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Scientific and Practical Considerations Related to Revising Bulletin 17B: The Case for Improved Treatment of Historical Information and Low Outliers

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Abstract

Since 1982, Bulletin 17B (B17B) has provided guidelines for conducting flood frequency analyses in support of federal projects in the U.S. The stability and consistency of B17B is widely recognized as a virtue, but research during the past 25 years suggests that substantially more accurate frequency estimates could be obtained if some of B17B's procedures were revised. Among other things, scientists and engineers have developed better methods for incorporating historical flood information into frequency analyses, and for addressing the problem of low outliers and zero flows, that take advantage of computational capabilities that were not available when B17B was published in 1982. Similarly, an additional 30 years of data are available to improve regional skew estimation. In this paper we consider both the technical aspects of proposed changes to B17B and some of the practical issues and implications related to altering procedures that have been in use for more than two decades.

Introduction

Flooding is the most pervasive natural hazard that affects people and property, annually causing dozens of deaths and billions of dollars in damages in the United States (Mileti, 1999). Flood losses could be substantially reduced through better land-use planning, improved building standards and other mitigation measures, but to achieve this result (given limited resources) accurate flood frequency estimates are required. Since 1982, Bulletin 17B (B17B) (IACWD, 1982) has provided guidelines for conducting flood frequency analyses in support of federal and many non-federal U.S. projects, for example for floodplain delineation and management, determining flood-insurance requirements, sizing spillways for small dams, determining levee heights, and for design of other hydraulic structures.

Thomas (1985) summarizes the developments that led to B17B, published in 1982 as an update to Bulletins 17 and 17A, which were completed in 1976 and 1977, respectively. The purpose of these Bulletins was to provide a uniform, nationwide, and consistent approach for flood frequency determination (Thomas, 1985; Kirby and

Moss, 1987). These criteria are important because of the role that flood frequency estimates play in the implementation of the National Flood Insurance Program. The frequency estimates are also used to inform decisions about allocation of resources employed for flood loss reduction.

Griffis and Stedinger (2007) discuss the components of B17B in detail and consider how the guidelines evolved from Bulletin 17 to 17B. All of the versions include use of the log-Pearson Type 3 distribution and method of moments for parameter estimation. Bulletin 17B specifies use of regional information to stabilize and improve estimation of the skewness coefficient. At the time it was written, Bulletin 17B was a remarkably forward-looking approach.

Research and development, however, has not stood still in the science and engineering related to flood frequency analysis. Recently an effort has been undertaken by the Hydrologic Frequency Analysis Work Group (HFAWG) to update B17B to take advantage of new techniques. HFAWG is a working group under the Subcommittee on Hydrology (SOH) of the Advisory Committee on Water Information. Further information on the HFAWG (including membership) is available at http://acwi.gov/hydrology/Frequency/index.html. The goal of the HFAWG is to evaluate new procedures and, where appropriate, recommend changes to the B17B guidelines.

This paper presents an overview of potential changes to B17B that HFAWG is considering. The proposed changes are described in detail in recent literature related to B17B. Here, we describe some technical advantages of newer methods, outline the current scope of work on potential B17B changes, and mention future studies.

Recent Flood Frequency Research Relevant to B17B

Since B17B was published, there has been much research in flood frequency analysis. Potter (1987), Cunnane (1988) and Bobee and Rasmussen (1995) present general summaries of this work, while Stedinger et al. (1993) and Griffis and Stedinger (2007) provide some practical details on newer frequency analysis methods that have been in development, and in some cases, in use. Griffis and Stedinger (2005a, 2005b) reviewed the literature on LP3 distribution characteristics and examined parameter estimation methods including moments, maximum likelihood, and mixed moments. They also investigated sample and weighted skew estimates (Griffis and Stedinger, 2005c). Their work suggests that: (1) the LP3 is a flexible, reasonable flood distribution choice; (2) method of moments with regional skew weighting performs well; and (3) some changes to B17B are warranted.

Research relevant to B17B can be classified into at least six general areas which are summarized in Table 1. All six of these areas are being explored with regard to the need for potential revisions to B17B. Two general areas of research appear to be highly promising with respect to improving B17B:

1. Improved methods for employing and displaying non-standard data (e.g. historical information or low outliers), specifically the Expected Moments Algorithm (EMA); and
2. Improved methods for developing regional skew information, specifically

Bayesian Generalized Least Squares (B-GLS).

Table 1: A Summary of Bulletin 17B-Related Recent Research

Topic	Description	References
plotting positions	plotting positions with quantile-unbiased concepts; threshold exceedance-based techniques for censored data, including historical and paleoflood data	Cunnane (1978), Hirsch and Stedinger (1987), Hirsch (1987), Wang (1991)
historical and paleoflood information	newer maximum likelihood and EMA techniques that incorporate different types of data including measurement error; compared performance with B17B historical weighting adjustment, compared with data sets	Stedinger and Cohn (1986), Lane (1987), Cohn et al. (1997), NRC (1999), England et al. (2003a), England et al. (2003b)
low outliers	improved outlier detection methods; compared use of EMA with B17B conditional probability adjustment	Spencer and McCuen (1996), Griffis et al. (2004)
confidence intervals	derived approximate confidence intervals for the LP3 distribution and using EMA; compared with normal-based confidence intervals used in B17B	Chowdhury and Stedinger (1991), Cohn et al. (2001)
sample skew and weighted skew	improved sample skew MSE equation; improved sample skew bias correction factors; use of an informative regional skew improves quantile estimates	Griffis et al. (2004), Griffis and Stedinger (2005c)
regional skew and regional regression	new ideas on generalized skew concepts; critique and limits of B17 skew map; a new Bayesian approach to GLS regression with diagnostics	McCuen (2001), Reis et al. (2004), Reis et al. (2005)

Methods for Employing Historical/Paleoflood Information

Starting in the mid-1980s, researchers began to recognize that the "weighted moments" procedure in B17B, which is used with historical and (possibly) paleoflood information, was not statistically efficient (Stedinger and Cohn, 1986). Efficient statistical approaches were available, but because they were based on a maximum likelihood fitting procedure that would have involved a substantial change to the essence of B17B, they were not attractive candidates for adoption into the B17B structure.

In the 1990s, Lane and Cohn introduced a new moments-based fitting procedure, the Expected Moments Algorithm (EMA) (Cohn et al., 1997, 2001; England, 2003a) as a potential alternative. EMA is a generalized moments-based estimator, consistent with what is currently specified in B17B, but adapted to be able to accept interval data in addition to point estimates; it can accept threshold exceedance (or nonexceedance) censoring techniques to handle many types of flood data that standard method-of-moments approaches cannot accommodate. EMA has been found to be efficient and nearly unbiased (Cohn and Lane, 1997; England, 2003a).

The amount of information available from historical and paleoflood information, where an appropriate estimation method is applied, can be substantial. The B17B weighting procedure is known to be relatively inefficient, only slightly increasing effective record lengths in typical situations. However, the EMA approach has been found to be nearly as efficient as the MLE, in some cases deriving dozens or possibly hundreds of years of effective record length where reliable long-term historical or paleoflood information can be obtained (England, 2003a). EMA has also been shown to work well in practice (NRC, 1999; England, 1999, 2003b).

The value of historical information has long been recognized, both in the research literature and in B17B itself. However, the B17B weighted moments approach, largely because of its inefficiency, is relatively insensitive to a variety of measurement errors mis-specifications related to the historical record. Because EMA makes more efficient use of the data, it is more sensitive to errors, and this may create new concerns about data quality. For example, in at least one case, researchers have made decisions not to rely on paleoflood information in an EMA analysis where the reliability of the data could not be determined (e.g., NRC, 1999). Mixed-population cases, where the historical and/or paleoflood data may represent a different distribution, should also be carefully considered for applicability.

Approaches for dealing with low outliers and zero flows

The B17B approach for zero flow and low outlier adjustments is the conditional probability adjustment (CPA; Jennings and Benson, 1969). Griffis et al. (2004) considered the use of the EMA algorithm as a substitute for the conditional probability adjustment that is currently employed by B17B when a low outlier is detected by the Grubbs-Beck test. While the new procedure would not change how outliers are identified, it would slightly alter the way the fitting procedure deals with them. Because it would rely on EMA components that would already be in place, it would allow simplification of B17B.

Griffis et al. (2004) found that this procedure was not substantially more efficient than the B17B approach. However, it is simpler to apply and has a sound basis in statistical theory. For these reasons, it seems appropriate to consider a change in this area. Using EMA, the statistical methods to handle low outliers would be the same as that used for high outliers, thus resulting in a uniform and consistent method to treat both tails of the distribution.

Improved Methods for Developing Confidence Intervals

The B17B confidence interval method is currently based on applying a procedure designed for the 2-parameter log-Normal distribution to the LP3 data. While the LP3 distribution with zero skew is equivalent to the 2-parameter log-Normal distribution, confidence intervals appropriate for this distribution will be generally too narrow for use with the 3-parameter LP3 (Stedinger, 1983). IACWD (1982 p. 28) recognized this weakness by noting “more adequate computation procedures for confidence limits for the LP3 distribution are needed.” Chowdhury and Stedinger (1991) developed improved LP3 confidence intervals for complete data, while Cohn et al. (2001) developed LP3 confidence intervals for EMA. These approaches address the need raised by IACWD, and provide more accurate coverages than those currently used in B17B as they properly account for skewness in the distribution rather than using a Normal approximation. The EMA confidence intervals also account for historical information, low outliers, and potentially other types of non-standard data. The B17B approach only addresses the systematic data, and it handles this incorrectly. Given the EMA confidence intervals work with the traditional systematic records, as well as with interval data, and that the coverages are more accurate, it would seem to make sense to adopt this more accurate and statistically correct method.

Summary of EMA

EMA can employ four main classes of information (England et al., 2003a): floods of known magnitude; floods of unknown magnitude that are less than some level (censored from below); floods of unknown magnitude that exceed some level (binomial censored); and floods with magnitudes described by a range (interval censored). Historical and paleoflood data generally are described in terms of exceedance or non-exceedance of one or more discharge thresholds (Q_o), and a low outlier can be described by a single low threshold. EMA directly utilizes flood data that includes multiple thresholds, low outliers, and measurement uncertainty with floods described by a range (Figure 1).

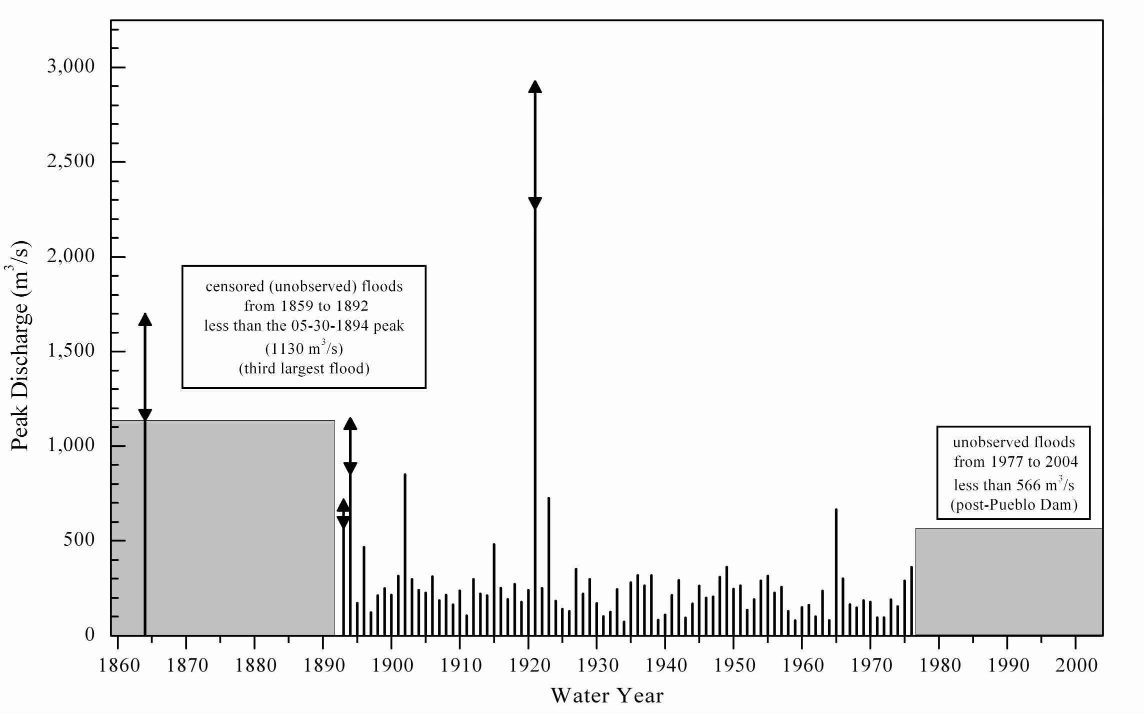

Figure 1. Peak discharge and historical flood estimates, Arkansas River at Pueblo, Colorado. Arrows on the 1864, 1893, 1894 and 1921 historical floods indicate floods described by a range for frequency analysis.

Improved Methods for Estimating Generalized/Regional Skew

In the mid 1980s Stedinger and Tasker (1985) developed a generalized least squares method for estimating regional hydrological statistics. This can be applied to the estimation of regional skew, and has been found to yield substantially more information that can be obtained from the Hardison "skew map" that is part of B17B. In particular, the estimated mean square errors for the Hardison map include both the model error and the sampling variability, and thus overstate the uncertainty in the regional skew, often by a factor of 3 or more. In short, by adopting an alternative estimator for regional skew, it is possible to improve greatly the precision of flood quantile estimates at both gaged, and ultimately, ungaged sites. This represents an important advance (Ries et al., 2005).

Currently, the USGS is testing an improved Bayesian GLS approach. It is expected that this will eliminate some of the quirky problems that have occasionally been identified with respect to the GLS method, while retaining the GLS efficiency.

Ongoing HFAWG Investigations for Potential Bulletin 17B Revision

The original B17B authors anticipated that the Bulletin would be periodically updated (IACWD, 1982): "This present revision is adopted with the knowledge and understanding that review of these procedures will continue. When warranted by experience and by examination and testing of new techniques, other revisions will be published." The HFAWG presented a plan to investigate possible improvements to B17B to SOH on January 12, 2006 (HFAWG, 2006). This plan was subsequently approved, and contains the following four main elements:

1. Evaluate and compare the performance of EMA (Cohn et al., 1997) to the B17B weighted-moments approach for analyzing data sets with historic information and paleoflood data.
2. Evaluate and compare the performance of EMA to the conditional probability adjustment of B17B for analyzing data sets with low outliers and zero flows.
3. Describe improved procedures for estimating generalized/regional skew.
4. Describe improved procedures for defining confidence limits.

The advantages and disadvantages of these potential improvements are briefly summarized in Table 2.

Potential Future Investigations

During the discussion and approval of the scope to investigate possible improvements to B17B, the SOH noted that the scope might be expanded to include several additional areas that are in need of research. They recommended work be done in the following main areas: ungaged watersheds, regulated watersheds, watershed changes (urbanization and deforestation), and climate change. Other research areas that may be undertaken after the investigations discussed above include: developing guidance for ungaged watersheds; frequency analysis based on rainfall-runoff models; procedures for evaluating nonhomogeneity in the annual peak flows; treatment of mixed populations; comparative analyses to validate Bulletin 17B results. This list is not exhaustive and may include other topics such as alternative frequency distributions and fitting methods such as L-Moments, Maximum Likelihood, and other regionalization schemes.

Table 2: Potential Improvements to Bulletin 17B, Advantages and Disadvantages

Issue	Advantage	Disadvantage
Historical Information/ High Outliers	EMA gives 100-year flood estimates with smaller MSE and less bias than B17 historical weighting. EMA allows for direct use of more types of historical data including measurement uncertainty	as longer records are used, climate change and nonstationarity need to be investigated
Low Outliers	EMA gives a consistent method for both low and high outliers; EMA is generally more efficient than conditional probability adjustment	potentially revisit low outlier test that would define the censoring threshold for EMA
Confidence Intervals	EMA employs correct approach for LP3 distribution	none
Regional Skew/Bayesian GLS	Bayesian GLS provides improved precision (and more accurate RMSE) of regional skewness estimate	potentially more complex

Summary

A substantial amount of research in flood frequency has been conducted in the 25 years since Bulletin 17B was last updated. Research of relevance to Bulletin 17B has been conducted on the following topics: plotting positions; historical and paleoflood information; low outliers; confidence intervals; sample skew and weighted skew; and regional skew and regional regression. In addition to research, there is an additional 30 years of data since the generalized skew map was published in Bulletin 17. The Hydrologic Frequency Analysis Work Group is currently conducting studies for possible revision to Bulletin 17B; these include examining EMA for historical information and low outliers; improved procedures for generalized/regional skew; and improved confidence interval methods. After this work is complete, future studies may focus on ungaged sites, regulated watersheds and watershed changes.

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