Subcommittee on Hydrology, Advisory Committee on Water Information
Hydrologic Frequency Analysis Work Group (HFAWG)

MEMORANDUM

TO: Subcommittee on Hydrology

FROM: Hydrologic Frequency Analysis Work Group

SUBJECT: Recommended Revisions to Bulletin 17B

DATE: June 12, 2013

It has been 30 years since the last revision of Bulletin 17B in March of 1982. At that time, it was recognized that continued investigation and improvements of flood frequency techniques were needed. In fact, Bulletin 17B (pages 27-28) included a list areas where additional research was recommended by the Work Group in 1982.

Basis for Recommendations

The Hydrologic Frequency Analysis Work Group (HFAWG) has completed a series of studies to develop and justify proposed revisions to Bulletin 17B in the following four main areas:

1. Historical information and the weighted-moments approach;
2. Low outlier detection and treatment;
3. Procedures for estimating generalized/regional skew; and
4. Procedures for estimating confidence limits.

These studies were based on the published literature and the testing plan presented to the Subcommittee on Hydrology in 2006 (HFAWG, 2006) and summarized by Will Thomas (HFAWG, 2007). The January 2006 proposal observes that "the possible changes are considered significant improvements and would warrant the publication of a new Bulletin 17C".

The results of the testing plan appear in Cohn et al. (2013a), with additional technical details in Cohn et al. (2013b), England and Cohn (2012), and Lamontagne et al. (2013) and references therein. The key change is the adoption of the Expected Moments Algorithm (EMA) framework for the analysis of data sets containing zeros, outliers, interval flow estimates, multiple thresholds, or historical and/or paleoflood information as the appropriate generalization of the method-of-moments to address such situations.

The simple and clear tests described in Cohn et al. (2013a) demonstrate that the Expected Moments Algorithm (EMA) with the log-Pearson Type III distribution appears to always perform as well, and in many cases with extreme censoring and/or historical information, does much better than the special algorithms in Bulletin 17B for dealing with such cases. Moreover, EMA is able to make use of a wider range of data types reflecting interval estimates and multiple threshold for historical information and low outliers, common data occurrences that B17B does

not address.

Recommended Revisions to Bulletin 17B

While retaining the basic structure of Bulletin 17B that uses the method of moments in log-space with the log-Pearson Type III distribution and weighted skew coefficient, the HFAWG recommends the adoption of several corrections and extensions to those procedures. Most of these revisions follow from the list of needed research included in Bulletin 17A and 17B. All of the changes are in the spirit of the procedures currently recommended in Bulletin 17B.

We recommend that a new Bulletin 17C be issued with the following revisions.

1. Historical Information, Low Outliers, Interval Data and Zero flows. Replace the Historical Weighting Procedure and the Conditional Probability Adjustment (CPA) with an Expected Moments Algorithm (EMA) analysis when such special procedures are needed.

2. Low Outlier Identification. Generalize the simple Grubbs-Beck outlier test recommended in Bulletin 17B with the new Multiple Grubbs-Beck test (Cohn et al., 2013a,b; Lamontagne et al., 2013) for the identification of potentially influential low flows.

3. Confidence Intervals. Replace the confidence interval formulas in Bulletin 17B which neglect the uncertainty in the estimated coefficient of skewness with a computation based on an EMA analysis, that includes skewness uncertainty and reflects historical information and low outlier adjustments based on Cohn et al. (2001) and subsequent numerical improvements for large skews.

4. Derivation of Regional Skew. Revise statements in Bulletin 17B on the derivation of a regional skewness estimator and its precision to reflect recent advances in regional statistical analyses

5. Plotting Positions. Replace the single threshold historical plotting position with the multiple-threshold plotting positions suggested by Hirsch and Stedinger (1987).

6. Climate Change. Replace the outdated statements in Bulletin 17B on “Climate Trends” with a revised statement reflecting the current understanding of climate variability and climate change.

7. Expected Probability. Remove the discussion of Expected Probability from Bulletin 17B. The method is no longer used.

Further details on the each of these seven recommendations are provided in a subsequent section.

The U.S. Army Corps of Engineers, Bureau of Reclamation, and U.S. Geological Survey have invested substantial resources in conducting technical studies and developing these recommendations. See Olsen (2011) and the March 2012 testing group memorandum (HFAWG, 2012).

Perspective on Recommended Bulletin 17B Revisions

The recent studies by Cohn et al. (2013a), Cohn et al. (2013b), England and Cohn (2012), and previously published studies on issues related to Bulletin 17B that are listed in Cohn et al. (2013a), Stedinger and England (2005), and Stedinger and Griffis (2008), provide the technical basis for making recommendations to revise some aspects of Bulletin 17B. In addition to the recent data testing and simulation studies described in Cohn et al. (2013a), there have been many additional studies conducted by HFAWG members, collaborators, and others since 1995. Beyond such studies, EMA has been used in several regional frequency studies (California, Iowa, Arizona) conducted by the USGS, and in site-specific investigations conducted by the USBR.

The use of EMA has three advantages.

1. EMA is the reasonable extension of the Bulletin 17B LP-III method of moments approach to deal in a consistent statistical framework with ALL of the sources of information likely to be available. For simple cases with only a systematic record and a regional skew, the EMA algorithm reverts to the method of moments recommended in Bulletin 17B.

2. EMA deals with interval and multiple threshold data that CPA and the Historical Weighted-Moments procedures in Bulletin 17B do not. This new capability allows use of an expanded data set as well as describing better what is actually known. Crest-stage gages and sites with historical information yield observations that are best described by intervals, where thresholds often change over time.

3. Adoption of EMA will provide confidence intervals (CIs) that include skew uncertainty, which is neglected in Bulletin 17B, and will reflect the information provided by observations described by different intervals, for which Bulletin 17B has no option.

Plans for Bulletin 17C

The Hydrologic Frequency Analysis Work Group (HFAWG) commenced discussions and outlined studies on potential improvements to Bulletin 17B at the November 2005 HFAWG meeting. Stedinger and England (2005) summarized the critical papers, results available at that time, and listed proposed changes to Bulletin 17C. After the January 2006 HFAWG presentation to SOH, we commenced development of testing plans (HFAWG, 2007) and outreach.

Stedinger and Griffis (2008) provide further discussion and perspectives on the flood frequency literature and investigations for improving Bulletin 17B. That editorial in the *ASCE Journal of Hydrologic Engineering*, along with presentations at many professional meetings, including ASCE, ASFPM, US Flood Management Association, and the Federal Interagency Hydrologic Modeling Conference (England and Cohn, 2007, 2008; Stedinger et al. 2008; Thomas et al., 2008, 2010; Lamontagne et al. 2013), and Federal agency discussions (Olsen, 2011), ensured that the profession was aware of our efforts and the likely outcome.

We have developed a plan and recommendations for retaining, updating, replacing and deleting each of the sections and appendices within Bulletin 17B. The recommended revisions and status of particular sections within Bulletin 17B are summarized in two tables that are presented below We recommend four activities to prepare and implement a Bulletin 17C.

1. Develop the Bulletin 17C Document
   - writing team consists of HFAWG members, with USGS, USACE, and Reclamation as major contributors;
   - develop outline of document;
   - prepare draft for review;
   - define review, comment and approval process (in conjunction with SOH, ACWI, and public comments);
   - prepare final version;
   - define future revision process.

2. Develop Supporting Materials to Bulletin 17C
   - web site for FAQ, references, software links (also used as outreach);
   - prepare various conference papers, journal articles and related reports;
   - webinars to SOH and wider hydrology and engineering community on the technical background, improvements and materials, such as EMA, MGB, etc.

3. Develop Software for Bulletin 17C
   - individual agency software packages are under development (USGS, USACE, Reclamation);
   - provide application examples with software.
   - NOTE: USGS has completed and released beta software with examples for testing, and has held several webinars in 2012 and 2013.

4. Conduct Outreach and Training on Bulletin 17C
   - present Bulletin 17C update plan at professional meetings;
   - develop training on Bulletin 17C materials;
   - provide software demonstrations and training with Bulletin 17C and specific software packages.

Details on Recommendations for Bulletin 17B Revisions

The recommended changes and status of particular sections within Bulletin 17B are summarized in Table 1 (Bulletin 17B Main Report) and Table 2 (Bulletin 17B Appendix below). Refer to pages 9-25 in IACWD (1982) for additional details.

Table 1: Bulletin 17B Main Report features, condition, and recommendation

Bulletin 17B Assumption or Step	***Procedure***	***Condition***	***Recommendation***
IV.	**Data Assumptions**		
IV.A.	Climatic Trends	OK	Update
IV.B.	Randomness of Events	OK	Update
IV.C.	Watershed Changes	OK	Keep and review
IV.D.	Mixed Populations	OK	Keep
IV.E.	Reliability of Flow Estimates	OK	Update/supplement
V.	**Determination of Flood Frequency Curve**		
V.A.	Series Selection - Annual floods	OK	Keep and Clarify
V.B.	**Statistical Treatment**		
V.B.1	The Distribution – LP3	OK	Keep
V.B.2.	Fitting the Distribution (Method of Moments)	OK	Generalize with EMA
V.B.3.	Estimating Generalized Skew	Narrow	Replace
V.B.4.	Weighting the Skew Coefficient	OK	Generalize
V.B.5.	Broken Record	OK	Generalize with EMA
V.B.6.	Incomplete Record/Crest-stage gages (CPA)	Limited	Replace with EMA
V.B.7.	Zero flood years (CPA)	Limited	Replace with EMA
V.B.8.	Mixed-population	OK	Keep and review
V.B.9.	Outliers (Grubbs-Beck test)	Limited	Generalize with MGB
V.B.10.	Historic flood data	Limited	Replace with EMA
V.C.	**Refinements to Frequency Curve**		
V.C.1.	Comparisons with Similar Watersheds	OK	Keep and review
V.C.2.	Flood Estimates from Precipitation	OK	Keep and review
VI.	**Reliability Application**		
VI.A.	Confidence Limits	Limited	Replace with EMA
VI.B.	Risk	OK	Keep
VI.C.	Expected Probability	Unnecessary	Delete
VII.	**Potpourri**		
VII.A.	Non-conforming special situations	OK	Amend
VII.B.	Plotting Positions	Limited	Generalize
VII.C.	Future Studies	OK	Update

Table 2: Bulletin 17B Appendix features, condition, and recommendation

Bulletin 17B Appendix	***Procedure***	***Condition***	***Recommendation***
1	References	Outdated	Update
2	Glossary and Notation	Outdated	Update
3	Table of K Values	Keep	Review and revise to electronic format
4	Outlier Test K Values	Unneeded	Delete
5	Conditional Probability Adjustment	Limited	Delete
6	Historic Data	Limited	Delete
7	Two-Station Comparison	OK	Keep
8	Weighted Independent Estimates	OK	Keep
9	Confidence Limits	Incorrect	Replace
10	Risk	Awkward	Keep and review
11	Expected Probability	Unnecessary	Delete
12	Flow Diagrams and Example Problems	Outdated	Update
13	Computer Program	Outdated	Update
14	"Flood Flow Frequency Techniques" report summary	Limited	Delete
New	Additional Resources For Special Situations (Provide links to FAQ, other websites, etc.)	---	New
New	Trend Tests	---	New
New	Multiple-Threshold Plotting Positions	---	New
New	Expected Moments Algorithm (EMA)	---	New

Pertinent information on seven of the recommendations follows. Additional details are provided in Cohn et al. (2013a), other reports presented to HFAWG, and references therein.

1. Historical Information, Low Outliers, Interval Data and Zero flows. Flood records can contain zeros and low outliers, potentially influential low flows, crest-stage observations with different thresholds, historical information with one or more thresholds, and perhaps quantification of uncertainty in the measurement of some large events, all of which can be efficiently, accurately, and consistently represented as interval data. B17B does not provide for interval data, thus an extension is needed to the Bulletin 17B weighted moments (WM) and conditional probability adjustment (CPA) procedures. The Expected Moments Algorithm (EMA) has been developed as a collaborative effort with the USGS, Reclamation, and Cornell University (Lane, 1995; Cohn et al., 1997; England et al., 2003; Griffis et al., 2004, Cohn et al. 2012). The Expected Moments Algorithm (EMA) provides a single statistically-consistent framework for estimating the parameters of the LP3 distribution with the wide range of data types experienced in practice (England and Cohn, 2012), and for estimating the uncertainty in estimated model parameters, flood quantiles and related parameters. We recommend that EMA be adopted as the appropriate extension of the current Bulletin 17B method-of-moments approach.

2. Low Outlier Identification. Bulletin 17B employs the Grubbs-Beck test for low outliers. That test is intended to determine if the smallest observation in a sample of size *n* is inconsistent with a normal distribution using a type I error of 10%. Experience has shown that flood frequency studies in the Western United States, and other arid areas, need to be sensitive to more than one outlier per sample. Furthermore, some records have one or more zero flows, and for such records the Grubbs-Beck test is not an appropriate test to employ to check if the smallest positive (non-zero) observation is an outlier at the 10% level. Thus we recommend that the Grubbs-Beck test in Bulletin 17B be generalized to the Multiple Grubbs-Beck (MGB) test described in Cohn et al. (2013b) and Lamontagne et al. (2013) to evaluate if one or more observations should be considered to be low outliers because they are potentially-influential observations that could negatively affect the fitted LP3 distribution. Furthermore we recommend that the Multiple Grubbs-Beck test be employed in the two step algorithm described in the Testing Report (Cohn et al., 2013a). Examples in Cohn et al. (2013a), Cohn et al. (2013b), and Lamontagne et al. (2013) illustrate the advantages of this MGB procedure.

3. Confidence Intervals. Currently the formulas in Bulletin 17B for generating confidence intervals assume the weighted skewness coefficient is without error. This misrepresents the uncertainty in flood quantile estimators and the errors that result are well documented (Chowdhury and Stedinger, 1991). As a result, the Bulletin 17B confidence intervals fail to cover quantiles with the specified frequency (Cohn et al., 2001). To eliminate that limitation, and to be consistent with the use of EMA for parameter and flood quantile estimation, we recommend that flood studies use the EMA procedures for describing the uncertainty in estimated parameters and quantiles. These EMA confidence interval procedures are initially described in Cohn et al. (2001) and have been revised to include gaussian quadrature numerical solution techniques that provide improved estimates for large skew coefficients. While one would hope that we could correct the confidence intervals now utilized in B17B, the ad-hoc nature of the adjustment procedures (historical, low outliers, zero flows, weighted skew) now employed by B17B simply does not lend itself to an accurate and uniform confidence interval estimation procedure.

4. Derivation of Regional Skew. The weighting of a regional skewness estimator with the at-site skewness estimator remains an important and innovative component of the Federal guidelines in Bulletin 17B. The current weighting formula is an important part of the 1982 revision. However the value of that step depends on use of the best available regional information and the appropriate description of the precision of that information, which enters into the calculation of the weighted skewness estimator. Bayesian GLS procedures extract far more regional information for skew estimation than is presented in B17B Plate 1, and provide a relatively unbiased estimate of their precision. Moreover, we have an additional 30 years of data with which to develop regional skew estimators. We recommend that the section on "Estimating Generalized Skew" be revised to reflect GLS Bayesian procedures described in USGS SIR 2010-5260, USGS SIR 2009-5043, USGS SIR 2009-5158, and USGS SIR 2009-5156.

5. Plotting Positions. Bulletin 17B recommends plotting procedures applicable for a single threshold. However modern applications employing multi-threshold crest stage data, or multiple threshold historical information, require a multiple-threshold plotting position strategy. Thus we recommend that the probability plotting position formula with a single threshold be replaced by the corresponding multiple-threshold plotting positions recommended by Hirsch and Stedinger

(1987) and the Handbook of Hydrology (Stedinger et al., 1993, p. 18.42. A plotting parameter *a* = 0, corresponding to a Weibull formula, is recommended as a default value, consistent with current practice. Other plotting parameters, including 0.40 (Cunnane), 0.44 (Gringorten), and 0.50 (Hazen) could also be considered. There would be no change for complete data sets that lack zeros, censored data, low outliers, or historical information.

6. Climate Change. The current statement in Bulletin 17B about "Climate Trends" is inaccurate based on our current understanding of climate variability and climate change, and should be re-written. (See IV. Data Assumptions, A. Climate Changes.). We recommend it be replaced with the following text:

"There is much concern about changes in flood risk associated with climate variability and long-term climate change. Time invariance was assumed in the development of this guide. In those situations where there is sufficient scientific evidence to facilitate quantification of the impact of climate variability or change in flood risk, this knowledge should be incorporated in flood frequency analysis by employing time-varying parameters or other appropriate techniques. All such methods employed need to be thoroughly documented and justified."

7. Expected Probability. Bulletin 17B contains a discussion of expected probability on page 24 with an expanded explanation including Tables and formula in Appendix 11. Given that results were only available for the case of normal data with zero skew, and that the one agency that used that adjustment no longer does so, we recommend that the discussion of Expected Probability in the Bulletin be omitted from Bulletin 17C.

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