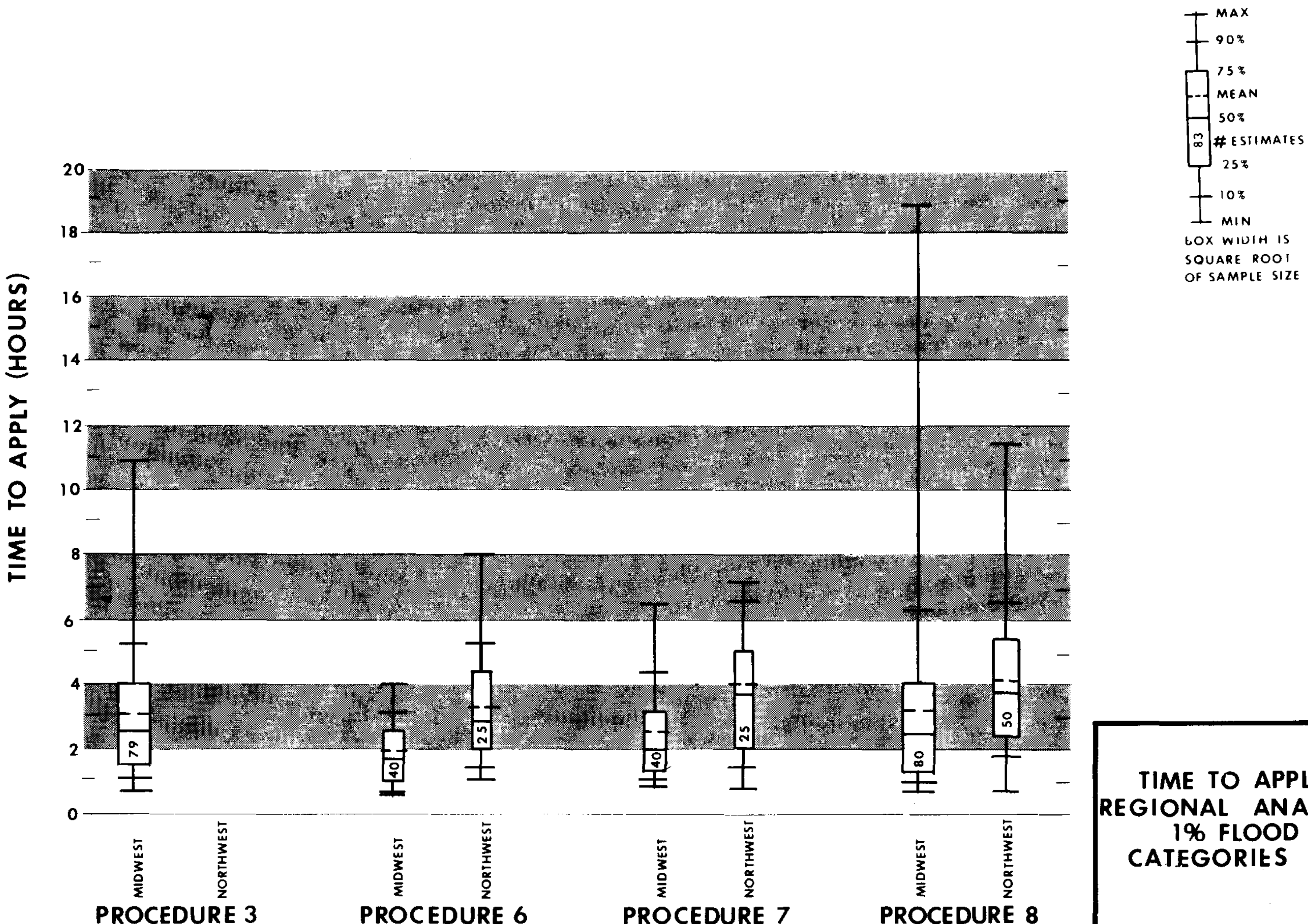
REPRODUCIBILITY
REGIONAL ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE A6 - 15

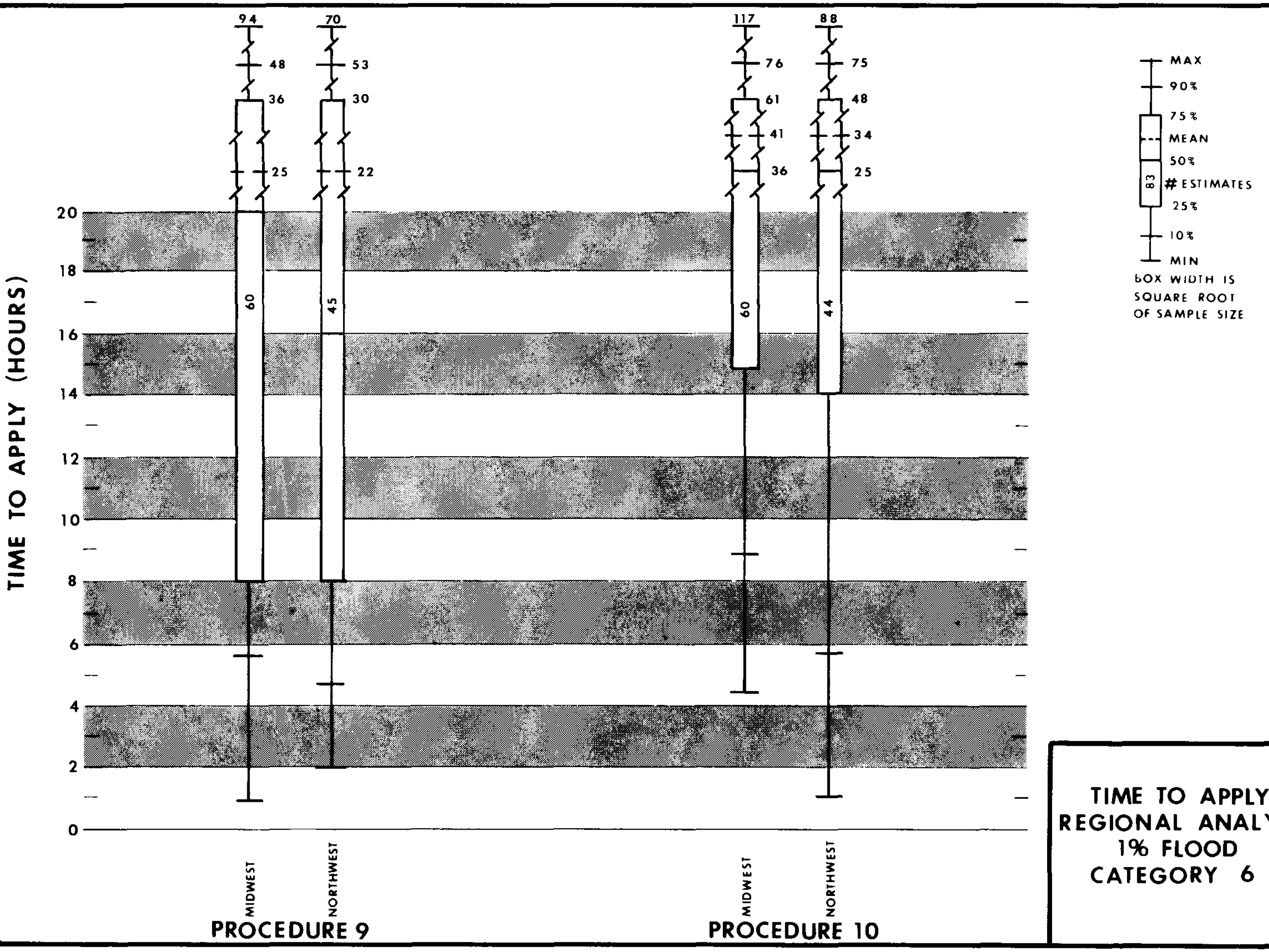


TIME TO APPLY
REGIONAL ANALYSIS
1% FLOOD
CATEGORIES 1,3

FIGURE A6 – 16



TIME TO APPLY
REGIONAL ANALYSIS
1% FLOOD
CATEGORIES 5, 6



TIME TO APPLY
REGIONAL ANALYSIS
1% FLOOD
CATEGORY 6

FIGURE A6-18

APPENDIX 7

TESTER EXPERIENCE

Average accuracy of all three percent-chance floods and time to apply the procedure were used to analyze the effect of different levels of hydrologic experience, frequency of procedure use, and field inspection. In order to have a significant sample size, the four tester information questions on the test record sheets were combined in the following way:

Frequency of procedure use
1. none or some
2. very

Knowledge of the hydrology region
1. none or some
2. very

Hydrologic experience
1. 0 - 5 years
2. 5 - 10 years

or

1. 0 - 2 years
2. 2 - 10 years

Regions
both regions were combined

The criteria are summarized by procedure in Tables A7-1 to A7-4. Tables A7-1 and A7-2 summarize the analysis of the hydrologic experience question; Table A7-3 summarizes the analysis of frequency of procedure use question; and Table A7-4 summarizes the analysis of the field inspection question.

Table A7-1

HYDROLOGIC EXPERIENCE

Procedure	Experience	Freq of Use	Knowledge of Region	Sample	Accuracy Mean	Accuracy SD	Time to Apply Mean	Time to Apply SD
USGS State	0 - 5	1	1	116	0.10	0.41	3.40	2.80
	5 - 10	1	1	94	0.21	1.73	3.17	2.96
Fletcher	0 - 5	1	1	127	0.79	1.36	2.96	2.51
	5 - 10	1	1	130	1.00	1.97	2.50	1.99
Reich	0 - 5	1	1	60	2.68	4.24	4.59	2.91
	5 - 10	1	1	92	3.08	7.35	3.79	2.20
Index Flood	0 - 5	1	1	110	0.06	0.52	3.56	2.65
	5 - 10	1	1	79	0.27	1.17	4.20	4.44
Rational	0 - 5	1	1	41	1.97	2.24	2.72	1.74
	5 - 10	1	1	71	1.80	2.71	2.42	1.61
TR-55 Charts	0 - 5	1	1	31	0.11	1.04	3.15	1.77
	5 - 10	1	1	31	0.11	1.04	3.15	1.77
TR-55 Graph	0 - 5	1	1	67	1.06	1.44	4.57	3.75
	5 - 10	1	1	83	1.77	4.16	3.93	2.54
TR-20	0 - 5	1	1	41	0.74	1.21	25.20	14.50
	5 - 10	1	1	34	0.63	1.05	21.40	21.50
HEC-1	0 - 5	1	1	33	0.35	0.99	40.00	25.30
	5 - 10	1	1	47	0.97	1.71	33.90	28.90

Note: Sample includes persons who did not make a field visit.

Frequency of use 1 = never or seldom
Knowledge of region 1 = none or some

Table A7-2

HYDROLOGIC EXPERIENCE

Procedure	Experience	Freq of Use	Knowledge of Region	Sample	Accuracy Mean	Accuracy SD	Time to Apply Mean	Time to Apply SD
USGS State	0 - 2	1	1	62	0.11	0.40	3.84	2.99
	2 - 10	1	1	148	0.17	1.40	3.09	2.82
Fletcher	0 - 2	1	1	68	0.79	1.28	3.10	2.62
	2 - 10	1	1	189	0.94	1.82	2.59	2.12
Reich	0 - 2	1	1	32	3.29	4.83	4.54	2.63
	2 - 10	1	1	120	2.83	6.65	3.99	2.50
Index Flood	0 - 2	1	1	59	0.10	0.61	3.69	2.47
	2 - 10	1	1	130	0.16	0.95	3.89	3.91
Rational	0 - 2	1	1	21	1.80	2.46	2.46	1.20
	2 - 10	1	1	91	1.88	2.57	2.55	1.75
TR-55 Charts	0 - 2	1	1	12	0.37	1.06	2.61	1.58
	2 - 10	1	1	47	0.34	1.15	3.19	1.77
TR-55 Graph	0 - 2	1	1	36	0.97	1.43	4.26	3.24
	2 - 10	1	1	114	1.60	3.63	4.20	3.12
TR-20	0 - 2	1	1	20	0.45	0.83	23.10	16.90
	2 - 10	1	1	55	0.77	1.22	23.50	18.50
HEC-1	0 - 2	1	1	11	0.53	0.81	34.60	17.60
	2 - 10	1	1	69	0.74	1.53	36.70	28.70

Note: Sample includes persons who did not make a field visit.

Frequency of use 1 = never or seldom
Knowledge of region 1 = none or some

Table A7-3

FREQUENCY OF USE

Procedure	Experience	Freq of Use	Knowledge of Region	Sample	Accuracy Mean	Accuracy SD	Time to Apply Mean	Time to Apply SD
USGS State	0 - 5	1	1	116	0.10	0.41	3.44	2.93
	0 - 5	2	1	11	0.03	0.46	2.41	1.65
USGS State	5 - 10	1	1	94	0.21	1.73	3.17	2.96
	5 - 10	2	1	43	0.07	0.69	2.85	3.40
Index Flood	5 - 10	1	1	79	0.26	1.17	4.20	4.44
	5 - 10	2	1	7	0.07	0.43	2.05	1.22
Rational	0 - 5	1	1	41	1.97	2.24	2.72	1.74
	0 - 5	2	1	6	2.20	1.96	4.08	1.21
TR-55 Graph	5 - 10	1	1	83	1.77	4.16	3.93	2.55
	5 - 10	2	1	17	0.96	1.06	2.58	1.73
TR-20	5 - 10	1	1	34	0.63	1.05	21.40	21.50
	5 - 10	2	1	5	0.11	0.63	7.70	4.60
USGS State	2 - 10	1	1	148	0.17	1.40	3.10	2.82
	2 - 10	2	1	52	0.07	0.65	2.75	3.14
Index Flood	2 - 10	1	1	130	0.17	0.95	3.89	3.91
	2 - 10	2	1	7	0.07	0.43	2.05	1.22
Rational	2 - 10	1	1	91	1.88	2.58	2.55	1.75
	2 - 10	2	1	6	2.49	1.69	3.95	1.50
TR-55 Graph	2 - 10	1	1	114	1.61	3.63	4.20	3.13
	2 - 10	2	1	17	0.96	1.06	2.58	1.73

Note: Sample includes persons who did not make a field visit.

Frequency of use 1 = never or seldom
Knowledge of region 1 = none or some

Table A7-4

FIELD INSPECTION

Procedure	Experience	Freq of Use	Knowledge of Region	Field Inspection	Sample	Accuracy Mean	Accuracy SD	Time to Apply Mean	Time to Apply SD
TR-55 Graph	0 - 5	1	1	No	67	1.05	1.44	4.57	3.75
	0 - 5	1	1	Yes	5	0.16	0.18	6.10	4.61
TR-55 Graph	5 - 10	1	1	No	83	1.77	4.16	3.93	2.55
	5 - 10	1	1	Yes	11	0.43	1.22	6.38	1.89
TR-20	0 - 5	1	1	No	41	0.73	1.21	25.10	14.50
	0 - 5	1	1	Yes	8	0.51	0.88	21.30	7.90
TR-20	5 - 10	1	1	No	34	0.63	1.05	21.40	21.50
	5 - 10	1	1	Yes	10	0.16	0.68	39.10	41.40
HEC-1	0 - 5	1	1	No	33	0.35	0.89	40.00	25.30
	0 - 5	1	1	Yes	5	2.24	2.35	55.40	11.50
HEC-1	5 - 10	1	1	No	47	0.97	1.70	33.80	28.90
	5 - 10	1	1	Yes	9	0.44	0.70	56.50	27.60
TR-55 Graph	2 - 10	1	1	No	114	1.61	3.63	4.20	3.13
	2 - 10	1	1	Yes	14	0.38	1.08	5.87	2.08
TR-20	2 - 10	1	1	No	55	0.78	1.22	23.50	18.50
	2 - 10	1	1	Yes	16	0.32	0.82	32.06	22.70
HEC-1	2 - 10	1	1	No	69	0.74	1.53	36.70	28.70
	2 - 10	1	1	Yes	13	1.14	1.72	55.70	23.50

Note: Frequency of use 1 = never or seldom
Knowledge of region 1 = none or some

APPENDIX 8

COMPARISON OF REGRESSION EQUATIONS WITH AND WITHOUT PILOT TEST STATIONS

USGS State Equations, the Fletcher procedure, and the USGS Index Flood Equations were tested against gaging stations that were used to develop the regression models. The USGS State Equations were applied at 58 stations in the test and all were used in developing the equations. The Fletcher procedure was applied at 52 stations in the test. Of these, 18 stations were used to develop the equations. The USGS Index Flood Equations were applied at 44 stations in the test. All stations except two (numbers 42 and 44) were used to develop the equations.

Nearly all flood-frequency estimates and resulting regression equations were developed prior to publication of U.S. Water Resources Council (WRC) Bulletin 17 (1976). The gage estimates computed by the Work Group for the same watersheds were made according to guidelines in WRC Bulletin 17A using generalized skew, low outlier testing, different treatment of historic data, etc. In addition, the length of record used in developing the flood-frequency estimates in these procedures was shorter than the record used to compute the gage estimates in the pilot test. This is particularly true for the USGS Index Flood Equations because most of the regression equations in the procedure were developed using discharge data prior to 1958. For these reasons, the flood-frequency gage estimates used in the pilot test for the regression-type procedures may differ significantly from those used to develop the regression equations.

The USGS State Equations for Ohio and Illinois were developed using WRC Bulletin 17 guidelines and annual peak data through the 1975 water year. Therefore, the estimates of the 50-, 10-, and 1-percent-chance flood discharges that were used in developing these equations should agree closer with the gage estimates in the pilot test than the other equations in the regression-type procedures.

A comparison of the 1-percent-chance flood discharges used to develop the Ohio and Illinois equations against the gage estimates in Table A2-1 provided the following information:

1. The gage estimates used in the pilot test were generally higher than those used to develop the equations.

2. For Illinois, the absolute difference between the two estimates averaged 12 percent with individual differences ranging from -19 to 30 percent.

3. For Ohio, the absolute difference between the two estimates averaged 7 percent with individual differences ranging from -8 to 24 percent.

It is reasonable to assume that the 1-percent-chance flood discharges used to develop the other USGS State Equations, the Fletcher procedure, and the USGS Index Flood Equations probably exhibit greater variation about the pilot test gage estimates than the percentages cited above.

Because the data base that was used to develop the Ohio and Illinois State Equations was readily available, the regression equations were recomputed without the stations in the pilot test. The new equations were then used to estimate the 50-, 10-, and 1-percent-chance flood discharges using the watershed characteristics as determined by the testers. The results are summarized in Tables A8-1 and A8-2 for Illinois and Ohio, respectively.

The Illinois equations were originally computed using 241 stations statewide. The 14 stations used in the pilot test were omitted and the equations recomputed. The same independent variables, drainage area, slope, and 2-year 24-hour rainfall, were again the most significant. The application of the new equations to the same watershed characteristics revealed that the average 50-, 10-, and 1-percent-chance flood discharges for each watershed were within 5 percent of the values reported by the tester. (See Table A8-1.)

The Ohio equations were recomputed for three of the four areas for which there were stations in the pilot test. Area 2 equations were recomputed by omitting three of the 46 stations used to develop the equations; area 3 equations were recomputed by omitting five of the 82 stations used to develop the equations; and area 5 equations were recomputed by omitting one of the 14 stations used to develop the equations. The same independent variables were again significant for each area. Area 1 had one station in the pilot test out of a total 40, but the equations were not recomputed. Area 4 did not have any stations in the pilot test. All estimates from the new equations for each area were within 9 percent of the estimates from the equations used in the pilot test. (See Table A8-2.)

Obviously, for Illinois and Ohio, the inclusion or exclusion of the pilot test stations in developing the regression equations would not affect the bias criterion variable. There was not sufficient time to recompute the regression equations for all the procedures because the necessary data were not readily available. It is probable that the results for Illinois and Ohio can be generalized to all the regression-type procedures. The number of pilot test stations in any given state or region represents such a small percentage of the total stations used to develop the equations that they do not have a significant influence on the equations' predictive ability. However, in a more comprehensive nationwide test, it may be desirable to test the regression equations without the test stations.

An analysis was also made of the six sites in Indiana to see if they were representative of all sites in the state. The absolute bias criterion was computed for the six sites in the pilot test using the regression and gage estimtes provided in USGS Circular No. 710 (Davis, 1974). These values were compared to the absolute bias criterion for all sites used to develop the Indiana State Equations. In addition, the absolute bias criterion from the pilot test is provided in Table A8-3 for comparison.

Table A8-1

COMPARISON OF THE MEAN FLOOD DISCHARGES ESTIMATED
FROM THE ILLINOIS STATE EQUATIONS WITH AND WITHOUT THE 14 STATIONS IN THE PILOT TEST

Watershed	Results based on published equations in WRI 77-117 (Curtis, 1977) (241 stations)			Results based on published equations minus 14 stations in pilot test (227 stations)			Percent Difference [(New Equations-Published equations) / Published equations]		
	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$
21	378	874	1,557	386	886	1,569	2.1	1.3	0.8
22	25	58	104	26	57	100	3.1	-2.4	-3.7
23	252	620	1,154	242	594	1,102	-4.0	-4.2	-4.7
28	152	366	677	153	372	698	1.2	1.7	3.1
29	287	645	1,124	287	662	1,096	0.0	2.7	-2.6
33	331	722	1,234	337	722	1,208	1.8	-0.1	-2.1
39	1,061	2,335	4,031	1,082	2,366	4,051	1.9	1.3	0.5
40	1,564	3,434	5,884	1,609	3,481	6,018	2.8	1.4	2.2
49	2,630	5,736	9,834	2,598	5,642	9,604	-1.2	-1.7	-2.4
50	2,079	4,487	7,645	2,123	4,548	7,696	2.1	1.4	0.7
51	4,360	9,612	16,700	4,442	9,881	17,101	1.9	2.7	2.3
53	3,664	7,744	13,020	3,631	7,664	12,785	-0.9	-1.0	-1.8
56	14,594	30,704	49,624	15,281	31,659	52,164	4.5	3.0	4.9
57	5,862	12,300	20,480	5,913	12,290	21,382	0.9	-0.1	4.2

Table A8-2

COMPARISON OF THE MEAN FLOOD DISCHARGES ESTIMATED
FROM THE OHIO STATE EQUATIONS WITH AND WITHOUT THE 9* STATIONS IN THE PILOT TEST

Watershed	Results based on published equations in Bulletin 45 (Webber and Bartlett, 1977)			Results based on published equations minus 9 pilot test stations			Percent Difference [(New equations-Published equations) / Published equations]		
	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$
26	137	328	646	150	155	701	9.0	8.3	8.8
27	55	134	154	59	144	277	6.6	7.8	8.9
34	474	1,270	2,816	467	1,250	2,784	-1.5	-1.6	-1.1
35	348	797	1,468	357	819	1,520	2.7	2.8	3.5
44	603	1,570	3,412	595	1,546	3,375	-1.4	-1.5	-1.1
46	1,623	3,315	5,715	1,696	3,451	5,906	4.5	4.1	3.4
59	14,387	26,844	46,130	14,303	26,661	45,843	-0.6	-0.7	-0.6
60	8,049	15,539	25,961	8,189	15,591	25,757	1.7	0.3	-0.8
108	2,321	4,874	8,555	2,344	4,875	8,544	1.0	0.0	-0.1

*Regression equations were not recomputed for area 1 which includes watershed 45.

Table A8-3

ABSOLUTE BIAS COMPARISON

Site No.	Absolute Bias Computed in Pilot Test			Absolute Bias From USGS Circular No. 710		
	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$	$Q_{0.50}$	$Q_{0.10}$	$Q_{0.01}$
41	.325	.247	.143	.340	.010	*
42	.192	.308	.535	.143	.100	*
43	.466	.461	.468	.753	.785	*
47	.039	.233	.386	.038	.088	*
48	.195	.212	.209	.188	.138	*
58	.130	.218	.228	.076	.122	.048
Average	.224	.282	.328	.256	.207	.048
Average absolute bias for all stations in Indiana (from Circular No. 710)-----------------------				.233	.230	.221

*1-percent-chance gage estimate not provided in Circular 710.

Table A8-3 illustrates that the average absolute bias values for the six pilot test stations in Indiana are nearly equal to the average absolute bias for all sites in Indiana that were used to develop the regression equations. That is, they appear to be representative of the total sample of Indiana stations. In addition, the absolute bias values from the pilot test agree fairly well with the values computed from Circular No. 710 for the 50- and 10-percent-chance floods. The 1-percent-chance gage estimate was provided for only one of the six stations. The regression equations were developed without estimates of the 1-percent-chance flood discharge for the other five stations, because their record length was judged to be too short.

APPENDIX 9

INPUT PARAMETER VARIABILITY

The input parameters for all procedures except TR-20 and HEC-1, the complex watershed modeling procedures, were analyzed to determine their measurement variability. The coefficient of variation (C_v) (standard deviation divided by mean) for each watershed was used for parameter comparison. The variability of C_v was represented by the mean and following percentiles: 100 (maximum), 90, 75 (upper quartile), 50 (median), 25 (lower quartile), 10, and 0 (minimum). Box plots showing the mean and percentiles were constructed to visualize the input parameter variability for the total analysis. In addition to the total analysis of parameter variability, limited regional and site size analyses were made. Twenty-six of the ninety-three parameters were applied to less than five watersheds resulting in samples of C_v less than five. These parameters were not included in the analysis because of their small sample sizes.

Parameter variability was defined as low if the 75th percentile (top of box) was below a C_v of about 0.10, medium if the range of the 25th and 75th percentiles (length of box) was between a C_v of 0.10 and 0.25, and high otherwise. A short box encompassing low C_v indicated that parameter variability between watersheds and within each watershed was small. A short box encompassing high C_v indicated that parameter variability between watersheds was small while the parameter variability within each watershed was large. A long box indicated that parameter variability between watersheds was great while parameter variability within each watershed varied.

Record sheets were designed to include parameters needed in flow calculations for each procedure. However, all listed parameters were not needed on all watersheds in the State Equations, Index Flood, and the TR-55 procedures. In spite of this, some testers calculated and recorded the unnecessary parameters. Although these unnecessary parameter estimates did not affect flow calculations, they were independent parameter estimates and were included in the input parameter analysis.

To simplify the variability analysis, the 67 parameters that were analyzed were grouped by similar names resulting in 31 parameters. Of these, seven were adjustment factors and analyzed separately. The remaining 24 parameters were then divided into four groups according to the skill and judgment necessary to estimate the parameter. In the following sections, a parameter group is described. Each parameter in that group is then defined and its variability evaluated. Finally, the general variability of that group is summarized. After all four groups have been evaluated, a discussion of the adjustment factor variability and an overall summary of parameter variability is made.

A. Parameters Read from a Map, Graph, or Table

Eight parameters encountered in the pilot test were read directly from a map. The process involved locating the watershed on the appropriate map and reading a parameter value. If the watershed was small, a value could be read directly. If the watershed was large, a grid sampling method may have been necessary. Little skill and judgment were necessary to determine the parameters in this group.

Geographic Zone

Geographic zone was used in eight procedures: the Indiana and Washington State Equations, Fletcher, and the Illinois, Indiana, Missouri, Ohio, and Idaho Index Flood. However, it was only used to determine which equation and/or graph was applicable. As a result, these zones, with the exception of Fletcher, were not recorded or included in the analysis.

The description of geographic zone in the Fletcher procedure is:

> determined by entering Figure 2 and reading the zone in which the centroid of the watershed lies. For each of the 24 different zones, there is a separate equation for estimating peak discharge . . .

Geographic zone variability was low, as shown in the box plot of Figure A9-1.

Geographic Factor

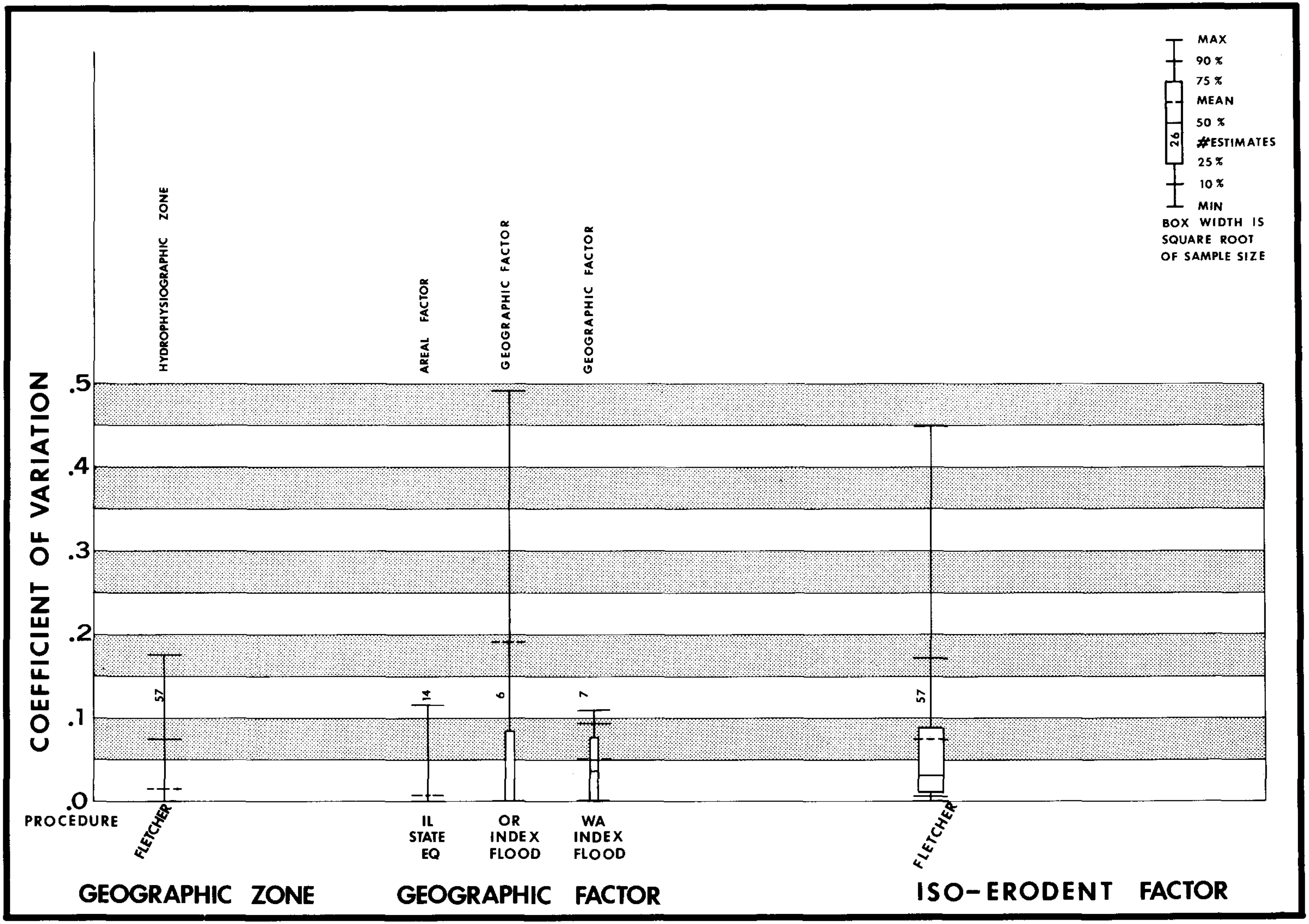
Geographic factor was used in five procedures: the Illinois and Montana State Equations and the Montana, Oregon, and Washington Index Flood. Of these, the Montana State Equation and Montana Index Flood were not included in the analysis because of their small sample sizes. Table A9-1 provides the descriptions of geographic factor for the remaining three procedures.

Table A9-1

GEOGRAPHIC FACTOR DESCRIPTIONS

Procedure	Name	Description
IL State Eq	Areal Factor	". . .determined from. . .Figure 4. . ."
OR Index Flood	Geographic Factor	". . .obtained by locating the drainage area under consideration on plate 2. . ."
WA Index Flood	Geographic Factor	". . .determined by outlining the basin on plate 5 and selecting the applicable factor. . ."

Geographic factor variability was low, as shown in the box plots of Figure A9-1. The Oregon Index Flood had an unusually high maximum C_v. Inspection of the five values that produced this maximum showed that one tester selected a different geographic factor than the other four. This may have been due to the small-scale maps as mentioned in the tester comments. This was also true for the Illinois State Equation.



MAX
90 %
75 %
MEAN
50 %
26
#ESTIMATES
25 %
10 %
MIN
BOX WIDTH IS
SQUARE ROOT
OF SAMPLE SIZE
COEFFICIENT OF VARIATION
.0
.1
.2
.3
.4
.5
HYDROPHYSIOGRAPHIC ZONE
AREAL FACTOR
GEOGRAPHIC FACTOR
GEOGRAPHIC FACTOR
57
14
6
7
57
PROCEDURE
FLETCHER
IL STATE EQ
OR INDEX FLOOD
WA INDEX FLOOD
FLETCHER
GEOGRAPHIC ZONE
GEOGRAPHIC FACTOR
ISO-ERODENT FACTOR

FIGURE A9-1

Iso-Erodent Factor

The iso-erodent factor was needed in flow calculations for the Fletcher procedure only. It is described as:

> . . .a precipitation parameter defined as the mean annual rainfall kinetic energy times the annual maximum 30-minute rainfall intensity...determined by entering the proper state . . .map. . .and interpolating between iso-erodent lines at the location of the centroid of the watershed.

Iso-erodent factor variability was low, as shown in the box plot of Figure A9-1.

Rainfall Intensity and Amount

Rainfall intensities and amounts of different durations were needed in flow calculations for five procedures: the Illinois State Equation, Reich, rational, TR-55 Charts, and TR-55 Graph. Table A9-2 provides the descriptions of rainfall intensity and amount for these procedures. TR-55 Charts and Graph required rainfall amounts while the other procedures required rainfall intensities. The rainfall intensities in the rational formula were a combination of two parameters, rainfall and time of concentration.

Table A9-2
RAINFALL INTENSITY AND AMOUNT DESCRIPTIONS

Procedure	Name	Description
IL State Eq	Rainfall Intensity	". . .the maximum 24-hour rainfall expected to be exceeded on an average of once every 2 years. . .from Hershfield. . . a constant of 2.5 was subtracted. . .in inches. . .from figure 3. . ."
Reich	30-Minute Rainfall	"Use USWB, TP40, or more reliable publication, to determine the maximum 30-minute rainfall for the required return period, P_{30m}, in inches."
Rational	Rainfall Intensity	". . .is determined from the intensity-duration-frequency curve for selected frequency and a duration equal to the time of concentration."
TR-55 Charts and Graph	24-Hour Rainfall	"This appendix contains maps of the conterminous United States showing 24-hour rainfall amounts up to the 100-year frequency. . ."

There were differences in rainfall intensity and amount variability, as shown in the box plots of Figure A9-2. The Illinois State Equation, TR-55 Charts, and TR-55 Graph had low variability. The Reich procedure had medium variability and the rational formula had high variability.

These differences in rainfall intensity and amount variability appeared to depend on the rainfall duration. The Illinois State Equation, TR-55 Charts, and TR-55 Graph included 24-hour rainfall intensities and amounts while Reich included 30-minute rainfall intensities. The values for the two durations were read from similar isohyetal maps that differed by an order of magnitude. Therefore, the differences in variability may have depended on duration because of this scale factor.

The rational formula included rainfall intensities with durations equal to the time of concentration. Time of concentration required tester judgment and its variability was higher than the variability of the rainfall intensities. The rainfall amounts were not recorded so it was not possible to compare their variabilities to those of the intensities. Time of concentration, therefore, increased the variability of rainfall intensity in the rational formula.

One C_v value in the application of the Illinois State Equation was unusually large. Inspection of the five estimates that produced this value showed one tester who recorded the value minus 2.5 as required in the flow calculations. The box plot was corrected to show the true variability in parameter determination.

The Reich procedure had unusually large maximum C_v. Inspection of the five rainfall intensity estimates that produced each maximum showed two tester estimates that were 10 times greater than the others.

The rational formula had two (10- and 100-year) unusually large maximums. Inspection of the five rainfall intensity estimates that produced each maximum showed one tester with a 2-year intensity greater than the 10- or 100-year, all three of which were four times smaller than the other four estimates.

Mean Annual Precipitation

Mean annual precipitation was used in five procedures: the Ohio, Washington, and Montana State Equations, and the Oregon and Washington Index Flood. Three of these procedures, the Montana State Equation and the Oregon and Washington Index Flood, were not included in the analysis because of their small sample sizes. In addition, mean annual precipitation was not needed in all Ohio State Equation applications. Table A9-3 shows the descriptions of mean annual precipitation for the remaining two procedures.

FIGURE A9-2

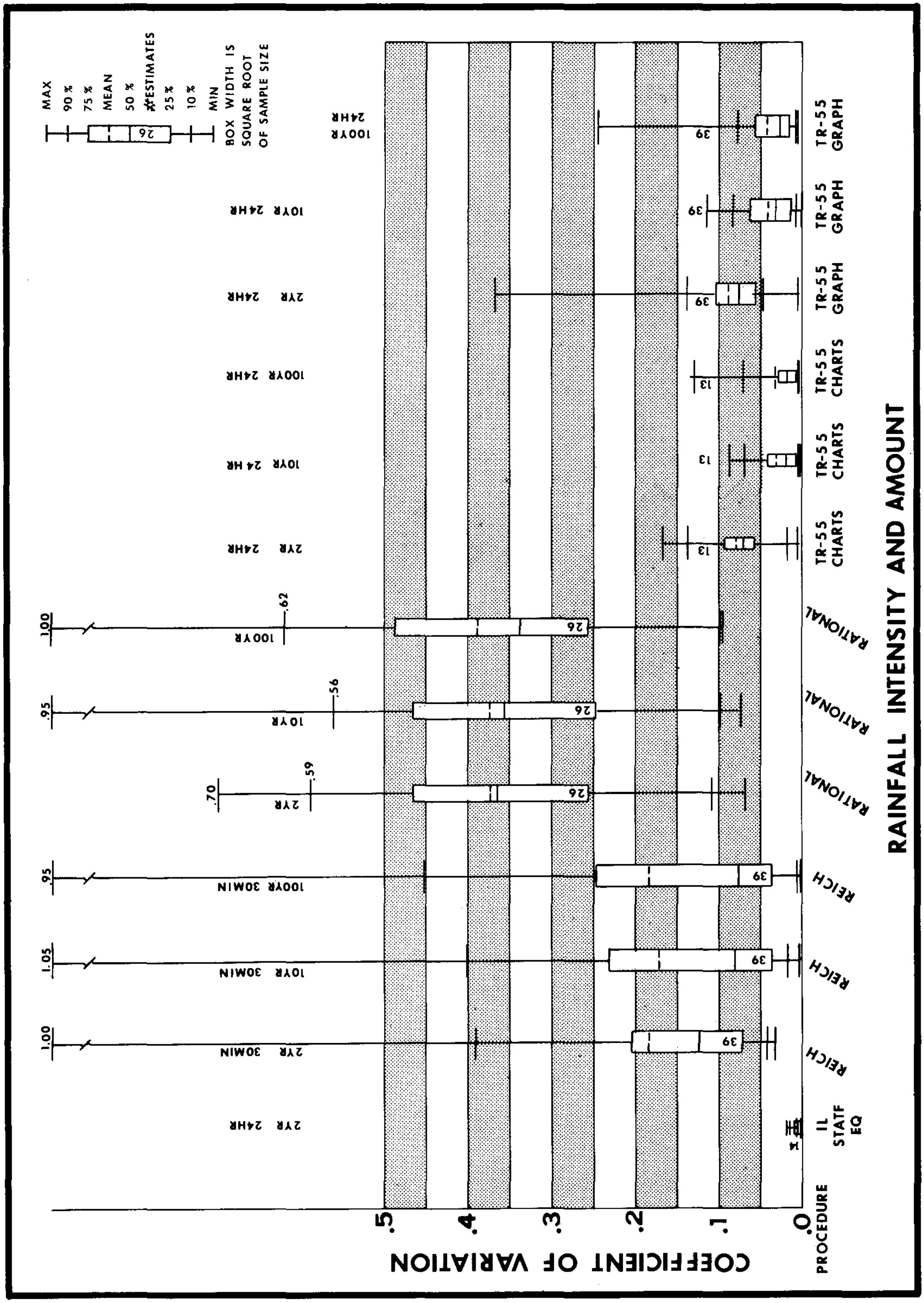

RAINFALL INTENSITY AND AMOUNT
COEFFICIENT OF VARIATION
PROCEDURE
.0
.1
.2
.3
.4
.5
MAX
90 %
75 %
MEAN
50 %
ESTIMATES
25 %
10 %
MIN
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE
IL STATF EQ
REICH
RATIONAL
TR-55 CHARTS
TR-55 GRAPH
2YR 24HR
2YR 30MIN
10YR 30MIN
100YR 30MIN
2YR
10YR
100YR
10YR 24HR
100YR 24HR
1.00
1.05
.95
.70
.59
.56
.62
100
39
26
13
1

Table A9-3

MEAN ANNUAL PRECIPITATION DESCRIPTIONS

Procedure	Name	Description
OH State Eq	Average Annual Precipitation	". . .in inches, determined from a map, shown in Fig. 3,. . .minus 27. . ."
WA State Eq	Mean Annual Precipitation	". . .in inches, is determined by the grid method from the isohyetal map. (pl. 2 in pocket). . ."

Mean annual precipitation variability was low, as shown in the box plots of Figure A9-3. Mean annual precipitation in the Washington State Equation had higher variability than the Ohio State Equation because the scale of the Washington map was too small in relation to the range in precipitation that was portrayed by the isohyets as mentioned in the tester comments.

In the application of the Ohio State Equation, six testers recorded mean annual precipitation minus 27 as required in the flow calculations. The box plot was corrected to show the true variability in parameter determination.

Average Annual Runoff

Average annual runoff was used in four procedures: the Indiana State Equation and the Oregon, Washington, and Montana Index Flood. The Montana Index Flood was not included in the analysis because of its small sample size. In addition, average annual runoff was not needed in all Indiana State Equation and Oregon Index Flood applications. Table A9-4 shows the descriptions of average annual runoff for the remaining three procedures. These descriptions are similar.

FIGURE A9-3

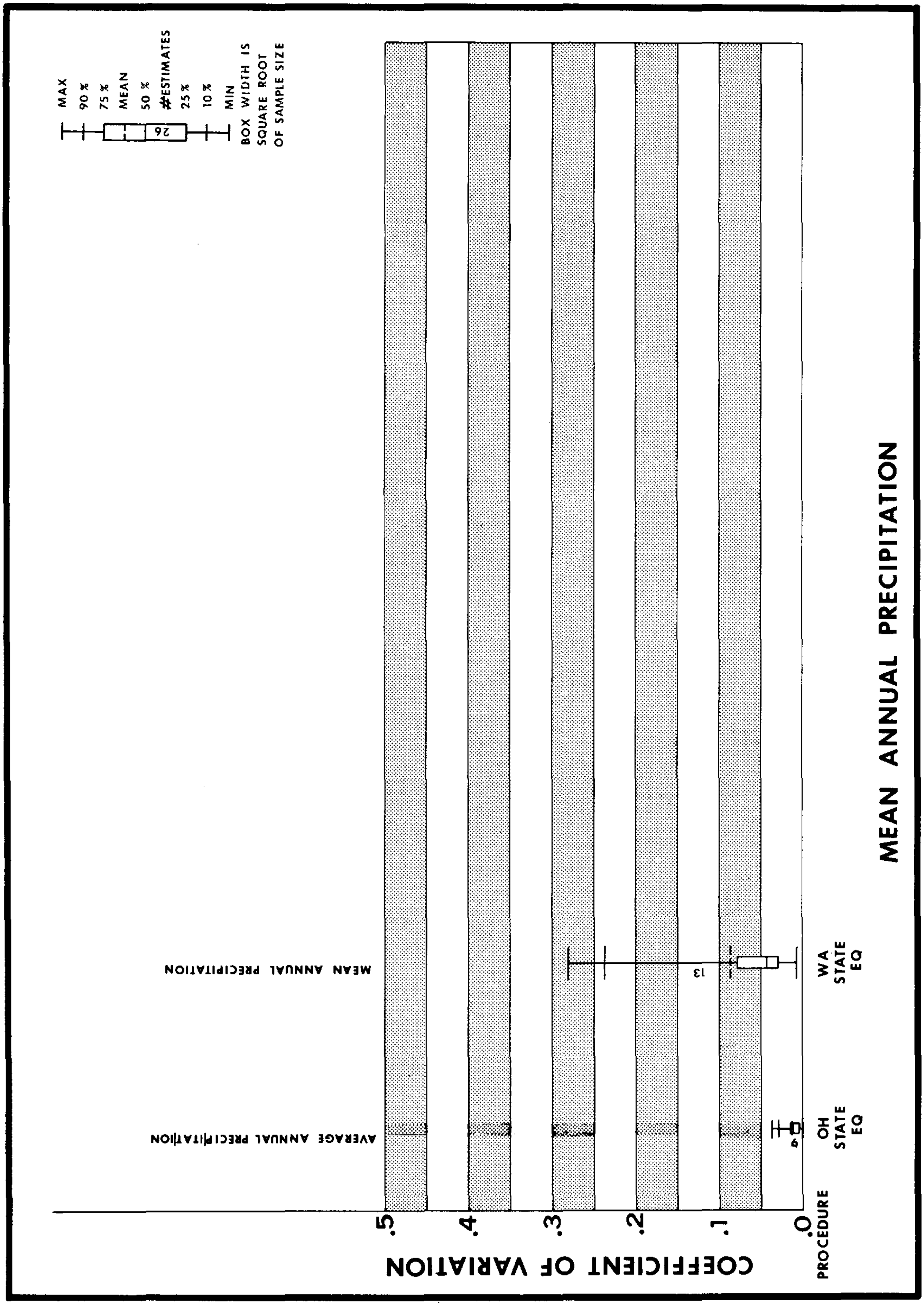

MEAN ANNUAL PRECIPITATION
MAX
90 %
75 %
MEAN
50 %
#ESTIMATES
25 %
10 %
MIN
26
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE
COEFFICIENT OF VARIATION
.5
.4
.3
.2
.1
.0
PROCEDURE
OH STATE EQ
WA STATE EQ
6
13
AVERAGE ANNUAL PRECIPITATION
MEAN ANNUAL PRECIPITATION

Table A9-4

AVERAGE ANNUAL RUNOFF DESCRIPTIONS

Procedure	Name	Description
IN State Eq	Precipitation Index	"The area variation in average annual excess precipitation, in inches, which is the mean annual precipitation minus the sum of the average annual evapotranspiration and mean annual snowfall (water equivalent). This is the average annual amount of precipitation that is available for runoff. . .It may be determined from Figure 4. . ."
WA Index Flood	Average Annual Runoff	". . .may be estimated from the runoff maps in plate 2. . .outline the drainage area under consideration on plate 2. For small drainage areas the average annual runoff can usually be estimated directly. For drainage areas which encompass many runoff lines, a sampling method may be used. With this method, a grid of squares is laid over the outlined area on plate 2 and the runoff value at the center of each square is recorded. The average of the recorded values is used as the estimate. . ."
OR Index Flood	Average Annual Runoff	". . .from plate 3. . .can be determined by locating the desired drainage area on the runoff map and integrating the isopleths within the area visually for small areas, or with a transparent grid."

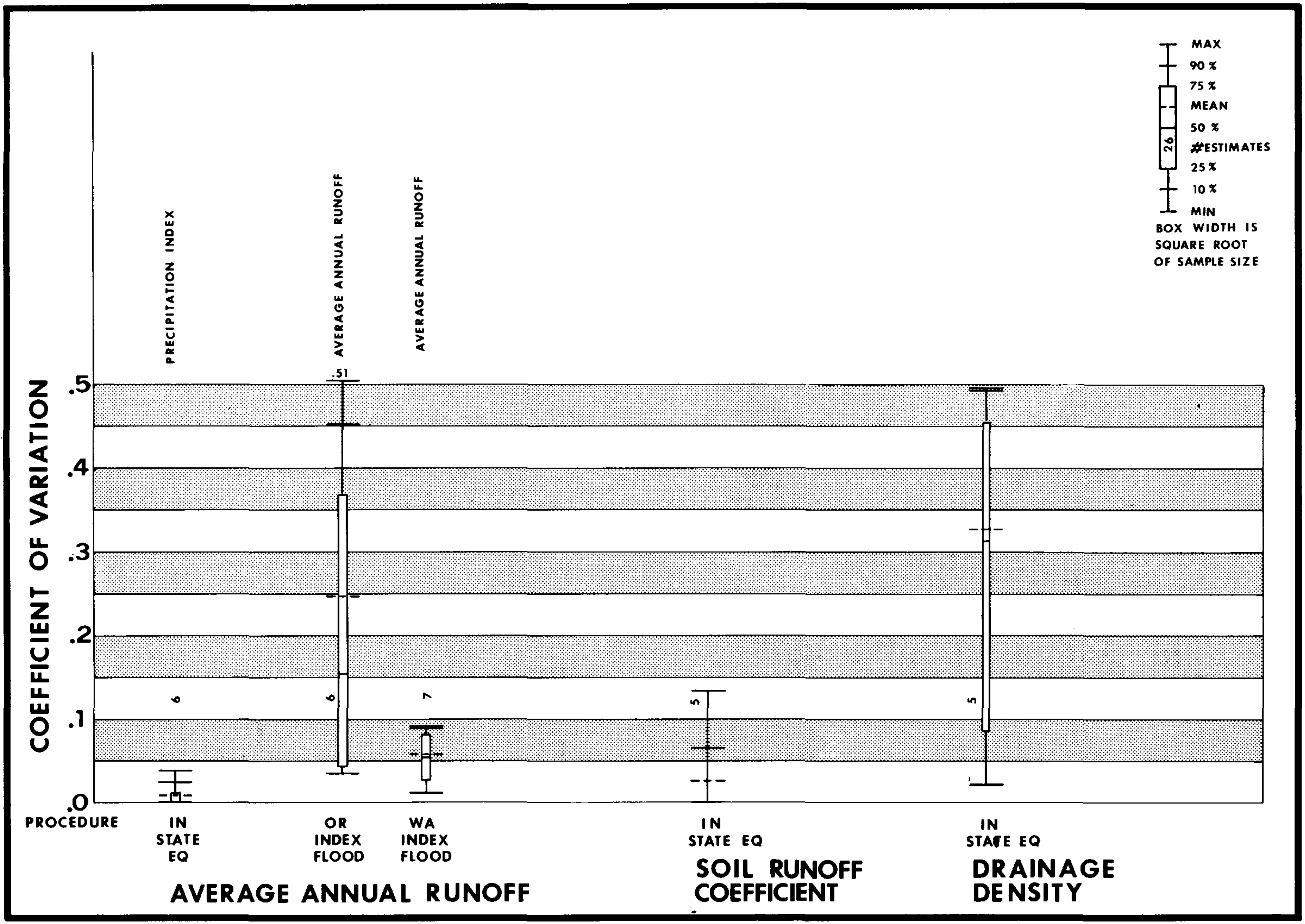
There were differences in average annual runoff variability, as shown in the box plots of Figure A9-4. The Indiana State Equation and Washington Index Flood had low variability while the Oregon Index Flood had high variability. Oregon Index Flood variability may have been the result of the small scale map from which to read values as mentioned in the tester comments.

Soil Runoff Coefficient

Soil runoff coefficient was needed in flow calculations on five of the six watersheds on which the Indiana State Equation was applicable. The soil runoff coefficient is described as:

> . . .the ratio of the volume of rainfall, P, to the total volume of runoff R occurring after the beginning of runoff. . . compiled by principal soil types and then grouped by hydrologic soil groups as shown by the map. . .

FIGURE A9-4



COEFFICIENT OF VARIATION
.5
.4
.3
.2
.1
.0
PROCEDURE
PRECIPITATION INDEX
AVERAGE ANNUAL RUNOFF
AVERAGE ANNUAL RUNOFF
.51
6
6
7
5
5
IN STATE EQ
OR INDEX FLOOD
WA INDEX FLOOD
AVERAGE ANNUAL RUNOFF
IN STATE EQ
SOIL RUNOFF COEFFICIENT
IN STATE EQ
DRAINAGE DENSITY
MAX
90 %
75 %
MEAN
50 %
#ESTIMATES
25 %
10 %
MIN
26
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE

Soil runoff coefficient variability was low, as shown in the box plot of Figure A9-4. Inspection of the five values that produced each C_v showed only one case where a tester selected a different soil runoff coefficient than the others.

Drainage Density

Drainage density was needed in flow calculations on five of the six watersheds on which the Indiana State Equation was applicable. The description of drainage density is:

> Total stream length in a watershed, in miles, divided by the drainage area, expressed in miles per square mile. . .Figures 2 and 3 are provided for estimating drainage densities for ungaged sites. . .To obtain design discharges, drainage density should be measured from county drainage maps.

Drainage density variability was high, as shown in the box plot of Figure A9-4. It was not known if testers determined drainage density by reading the figures or measuring from county drainage maps. As a result, the variability probably depended on whether the tester used the figures or the maps to determine drainage density. The length of the box indicated that tester variability was not as great on some watersheds as on others. Additional analyses showed this changing variability may have been site size dependent in that drainage density was more variable on 50 to 100 square-mile watersheds than on 10- to 50-square-mile watersheds.

Summary and Conclusions

Table A9-5 summarizes the range of variability of the input parameters that were read from a map, graph, or table. Five parameters had low and one parameter had high variability. Two parameters had low, medium, and/or high variability depending on the procedure. The rainfall intensity in the rational formula had high variability because it was a combination of two other parameters, rainfall and time of concentration, the latter of which required direct tester knowledge and judgment. The different map scales and map clarities may have explained other parameter variability.

Table A9-5

VARIABILITY SUMMARY OF PARAMETERS READ FROM A MAP, GRAPH, OR TABLE

Low	Medium	High
Geographic Zone		
Geographic Factor		
Iso-erodent Factor		
Rainfall Intensity and Amount-IL State Eq -TR-55 Charts and Graph	Rainfall Intensity and Amount-Reich	Rainfall Intensity and Amount-Rational
Mean Annual Precipitation		
Average Annual Runoff- IN State Eq WA Index Flood		Average Annual Runoff-OR Index Flood
Soil Runoff Coefficient		Drainage Density

All parameters in this group, except rainfall intensity and amount, were input parameters to the regression procedures (Categories 1 and 3). Rainfall intensity and amount was an input parameter to both regression and rain-runoff procedures (Categories 5 and 6).

B. Parameters Measured from a Topographic Map

Fourteen parameters encountered in the pilot test were measured from a topographic map. Five parameters, site elevation, length and width of basin, and latitude and longitude were not included in the analysis because the parameters were applied to less than four watersheds.

The process involved identifying the site and outlining the watershed. The parameters were then measured based on the different characteristics within the watershed boundary. Determination of these parameters required some skill and judgment including reading and interpreting topographic maps, outlining watershed boundaries, determining and extending the main channel, and measuring by planimeter, grid overlay, or dividers.

Drainage Area

Drainage area was the only parameter common to all procedures. However, the Montana State Equation and the Idaho and Montana Index Flood were not included in the analysis because of their small sample sizes and the Reich procedure was not included because drainage area was not recorded on the record sheet. Testers applied more than one procedure to a watershed and did not recompute drainage area for each application. As a result, there were only about 200 independent estimates of drainage area. The analysis, though, considered all procedure estimates because each estimate was unique to each procedure.

The description of drainage area was essentially the same for all procedures and is: ". . .the area contributing surface flows to the site as outlined along the drainage divide on the best available topographic maps."

Drainage area variability was low, as shown in the box plots of Figure A9-5. The Fletcher procedure had an unusually large maximum C_v. Inspection of the five drainage area estimates that produced this maximum showed that on one watershed a tester estimated the drainage area four times larger than the other four testers.

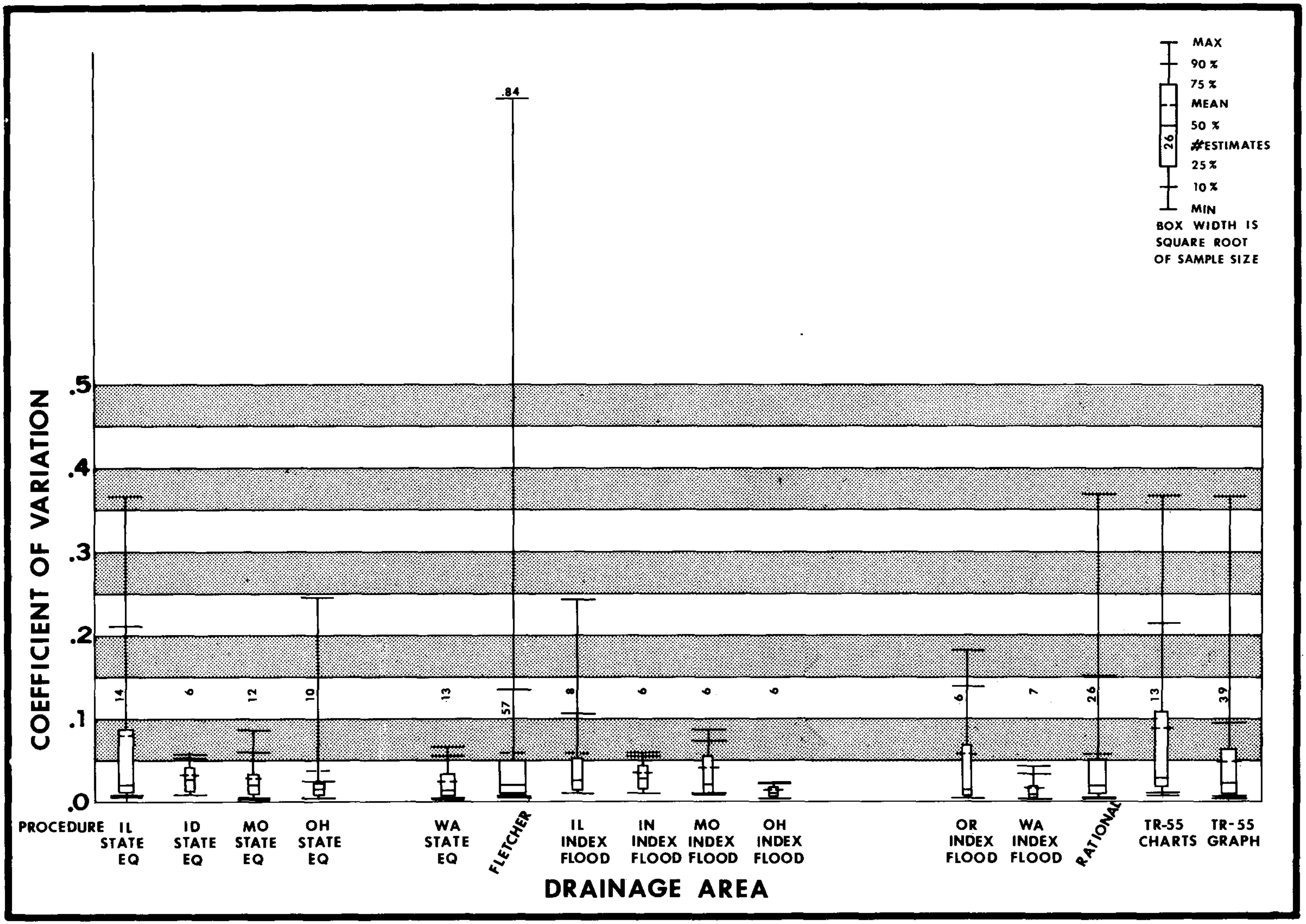
Main Channel Length

Main channel length was used directly in two procedures: the Indiana State Equation and Reich. However, it was not needed in all Indiana State Equation applications. Table A9-6 provides the descriptions of main channel length for these procedures. Although these descriptions are similar, the Reich procedure is less detailed and requires judgment. This could lead to problems for an inexperienced tester.

Table A9-6

MAIN CHANNEL LENGTH DESCRIPTIONS

Procedure	Name	Description
IN State Eq	Channel Length	"Distance along a stream, in miles, from a gaging station (or point of discharge) to the watershed divide. It is measured with dividers spaced at 0.1 mile on the Geological Survey 7-1/2-minute series topographic maps."
Reich	Main Channel Length	"Measure the length of the main channel. . .that affects travel time. . .in feet. . ."



MAX
90 %
75 %
MEAN
50 %
26
#ESTIMATES
25 %
10 %
MIN
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE
COEFFICIENT OF VARIATION
.0
.1
.2
.3
.4
.5
.84
14
6
12
10
13
57
8
6
6
6
6
7
26
13
39
PROCEDURE
IL STATE EQ
ID STATE EQ
MO STATE EQ
OH STATE EQ
WA STATE EQ
FLETCHER
IL INDEX FLOOD
IN INDEX FLOOD
MO INDEX FLOOD
OH INDEX FLOOD
OR INDEX FLOOD
WA INDEX FLOOD
RATIONAL
TR-55 CHARTS
TR-55 GRAPH
DRAINAGE AREA

FIGURE A9-5

There were differences in main channel length variability, as shown in the box plots of Figure A9-6. The Indiana State Equation had low variability and the Reich procedure had medium variability. The variability in the Reich procedure may have been due to the less detailed description of main channel length and the judgment required to calculate it. Note, though, that the Reich procedure was applied to more than six times as many watersheds as the Indiana State Equation. This difference in sample sizes may also have been a contributing factor to this difference in variability.

One C_v value in the application of the Reich procedure was unusually large. Inspection of the five estimates that produced this value showed two testers who recorded main channel length in miles rather than feet. The box plot was corrected to show the true variability in parameter determination.

Main Channel Slope

Main channel slope was used in five procedures: the Illinois, Indiana, Ohio, Missouri, and Montana State Equations. The Montana State Equation was not included in the analysis because of its small sample size. In addition, main channel slope was not needed in all Indiana State Equation applications. Table A9-7 provides the descriptions of main channel slope for the remaining four procedures. These descriptions are similar although the Missouri State Equation description is more detailed.

Main channel slope variability was medium, as shown in box plots of Figure A9-6. The Indiana State Equation had an unusually large maximum C_v. Inspection of the three main channel slope estimates that produced the maximum value showed that one tester estimated the main channel slope six times greater than the other two. However, this error did not affect flow estimates because the procedure did not require main channel slope in the estimate.

Average Watershed Slope

Average watershed slope was needed in TR-55 Charts calculations only. It was used to determine which peak rate of discharge graph (1-percent, 4-percent, or 16-percent slope) was applicable. It was also used to determine if the average watershed slope deviated from the assumed average watershed slopes. If it did, a slope adjustment was made. There is no description of average watershed slope in the text of TR-55 Charts.

Average watershed slope variability was high, as shown in the box plot of Figure A9-6. This may have been due to the lack of a complete description of average watershed slope which, according to the tester comments, created confusion between average watershed slope and channel slope. The length of the box indicated that tester variability was not as great on some watersheds as on others. Additional analyses showed that the wide range of variability may have been regional in that average watershed slope on Midwest watersheds was more variable than on Northwest watersheds.

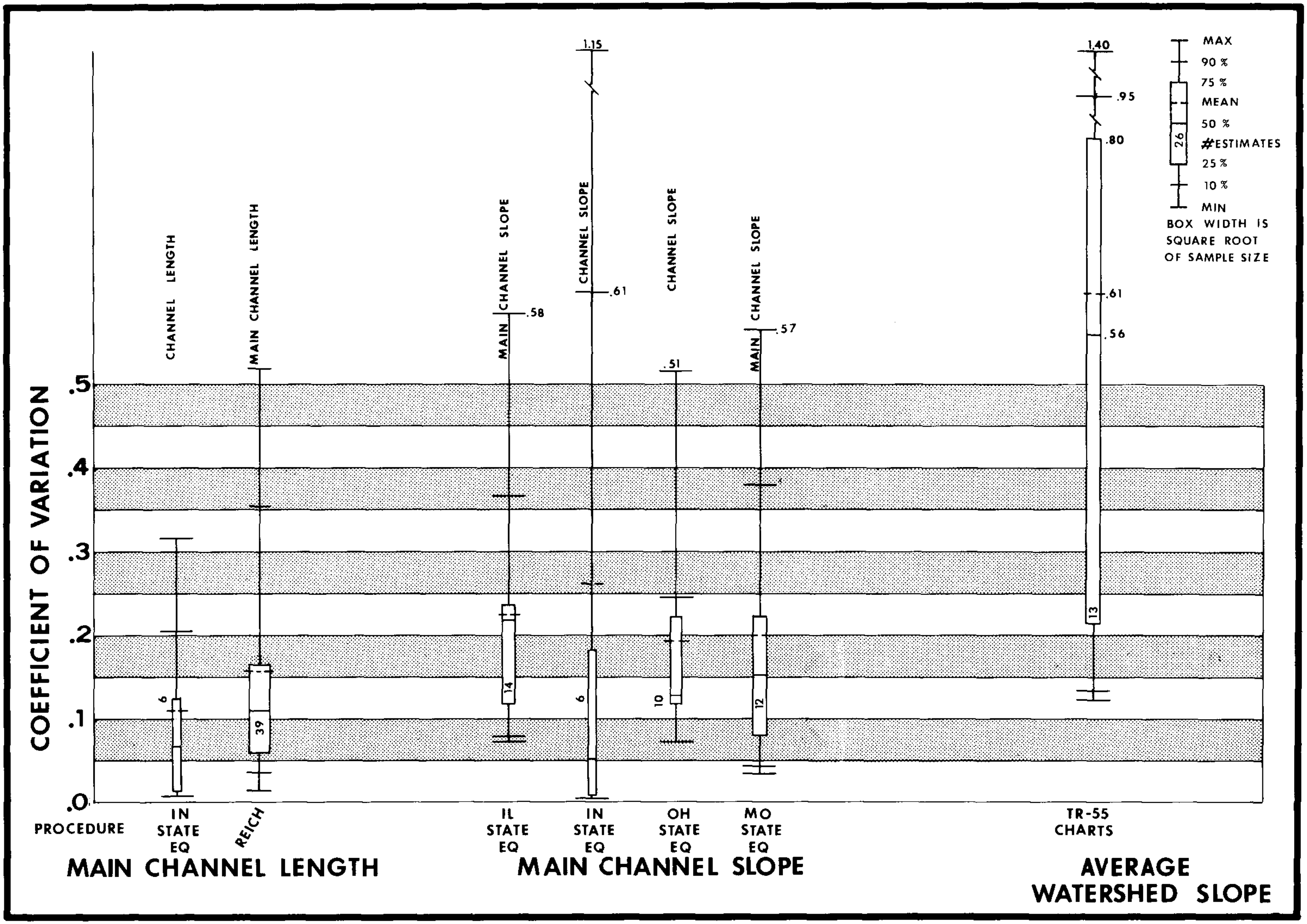

COEFFICIENT OF VARIATION
.0
.1
.2
.3
.4
.5
PROCEDURE
IN STATE EQ
REICH
IL STATE EQ
IN STATE EQ
OH STATE EQ
MO STATE EQ
TR-55 CHARTS
MAIN CHANNEL LENGTH
MAIN CHANNEL SLOPE
AVERAGE WATERSHED SLOPE
CHANNEL LENGTH
MAIN CHANNEL LENGTH
MAIN CHANNEL SLOPE
CHANNEL SLOPE
CHANNEL SLOPE
MAIN CHANNEL SLOPE
6
39
14
6
10
12
13
.58
1.15
.61
.51
.57
1.40
.95
.80
.61
.56
MAX
90 %
75 %
MEAN
50 %
26
#ESTIMATES
25 %
10 %
MIN
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE

FIGURE A9-6

Table A9-7

MAIN CHANNEL SLOPE DESCRIPTIONS

Procedure	Name	Description
IL State Eq	Slope	". . .determined between points 10 percent and 85 percent of the total distance measured along the low-water channel from the site to the basin divide."
IN State Eq	Channel Slope	"The difference in elevation at points 10 percent and 85 percent of the distance along the channel from a gaging station (or point of discharge) to the watershed divide, divided by the distance between the two points. Expressed in feet per mile and determined from 7-1/2-minute series topographic maps. . ."
OH State Eq	Main Channel Slope	". . .in feet per mile, is the difference between the elevations at 10 and 85 percent of the channel distance from the gaging station to the basin divide, divided by the channel distance between the two points as determined from topographic maps."
MO State Eq	Slope	". . .in feet per mile, is the average slope between points 10, and 85 percent of the distance along the mainstream channel from the site to the basin divide. Distance is measured by setting draftsman's dividers at 0.1 mile spread and stepping along the channel. The main channel is defined above stream junctions as the one draining the largest area. Elevation differences between the 10- and 85-percent points are divided by the distance between the points to evaluate the slope."

Mean Altitude

Mean altitude was included on the record sheets of three procedures, the Oregon, Missouri, and Washington Index Flood, although it was not needed in any flow calculations. The Missouri and Washington Index Flood were not included in the analysis because of their small sample sizes. The description of mean altitude in the Oregon Index Flood is:

> . . .using a transparent grid overlay made to map scale, although a planimeter may be used if time permits. . .the grid is placed over the map of the drainage basin, and the altitude of each intersection of the grid is recorded on a tally sheet. The mean altitude is determined by adding the altitudes so recorded and dividing by the number of items.

Mean altitude variability was low, as shown in the box plot of Figure A9-7.

Average Basin Elevation Index

Average basin elevation index was needed in flow calculations on five of the ten watersheds on which the Ohio State Equation was applicable. The description of average basin elevation index is:

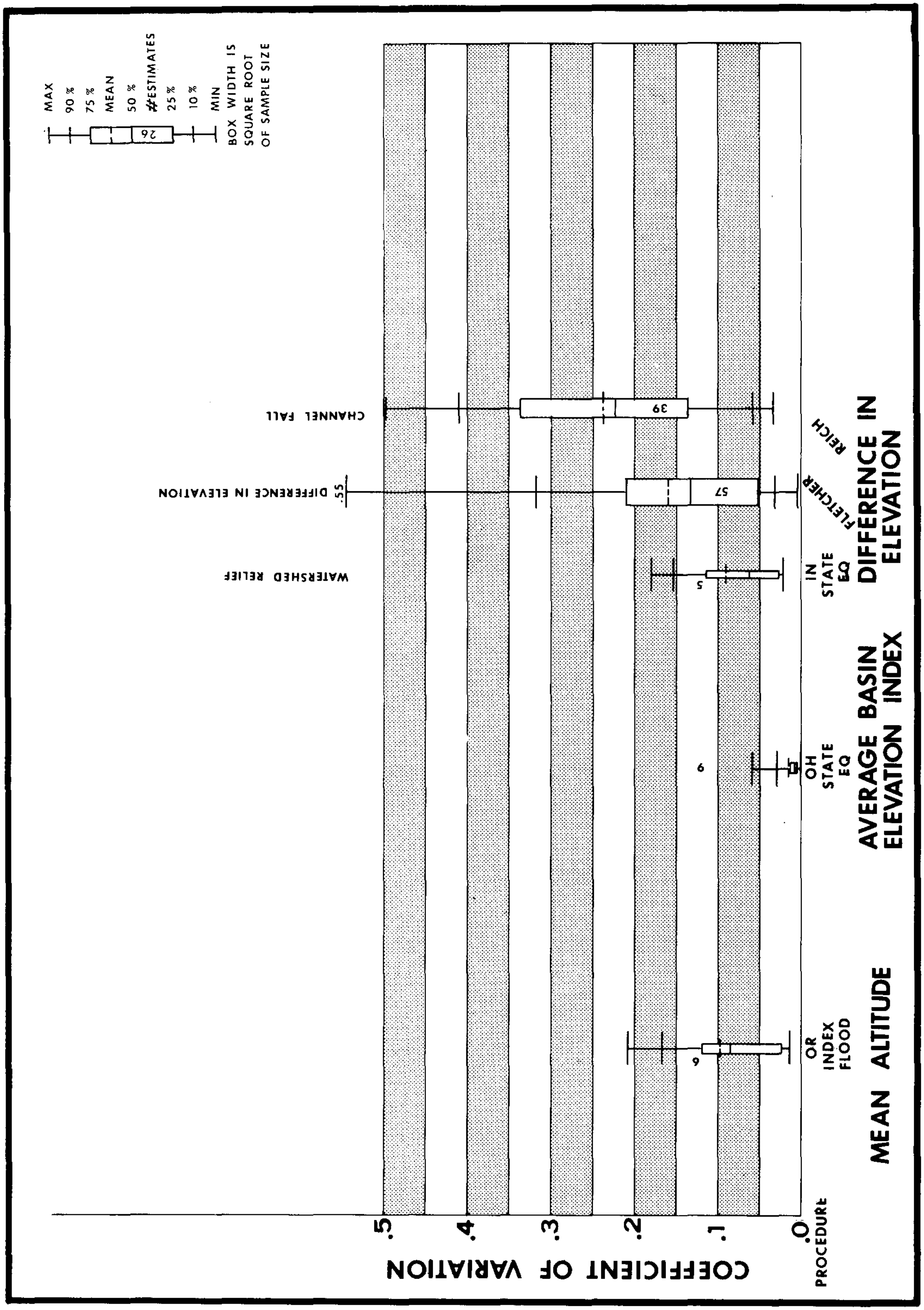
> . . .in feet above mean sea level, is computed by averaging the elevations at the 10 and 85 percent distance points along the channel as determined from topographic maps. . .in 1,000's of feet above mean sea level.

Average basin elevation index variability was low, as shown in the box plot of Figure A9-7.

Difference in Elevation

Difference in elevation was used in three procedures: the Indiana State Equation, Fletcher, and Reich. However, it was not needed in all Indiana State Equation applications. Table A9-8 provides the descriptions of difference in elevation for these procedures. Fletcher and Reich describe the same parameter, yet Reich's description is less detailed and requires judgment. These descriptions differ from the Indiana State Equation in that the highest point of the Indiana State Equation does not have to be at the head of the main channel.

FIGURE A9-7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PROCEDURE
MAX
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#ESTIMATES
25 %
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MIN
26
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE
9
OR INDEX FLOOD
MEAN ALTITUDE
6
OH STATE EQ
AVERAGE BASIN ELEVATION INDEX
WATERSHED RELIEF
5
IN STATE EQ
DIFFERENCE IN ELEVATION
.55
57
FLETCHER
CHANNEL FALL
39
REICH
DIFFERENCE IN ELEVATION

Table A9-8

DIFFERENCE IN ELEVATION DESCRIPTIONS

Procedure	Name	Description
IN State Eq	Watershed Relief	"The difference in elevation, in feet, between the highest point on the watershed perimeter and the stream at the gaging station (or point of discharge) determined from Geological Survey 7-1/2-minute topographic maps."
Fletcher	Difference in Elevation	". . .difference in elevation of the main channel between the most distant point on the watershed boundary and at the design point in feet."
Reich	Channel Fall	"Measure. . .the main channel. . . fall that affects travel time."

There were large differences in difference in elevation variability, as shown in the box plots of Figure A9-7. The Indiana State Equation had low variability, the Fletcher procedure had medium variability, and the Reich procedure had high variability. The variability in the Fletcher procedure may have been due to the difficulty in defining the main channel and its terminus as mentioned in the tester comments. The variability in the Reich procedure may have been due to the less detailed description of channel fall and the judgment required to calculate it.

One C_v value in the application of the Reich procedure was unusually large. Inspection of the five values that produced this maximum showed that one tester recorded difference in elevation in thousands of feet rather than feet. The box plot was corrected to show the true variability in parameter determination.

Area of Lakes and Ponds

Area of lakes and ponds was used in eight procedures: the Ohio State Equation, Fletcher, and the Illinois, Indiana, Idaho, Montana, Oregon, and Washington Index Flood. Four of these procedures, the Ohio State Equation and the Indiana, Idaho, and Montana Index Flood, were not included in the analysis because of their small sample sizes. Table A9-9 provides the descriptions of area of lakes and ponds for the remaining four procedures. All of these descriptions are similar except for the inclusion or exclusion of swamps.

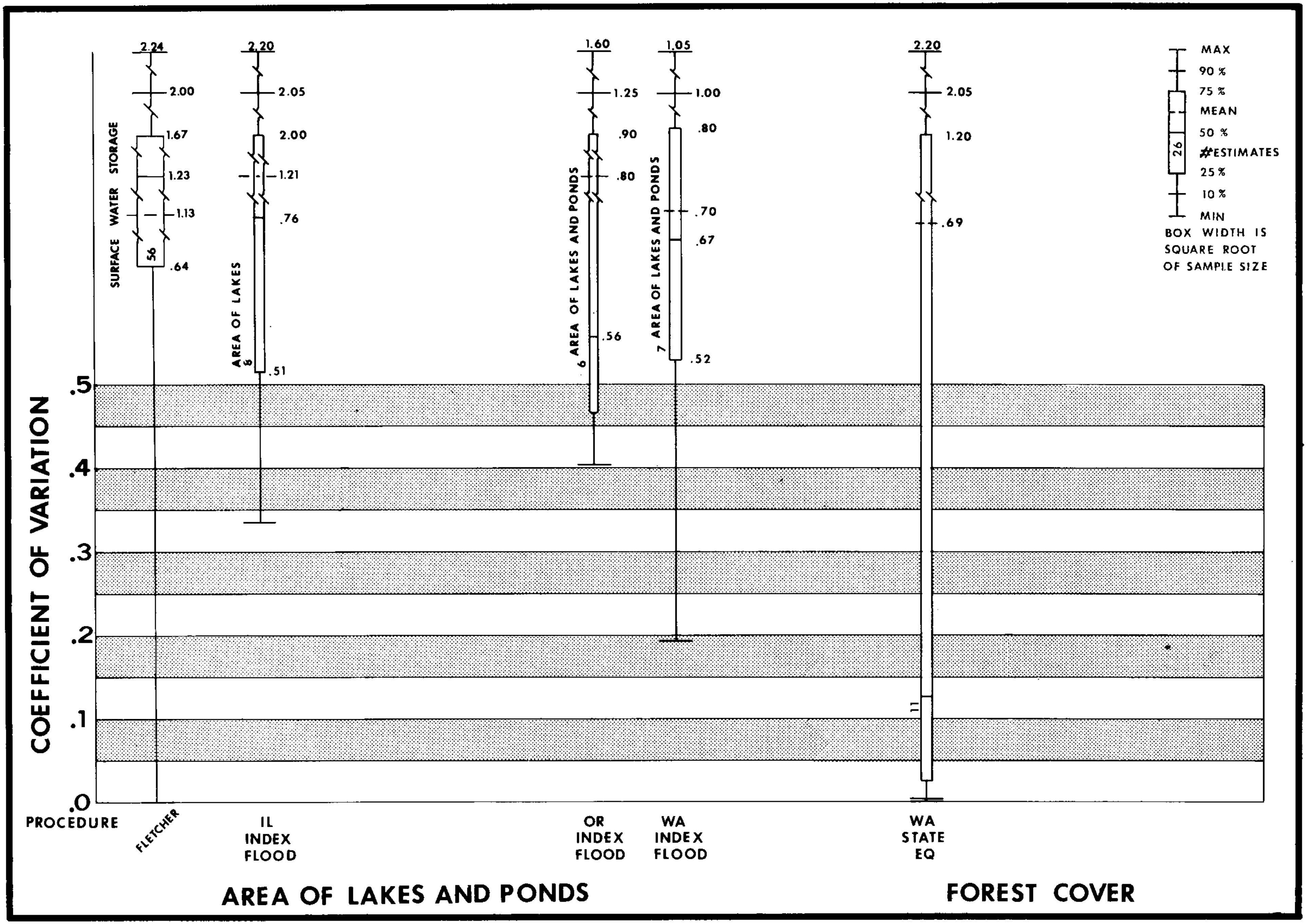
Table A9-9

AREA OF LAKES AND PONDS DESCRIPTIONS

Procedure	Name	Description
Fletcher	Surface Water Storage	". . .is the watershed area covered by lakes, swamps, etc., divided by the total area and multiplied by 100. The estimate of discharge, . . . will be adjusted for values . . .greater than 4."
IL Index Flood	Area of Lakes	". . .determine the area of lakes in the drainage basin above the site from the best available map. Compute the percentage of lakes by dividing the lake area by the total drainage area and multiplying by 100."
WA Index Flood	Area of Lakes and Ponds	". . .area of lakes and ponds within the outlined drainage on the topographic map may be measured by using either a planimeter or a grid. . .expressed as a percentage of the total drainage area with 0.01 percent. . .as a lower limiting value."
OR Index Flood	Area of Lakes and Ponds	". . .measure the area of lakes and ponds that lie within the drainage boundary and contribute to flow therein. Divide the area of lakes and ponds by the total area of the basin and multiply the quotient by 100 to obtain percentage. . .a value of 0.01 percent is used as a minimum."

Two of the procedures, Fletcher and the Illinois Index Flood, required area of lakes and ponds only if it exceeded a given minimum. As a result, 24 percent of the testers applying Fletcher recorded less than 4 percent rather than the measured value and 5 percent applying the Illinois Index Flood recorded less than 0.2 percent rather than the measured value. Only measured values were used in the analysis.

Area of lakes and ponds variability was high, as shown in the box plots of Figure A9-8. This variability was largely the result of the small values of area of lakes and ponds. All values analyzed were less than 10 percent and, excluding the Fletcher procedure, all values were less than 3 percent. When identifying, outlining, and measuring such small percentages of the total drainage area, it is hard to have agreement between testers. In addition, including only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.4
.3
.2
.1
.0
PROCEDURE
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1.23
1.13
.64
SURFACE WATER STORAGE
56
FLETCHER
2.20
2.05
2.00
1.21
.76
.51
AREA OF LAKES
8
IL
INDEX
FLOOD
1.60
1.25
.90
.80
.56
AREA OF LAKES AND PONDS
6
OR
INDEX
FLOOD
1.05
1.00
.80
.70
.67
.52
AREA OF LAKES AND PONDS
7
WA
INDEX
FLOOD
2.20
2.05
1.20
.69
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50 %
26
#ESTIMATES
25 %
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MIN
BOX WIDTH IS
SQUARE ROOT
OF SAMPLE SIZE
AREA OF LAKES AND PONDS
FOREST COVER

FIGURE A9–8

measured values of area of lakes and ponds increased the variability for these procedures.

Forest Cover

Forest cover was used in two procedures: the Washington State Equation and the Idaho Index Flood. However, it was not needed in all applications of either procedure. The Idaho Index Flood was not included in the analysis because of its small sample size. The description of forest cover for the Washington State Equation is:

> . . .the percentage of the drainage area covered by forests, as determined by the grid method from a topographic map. A minimum value of 0.01 percent. . .

Forest cover variability was high, as shown in the box plot of Figure A9-8. The length of the box indicated that tester variability was not as great on some watersheds as on other watersheds. Additional analyses indicated that this variability may have been site size dependent in that forest cover was much more variable on less than 10-square-mile watersheds. However, sample sizes were small and the effects of this are unknown.

Forest cover variability was probably the result of varied tester identification and delineation of forest cover on a topographic map. Some factors that could have affected a tester's interpretation were more recent aerial photographs or suspected changes that have occurred since the topographic maps were printed.

Summary and Conclusions

Table A9-10 summarizes the range of variability of the input parameters that were measured from a topographic map. Three parameters had low variability and four parameters had medium or high variability. Two parameters had low, medium, and/or high variability depending on the procedure. The description and resulting skills and judgment to determine these parameters explained some of their variability. For example, the main channel length and channel fall in the Reich procedure had medium and high variabilities, respectively, because the less detailed definitions required more tester judgment. In other procedures, the map scale may have been an important factor.

Table A9-10

VARIABILITY SUMMARY OF PARAMETERS MEASURED FROM A TOPOGRAPHIC MAP

Low	Medium	High
Drainage Area		
Main Channel Length-IN State Eq	Main Channel Length-Reich	
Mean Altitude	Main Channel Slope	Average Watershed Slope
Average Basin Elevation Index		
Difference in Elevation-IN State Eq	Difference in Elevation-Fletcher	Difference in Elevation-Reich
		Area of Lakes And Ponds
		Forest Cover

Five parameters in this group (main channel slope, mean altitude, average basin elevation index, area of lakes and ponds, and forest cover) were input parameters to regression procedures (Categories 1 and 3) only. Four parameters (drainage area, main channel length, average watershed slope, and difference in elevation) were input parameters to regression and/or rain-runoff procedures (Categories 5 and 6).

Comparison of the two slope parameters showed that main channel slope was less variable than watershed slope. This was probably because main channel slope was better described and easier to measure.

C. Parameters that Required Direct Tester Knowledge and Judgment

Two parameters encountered in the pilot test required direct tester knowledge and judgment to determine the parameter value. As a result, tester experience may have been an important factor in their interpretation.

Cover Factor

Cover factor was needed in flow calculations for the Reich procedure only. The description of cover factor is:

> Estimate the watershed's overall cover factor, F, from Table 2 (type, condition, and range of cover factor). . .check your value against Table 3.

Cover factor variability was high, as shown in the box plot of Figure A9-9. In the application of the Reich procedure, two testers recorded estimates outside the tabulated range (1.0 to 7.5) of cover factor values. One estimate appeared to be a misplaced decimal error because the infiltration index (land use factor times cover factor) was correct. The box plot was corrected to show the true variability in parameter determination.

Runoff Coefficient

Runoff coefficient was needed in flow calculations for the rational formula only. The description of the runoff coefficient is:

> . . .a function of land use (attached Table 1). For drainage areas having non-homogeneous land use, a weighted estimate of C can be determined from $C = \sum_{i=1}^{i=n} LU_i C_i$ where n is the number of different land uses, C is the runoff coefficient for land use i, and LU is the fraction of land use i. (note: $\sum_{i=1}^{i=n} LU_i = 1$).

Runoff coefficient variability was medium, as shown in the box plots of Figure A9-9.

Summary and Conclusions

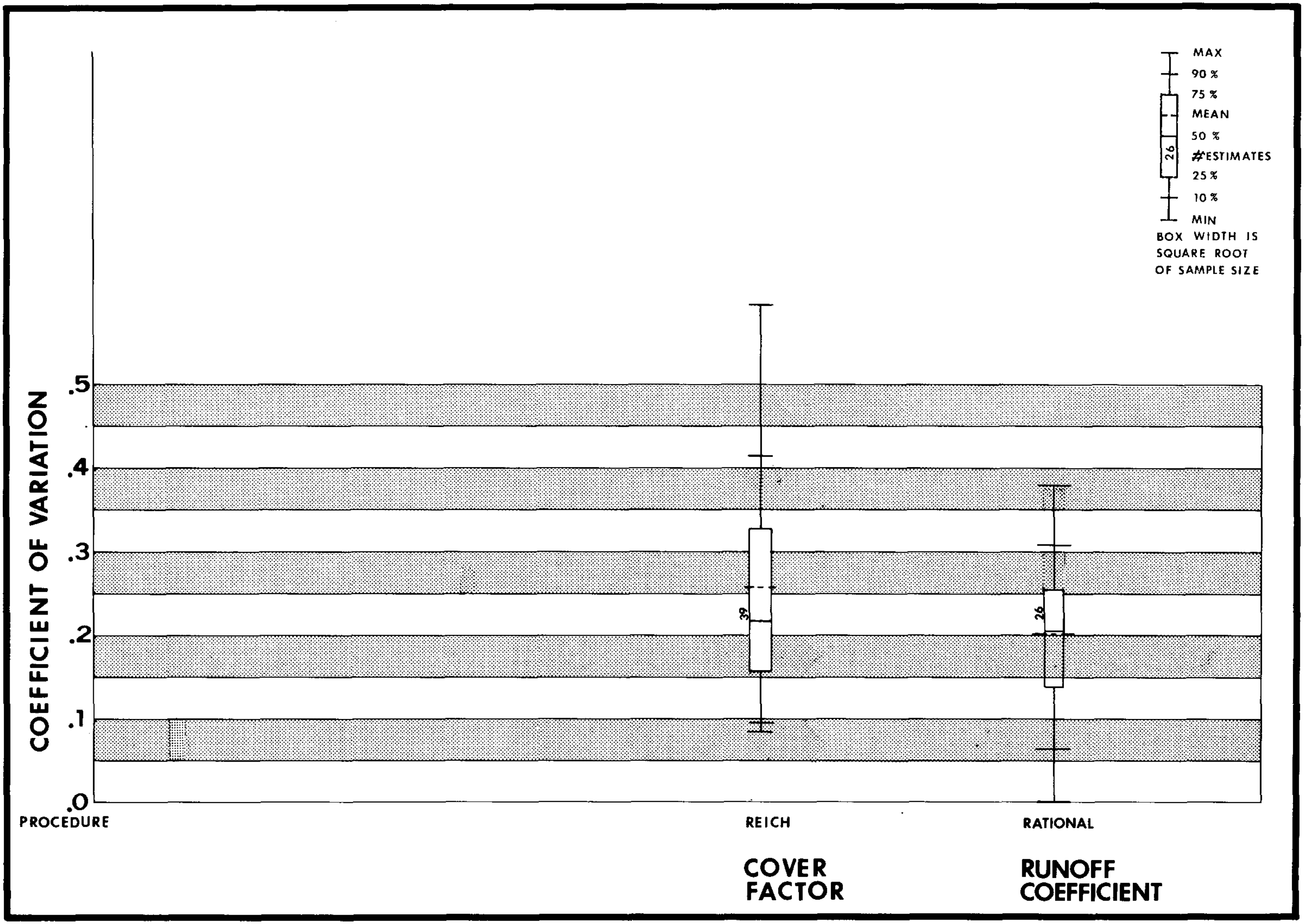
Both input parameters, runoff coefficient and cover factor, that required direct tester knowledge and judgment in their determination had medium or high variability and were input to the rain-runoff procedures of Category 5.

D. Parameters that Were a Combination of Other Parameters

Five parameters encountered in the pilot test were the combination of previously calculated parameters. Given the component parameters, no judgment was required to combine them. The parameter variability then depended on the variability of the components and the effects of their combination.

Watershed Shape Factor

Watershed shape factor was included on the record sheet of the Indiana State Equation although it was not needed in any flow calculations. The description of watershed shape factor in this procedure is "The ratio of stream length to the diameter of a circle having the same area as the watershed. . .computed by. . . $0.89LA^{-\frac{1}{2}}$."


MAX
90 %
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MEAN
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MIN
26
BOX WIDTH IS
SQUARE ROOT
OF SAMPLE SIZE
COEFFICIENT OF VARIATION
.5
.4
.3
.2
.1
.0
39
26
PROCEDURE
REICH
RATIONAL
COVER
FACTOR
RUNOFF
COEFFICIENT

FIGURE A9-9

Watershed shape factor variability was medium, as shown in the box plot of Figure A9-10. Comparison of the main channel length and drainage area variabilities and watershed shape factor variability showed watershed shape factor variability to be greater than or equal to the variability of either component. Main channel length was probably responsible for the majority of the variability in the watershed shape factor as evidenced by their similar box plots.

Infiltration Index

Infiltration index was needed in flow calculations for the Reich procedure only. The description of infiltration index is:

> Determine the infiltration index, land use factor times cover factor.

Infiltration index variability was high, as shown in the box plot of Figure A9-10. Comparison of land use factor and cover factor variabilities and infiltration index variability showed infiltration index variability to be greater than the variability of either component about two-thirds of the time. However, all three had high variability.

Land Use Factor

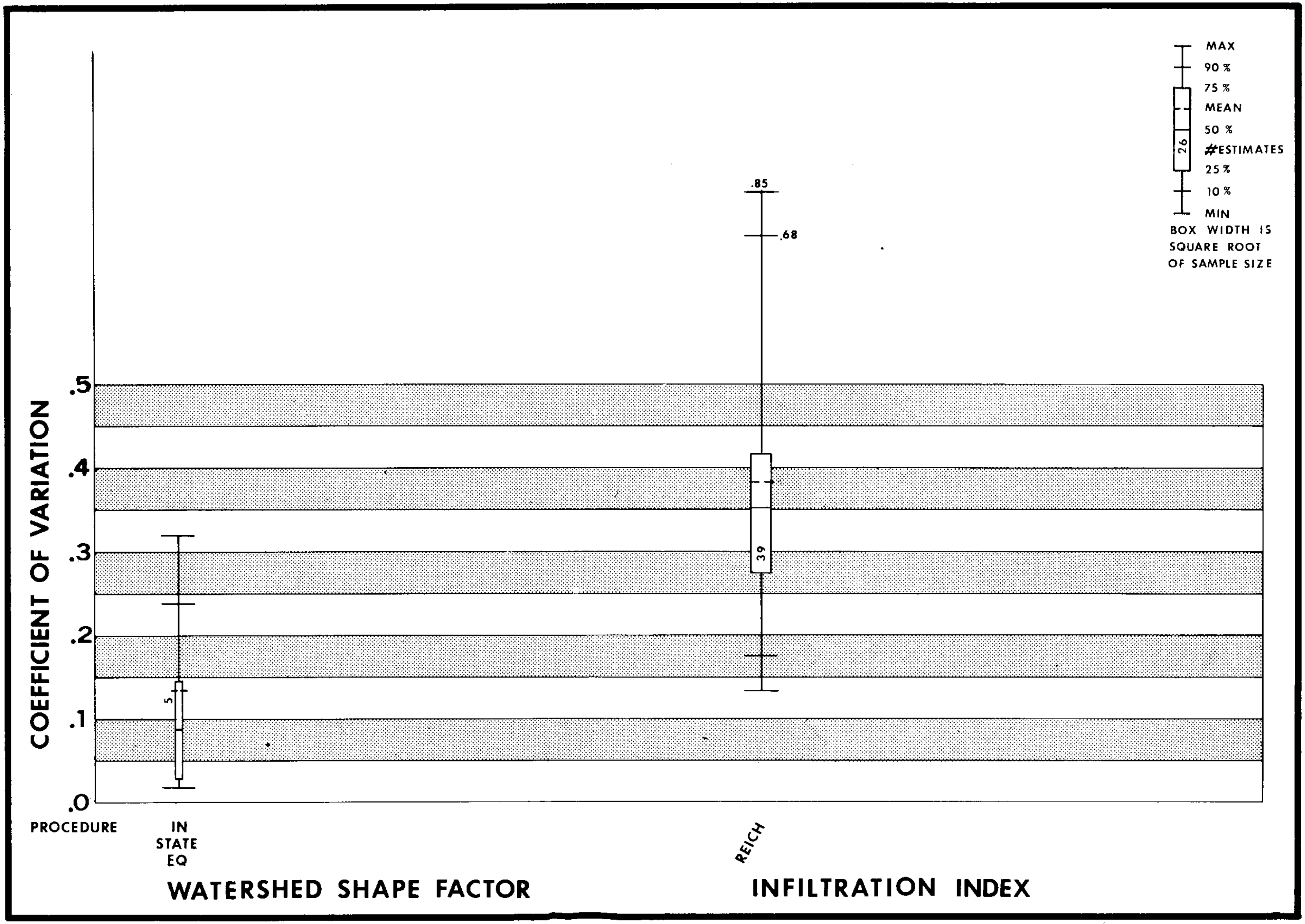
Land use factor was needed in flow calculations for the Reich procedure only. The description of land use factor is:

> Complete lines A through J selected from Table 1. (A, texture; B, strength of aggregates; C, size of aggregates; D, shape of aggregates; E, permeability; F, internal soil drainage; G, erosion class; H, land capability; I, surface drainage; and J, slope.) The addition of these gives f as per example.

Land use factor variability was high, as shown in the box plot of Figure A9-11. This could have been because site specific information to determine this parameter was not included in the resource package. Inspection of tester estimates of this parameter showed five estimates that were up to five times larger than the maximum possible land use factor (0.715). One estimate appeared to be a recording error because it was the same as the tester's estimate of infiltration index.

Time of Concentration

Time of concentration was needed in flow calculations for three procedures: Reich, rational, and TR-55 Graph. Table A9-11 provides the descriptions of time of concentration for these procedures. The Reich procedure and the rational formula descriptions differ from TR-55 Graph in that time of concentration in the latter procedure requires direct tester knowledge and judgment to compute.


COEFFICIENT OF VARIATION
.0
.1
.2
.3
.4
.5
MAX
90 %
75 %
MEAN
50 %
#ESTIMATES
25 %
10 %
MIN
BOX WIDTH IS
SQUARE ROOT
OF SAMPLE SIZE
26
.85
.68
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5
PROCEDURE
IN
STATE
EQ
REICH
WATERSHED SHAPE FACTOR
INFILTRATION INDEX

FIGURE A9-10

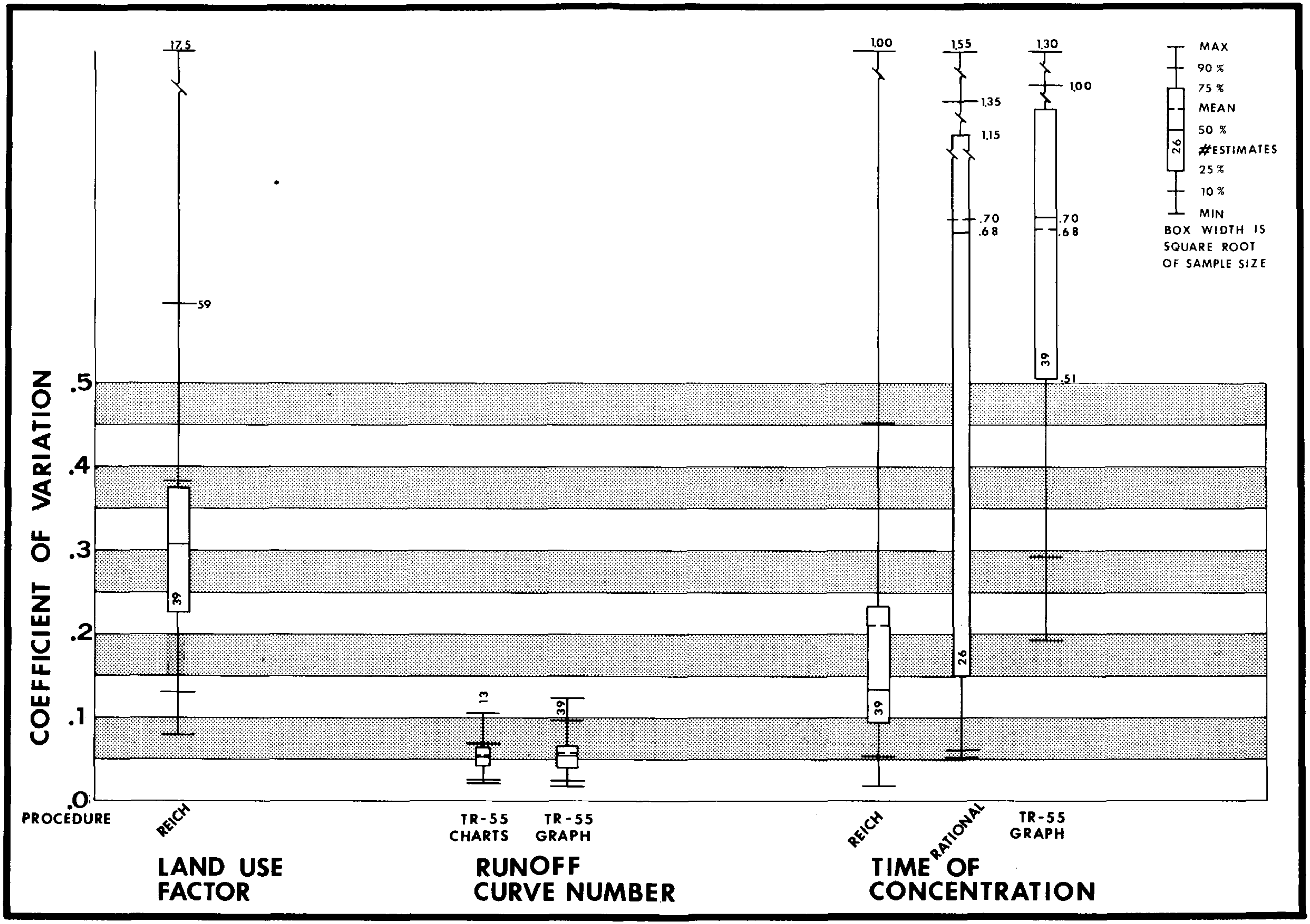

COEFFICIENT OF VARIATION
.0
.1
.2
.3
.4
.5
PROCEDURE
REICH
TR-55 CHARTS
TR-55 GRAPH
REICH
RATIONAL
TR-55 GRAPH
LAND USE FACTOR
RUNOFF CURVE NUMBER
TIME OF CONCENTRATION
17.5
59
39
13
39
1.00
39
1.55
1.35
1.15
.70
.68
26
1.30
1.00
.70
.68
39
.51
MAX
90 %
75 %
MEAN
50 %
#ESTIMATES
25 %
10 %
MIN
26
BOX WIDTH IS SQUARE ROOT OF SAMPLE SIZE

FIGURE A9–11

Table A9-11

TIME OF CONCENTRATION DESCRIPTIONS

Procedure	Name	Description
Reich	Time of Concentration	". . .main channel length and its fall... to determine B from Fig. 1."
Rational	Time of Concentration	"Estimate time of concentration, T_c, (hours) from $T_c = 0.000136^{0.77}/S^{0.385}$ where L = length of drainage area (in feet), S = average slope (in ft/ft), or any method you normally use to compute time of concentration."
TR-55 Graph	Time of Concentration	". . .time it takes for runoff to travel from the hydraulically most distant part of the watershed to the point of reference. It is usually computed by determining the water travel time through the watershed. . ."

There were differences in time of concentration variability, as shown in the box plots of Figure A9-11. The Reich procedure had medium variability and the rational formula and TR-55 Graph had high variability.

Reich procedure variability may have been the result of two things mentioned in the tester comments. First, the figure used to determine time of concentration had to be extended on the upper end. Second, the figure provided by the Work Group differed by as much as 20 percent from the figure in the formal publication. The variability may have depended in part on which figure the tester used to determine time of concentration.

Comparison of main channel length and channel fall variabilities and time of concentration variability in the Reich procedure showed channel fall was generally more variable and main channel length was less variable than time of concentration. However, all three had medium variability.

TR-55 Graph had consistently higher variability than the rational formula as evidenced by its short, higher box. This was due to the tester knowledge and judgment required to compute time of concentration. The rational formula had changing variability as evidenced by the long box. This indicated that tester variability was not as great on some watersheds as on others. Additional analyses showed this changing variability may have been regional in that time of concentration was more variable in the Northwest than in the Midwest.

Runoff Curve Number

Runoff curve number was needed in flow calculations for TR-55 Charts and Graph. It is obtained from land use and hydrologic soil group information as:

> . . .Table 2-2 gives CN's for agricultural, suburban, and urban land use classifications. The suburban and urban CN's are based on typical land use relationships that exist in some areas. . .

Runoff curve number variability for these procedures was low, as shown in the box plots of Figure A9-11. The soils data or hydrologic soil groups were provided to the testers and this may have reduced parameter variability.

Summary and Conclusions

Table A9-12 summarizes the range of variability of the input parameters that are a combination of other parameters. One parameter had low variability and four parameters had medium and/or high variability. Watershed shape factor was an input parameter to regression procedures (Categories 1 and 3). All other parameters in this group were input to rain-runoff procedures (Categories 5 and 6).

Table A9-12

VARIABILITY SUMMARY OF PARAMETERS THAT WERE A COMBINATION OF OTHER PARAMETERS

Low	Medium	High
Runoff Curve Number	Watershed Shape Factor	Infiltration Index
		Land Use Factor
	Time of Concentration-Reich	Time of Concentration-Rational TR-55 Graph

Table A9-13 compares the variability of the parameter and its components in those cases where the components were also recorded. A parameter that was a combination of previously calculated parameters was generally at least as variable as its most variable component. Therefore, it is wise to define such components in terms of low variability parameters.

Table A9-13

VARIABILITY SUMMARY OF PARAMETERS AND COMPONENTS

Parameter	Parameter Variability	Component	Component Variability
Watershed Shape Factor	Medium	Drainage Area	Low
		Main Channel Length	Low
Infiltration Index	High	Land Use Factor	High
		Cover Factor	High
Time of Concentration-Reich	Medium	Main Channel Length	Medium
		Channel Fall	Medium

E. Adjustment Factors

Seven adjustment factors were encountered in the pilot test: antecedent precipitation index adjustment, late-peaking storm adjustment, slope adjustment factor, shape adjustment factor, ponding and swampy adjustment factor, impervious area adjustment factor, and hydraulic length adjustment factor. In evaluating the variability of the adjustment factors, it was necessary to consider two things: (1) What percentage of the testers correctly identified the applicability of the adjustment factor to the test watershed and (2) given that the adjustment factor was applicable, what was the variability of the adjustment factor values.

In the pilot test, it was not possible to answer these questions. The test record sheet did not specifically ask if the adjustment factor was applicable to the test watershed. Instead, it listed all possible adjustment factors followed by blanks. As a result, it was not known how many testers actually needed and used the adjustment factor in their calculations and how many simply filled in the blank on the record sheet. Antecedent precipitation index adjustment and late-peaking storm adjustment in the Reich procedure required tester knowledge of the watershed and judgment to determine if the adjustment was applicable. When it was, the adjustment was a straightforward process of increasing the peak flow from the design charts by 20 and 50 percent, respectively. The variability of these adjustment factors then was in whether or not they were correctly identified as being applicable, not in their recorded values. Because this information was not available in the pilot test, their input parameter variability was not evaluated.

Determination of the remaining five adjustment factors involved determining a parameter and, given the adjustment criteria, determining if the adjustment was applicable. When it was, the adjustment was generally a straightforward process of reading from a table or graph. The variability of these adjustment factors was in whether or not they were correctly identified as being applicable as well as in the recorded values. Because the applicability question was not addressed in the pilot test, the variability analysis of these adjustment factors assumed that a tester who recorded an adjustment correctly identified its applicability and used it in their calculations. The impervious area adjustment factor of the TR-55 Charts and Graph was not included in the analysis because only natural watersheds were included in the pilot test.

Slope Adjustment Factor

Slope adjustment factor was optional in flow calculations for TR-55 Charts. Of the testers applying TR-55 Charts, 6 percent did not record a value, implying a factor of 1.0. It was also included on the record sheet of TR-55 Graph although it was not needed in any flow calculations. In spite of this, 24 percent of the testers applying TR-55 Graph recorded an adjustment factor.

The description of slope adjustment factor for the TR-55 Charts is:

> . . .charts for FLAT slope are based on 1-percent slope, for MODERATE 4-percent slope, and for STEEP slope on 16-percent slope. For slopes other than 1, 4, and 16 percent, use the factors shown in Table E-1 to modify the peak discharges.

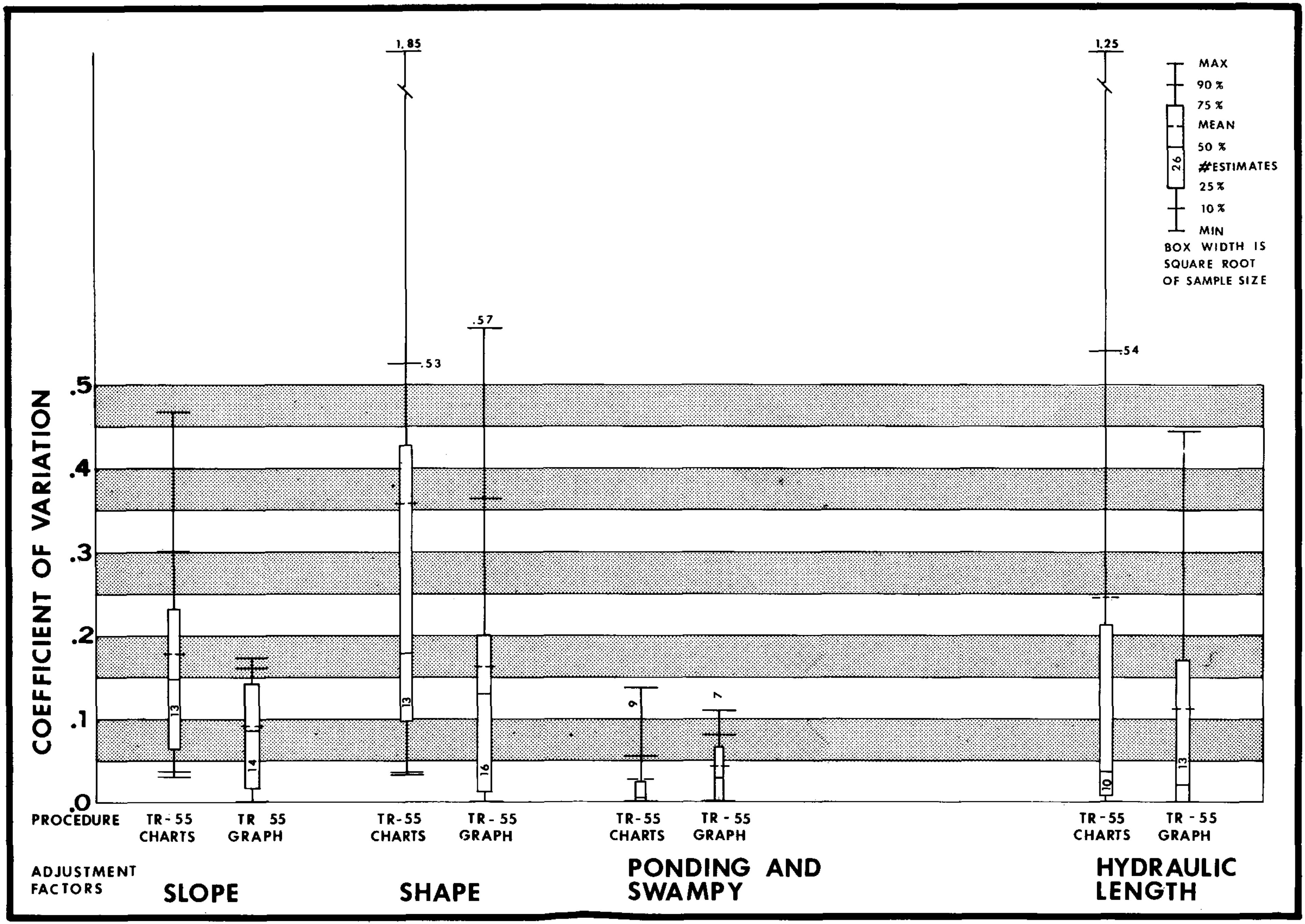
Slope adjustment factor variability for these procedures was medium, as shown in the box plots of Figure A9-12. Also, TR-55 Charts was more variable than TR-55 Graph.

Comparison of the slope adjustment factor and average watershed slope for TR-55 Charts showed there was much more variability in the watershed slope than in the adjustment factor. This may have been due to the small range of possible slope adjustment factor values (0.4-1.43).

Shape Adjustment Factor

Shape adjustment factor was optional in flow calculations for TR-55 Charts. Of the testers applying TR-55 Charts, 17 percent did not record a value, implying a factor of 1.0. It was also included on the record sheet of TR-55 Graph although it was not needed in any flow calculations. In spite of this, 24 percent of the testers applying TR-55 Graph recorded an adjustment factor.

The description of shape adjustment factor for the TR-55 Charts is: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MAX
90 %
75 %
MEAN
50 %
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25 %
10 %
MIN
26
BOX WIDTH IS
SQUARE ROOT
OF SAMPLE SIZE
PROCEDURE
TR-55 CHARTS
TR 55 GRAPH
TR-55 CHARTS
TR-55 GRAPH
TR-55 CHARTS
TR-55 GRAPH
TR-55 CHARTS
TR-55 GRAPH
ADJUSTMENT FACTORS
SLOPE
SHAPE
PONDING AND SWAMPY
HYDRAULIC LENGTH

FIGURE A9-12

. . .A watershed shape factor, ℓ/w (where w is the average width of the watershed and ℓ is the hydraulic length of the watershed), is then fixed for any given drainage area. . . There are watersheds that deviate considerably from these relationships. The peaks can be modified for other shape factors. The procedure is as follows:

1. Determine the hydraulic length of the watershed and compute an "equivalent" drainage area using $\ell=209a^{0.6}$ or Figure E-1.

2. Determine the "equivalent" peak flow from the charts for the "equivalent" drainage area.

3. Compute the "actual" peak discharge for the watershed by multiplying the equivalent peak discharge by the ratio of actual drainage area to the equivalent drainage area.

There was a large difference in shape adjustment factor variability between these two procedures, as shown in the box plots of Figure A9-12. TR-55 Graph had medium variability and TR-55 Charts had high variability.

TR-55 Charts also had an unusually large maximum C_v. Inspection of the five values that produced this maximum showed that one tester estimated the slope adjustment factor to be 25 times larger than the other four.

<u>Ponding and Swampy Adjustment Factor</u>

Ponding and swampy adjustment factor was optional in flow calculations for TR-55 Charts and was generally not applicable to TR-55 Graph. Of the testers applying TR-55 Charts and Graph, 55 percent and 82 percent, respectively, did not record a value, implying a factor of 1.0.

The description of ponding and swampy adjustment factor for the TR-55 Charts is:

> Peak flows determined from Appendix D assume that topography is such that surface flow into ditches, drains, and streams is approximately uniform. On very flat areas where ponding or swampy areas occur in the watershed, a considerable amount of the surface runoff may be retained in temporary storage. . . determine this reduction based on the ratio of the ponding or swampy area to the total watershed area for a range of storm frequencies.
>
> Table E-2 contains adjustment factors to be used when the ponding or swampy area are located in the path of flow in the vicinity of the design point. Table E-3. . .when a significant amount of the flow from the total watershed passes through ponding or swampy areas and these areas are spread throughout the watershed.

Table E-3. . .when a significant amount of the flow passes through ponding and swampy areas that are located only in the upper reaches of the watershed.

Ponding and swampy adjustment factor variability for these procedures was low, as shown in the box plots of Figure A9-12.

Hydraulic Length Adjustment Factor

Hydraulic length adjustment factor was optional in flow calculations for TR-55 Charts. Of the testers applying TR-55 Charts, 57 percent did not record a value, implying a factor of 1.0. It was also included on the record sheet of TR-55 Graph although it was not needed in any flow calculations. In spite of this, 24 percent of the testers applying TR-55 Graphs recorded an adjustment factor.

The description of hydraulic length adjustment factor for TR-55 Charts is ". . .adjustment factor for percent of hydraulic length modified." Hydraulic length is described as "the greatest flow length in feet" and modified "is where the natural condition of the main channel has been hydraulically improved."

Hydraulic length adjustment factor variability was medium, as shown in the box plots of Figure A9-12. TR-55 Charts had an unusually large maximum C_v. The two recorded values that produced this maximum were 1.0 and 15.0. However, the largest adjustment factor was about 2.2 for the tester's curve number and 100 percent modification. Therefore, an hydraulic length adjustment factor of 15 was impossible.

F. Summary and Conclusions

In general, input parameters for rain-runoff procedures (Categories 5 and 6) were more variable than input parameters for regression procedures (Categories 1 and 3). The relative variability of the groups of parameters, from least to most, was: (1) parameters read from a map, graph, or table; (2) parameters measured from a topographic map; (3) parameters that were a combination of other parameters; and (4) parameters that required direct tester knowledge and judgment. This was based on the number of parameters within a group with low variability versus those with medium or high variability.

A parameter with low variability in the total analysis had low variability in the regional and site size analyses. This was also true for high variability. Although the relative variability of the parameters did not change across regions, procedures that were analyzed by region showed a higher degree of parameter variability in the Northwest. Due to small sample sizes, no input parameter variability trends were detectable across site sizes.

This analysis is admittedly just a beginning. Many more analyses and conclusions regarding input parameter variability are possible and necessary from the pilot test data base. Some suggestions for further analysis are:

1. Conduct a sensitivity analysis to determine the absolute effect of input parameters on the resulting peak flow estimates. This combined with the above variability analysis would help answer the flow variability question.

2. Analyze unusual parameter values to determine if these values are recording errors or if these values were used, as recorded, in flow calculations. If the unusual values are recording errors, the parameter variabilities should be reanalyzed.

3. Analyze input parameter variability in relation to combinations of tester experience, knowledge of the procedure, knowledge of the region, and field visit. This analysis would determine what effect tester background and field visit had on parameter variability, especially those parameters requiring tester judgment.

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