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Adoption of Flood Flow Frequency Estimates at Ungaged Locations

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14. ABSTRACT
The purpose of this paper was to present the concept of adopting flood flow frequency relationships at ungaged locations based on all the available information. This method essentially compares the flood flow frequency results of various procedures and adopts a function which may constitute the results of one procedure or may be a constructed function which in its entirety is none of those analytically or otherwise determined. The emphasis was placed on the need of the professional performing the analysis to understand available procedures, study considerations which affect the analysis and utilization of field reconnaissance information, all of which influence the evaluation process and subsequent reliability of the results. An appendix was included which described in detail selected categories of procedures commonly used in analysis of flood flow frequency relationships for ungaged locations. The appendix included descriptions of the methodologies involved in using the individual procedures and listed the primary advantages and limitations of each. The use of the adopted frequency curve concept provides insight as to the variability and reliability of the results, places proper emphasis on the end product, the frequency curve, and generally results in better flood flow frequency estimates.

15. SUBJECT TERMS
flood flow, flood frequency, frequency curves, estimating, flood discharge, hydrograph analysis, discharge (water), analytical techniques, hydrologic aspects, watersheds (basins), precipitation (atmospheric), ungaged locations

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US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

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INTRODUCTION

Hydrologic aspects of studies requiring flood analyses are typically consummated with the determination of flood flow frequency relationships at desired locations. These relationships are used in many types of water resource studies and include evaluations for determining the potential flood hazard of an area, planning of flood loss reduction measures, assessing impacts of alternative land use patterns, and design of secondary and primary flood control facilities. The level of detail of these studies ranges from the design of municipal culverts to planning and design of facilities for complex river systems. The major problem in developing these relationships is typically the determination of reliable estimates at locations where data are limited or nonexistent. These locations are generally called ungaged locations and constitute over 90 percent of all the sites analyzed. The hydrologic procedures used in evaluating these locations vary significantly both in technique and level of sophistication. In general, they may be grouped as transfer methods, statistical methods, simplified equations and simulation models.

The selected procedures used to evaluate ungaged locations should be based on the type of study, the constraints of the study, data availability, physical and meteorological characteristics of the basin and region, institutional policies and the experience and capability of the professional performing the analysis. The reliability of the resulting flood flow frequency estimates also corresponds to the above considerations but rests largely with the person conducting the investigation. Advocates of various procedures continuously expound upon and illustrate favorable comparison results of their methods over other procedures in the literature. Many, however, ignore the above mentioned considerations in their comparisons, especially the experience and judgment aspects of other professionals to adequately adapt the procedures to different analysis situations. The person performing the flood flow frequency analysis must realize that each study situation is unique and must consider all the factors prior to selecting procedures for analysis.

The purpose of this paper is to present the concept of adopting flood flow frequency relationships at ungaged locations[1*] based on all the available information. This method essentially compares the flood flow frequency results of various procedures and adopts a function which may constitute the results of one procedure or may be a constructed function which in its entirety is none of those analytically or otherwise determined. The emphasis is placed on the need of the professional performing the analysis to understand available procedures, study considerations which affect the analysis and utilization of field reconnaissance information, all of which

*References are listed on Appendix B.

influence the evaluation process and subsequent reliability of the results. An appendix is included which describes in detail selected categories of procedures commonly used in analysis of flood flow frequency relationships for ungaged locations. The appendix includes descriptions of the methodologies involved in using the individual procedures and lists the primary advantages and limitations of each.

OVERVIEW OF PROCEDURES

The types of procedures used to determine flood flow frequency estimates at ungaged locations fall into four general categories: data transfer methods, statistical methods, empirical equations, and simulation models. To enable more specific discussion and understanding of the procedures, they were further subdivided into eight categories to generally coincide with those adopted by the Water Resources Council's sponsored task force on flood flow frequencies for ungaged watersheds.[2] Although these classifications constitute by far the majority of the procedures commonly used, they are not totally inclusive. Numerous variations and levels of sophistication of each of the procedures also exist. The following paragraphs briefly describe the eight classifications of procedures and their primary products.[3] Appendix A describes in detail the basic methodology, advantages, and limitations of the individual procedures.

Statistical Estimation of Qp (Category I). This procedure uses accepted statistical methods to develop prediction equations for selected peak discharge frequency relationships. The equations are based on regression analysis which correlates regional gaged parameters to those at the ungaged location. The result is a set of equations to determine selected peak frequency discharges.

Statistical Estimation of Moments (Category II). This procedure is similar to the one previously discussed except the statistically derived prediction equations are developed to provide the three moments of the frequency function (mean, standard deviation and skew) at the ungaged locations. Regression analysis is performed to correlate hydrologic parameters at gaged locations to the three moments. The equations for the three moments are used to predict a flood flow frequency function at the ungaged basin.

Index Flood Estimate (Category III). The index flood estimate procedure also uses regression analysis of regional gaged basin data to derive prediction equations. This analysis differs from the previous methodology by generating an index flood which may be multiplied by regionally determined ratios to determine selected frequency events. The mean annual flood event is typically used as the index flood. The results are selected peak flood flow frequency equations which are a function of definable hydrologic characteristics.

Transfer Methods (Category IV). The Water Resources Council's task force describes this classification as the transfer of selected discharge frequency relationships from a gaged location to a desired ungaged location immediately upstream or downstream of the gage. An adjustment to the peak discharge is based on a function of the two drainage area sizes. This classification has been broadened herein to include direct transfer of discharge frequency relationships from hydrologically similar gaged locations to ungaged locations.

Empirical Equations (Category V). These equations are typically used to design small municipal facilities. The most common of these is the rational formula which estimates selected peak flood flow frequency relationships based on rainfall intensity, drainage area size and a coefficient to capture hydrologic characteristics of a watershed. The peak discharges can be used to develop a discharge frequency curve.

Single Event Simulation (Category VI). Single event simulation models attempt to model the hydrologic process by approximating the precipitation, losses, overland flow and main conveyance flow characteristics of a watershed. Hypothetical rainfall frequency patterns are used in the model, which is calibrated to available information so that the rainfall frequency approximates runoff frequency. The results are sets of flood flow frequency hydrographs which are used to develop frequency curves at prescribed locations.

Mutliple Discrete Events (Category VII). The multiple discrete event analysis uses single event simulation models to perform the evaluations. The difference between the two procedures is that selected discrete rainfall events for each year of the period of record are used instead of hypothetical rainfall frequency values. The results yield maximum peak annual hydrographs for each year of the period of record. These values are subsequently used to develop corresponding frequency curves at the desired locations.

Continuous Record (Category VIII). This method provides a continuous simulation of the hydrologic rainfall-runoff process for a specified period of record. Continuous historic rainfall records are typically used in the model. The model is calibrated to available information. The results are a continuous set of runoff hydrographs. The peak event for each year of the period of record is used to develop a frequency curve.

STUDY CONSIDERATIONS

It is important that professionals performing flood flow frequency analysis of ungaged areas understand the factors involved in a study prior to selection of the analytical techniques to be used. The final selection of the procedures should not be predetermined but well thought through based on the study considerations. Each study is so unique that procedures may vary significantly. The reliability of the final results are correspondingly dependent upon the factors and nature of the study. The following lists these considerations which are discussed in more detail in subsequent paragraphs.

- Study type and purpose
- Time and resources (manpower, monies, etc.)
- Physical and meteorological characteristics of the study area and region
- Availability of data and previously developed procedures and models
- Institutional policies regulating the study and methodologies
- Experience, judgment and capability of the professional performing an analysis

Study Type and Purpose. Flood discharge frequency relationships are utilized in a variety of studies which vary significantly both in scope and level of detail. In general, the studies may be categorized as flood hazard information studies, planning investigations and design analyses. Historically, flood flow frequency estimates of ungaged areas for design analyses have often yielded conservative results; i.e., the determined discharges are estimated high for corresponding probability of occurrences. The logic for generating conservative results is the unknown reliability of the estimates and the corresponding need for safety considerations of the facility being designed. Unfortunately, many professionals have instilled the logic into flood hazard and planning investigations. Conservative estimates for these studies tend to yield undue economic hardships (flood insurance costs, development costs, etc.) for the former and subsequent improper economic results for feasibility investigations in the latter. It is imperative that the flood flow frequency relationships for these studies, as well as design analyses where safety is not a factor, be as reliable as possible. The following are examples of typical types of studies where flood flow frequency relationships at ungaged locations are required.

- Flood Hazard Potential Investigations - These studies provide flood hazard information and typically use discharge frequency data to obtain elevation frequency functions at desired locations. The studies vary significantly in scope and level of detail. Examples are: telephone requests, Federal Insurance Administration investigations, and information for flood plain zoning, development, etc.

- Planning Studies - Planning studies typically use flood flow frequency information to develop subsequent economic evaluations and environmental impacts. Examples of these studies are feasibility evaluations of physical flood control works and nonstructural alternatives, and impact evaluations of alternative land use patterns.

- Design Studies - Design studies use flood flow frequency estimates for design of a broad scope of facilities ranging from major projects where failure may result in catastrophic losses to smaller scaled projects where failure may only result in nuisance or nonconsequential losses. Examples of design studies utilizing flood flow frequency relationships are: the design of major physical flood control facilities; design of secondary drainage systems; and the design of a single culvert or bridge.

The type and objectives of the study define how flood flow frequency relationships will be utilized and play a major role in selection of procedures and corresponding levels of detail required. For example, simple watershed studies involving the determination of the flood hazard potential may use techniques which determine only the peak flood flow frequency relationships. Other studies involving complex watershed systems where timing is important, reservoir evaluations or alternative future land use pattern assessments typically require techniques that generate entire hydrographs.

Time and Resources Availability. Theoretically, study considerations of time, monies, manpower, and analytical processing capabilities should not influence the manner in which the hydrologic aspects of a study are conducted. The analysis methods should be based on the overall study objectives and needs, i.e., the types of hydrologic information required (peak flows, complete hydrographs, locations for analysis, etc.) and the desired degree of reliability of the estimates. Realistically, however, these factors do place constraints on the hydrologic methodologies used. The selection of the hydrologic methods for analysis should be based on an interactive process with other study disciplines (economics, design, environmental, etc.). The scope and detail of the hydrologic analysis should initially be determined, based entirely on the study objectives and needs without consideration of time, monies, manpower, etc., constraints. The reliability of the resulting estimates should be scaled to be consistent with those being generated by other disciplines, all of which are influenced by the above mentioned study constraints. Constant communication between the study disciplines and managers is required to properly define the appropriate level of detail for the study. The hydrologic methodology and procedures finally adopted must maintain the capability to successfully prosecute the analysis to meet the initial study objectives and needs in a level of detail that is appropriate with institutional criteria and consistent with other study disciplines.

Hydrological Characteristics. Hydrological characteristics are defined as meteorological and physical basin parameters that directly impact the runoff response characteristics (volume, magnitude and timing) of a watershed. It is important that the professional performing the analysis of the ungaged area recognize the significance of these parameters since they form the bases of data for simulation modeling and statistical correlation analyses. The meteorological and physical basin parameters are generally obtained from cartographic data sources, recorded documents, and field reconnaissance. The meteorological characteristics pertinent to analysis of ungaged areas are listed below.

- Type of precipitation (rainfall, hurricanes, snowmelt)
- Orographic effects
- Direction of storm movements
- Precipitation intensity patterns

Once the precipitation is on the watershed, the physical characteristics of the watershed affect the volume, magnitude and timing of the runoff response. Essentially, they influence the losses, overland flow and flow through the main conveyance systems of the basin. Physical basin characteristics form the bases of analyses for almost all procedures used to analyze ungaged areas. An understanding of these parameters and their interrelationships is imperative for the person conducting the analysis. Primary physical basin characteristics are listed below.

- Drainage area size
- Basin topology
- Watershed surface slope
- Slope of the main conveyance system
- Land use cover
- Soil type

- Basin shape
- Basin storage
- Roughness of overland flow systems
- Roughness of major and secondary systems

Availability of Information. The availability of information such as previously developed models and statistical relationships, information on meteorological physical basin characteristics and documented results can greatly influence the procedures used in performing discharge frequency analyses of ungaged areas. It is important that a research of available information be conducted prior to initiation of this analysis.

Institutional Policies. Institutional policies, criteria and regulations can greatly influence the conduction of the analysis on ungaged basins. These policies typically establish "traditional" methods and procedures which become agency requirements for in-house hydrologists or firms performing evaluations for the particular agency. Through subsequent experience and/or instructional training, the professional becomes familiar and proficient with certain procedures which are standard and acceptable to the agency or firm for which he works. This knowledge may be beneficial in enabling better input judgments and overall efficiency. It can, however, create a bias against certain methods or eliminate otherwise appropriate methods from due consideration.

Experience and Capabilities of the Hydrologist. The experience, judgment and general capabilities of the hydrologist or others performing the analyses of ungaged areas are the most important aspects for obtaining reliable results. The professional must be familiar with not only various methods to determine discharge frequency functions but must also understand the type and purpose of the overall study, manage his resources accordingly, obtain pertinent information and conduct the study in a manner acceptable to his agency or firm. This is not an easy task and the importance of the experience and capabilities of the person conducting the hydrologic assessments should not be overlooked or minimized. Obtaining reliable flood flow frequency relationships at ungaged locations depends more on the professional performing the study than on the procedures used.

FIELD RECONNAISSANCE

Field reconnaissance is one of the most valuable yet ignored tools for obtaining reliable flood frequency estimates at ungaged locations. Field reconnaissance encompasses interviews of agency personnel and local residents, visual inspection of the study area and review of pertinent local documents. Examples of information that may be obtained from field reconnaissance are listed below.

- Meteorologic and physical basin characteristics
- Historic high water marks

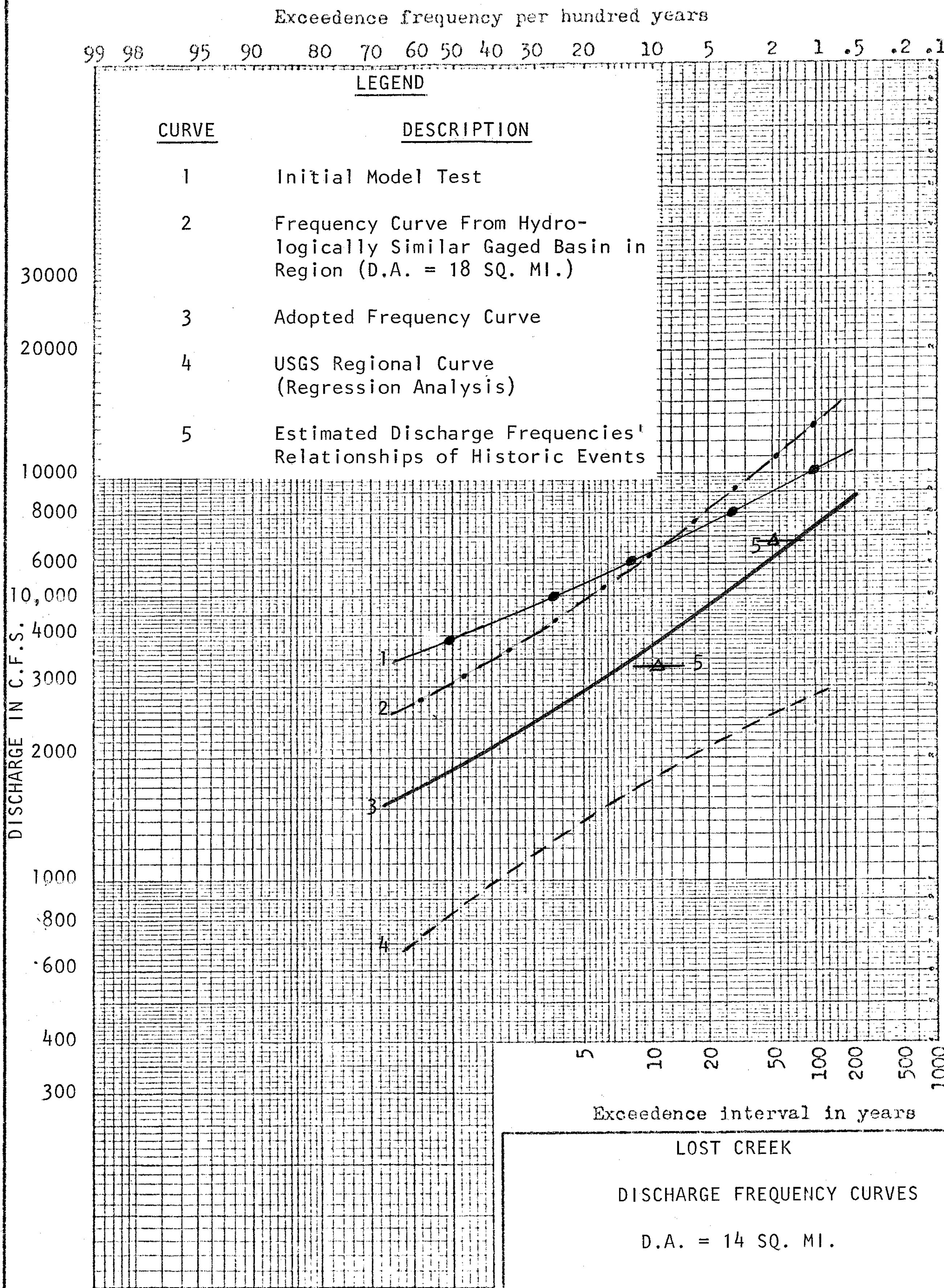
- General knowledge of direction of flow, blockage by debris, frequency of bridge and road overtopping, etc.
- Design discharges of highway bridges, storm sewers, culverts, channels, etc.
- Knowledge of specific and anticipated future development including: major and secondary flood control works, subdivisions, shopping centers, alternative land use patterns, etc.
- Newspaper and other documented descriptions of historic events
- Photographs of historic events

In general, the field reconnaissance of the study area should be made after the various study considerations have been examined and the study purpose and constraints established. The information obtained should be used to formulate the strategies for analyzing the ungaged locations. The data, which should be well documented, lend credibility to the study. This is especially important since several recent court cases have addressed the reliability of the hydrologic aspects of studies. The use of field reconnaissance data is perhaps more important for major studies involving unique systems where simulation models are required. Frequency of road and bridge overtoppings, high water marks, etc., may be the only information available for calibrating these models.

ADOPTED FREQUENCY CURVE CONCEPT

The general concept of adopting a flood flow frequency function based on all the available flood frequency information is not new and, in fact, has indirectly been practiced by capable hydrologists for years. The concept emphasizes the need to obtain all the flood frequency information possible within the study objectives and the judgment capability of the hydrologist to interpret the information sets and adopt the most reliable flood flow frequency estimate. The concept is based on obtaining flood frequency estimates at the desired ungaged location from several procedures and sources and displaying the results in a discharge versus frequency graph. The hydrologist may then adopt the results of one of the procedures, if deemed the best estimate, or can arbitrarily draw a more reliable function based on his knowledge of all the information. Types of flood frequency data that can be plotted at the ungaged location are listed below. The data used varies for a given study. Figure 1 illustrates an example of the concepts.

- Direct transfer of flood frequency relationships from hydrologically similar gaged basins having the same order of magnitude in drainage area size.
- Statistically derived flood frequency relationships for the region.
- Results of empirical equations (small basins only).



LOST CREEK

DISCHARGE FREQUENCY CURVES

D.A. = 14 SQ. MI.

FIGURE 1

- Estimates of historic and regionally developed synthetic discharge frequency relationships
- Nearby bridge design discharge frequency relationships
- Initial simulation model results (This may include sensitivity results of model parameters)
- Regional synthetic floods (Standard Project Flood, etc.)

The concepts presented require the person performing the study to have an understanding of the derivation and utilization of various procedures, the applicability and limitation of the procedures based on the study considerations, and the need to supplement information using field reconnaissance. The significance of these procedures typically increases with the magnitude of the study. For analyses using statistical procedures, and where simulation models are not applicable, the results should be compared for reasonableness using frequency curves and field reconnaissance information from hydrologically similar gaged basins. For situations requiring simulation modeling, the same comparisons should be made as well as those generated from available statistical procedures. For the latter situation, the simulation model is calibrated to the adopted flood frequency relationship. The advantages of displaying the available flood flow frequency data and of adopting a frequency curve are listed below.

- Illustrates the variability of the estimates, whereas, the use and plot of a single procedural result often leads to a false sense of reliability
- Emphasizes the sensitivity of the end product (frequency curve)
- Permits inspection of reasonableness of the discharge frequency relationships, selected peak discharges, slope of the frequency function, etc.
- The adopted function may be used for calibration of simulation models
- Provides hydrologists with a better understanding of the procedures and results, enabling better judgments and subsequently more reliable estimates
- Provides reviewers with a better understanding of the variability, sensitivity and reasonableness of results

SUMMARY AND CONCLUSIONS

Hydrologists and others performing analysis of flood flow frequency relationships at ungaged locations are often proponents of a single procedure for use in the analysis process. Statisticians often advocate statistical procedures regardless of the study situation, whereas, advocates of specific models market and apply their techniques when other procedures are more applicable and cost effective. The reason for this is due partially to academic training and institutional policies, which either purposefully expound certain procedures, or the procedures are inherently ingrained by traditional acceptability. There is the need for hydrologists to broaden their perspective by utilizing data determined from other procedures and sources in their analyses of ungaged locations. This requires the basic understanding of the derivation and utilization of various procedures and the applicability and limitations of the procedures based upon various study considerations. The application and results of the applied procedures should be supplemented by knowledge and data obtained from hydrologically similar basins and field reconnaissance.

The resulting discharge frequency relationships should be displayed on the same graph for a desired ungaged location. The hydrologist may subsequently adopt a flood flow frequency function at the ungaged location based on his understanding of the reliability of all the information. The use of the adopted frequency curve concept provides insight as to the variability and reliability of the results, places proper emphasis on the end product, the frequency curve, and generally results in better flood flow frequency estimates.

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APPENDIX A

PROCEDURES USED IN ANALYSIS OF UNGAGED LOCATIONS

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PROCEDURES USED IN ANALYSIS OF UNGAGED LOCATIONS

OVERVIEW

This appendix is intended to supplement the discussions in the main body of the paper which describe the procedures used to determine flood flow frequency estimates at ungaged locations. The purpose is to provide more detailed discussions of the eight categorized procedures including the basic methodology required for analysis, the applicability/advantages and limitations/disadvantages of each.

STATISTICAL ESTIMATION OF Qp (CATEGORY I)

This procedure derives prediction (regression) equations for selected peak frequency discharges by correlating observed data at regionally gaged locations to desired ungaged locations using definable meteorological and physical basin characteristics. The primary advantages of this procedure are that they are statistically based and specific peak flood flow frequency relationships can be determined. Once the prediction equations are derived for a region they can be expediently applied. Major limitations of the procedure are that they require knowledge of both statistics and hydrology to develop the prediction equations properly and the equations yield only peak flood flow frequency. Table A1 lists the applicability/advantages and limitations/disadvantages of the procedure in detail. The following lists the general methodology involved in developing the prediction equations for the desired peak flood flow frequency relationship.[4]

- Select long-term regionally based streamflow gage stations with similar meteorological and physical characteristics as the desired ungaged areas.
- Determine flood flow frequency relationships at gaged locations according to current criteria.[5]
- Select the magnitude of Q_p (say the peak one-hundred year discharge, Q_{100}) to be evaluated.

TABLE A1
STATISTICAL ESTIMATION OF Qp
CATEGORY I

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
• Procedures are based on accepted statistical methods.	• Requires knowledge of both statistics and hydrology in derivation and utilization.
• Procedures are available for most of the country.	• Procedures require numerous regression analyses and is time consuming to develop.
• Reliability of the prediction equations is known for gaged areas used in derivation.	• Only provides estimates of specific peak flood flow frequency relationships.
• Estimates are reliable for hydrologically similar basins as those used in the derivation.	• Cannot evaluate effects resulting from modifications in the system (physical works and alternative land use patterns).
• Once developed, the procedure is quick and easy to use.	• Procedures are often misused by application for areas with different stream patterns and other hydrologic characteristics from the gaged locations used in the derivation.
• Permits direct calculation of specific peak flood flow frequency estimates that are individually and statistically derived.	• Cannot adequately evaluate hydrologically unique areas in the region.
• Procedures may be used in conjunction with other procedures such as to provide calibration relationships for simulation models.	• Easy to use and may be used where other methods are more appropriate.
• Provides a quick check for reasonableness for situations requiring use of other procedures.	• Derivation requires several hydrologically similar gaged basins in the region.
	• Does not assume a distribution; hence reliability confidence limits) cannot be calculated.

- Select meteorological and physical basin characteristics that are expected to correlate to Q_{100} and tabulate for each area.
- Calculate the regression equations eliminating those meteorological and physical basin characteristics in subsequent iterations that contribute least to the determination coefficients.
- Select the regression equation having the highest determination coefficient and lowest standard error. The equation with fewest independent variables is selected if the above are equivalent.
- Compute the regression constants (residuals) constituting the unexplained differences and draw isopleths on a regional map.
- The Q_{100} may be determined at the desired ungaged areas using the residual map and regression equation results. An example of the type of equation is $Q_{100}=K.DA^{x}\cdot S^{Y}$.
- Repeat the procedures for other desired peak frequency events (say Q_{25}, Q_{10}, Q_{2}).
- A flood flow frequency function may be constructed at the ungaged location using the equation results for the selected peak flood flow frequencies.

STATISTICAL ESTIMATION OF MOVEMENTS (CATEGORY II)

The statistical estimation of movements procedure is similar to the statistical estimation of Qp except an equation is derived to correlate the statistical moments of the frequency function at gaged locations to the ungaged locations instead of selected peak discharge frequencies. The end results are prediction equations which define the moments of the estimated frequency curve at the ungaged location. The capability to derive the frequency curve directly is the major advantage over the previously described procedure if the entire range of flood flow frequencies are required in the analysis. The principal advantages over other nonstatistical procedures are that the results are statistically based and may be expeditiously utilized once they are derived for a region. The primary limitations over nonstatistical procedures are the necessity of statistical knowledge and that the procedure does not generate entire hydrograph information. Table A2 lists the applicability/advantages and limitations/disadvantages of the procedure in more detail. The general procedure used to determine statistical estimation on the moments of flood flow frequency relationships are listed below.[4]

- Select long-term regionally based streamflow gaged stations with similar meteorological and physical basin characteristics as the desired ungaged areas.

- Determine flood flow frequency estimates at the gaged locations according to current criteria.[5]

TABLE A2
STATISTICAL ESTIMATION OF Qp
CATEGORY II

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
• Procedures are based on accepted statistical methods.	• Requires knowledge of both statistics and hydrology in derivation and utilization.
• The entire frequency function is developed from the three moments; means, standard derivation and skew.	• Procedure requires regression analysis for the two or three moments of the frequency.
• Reliability of the prediction equations is known for gaged areas used in derivation.	• May be time consuming to develop.
• Estimates are reliable for hydrologically similar basins as those used in deviation.	• Does not calculate specific flood flow frequency events.
• Once developed, the procedure is quick and easy to use.	• Only provides estimates of peak flood flow frequency relationships.
• Procedures may be used in conjunction with other procedures such as to provide calibration results for simulation models.	• Cannot evaluate effects resulting from modifications in the system (physical works and alternative land use patterns).
• Provides a quick check for reasonableness for situations requiring use of other procedures.	• Cannot adequately evaluate many complex river systems.
	• Cannot evaluate hydrologically unique areas in the region.
	• Ease of use may result in improper application.
	• Derivation requires several hydrologically similar gaged basins in the region.

- Calculate the three moments of the frequency curves, the mean (M), standard deviation (S), and skew (G). Note: Most practicing professionals feel that it is impossible to relate the skew coefficient (G), and often the standard deviation (S) in a statistically meaningful manner to basin characteristics.
- Select meteorological and physical basin characteristics that are expected to correlate to M, S, and G and tabulate for each area.
- Calculate the regression equations for each of the moments, eliminating those meteorological and physical basin characteristics in subsequent interactions that contribute least to the determination coefficients.
- Select the regression equation for each with the highest determination coefficient.
- Compute the regression constants (residuals) constituting the unexplained differences and draw isopleths on a regional map (one map for each moment).
- A prediction equation for each moment is constructed from the residual maps and regression equation results. A typical example for the mean is M=K.DAx.SY.
- Construct a flood flow frequency function at the desired ungaged location from the prediction equations of the three moments.
- Develop confidence limits corresponding to the frequency curve based on M, S, and G.

INDEX FLOOD ESTIMATE (CATEGORY III)

The index flood estimate uses similar procedures as the two previously discussed statistical methods except the regression analysis is performed for a selected index flood (usually the mean annual event, q). Regional ratios developed from gaged locations for selected discharge frequencies are applied to the statistically developed q event at the ungaged location to yield the desired set of flood flow frequency relationships. The primary advantage of the index flood procedure over the other statistical methods previously discussed is that the regression analysis is required only for the mean annual event. The major limitation is that procedure yields the same variance (slope of the discharge frequency function) for all applications. The advantages and limitations of the procedure over other nonstatistical methods are the same as discussed for the two other statistical methods. Table A3 discusses the applicability/advantages and limitations/disadvantages of the index flood estimate procedure in detail. The basic procedure used to develop index flood frequency functions for ungaged areas is described below.[6]

- Select long-term regionally based streamflow gaged stations with similar meteorological and physical basin characteristics.
- Determine flood flow frequency estimates at the gaged locations according to current criteria.[5]

TABLE A3
INDEX FLOOD ESTIMATE
CATEGORY III

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
• Procedure is easier to develop than other statistical methods, and has only one regression analysis.	• Procedure yields same variance (slope of frequency curve) for all applications.
• Procedures are commonly used and based on accepted statistical methods.	• Probably least accurate of the statistical procedures.
• Reliability of prediction equation for index flood is known for derivation.	• Requires knowledge of both statistics and hydrology in derivation and utilization.
• Estimates are reliable for hydrologically similar basins as those used in derivation.	• May be time consuming to develop.
• Once developed, the procedure is quick and easy to use.	• Only provides estimates of peak flood flow frequency relationships.
• Procedures may be used in conjunction with other procedures such as to provide calibration results for simulation models.	• Cannot evaluate effects resulting from modifications in the system (physical works and alternative land use patterns).
• Provides a quick check for reasonableness for situations requiring use of other procedures.	• Cannot adequately evaluate many complex river systems.
	• Cannot evaluate hydrologic unique areas in the region.
	• Ease of use may result in improper application.
	• Derivation requires several hydrologically similar gaged basins in the region.

- Flow frequency data for each gaged location are made nondimensional by dividing selected discharge frequencies by q.
- The median ratios for the selected discharge frequencies of each gaged location are plotted for the ratio to mean annual flood versus the return period in years.
- A regional curve is fitted through these plotted data.
- Regression analysis is performed to derive a prediction equation relating q to definable meteorological and physical basin characteristics.
- A flood flow frequency function at the desired ungaged location may be developed by first using the derived prediction equation to develop the mean annual flood and then converting the ratio scale of the regional-frequency curve to flow by multiplying the ratios by the estimated mean annual flood. Examples of use are $Q_{10}=1.56q$ and $Q_{100}=2.63q$.

TRANSFER METHODS (CATEGORY IV)

The Water Resources Council's task force has defined this category as transferring selected peak flood flow frequency values immediately upstream or downstream of a gaged location to the desired ungaged location based on an adjustment applied to the relation of drainage area sizes. This discussion broadens this procedure to include the direct transfer of peak flood flow frequency values or entire flood flow frequency functions from similarly gaged locations to the desired ungaged location. The procedures are valuable primarily for a quick check for reasonableness of other procedures, both for the magnitude of selected events and for the slope of the resulting derived flood flow frequency function. For situations where tributary or local inflows are not significant, the peak discharges both upstream and downstream of the gaged location would generally be functionally and inversely proportional to their respective drainage area sizes. This is due to the natural storage or flood wave routing effect on the peak discharges. The reverse (functionally and directly proportional to drainage areas) may be true if inflows are significant. Other hydrologic characteristics may also influence these relationships. The determination of proper correlation factors for adequate transfer results is not a simple process and may vary significantly with each location. This fact, as well as the relative ease of use, has resulted in many analysts placing improper confidence in the results. In general, the application of these procedures is limited to checks for reasonableness of other procedures. The applicability/advantages and limitations/disadvantages are discussed in Table A4.

TABLE A4
TRANSFER METHODS
CATEGORY IV

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
(WRC Transfer of Qp)	(WRC Transfer of Qp)
• Procedure is easy and quick to use.	• Procedure ease of use may result in improper application.
• Provides reliable estimates immediately upstream and downstream of gage location if hydrologic characteristics are consistent.	• Can only be utilized immediately upstream and downstream of gaged area where hydrologic characteristics are consistent.
• Procedure is commonly used and generally acceptable.	
(Direct Transfer)	(Direct Transfer)
• Provides quick estimate where time constraints are binding and other procedures are not applicable.	• Estimates are not accurate enough for most analysis requirements.
• Can readily be used as a check for reasonableness of results from other procedures.	• Cannot be used for modified basin conditions.
• Provides valuable insight as to the regional slope characteristics of the flood flow frequency relationships.	• Can only be used as check in areas where hydrologic characteristics are nearly similar and with drainage areas within the same order of magnitude.

EMPIRICAL EQUATIONS (CATEGORY V)

The use of the simplified empirical equations to estimate peak frequency discharges is prominent among engineers performing culvert analyses and municipal engineering work. The use of empirical equations to determine flood flow frequency estimates at ungaged locations is many times that of all the other procedures combined. The equations are more commonly used by Civil Engineers who performed various types of engineering analyses than by practicing hydrologists. The most commonly used method is the rational equation or modifications of the rational equation which have been developed primarily for analysis of small urban areas. The ease of application and experience obtained from their longevity of use have made these equations applicable for estimating peak discharge frequency for design of flood related facilities in small areas. In general, these equations are based on frequency rainfall intensities obtained from charts having a duration equal to the time of concentration. The rainfall intensity is multiplied by the drainage area size and finally adjusted by a reduction factor which accounts for the lumped effect of the physical characteristics of the basin. Table A5 lists the applicability/advantage and limitation/disadvantage of the empirical equation procedures.

TABLE A5
EMPIRICAL EQUATIONS
CATEGORY V

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
• Provides quick means of estimating peak discharge frequency for small areas.	• Generally are not applicable for areas greater than one square mile.
• Concepts can be understood by nonhydrologists.	• Estimate only the peak discharge frequency relationships.
• Suitable for many types of municipal engineering analyses (storm sewers, culverts, small organization impacts, etc.)	• Cannot be used to design storage facilities.
• Familiarity of procedures and use has led to politically acceptable solutions for small areas.	• Cannot adequately evaluate complex systems where timing and combining of flood hydrographs are important.
• Can be used as a check for reasonableness of more applicable procedures in small areas.	

SINGLE EVENT SIMULATION (CATEGORY VI)

Simulation models are used in flood frequency analyses by approximating the rainfall-runoff process to obtain hydrographs which are subsequently used to develop flood flow frequency estimates at desired locations. Single event simulation models perform the analyses using a single storm event which results in a corresponding runoff hydrograph. The continuous simulation models perform the analysis by typically using continuous rainfall for a designated period of record which generates corresponding continuous runoff hydrographs. There are numerous variations and levels of sophistication in both types of models. The discussion of single event simulation models presented herein are those that perform evaluations using hypothetical frequency rainfall data. In general, the input parameters of the model are obtained from similar hydrologic gaged basin analyses, previous studies or estimates made by the hydrologist. The models are calibrated to historic flood events and/or adopted frequency functions. The final results are runoff frequency hydrographs for selected events which are assumed to approximate the frequency of the input rainfall data. The primary advantages of the single event simulation models are the capability to generate entire hydrographs which are necessary for complex systems, many urbanized studies, reservoir analyses, local protection work, etc. The use of statistically developed rainfall intensities and patterns yields resulting balanced floods throughout the watershed. This is opposed to other procedures which are derived by using historic records that, due to the brevity of the record or modifications changing the runoff response of the system during the period of record, produce biased results. Another advantage is that the modeling parameters may be regionally developed using regression analyses obtained from gaged locations. The single event models are also simpler to use and calibrate and have lower analysis costs than continuous simulation models. The principal advantages are: they can be significantly more difficult to use (also more expensive) than statistical procedures, they must be calibrated (the relationship between rainfall frequency and runoff frequency can vary significantly due to loss rates, seasonal effects, etc.), and they greatly simplify the hydrologic process as opposed to many continuous simulation models. A more technically related disadvantage is the difficulty in developing consistent frequency rainfall depth-area patterns for complex basins where subbasin drainage areas are orders of different magnitude. The depth-area relationship decreases with drainage area size for a given rainfall frequency. A detailed listing of the applicability/advantages and limitations/disadvantages is provided in Table A6. The following lists the basic single event simulation procedures used in analysis of ungaged areas.

- Review of available information
- Field reconnaissance
- Delineation of subbasins
- Determination of hypothetical rainfall frequency patterns and selected historic events (for calibration)

TABLE A6

SINGLE EVENT SIMULATION

CATEGORY VI

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
• Generates other hydrologic information rather than peak discharges (volumes, time to peak, rate of rise, etc.).	• Balanced flood concept is difficult to understand.
• Generates balanced floods as opposed to historically generated events which may be biased.	• Modeling requires more time, data, resources (costs) than statistical procedures.
• Enables evaluation of complex systems and modifications to the watersheds.	• Hydrologists must understand the concepts utilized by the model.
• Provides good documentation for quick future use.	• Requires calibration to assure rainfall frequency and approximates runoff frequency.
• Uses fewer parameters than most continuous simulation models.	• Unit hydrograph assumes linear relationship with runoff.
• Approximates the hydrologic runoff process as opposed to statistical methods.	• Requires data processing capabilities.
• Procedures are more economical than continuous simulation procedures.	• Procedures greatly simplify the hydrologic process.
• Calibration procedures are easier than continuous simulation models	• Procedures are generally limited to basins greater than one square mile.
• Models may be calibrated to either simple or complex systems.	• Parameters are difficult to obtain for existing and modified conditions.
	• Difficult to obtain antecedent moisture conditions.
	• Depth-area of rainfall varies with drainage area size.

- Estimate loss rates
- Determine unit hydrograph (kinematic wave, etc.)
- Develop routing criteria
- Make initial run of model
- Calibrate model to historic events and gaged and/or adopted flood frequency curves at selected locations by adjusting loss rate parameters.
- From final model results, construct frequency functions at all desired locations

MULTIPLE DISCRETE EVENTS (CATEGORY VII)

The concepts of using multiple discrete event in developing flood frequency functions is a cross between single event simulation using hypothetical rainfall frequency events and continuous simulation using historic events for a period of record. The process more nearly represents the latter, by selecting historic events from the period of record of rainfall that potentially may influence the development of the frequency function. A single event simulation model is used instead of a continuous simulation model. The advantages and disadvantages of this procedure over statistical procedures are similar to the single event simulation models. The primary advantages of multiple discrete models over single event models are ease in understanding the basic concepts, accounting for antecedent moisture conditions and direct determination of coincident frequency functions (downstream of the confluence of major tributaries, leveed interior flood control analyses involving gravity outlets, etc.). The major disadvantage is the large number of events that must be analyzed and calibrated. The basic procedure is described below.

- Review of available information.
- Field reconnaissance.
- Delineation of subbasins.
- Determination of historic events of each year that might result in peak annual discharges. This is required for each year in the designated period of record.

- Estimate loss rates.
- Determine unit hydrograph (kinematic wave, etc.) parameters.
- Develop routing criteria.
- Evaluate each event, eliminating those that do not yield the peak annual flood event within the watershed (Note: the storm that generates the peak annual event may vary depending upon location in the watershed).
- Construct a frequency curve at calibration locations, within the watershed, gages, adopted frequency functions, etc.
- Modify loss rates and perform model interactions until deemed calibrated.
- From the resulting period of record peak annual events, construct frequency curves at desired locations.

TABLE A7
MULTIPLE DISCRETE EVENTS
CATEGORY VII

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
• Concepts are easier to understand than those associated with hypothetical frequency events.	• Requires numerous storm analyses and subsequent event analyses.
• Antecedent moisture conditions are determined	• Important events may be overlooked.
• Depth-area precipitation problems are eliminated.	• Results may be biased by historic records.
• Evaluates fewer events than continuous simulation models.	• Procedures use simplified hydrologic process.
• Enables evaluations of complex systems and physical modifications in the watershed.	• Requires data processing capabilities.
• Uses fewer parameters than continuous simulation models.	• Parameters are difficult to obtain.
• Approximate hydrologic process as opposed to statistical methods.	• Unit hydrograph assumes linear relationship with runoff.
• Provides good documentation for future use.	• Requires calibration which is more time consuming than single event due to the large number of events that are processed.
	• Procedure is significantly more expensive than single event modeling.
	• Procedures generally not feasible for small study areas, short time constraints, etc.

CONTINUOUS RECORDS (CATEGORY VIII)

Continuous records procedure is defined herein as the utilization of simulation models that use continuous rainfall data to generate correspondingly continuous runoff hydrographs. The models range in sophistication from those that greatly simplify the hydrologic process to sophisticated models which nearly simulate the interrelationship of the physical runoff process of a watershed. The attractiveness of continuous simulation models is that they are generally more physically based than other procedures and are therefore conceptually easier to understand. The rainfall data are generally input for historic period of record based on the correlation with regional rainfall records. The basin topology and physical characteristics are determined from cartographic sources, regional data, previously developed documents, field reconnaissance, or estimated by the hydrologist. The results are a complete simulation of the period analyzed with the peak annual discharges used for determining the frequency curves at desired locations in the basin. For watersheds with gaged data, the model may be calibrated to those gaged by adjusting the physical characteristics of the basin and assuming model results provide similar flood frequency estimates at other locations within the basin. For watersheds without stream gages, the model may be calibrated to adopted frequency functions or to hydrologically similar gaged basins in the region and the physical characteristics transferred or statistically correlated to the desired ungaged locations. The calibration process may be extensive, requiring calibration of flood volumes, timing responses and peak discharges for the period analyzed. The primary applicability/advantages and limitations/disadvantages of continuous simulation models are listed in Table 8. The following list describes the basic methodology involved in application of continuous simulation model to determined flood flow frequency relationships at ungaged locations.

- Review available information.
- Field reconnaissance.
- Delineation of subbasins.
- Determine period of record to be used in the analysis.
- Determine appropriate continuous rainfall record.
- Determine model runoff parameters.
- Develop routing criteria.
- Calibrate model for appropriate volumes, timing and peak discharges.
- From the resulting annual peak discharge values, construct a flood frequency curve at the desired locations.

TABLE A7
MULTIPLE DISCRETE EVENTS
CATEGORY VII

APPLICABILITY/ADVANTAGES	LIMITATIONS/DISADVANTAGES
• Concepts are easily understood.	• The calibration process is extensive and generally must be performed by qualified experienced hydrologists.
• Concepts are more physically based than other procedures.	• Procedures are expensive and time consuming to use, impractical for moderate or small resources allocated projects.
• Antecedent moisture conditions are automatically accounted for.	• The results may be biased by the use of historic rainfall data.
• Can be used in unique basins where other procedures such as statistical procedures are not applicable.	• The procedures required large analytical processing capabilities.
• Process analyses in single computer runs as opposed to handling numerous discrete events.	• The models typically require a large amount of data to properly define the parameters.
• Can automatically determine annual peak floods at various locations even if their frequencies are different.	
• Can model the effects of complex systems and physical works.	

APPENDIX B

REFERENCES

REFERENCES

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