

**Hydrologic Frequency Analysis Work Group Meeting**  
**March 19, 2012**  
**Michael Baker, Jr.**  
**3601 Eisenhower Ave., Alexandria, VA**

The Hydrologic Frequency Analysis Work Group (HFAWG) met at the office of Michael Baker, Jr., 3601 Eisenhower Ave., Alexandria, Virginia on March 19, 2012. A major objective of the meeting was to present and discuss the technical studies on the Expected Moments Algorithm (EMA) and Bulletin 17B based on theory, test results using data from 82 gaging stations, Monte Carlo experiments, and resampling of observed data. The test results are described in a report titled “Updating Bulletin 17B for the 21st Century”, Cohn et al (2012), that was provided to the HFAWG on March 5. The testing report is posted on John England’s web site at <ftp://ftp.usbr.gov/jengland/HFAWG>. Another major objective of the March 19 meeting was to discuss and determine recommended revisions to Bulletin 17B. The agenda for the meeting is given as Attachment 1. The recommended revisions to Bulletin 17B were sent out prior to the March 19 meeting. A few revisions were made in the recommended changes to Bulletin 17B at the March 19 meeting to clarify the intent of the revisions and those Recommendations are shown in Attachment 2. The list of attendees is given in Attachment 3. Eighteen people attended the meeting in person and 11 people attended by conference call and live meeting. All the powerpoint presentations given at this meeting are posted at <ftp://ftp.usbr.gov/jengland/HFAWG>.

**History and Overview of EMA-Bulletin 17B Current Investigations**

After introductions, Will Thomas, Michael Baker, Jr., gave a brief history of the HFAWG, the purpose of the HFAWG and accomplishments to date. The work group has been meeting since January 2000 and all the minutes of the work group are on the web site at <http://acwi.gov/hydrology/Frequency>. Will noted that the work group first developed a testing plan for EMA and Bulletin 17B in November 2005 with the testing to be done on gaging station data. A Data Subgroup of the HFAWG developed a more detailed plan for testing EMA and Bulletin 17B on gaging station data and Monte Carlo simulations. In August 2007, annual peak data for 82 long-term gaging stations and synthetic frequency curves for six different combinations of frequency distributions were sent to John England, USBR, and Tim Cohn, USGS, for testing. In November 2009 the HFAWG met to discuss test results completed by John and Tim and Nancy Steinberger, FEMA, on the data for the 82 long-term stations. At the November 2009 meeting, the testing plan further evolved to include random sampling from the observed data, to summarize Monte Carlo simulations from published papers and to summarize frequency results for data sets with multiple thresholds, interval data, zero flows, etc. As shown in the agenda in Attachment 1, the meeting on March 19, 2012 was to discuss all the technical studies based on testing results from the 82 stations, the Monte Carlo simulation experiments and the resampling of the observed data. The major change in the testing since November 2009 was the development of a Multiple Grubbs-Beck test by Tim Cohn for detecting low peaks.

**Recommended Revisions to Bulletin 17B**

John England, USBR, continued the meeting by discussing the Recommendations for revising Bulletin 17B developed by the Testing Group (Tim Cohn, John England, Nancy Barth, USGS, and Beth Faber,

USACE). The objective was to provide these Recommendations to give the work group an overview of where the meeting was headed and then to discuss the testing results that support these Recommendations. The Recommendations Memorandum was slightly revised during the March 19 meeting and is given in Attachment 3. The Recommendations for revising Bulletin 17B are as follows (all the references cited below are on John England's ftp site noted above):

- 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 test recommended in Bulletin 17B with the new Multiple Grubbs-Beck test (Cohn et al., 2011, 2012).
- 3. Confidence Intervals.** Replace the 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 (Cohn et al., 2001).
- 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 by USACE.

### **Low Outliers and MGB Examples Explained**

A major change in the testing procedures since the November 2009 meeting is the development of a Multiple Grubbs-Beck test by Tim Cohn, USGS. This new test is described in a report titled "A Generalized Grubbs-Beck Test for Detecting Multiple Potentially Influential Low Outliers in a Flood Series", Cohn et al (2011), that is posted on John England's ftp site (<ftp://ftp.usbr.gov/jengland/HFAWG>). Tim Cohn gave a presentation on the new test and the theory behind the test. He explained how low peaks often exhibited too much leverage on the upper end of the frequency curve and needed to be censored.

### **Monte Carlo Testing Results: LP3 and Robustness (non LP3)**

After describing the new Multiple Grubbs-Beck (MGB) test, Tim gave a presentation describing the Monte Carlo simulations and the resampling of the observed data. Three different estimates were evaluated:

- Bulletin 17B with the Grubbs-Beck (GB) test for detecting low peaks (existing procedure),
- Bulletin 17B with the new Multiple Grubbs-Beck (MGB) test for detecting low peaks, and
- EMA with MGB (new procedure recommended by the Testing Group).

Tim's presentation indicated that EMA with MGB performed as well or better than the existing Bulletin 17B technique (with the GB test) in estimating the 1-percent chance flood discharge based on simulated data. Tim performed 1,000 simulations for the Monte Carlo experiments and presented his results in box plots that demonstrated the EMA/MGB estimates were generally closing to the true 1-percent chance flood discharge, had less variability than the Bulletin 17B/GB estimates, and more effectively utilized historical information. For the resampling experiments at six long-term stations with greater than 100-years of record, the comparisons were not as clear. The only consistent pattern was that EMA/MGB generally outperformed the other estimators when historical information was present.

### **Results from Testing 82 Sites**

Nancy Barth, USGS, described the testing results for the 82 gaging stations for the three estimators noted above. Nancy summarized the Relative Percent Differences (RPD) for the 10-, 1- and 0.2-percent chance flood discharges for the observed data for four categories of stations:

- Systematic gage data only, no historical or low outlier data (23 sites),
- Historical data, could include high outliers (18 sites),
- Low outliers, no historical information (20 sites),
- Low outliers, historical and/or high outliers (21 sites).

The test results on the 82 stations generated a lot of discussion. For 16 of the 82 stations, the MGB test identified 20 or more low peaks as being potentially influential. This bothered some members of the HFAWG because many of the influential low peaks did not appear to be outliers by visual inspection. Tim explained that we should not consider these low peaks to be outliers according to the definition in Bulletin 17B but we should think of these low peaks as potentially influential low peaks that needed to be censored in order to get more reasonable estimates of the larger flood discharges such as the 1-percent chance flood discharge. The maximum number of low peaks that can be censored in the EMA/MGB procedure is 50 percent of the data.

Zhida Song-James, Michael Baker, Jr., questioned that if up to 50 percent of the peaks are censored, is the EMA/MGB procedure appropriate for estimating the 2-year flood or less? Tim and others commented that neither the EMA/MGB nor Bulletin 17B/GB based on annual maximum data are appropriate for estimating low flood discharges with a 2-year or less recurrence interval. The partial-duration series should be used for this purpose. John England pointed out that one of the frequently asked questions on the HFAWG web site addressed this question. A partial quote from that FAQ is as follows: "Bulletin 17 methodology is not designed for and should not be used to determine high-frequency low recurrence-interval flood magnitudes or to determine the risks due to occurrence of low-magnitude floods. This is the case whether or not there are low outliers, even if the computation does yield a value for the 1.1-year flood." This point will be made clear in any future revision of Bulletin 17B.

John England pointed out that USBR and other agencies have been using a top-fitting (upper 50-percent of data) method in the arid west for years. So censoring up to 50-percent of the data is not a new approach in the more arid west. Beth Faber, USACE, pointed out that the Conditional Probability Adjustment described in Appendix 5 of Bulletin 17B only fits the upper half of the frequency curve in determining the synthetic moments of the LP3 adjusted frequency curve. Censoring up to half the data seemed to be a concern for some participants at the meeting.

Nancy Steinberger, FEMA, pointed there does not seem to be much difference between the EMA/MGB and Bulletin 17B/GB estimates for the 82 stations. The Testing Group acknowledged this to be the case. The issue with using observed data is that one does not know the true flood discharges so comparison of test results is somewhat subjective. This is why the Monte Carlo experiments were performed for simulated data using a combination of assumed frequency distributions.

Nancy also pointed out that when there is only systematic data, the two methods should give the same results (and they do). Nancy asked what percentage of all flood frequency analyses use only systematic data. After the March 19 meeting, the Testing Group compiled some statistics on stations with historical information, peaks below a threshold, low peaks, etc. for three states where USGS has ongoing or completed studies. These results are: California – 43 percent of the stations have a perception threshold (historic, broken systematic record and/or interval data), 44 percent of the stations have low peaks as identified by MGB; Arizona – 62 percent of the stations have historic record, 62 percent of the stations have low peaks as identified by MGB; Iowa – 42 percent of the stations are CSG stations with less than data, 34 percent of the stations have historical information, 36 percent of the stations have low peaks as identified by MGB. This limited analysis indicates that a significant percentage of gaging stations have non-systematic data.

One of the recommended revisions for Bulletin 17B is to adopt new confidence intervals that reflect the uncertainty in the skew coefficient, historical information and low outlier adjustments. Bill Merkel, NRCS, stated it would be interesting to see what differences there are between the new EMA confidence intervals and those from Bulletin 17B. Subsequent to the March 19 meeting, the Testing Group provided examples comparing the confidence intervals for the Sandy River near Marmot, Oregon that has just systematic data. The new confidence intervals were compared for station skew and weighted skew using two different values for generalized skew. This comparison indicated that the new confidence intervals will be wider than those in Bulletin 17B but that more accurate values of generalized skew can decrease the width of the EMA confidence intervals.

Nancy Steinberger also asked about the challenges of adopting the new method that is more complex and asked what training would be provided. The Testing Group acknowledged that training was needed and that easy to use software with documentation was needed. The USGS is developing a version of PeakFQ that implements EMA with the MGB test. This new program will have prompts that assist the user in establishing thresholds for historic data and intervals for missing data. USACE also plans to include EMA/MGB in a future version of their program HEC-SSP. Both agencies will be providing training on the new procedure.

The points noted above were some of the major points of discussion that were captured by the Chair. Any omissions are related to the Chair not capturing the discussion in sufficient detail to describe in these minutes.

### **EMA Multiple Censoring Examples**

John England discussed several case studies that he had previously completed where the available data required multiple censoring levels. The objective of this presentation was to illustrate that EMA could accommodate and utilize non-standard data. The case studies included:

- Santa Ynez River, California – there were three historical thresholds for this site with two of the thresholds based on paleoflood investigations and one on the 1862 historical flood,
- American River, California – there were three paleoflood and historical periods where intervals were used to describe the magnitude of the paleofloods and 1862 historical flood,
- Skokomish River, Washington – extreme high flows can bypass the gaging station at this site so +/- 25 percent uncertainty was used to specify upper and lower discharges for the six extreme floods,
- Arkansas River, Colorado – a paleoflood threshold and interval range was used, a lower historical threshold was used, several peaks in the systematic record were given an interval range due to their uncertainty and another even lower threshold was used for recent unobserved floods,
- Pecos River, New Mexico – three historical thresholds were used in combination with interval ranges for several of the historical floods.

John's report titled "Diverse Extreme Flood Data for Flood Frequency and Case Studies with the Expected Moments Algorithm" that discusses all the case studies is posted at his ftp site (<ftp://ftp.usbr.gov/jengland/HFAWG>). These case studies illustrate the multiple thresholds that can exist at gaging stations and how EMA can be used to effectively utilize the historical or paleoflood data.

### **Overview of Bayesian GLS and Regional Skew Studies**

Another recommended revision to Bulletin 17B is to revise statements about the development of generalized or regional skew. Jerry Stedinger, Cornell University, described the Bayesian Generalized Least Square (GLS) regression approach that USGS is using in a number of studies. For this approach, the uncertainty in the station skew is considered in the GLS regression approach on watershed characteristics. Jerry illustrated that the MSE of generalized skew from this new method is significantly reduced over the existing Bulletin 17B map. Improvements in estimating generalized skew will lead to improvements in estimating the flood discharges such as the 1-percent chance flood discharge. Jerry described USGS regional skew studies in the southeast US, and California and reported that USGS is undertaking regional skew studies in Arizona, Iowa and the Missouri River basin. The objective is eventually to have generalized skew defined in all states and to replace the skew map in Bulletin 17B.

Nancy Steinberger commented that the Bayesian GLS (B-GLS) method was complicated and asked if the adoption of this method should be a separate issue. The Testing Group responded that B-GLS will not be required but simply recommended as one of the better methods for regionalizing skew.

### **Summary and Path Forward**

There was a lot of good discussion at the meeting and some differences of opinion. Martin Becker recommended that the Testing Group respond to all questions received prior to the March 19 on the Testing Report and that all participants provide any additional questions by Friday, March 23. Some additional questions and comments were received after the meeting and responses to all comments were sent out in a single document by the Chair on Monday, March 26. These responses provided a lot of additional information about the recommended EMA/MGB procedure. The March 26 response document is also posted on John England's ftp site (<ftp://ftp.usbr.gov/jengland/HFAWG>).

The Testing Report, the many references posted on John England's ftp site, the March 26 responses to comments on the Testing Report, these minutes and assorted emails since the March 19 email constitute a summary of the testing of EMA and Bulletin 17B. The Monte Carlo simulations performed by Tim Cohn indicated that EMA/MGB performed as well as or better than Bulletin 17B/GB when historical information, low outliers and non-standard data were available. Data for three states where USGS has completed or is conducting regional flood studies indicated that a large percentage of gaging stations have non-standard (non-systematic) data. In addition, John England described data at five stations where multiple thresholds can be used to more effectively utilize the paleoflood and historical data. The test results for the 82 long-term stations were not as conclusive as the Monte Carlo simulations in indicating the most reasonable method because the true design discharges are unknown.

The remaining issues with respect to EMA/MGB seem to revolve around having user friendly software and good documentation for establishing thresholds for historical data and intervals for missing data. The USGS is working on the user friendly program that was demonstrated during the waning hours of the March 19 meeting. This program still has some issues and is not working perfectly but the needed changes are recognized and understood. This program should be fully operational in the near future. Also it is agreed that training is needed for applying the new method and agencies like USGS, USACE and USBR will be providing this training.

Confidence intervals for EMA are complex when there are low peaks censored. The theory is well established and Tim Cohn is making a few revisions to the computational code to be sure these confidence intervals are being correctly estimated.

Given all the information provided in the last couple of weeks, the Chair believes a decision can be made on moving forward with the recommended revisions to Bulletin 17B. With transmission of these minutes, the Chair will ask members if they are in favor of moving forward with revising Bulletin 17B to include the EMA/MGB procedure and other revisions documented in Attachment 2 of these minutes.

Will Thomas  
Chair of the HFAWG  
April 1, 2012 – revised April 2, 2012

**Attachment 1**  
**Subcommittee on Hydrology, Advisory Committee on Water Information**  
**Hydrologic Frequency Analysis Work Group (HFAWG) Meeting**

March 19, 2012

Michael Baker, Jr., Inc., 3601 Eisenhower Ave., Alexandria, VA

**Detailed Agenda**

Meeting Objectives:

1. Present recommended revisions to Bulletin 17B.
2. Present and discuss technical studies on EMA and Bulletin 17B based on theory, testing results using data from 82 stations, Monte Carlo experiments, and resampling. These studies are the technical basis for the recommended revisions.
3. Discuss and determine recommended revisions to Bulletin 17B.
4. Discuss future HFAWG activities, including chair and officers, charge statement, members, and future activities.

<i>Time</i>	<i>Topic, Presentation and Relevant Documents</i>	<i>Presenters/ Discussion Leads</i>
9:00 am - 9:15 am	Gathering of Attendees: HFAWG Members, Observers, Introductions	All
9:15 am - 9:30 am	History, Overview of EMA-Bulletin 17B current investigations, and objectives <ul style="list-style-type: none"> <li>• <i>Overview of Testing and Investigations (slides)</i> – Will Thomas</li> </ul>	Will Thomas, HFAWG Chair
9:30 am – 10:00 am	Recommended Revisions to Bulletin 17B <ul style="list-style-type: none"> <li>• <i>Recommendations Memorandum (handout)</i> – John England</li> <li>• <i>Presentation of Recommendations (slides)</i> – John England</li> <li>• <i>Overview of Technical Presentations and Recommendations (slides)</i> – John England</li> </ul>	John England, Tim Cohn, Beth Faber
10:00 am – 11:00 am	Overview of Testing Methods and Results for 82 data sites <ul style="list-style-type: none"> <li>• <i>Testing Report (handout)</i> – Tim Cohn</li> <li>• <i>Multiple Grubbs-Beck (MGB) Report (handout)</i> – Tim Cohn</li> <li>• <i>Low Outliers and MGB Examples Explained (slides)</i> – Tim Cohn</li> <li>• <i>Results from Testing 82 sites (slides)</i> – Nancy Barth</li> </ul>	Nancy Barth, Tim Cohn, John England
11:00 am – 12:00 pm	Overview of Recent EMA-Bulletin 17B Monte Carlo Testing; Summary of prior Monte-Carlo studies and EMA multiple-censoring applications <ul style="list-style-type: none"> <li>• <i>Refer to Testing Report (handout)</i> – Tim Cohn</li> <li>• <i>Monte Carlo Testing Results: LP3 and robustness (non LP3) (slides)</i> – Tim Cohn</li> <li>• <i>EMA Multiple Censoring Report (handout)</i> – John England</li> <li>• <i>EMA Multiple Censoring Examples (slides)</i> – John England</li> <li>• <i>EMA Confidence Intervals for Testing sites and Monte Carlo Examples (slides)</i> – John England, Tim Cohn, Nancy Barth</li> </ul>	Tim Cohn, Nancy Barth, Beth Faber, John England
12:00 pm - 1:00 pm	Working Lunch - Discussion of Testing Results and Recommended Bulletin 17B Revisions	All

<i>Time</i>	<i>Topic, Presentation and Relevant Documents</i>	<i>Presenters/ Discussion Leads</i>
1:00 pm – 2:00 pm	Continued Discussion of Testing Results and Recommended Bulletin 17B Revisions <i>Overview of Bayesian GLS and Regional Skew Studies (slides)</i> – Jery Stedinger	Jery Stedinger, All
2:00 pm- 3:00 pm	Recommended Bulletin 17C Document: Outline and Discussion <ul style="list-style-type: none"> <li>• <i>Refer to Recommendations Memorandum (handout)</i> – John England</li> <li>• <i>Refer to Presentation of Recommendations (slides)</i> – John England</li> </ul>	John England, Tim Cohn, All
3:00 pm – 3:30 pm	Resolve Recommended Bulletin 17B changes if the decision is to develop a new Bulletin 17C	Will Thomas
3:30 pm - 4:30 pm	Discussion of future HFAWG activities: membership and officers; charge for the group and future activities; nonstationarity - land use change, regulated flows, climate variability, etc. other needed studies or additions to Bulletin 17B or potential improvements	All

Handouts to Be Distributed At Meeting

- Detailed Agenda (this document)
- Revised Recommendations Memorandum
- Testing Report (82 sites, Monte Carlo, etc.) – Updating Bulletin 17B for the 21th Century (Cohn and others, March 8, 2012)
- Multiple Grubbs-Beck Report – A Generalized Grubbs-Beck Test for Detecting Multiple Potentially Influential Low Outliers in Flood Series (Cohn and others, June 8, 2011)
- Multiple Censoring Report – Diverse Extreme Flood Data for Flood Frequency and Case Studies with the Expected Moments Algorithm (England and Cohn, March 13, 2012)

Document Repository

The revised Recommendations Memorandum now provides direct links to electronic versions of these handouts.

Documents are posted at the anonymous ftp site:

<ftp://ftp.usbr.gov/jengland/HFAWG/>

## Attachment 2.

### MEMORANDUM

TO: Hydrologic Frequency Analysis Work Group

FROM: Testing Group, Bulletin 17B Potential Revisions

Timothy A. Cohn, U.S. Geological Survey  
John F. England, Jr., Bureau of Reclamation  
Beth A. Faber, U.S. Army Corps of Engineers  
Nancy A. Barth, U.S. Geological Survey

SUBJECT: Final Recommended Revisions to Bulletin 17B  
Based on Hydrologic Frequency Work Group Meeting Comments and Feedback

DATE: March 26, 2012

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 of some additional needed studies that were identified by the Work Group in 1982.

The Testing Group has completed the testing and studies recommended by the Data Group and the HFAWG as summarized by Will Thomas (HFAWG, 2007). The results appear in Cohn et al. (2012), with additional technical details in Cohn et al. (2011), England and Cohn (2012), and references therein. *The simple and clear tests described in Cohn et al. (2012) 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.*

## 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, we recommend 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 the procedures currently recommended in Bulletin 17B.

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

**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 test recommended in Bulletin 17B with the new Multiple Grubbs-Beck test (Cohn et al., 2011, 2012).
- 3. Confidence Intervals.** Replace the 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 (Cohn et al., 2001).
- 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.

*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).*

Further details on these recommendations, as well as some additional recommendations, are described below.

## **Background**

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. In January 2006, the HFAWG submitted a proposal to the Subcommittee on Hydrology (SOH) to commence studies to investigate potential changes in the following four areas (HFAWG, 2006a):

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.

The January 2006 proposal observes that “the possible changes are considered significant improvements and would warrant the publication of a new Bulletin 17C”.

A draft scope of work was developed and discussed by HFAWG in March 2006 (HFAWG, 2006b). It was agreed by HFAWG members that testing and investigations based on streamflow data, streamflow resampling, and Monte-Carlo experiments were warranted. A Data Group and Testing Group were created by HFAWG to commence the work. The Data Group outlined the data sets and testing methods to

be completed (HFAWG, 2007). A literature review and summary of prior studies would also be performed, including plotting positions. These studies would address items 3, 4 and 5 listed in Bulletin 17B under “Future Studies” (p. 28). Stedinger and Griffis (2008) provide further discussion and perspectives on the literature and investigations. That editorial in the Journal of Hydrologic Engineering, along with presentations at professional meetings (e.g. England and Cohn, 2007, 2008; Stedinger et al. 2008; Thomas et al., 2008, 2010), and with Federal agency discussions (Olsen, 2011) ensured that the profession was aware of our efforts and the likely outcome.

## **Details on Recommendations for Bulletin 17B Revisions**

The recent studies by Cohn et al. (2011), Cohn et al. (2012), England and Cohn (2012), and previously published studies on issues related to Bulletin 17B that are listed in Cohn et al. (2012), 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. (2012), there have been many additional studies conducted by HFAWG members, collaborators, and others since 1995. 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.
2. EMA deals with interval and multiple threshold data that CPA and the Historical Weighted-Moments procedures do not. This new capability allows one to use much more data, as many crest-stage gages and many other sites have interval data.
3. Adoption of EMA will provide confidence intervals (CIs) that include skew uncertainty based on all information, which is neglected in Bulletin 17B.

The recommended changes and status of particular sections within Bulletin 17B are summarized in Table 1 (Main Report) and Table 2 (Appendix below). Refer to pages 9-25 in IACWD (1982) and Cohn et al. (2012) for additional details.

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

<i>Bulletin 17B Assumption or Step</i>	<i>Procedure</i>	<i>Condition</i>	<i>Recommendation</i>
<b>IV.</b>	<b>Data Assumptions</b>		
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
<b>V.</b>	<b>Determination of Flood Frequency Curve</b>		
V.A.	Series Selection - Annual floods	OK	Keep and Clarify
<b>V.B.</b>	<b>Statistical Treatment</b>		
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
<b>V.C.</b>	<b>Refinements to Frequency Curve</b>		
V.C.1.	Comparisons with Similar Watersheds	OK	Keep and review
V.C.2.	Flood Estimates from Precipitation	OK	Keep and review
<b>VI.</b>	<b>Reliability Application</b>		
VI.A.	Confidence Limits	Limited	Replace with EMA
VI.B.	Risk	OK	Keep
VI.C.	Expected Probability	Unnecessary	Delete
<b>VII.</b>	<b>Potpourri</b>		
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

<i>Bulletin 17B Appendix</i>	<i>Procedure</i>	<i>Condition</i>	<i>Recommendation</i>
1	References	Outdated	Update
2	Glossary and Notation	Outdated	Update
3	Table of K Values	Unneeded	Delete
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	Incorrect	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. (2012), 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, crest-stage observations with different thresholds, historical information with one or more thresholds, and perhaps interval estimators describing uncertainty in the measurement of some large events. Thus an extension is needed to the Bulletin 17B weighted moments (WM) and conditional probability adjustment (CPA) procedures that include using a weighted coefficient of skewness (Skew) estimator. 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. (2011) to evaluate if one or more observations should be considered to be low outliers because they are potentially-influential observations at the 10% level. Furthermore we recommend that the Multiple Grubbs-Beck test be employed sequentially as it is in Cohn et al. (2012) so that it checks whether any observation less than the median is significant at the 1% level, before checking if any observations larger than that critical observation are significant at the 10% level. Examples in Cohn et al. (2011) and Cohn et al. (2012) 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 (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.

**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. We recommend that the section on “Estimating Generalized Skew” be revised to reflect 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), the Handbook of Hydrology (Stedinger et al., 1993, p. 18.42), and discussed in Cohn et al., 2012. 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 speculation about changes in flood risk over time. Available evidence indicates that major changes may be occurring over decades or centuries. While time invariance was assumed when developing this guide, where changes in climate and flood risk over time can be accurately quantified, the impacts of such changes should be incorporated in frequency analysis by employing time-varying LP3 parameters or using other appropriate and statistically justified techniques. All such methods 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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### **Attachment 3. List of Attendees at the March 19, 2012 meeting of the HFAWG**

#### **Attending in person:**

John England, Bureau of Reclamation  
Jerry Coffey, Statistician (retired from OMB)  
Carolyn Plank, U.S. Geological Survey (USGS)  
William Merkel, Natural Resources Conservation Service (NRCS)  
Don Woodward, Global Ecosystems Center (retired from NRCS)  
Tim Cohn, USGS  
Nancy Barth, USGS  
Mohammad Haque, Nuclear Regulatory Commission (NRC)  
Siamak Esfandiary, Federal Emergency Management Agency (FEMA)  
Martin Becker  
Zhida Song-James, Michael Baker, Jr.  
Julie Kiang, USGS  
Sam Lin, Federal Energy Regulatory Commission  
Beth Faber, Hydrologic Engineering Center, U.S. Army Corps of Engineers (USACE)  
Will Thomas, Michael Baker, Jr.  
Robert Mason, USGS  
Jery Stedinger, Cornell University  
Ken Eng, USGS

#### **Attending by conference call and live meeting:**

Sanja Perica, National Weather Service  
Joe Krolak, Federal Highway Administration  
Bruce Rindahl, Ventura County, CA  
Mark Bandurraga, Ventura County, CA  
Gary Estes, Citizen Advocate  
Nancy Steinberger, FEMA  
Michael Anderson, California Department of Water Resources  
Tom Nicholson, NRC  
Andrea Villeaux, USGS  
Joe Kanney, NRC  
Chandra Pathak, USACE