Responses to email regarding uses and understanding of 500-year and 1,000-year estimates

On October 15, 2007, HDSC submitted the following to its colleagues, collaborators and other interested parties:

HDSC is considering discontinuing the publication of 1,000-year precipitation frequency estimates because of the severe uncertainty associated with computing such extreme events. We'd like to get your opinion regarding the use and understanding of 500-year and 1,000-year precipitation frequency estimates. Are these estimates being used, and if so, for what purpose?

122 individuals responded. The responses are provided below and are *generally* in the order of: (A) those supporting discontinuance of both, 500-year and 1,000-year estimates to those who use 500-year estimates but not 1,000-yr estimates, and (B) those who use or would like us to continue publishing 1,000-year estimates.

The affiliation of each responder (in parentheses) is shown to provide an idea of organizations/type of users most interested in such precipitation frequency estimates.

Please note that these are responses from individuals and do not necessarily represent an official opinion of the organization shown in their affiliation.

A) Support discontinuance of and/or don't use either 1000-yr estimates, or both 500-yr and 1000-yr estimates. (May support 500-yr but not 1,000-yr)

- I would recommend discontinuance. The 500- and 1000-year projections are wildly speculative, and rarely used or relied upon. Please concentrate all firepower on realistically updating all extreme precip atlases for storms up through 100-years throughout the country. (Private consultant)
- I normally do not use any precipitation data greater than 100-yr because it is so uncertain and statistically risky. If I need to look at less frequent data I use the Probable Maximum Flood or Probable Maximum Precipitation data. When using one of the 4 standard SCS design storm distributions and the published rainfall frequencies, the design will usually be adequate for most actual storm events. I find the greatest problem when reviewing calculations done by others is the over estimation of the Time of Concentration. The larger the Tc, the smaller the Peak Discharge from the watershed. However, if you do an adequate job of determining the Tc value, the peak discharge computed values will match actual flows when you have data to model actual rainfall events. As for the 500- and 1000-yr rainfall data, I do think they are very statistically uncertain and recommend they never be used for design purposes. If you have a historical record storm in an area that should be used for design purposes, then model the actual storm rather than trying to convert it to a probability storm event. (Member of StormTalk Forum)
- I would concur with discontinuing the 1000-year precipitation value. Predicting this based on 40 to 70 years of data seems extremely optimistic, based on my statistics background. This value could be used in some instances where reservoir spillway design needed to something greater than the 100-year (or 500-year) event, but less than the probable maximum precipitation. However, I still think it would be better to discontinue the value. (Private consultant, Montana)
- Yea, Get rid of it. Our lifespans aren't close to 500 or 1000 years yet so predictions out that far are kind of crazy especially if you believe that we have caused global warming due to industrialization in the last 100 years. (Water Quality Control Board, California)
- I pretty much feel 1000 year estimates are in the realm of fantasy. I would extend the comment to the 500 year. Please see the book by Hosking and Wallis on regional frequency analysis, where they do a good job of exposing the problem of model error (the wrong distribution) in statistical estimates related to flow frequency and ddf curves. Basically, they note that model error is the major component of the error for return intervals greater than 100 year. I think there is more to it than in their discussion, but they make the essential point.

  …Mostly, the attempts to extrapolate the curve have had added importance for dam safety investigations to estimate the PMP interval. I think this application of risk analysis has been done so people can say that the likely failure of a dam due to a large rainfall is very unlikely, so we do not have to fix the spillway. The truth is, we don't know the likelihood of this precipitation, but we cannot afford to fix spillway deficiencies in the country, so lets just say it is not likely that the deficiency will be exposed by a near PMP event. FERC also use rare precipitation probabilities for licensing certain facilities. I am sure almost every state dam safety office uses some rare precipitation estimates for certifying dams. The 500 year has had some importance in the national flood insurance program. Most recently an internal FEMA task force recommended using the 500 year flood to do a better job of conveying the residual risk to those who have a 100 year level of protection. Personally, I think any estimate of the 500 year flood is valueless for this purpose. The Corps of Engineers extrapolates frequency curves to compute net benefits for flood damage reduction projects. Again, the uncertainty in the estimates are very large because of the uncertainty in estimating events exceeding the 100 year. Basically I am all for not showing the ddf curves past the 100 year. You will probably get a lot of protests from various groups who need something based on their regulations (both federal and state) my suggestion would be to only display up to the 100 year, and then provide the regional growth curves and perhaps a map of the mean precipitation estimates so that if someone wants to extrapolate the curve, that is their business, but you are not recommending it. (Private consultant)

- I completely endorse this move. The problems associated with the enormous error bars are magnified further by the fact that the climate is decidedly non-stationary. I know of many instances where the current precipitation climate is absolutely changed from as recently as 20-30 years ago. How can we presume to know what 500- and 1000-year returns are? (NOAA/NWS)
- Whenever a hydrologist friend of mine would see a reference to a 500 year or 1000 year event, he would refer to them as "wrath of god" events. Because of the huge uncertainty in assigning precipitation values, mentioned in your note below, I look upon these values with huge skepticism and do not use them in my work. I would have no problem with NOAA discontinuing their publication, because I think that publishing such estimates leads some to believe that we know more about extremely low probability precipitation events than we actually do. When we have precip. stations with hundreds of years of reliable records, then maybe we can talk about estimating 1000 yr. precip. values. (Forest hydrologist)
- In all candor I consider such predictions to be so uncertain as to be misleading. Most people, including most practitioners who should know better, have no real grasp of the implications. It would probably not be so bad if we had not ever started using the "return period" nomenclature, which is very deceptive in and of itself. It is much less misleading to say "probability of .001" than to say "1000 year return period". (one of my pet crusades) I move that the publication of these estimates be discontinued. Anyone who needs them for public safety purposes should have to derive them themselves. (Department of Transportation, Texas)
- As a transportation agency, we have no situations where we would use such information in the design of our facilities, so we would suffer no ill consequences if you were to no longer publish these estimates. Further, I would question the validity of such information given the relatively short historical record and the lack of climate stability over such long timeframes. (Department of Transportation, California)
- Frankly I don't know of anyone who has actually used the >100 year events or even "rainfall of record". Without clear basis of formation, anyone that used the numbers would be committing their design, construction, and operations to massive costs without sufficient, adequate, practical basis of design. Case in point in a MidEast country the government said to use the Omanii standards of 1/1000 years, my reply - you can't afford and the basis is at best a ten-year (not even sunspot cycle or Global Warming influences). Eventually the question is how much money do you have to spend...came out to 1/25yr+/- 5 years. Even during the floods of the Mississippi which were estimated to be a 1/200 year flood, the levees held expect for blowouts and some overtopping...therefore the CoE over-designed and cost the taxpayers a lot more money, but protected a lot of people. Eliminate ANY period opf over 100 years, i.e., 101 years. Provide adequate statistical basis for +/- 1SD, 2SD, 3SD. Include one set for peak and one for minimum during sunspot cycles. Include 1-plus for "Global Warming" (University, California)
- From time to time, I've been asked to estimate the 500-year flow event (usually for bridges using a % or the 100-year flow). In my opinion, the use of a 1000-year estimate would be very limited - not to mention based on sketchy probabilities. Even the COE would have limited use of this data and if it wasn't available would

make use of other estimating means. (Private consultant)

- I don't use them but get requests for the 500-year event thanks to FEMA. I give the requesters the same story - with only 100 years or so of data you are really pushing the envelope in determining the 500 and 1000 year event. Yeah, you can include confidence intervals but most users ignore them. Besides the sampling issues, which are severe enough in discourage their use in my opinion, we can expect to see human-induced climate change over the next century and beyond. This will likely include significant changes in the climatology of heavy precipitation events, making the calculations more meaningless. I say pitch 'em. (State Climatology Office, Illinois)
- We don't currently use the 500-year and 1000-year precipitation frequency estimates. Our design guidelines for dams key on the 100-year storm for lesser-hazard dams, and on the PMF, derived from HMR-51 and 52, for High Hazard dams. For an existing High Hazard dam, our guideline is 50% of the PMF. The attached paper talks about the problems with this approach. I believe the dam safety community would be interested in a study which could be used in dam designs to provide a consistent level of protection - this would go along with the risk-based concepts that many federal agency dam owners seem to be adopting. Alternately, an update of HMR-51 and 52, and for that matter 100-year rainfall maps for New York, would be a very welcome start. (Dept. of Environmental Conservation, New York)
- I concur with the implications of the statement “severe uncertainty associated with computing such extreme values”. This statement in itself alludes to the ease of using computer software to push the mathematical/technical limits in extrapolating data without stringent consideration of the data base from which the statistical projections are being developed. The other problem I have with these data projections is the relative ease for a neophyte to possibly misuse or misinterpret such data (i.e., particularly the 1000-year projections) as being the PMP or being the most extreme rainfall for that selected location. I for one have never had the need for these two projections and would recommend that they be deleted to avoid their misuse and alleviate the consideration of these data as being what they are claimed to be – i.e. the 500-year or the 1000-year rainfall event. One other point that I have for future consideration is “What is the possibility for the inclusion of PMP data values (even if they are interpolated from the old HMR-51 data maps) within this software in lieu of these two rainfall projections?” The inclusion of PMP data would lend another significant advantage to an already powerful data projection tool. Thank you. (Private consultant, North Carolina)
- Yes, drop the 500 and 1000-year frequencies. We never use them. (Private consultant)
- We do not use the 1000 year estimates. (Water Research Center, Florida)
- The highest frequency I normally use is 100 years. I have no problem with NOAA discontinuing the 1,000 year event. (Private consultant)
- Speaking for me personally, I would support dropping at least the 1000-year precipitation frequency estimates for just the reason stated. 100-year makes sense and 500-year is marginal due to uncertainty to me but 1000-year has far too much uncertainty to be used without being confused. (NOAA/NWS/Ohio)
- As a water resource engineer designing stormwater detention facilities in Virginia, the 500-yr and 1,000-yr events are not used. Localities specify control of the 100-yr event, most of the time. After a few terrible hurricanes in past 5 years that left many older farm ponds breached and increased flooding, larger storm events are being looked at. There has been a push by the Commonwealth of Virginia to see if a detention facility is able to retain the runoff volume generated from a 1/2 Probable Maximum Precipitation (PMP) event. See HR 51 from NOAA for the full document. Since most designers use the TR-55 method to generate runoff data for detention facilities, it had been interesting to see how the PMP event. There are many different rain events that can be used for different drainage areas and time frames. None yet had been prescribed by regulation body, so it is up to the engineer to use his best judgment on which storm event to use and how to apply it. (Private consultant, Virginia)
- I have a seen a few comments in support of keeping the 1000-year events. As stormwater/water resources engineers, we increasingly focus on smaller, more frequent storm events (such as the 1-year or even less) and never utilize the 1000-year estimates. Therefore, we would support you in discontinuing the 1000-year estimates. (Private consultant, Pennsylvania)

- I have not had occasion to use the 1000 year precipitation and since we do bridge and detention pond design, I don't intend too. I think including that frequency in the tables implies to those outside the hydraulics and hydrology world and to some in it that the accuracy of prediction is good enough for use in design since it was published. This may or may not be true of course depending on the application but we do know the accuracy gets worse as you progress up the scale. I am in favor of removing it from the tables. (Department of Transportation, Tennessee)
- The South Carolina State Climatology Office frequently uses precipitation frequency estimates, but never for a period greater than 100 years. I don't believe in my 15 years working with the SC State Climate Office I've ever responded to a request for a 1,000 year precipitation frequency. (State Climatology Office, South Carolina)
- This is an interesting question... it would seem as though pcpn with those recurrence intervals would be approaching the maximum possible pcpn rates if there is such a thing... and maybe that is a moving target with climate change influence. We have no specific need for such data. I would be interested to hear about any responses you get where people are using these frequencies and it may be worth posting to your email list since it may give other customers some ideas. I would also like to get a list of any other uses that people have provided for any of the lower recurrence intervals for use in a fact sheet for marketing the product to try to obtain funding for updated analyses. (NOAA/NWS, Alaska)
- I would not even accept an 1000-year prediction due to the uncertainty. Please discontinue any 1000-year predictions. (Department of Transportation)
- We have not had a need to use those precip data since I've been here at the District (3 years). We are more likely to use the extreme storm concepts from the Corps such as standard project flood, PMP, PMF for dam break analyses and levee design. So if you don't provide the 500-yr or 1000-yr results, that probably wouldn't affect our operations. (County Watershed Protection District, California)
- Here are some comments from the Oklahoma Climatological Survey: From a climatologists' point of view, I find 500- and 1000-year events to be useful only in a gee-whiz novelty kind of way, especially for the 1000-year estimates. The datasets behind them are far from robust. There may, however, be standing regulations/specifications in the engineering realm that require reference to these values. In these cases, I recommend education about the nature and reliability of very-long-period recurrence statistics. (Oklahoma Climatological Survey)
- Our need for precipitation frequency estimates is for analysis, design, and regulation of water resources matters. Return periods up to 100 years are of great interest to us. For needs greater than that we use PMP techniques. We feel they are justifiable and appropriate. Therefore we have no interest in frequency estimates far greater than the data record. (State government office, North Dakota)
- I agree that 1000-year precipitation frequency estimates are of little value. Possibly 300 years from now they will have more meaning. (University, Arizona)
- I use precipitation frequency estimates. For the most part, I do not use those greater than 100-years. I use them to compare to streamflow frequency and see how significant a given flash flood event might have been. If uncertainty was better with the 500- and 1000-year precipitation frequency estimates, I would make more use out of them. (NOAA/NWS, Alabama)
- We still use the 500-yr precipitation estimates for FEMA related H&H studies. For new detailed studies, FEMA still requires a profile and floodplain for the 0.2% chance event. (Private consultant, Texas)
- We typically don't use any rainfall frequency in an official capacity beyond the 100-year storm. We do have passing interest in the 500-year storm for dealing with the calculation of the 500-year flood, but don't use it in any official regulation as yet. (County Flood Control, California)
- We use the 500-yr for all of our bridge hydraulics as an overtopping extreme event. This is a requirement of the Utah Department of Transportation. I have never used the 1,000 yr. We of course use 100 yr and below constantly. (Private consultant, Utah)
- Certainly the 1K yr greatly exceeds NCDOT needs for engineering purposes.The 500yr is investigated for

use in developing bridge scour predictions (considered by FHWA to be the super storm) (Department of Transportation, North Carolina)

- I'm an engineer in a private firm in Hampton Roads, Virginia. The most severe storm that we design to is the 100-year event, and this is to ensure there is no structural flooding. Super highways are designed to the 50-year event. Back in 1999, I think, we experienced hurricane Floyd. Floyd interacted with a cold front over York County, VA, and dropped more than 15-inches of rain in a 24 hr period. Some people have said that this was a 500-year storm, but I have never had to calculate it. (Private consultant, Virginia)
- I'm only speaking for myself, but 1000 year values are not of much value in my work. The 500 year values are of some value because flood frequency modeling I'm familiar with often includes at least the ABILITY to calculate the 500 year flood. (We make the assumption that the 500-year flood is caused by the 500-year precipitation). So, in short, I would be fine in seeing the 1000-year data being discontinued, but I think I'd like to continue seeing the 500-year data be supported. (University, Maryland)
- We typically do not deal with 1000-year precipitation frequencies but we have had to determine the 500-year flood flows in Connecticut. The State of Connecticut has a policy to restrict certain types of uses within the 100 & 500-year flood zones that have State funding. I used USGS Regression equations to determine this but I also wanted to have 500-year precipitation data to plug into a HEC-1 model of the watershed but it was not available for our area. (Private consultant, Connecticut)
- We typically do not utilize the 1000-year estimates here at the Southwest Florida Water Management District. However, we do utilize the 500-year precip frequency estimates for flood risk analysis. As part of FEMA's National Flood Insurance Program, an analysis of the 500-year floodplain is required for detailed, riverine studies. In ungaged areas, this analysis requires a 500-year rainfall estimate. (Resource Management Dept., Florida)
- Unfortunately, I have only seen the 500-year and 1000-year return frequency precips used as propaganda after a major flood. In dam design, we typically refer to PMP events for anything more extreme than the 100-year storm. Will these email replies be posted anywhere? I believe it would make for good discussion. (Private consultant, North Carolina)
- One quick answer is that I would expect that your 500-yr depths are used quite commonly for FEMA floodplain mapping (I have done so myself), which is often done using design storms and requires 100-yr and 500-yr analyses. The uncertainties are indeed large, but delineation of a 500-year floodplain is standard procedure for areas of "detailed" study. (U.S. Geological Survey, Illinois)
- I do not have particularly strong feelings either way. I always take 500+ with a grain of salt anyway, and I do find it useful to know approximately what these values are. If they are removed, something the USGS does might be adopted, which is to report a large flood beyond the 100-year value as "1.7 times as large as the 100-year flood value". (NOAA/NWS/Western Region)
- We have used the 500-year data for scour analysis at bridges. However, we have not yet seen a use for the 1,000-year recurrence interval. (Private consultant)
- I'm …of the Hydraulics and Hydrology Engineering Team of the Corps of Engineers' Buffalo District. I've been involved with using hypothetical rainfall in rainfall-runoff computer modeling for over 30 years. I often use hypothetical rainfall up to and including the 0.2% (500-year) storms. If I need to model for storms greater then the 0.2% event I use the Corps Standard Project Storm (SPS) event. The peak discharges generated using the SPS are in the 40% to 60% range of the Probable Maximum Flood peak discharges and - unofficially - are normally between a 0.1% (1000 - year) and 0.05% (2000 - year) event. I've attached the Corps guidance of the Standard Project Flood - in case you are not familiar with this concept. For 0.5% (200-- year) and 0.2% (500 - year) rainfall events - I normally have to extrapolate from less frequent rainfall events. It is my experience from in using extrapolated rainfall that I need to be extremely careful in both interpreting the rainfall from regional publications - such as TP-40 - and smoothing or fitting a curve to rainfall amounts. If I take my time and check my work - I usually get good results. (U.S. Army Corps of Engineers, New York)
- Thanks for keeping us in the loop. We appreciate all of the effort that went into Atlas 14 for the Ohio River

Basin. Regarding the 1000-yr flood, I can imagine the uncertainty is huge. We never use that event here for any highway or bridge or dam design (that I know of). However, the 500-yr flood is used for scour analysis as a check (after the depths are computed for the 100-yr event). Still, our bridge people now are using 500-yr flows based on regression equations for peak flow and I'm not sure they would want to use a rainfall/runoff model. FEMA flood studies (FIS) usually provide a delineation for the 500-yr flood plain, so there may be some value in the 500-yr precip for them. … Otherwise, the big precip event we are interested in for earth dam spillway design is the PMP (probable maximum precip). That may not be something you derive from historical rainfall data, but I was wondering if maybe you have a reference on what the most current estimates are for the mid-Atlantic states (or the US). What I have now is Hydromet Report #33 dated 1956 (which is even older than TP 40!). (State Highway Administration, Maryland)

- Per the below, I'm writing to let you know that the 500-year estimate is useful. I am aware of at least one municipality that actually requires review of a 500-year event for design of storm water management systems. They incorporated this design requirement after a severe storm event, estimated to exceed the 100-year storm event, caused much damage in their community. (Private consultant)
- In Arizona we are using the 500-yr estimates for bridge design. That is, our superstructures and foundation elements (scour) are analyzed with the 500-yr event peak flows. The bridge opening itself is sized with the 50-year event on interstates and major state highways, and as low as the 25-yr event peak flows are applied to size lower class roadways bridge openings. Thanks. (Department of Transportation, Arizona)
- The 500 year precipitation frequency events are sometimes used for designing the size of dam spillways (regular spillway or overflow spillway) because of the possible catastrophe if the flow exceeds spillway capacity. The 500 year precipitation frequency events are also sometimes used for dam failure inundation area mapping. (Private consultant)
- Our company processed and studied flood insurance studies for FEMA. Rainfall-runoff analysis is one of the methods used in determining discharges for flood insurance studies. For detailed studies, 10-, 50-, 100-, and 500-yr floods are required to study. The 100-yr floodplain boundary is shown as Zone AE and 500-yr floodplain boundary is shown as Zone X shaded on the flood insurance rate maps. As you know, these maps are used by several agencies, organizations and individuals. We need standard analysis and data to be used for the entire country. NOAA is the only agency that can fulfill this role. I would like to request that NOAA should at least include the 500-yr precipitation frequency estimates in its analyses and publications. (Private consultant)
- Based on my 30+ years of experience in Hydraulics for the Corps of Engineers, I see little value in including the 1000-year rainfall. Events of this severity might be better estimated by applying a selected percentage of the Probable Maximum Storm or the Corps' Standard Project Storm method. The 500-year rainfall is of value and I think should be retained. FEMA's FIS program requires the 500-year flood to be analyzed and a hydrologic model using the 0.2% chance rainfall event is a workable procedure. Corps feasibility studies also will include computing flood profiles through the 500-year event as part of the economic damage analysis and for the design and evaluation of flood reduction measures. (Hydraulic Consultant, COE retired)
- The importance of these rare events will increase significantly as FEMA and COE will continue to develop their levee safety/certification programs. For example, the used of 500 to 100 year events for design of levees is an accepted practice in Europe. It is important to have an agency such as NOAA publish such estimates, despite uncertainties, to give the design community and local/sate jurisdictions a common basis for approaching design of critical structures such as levees and small dams. Please continue making these estimates. (Urban Drainage & Flood Control District, Colorado)
- The Virginia Department of Transportation currently considers the 500-yr. recurrence interval for both rainfall and runoff for the purposes of determining the effects of a super or check event on larger streams and watersheds. We also do it because FEMA currently publishes 500-yr. flood profiles. At this time I would think it unlikely that the Department would consider 1000-yr. recurrence interval rainfall or runoff events in its hydraulic designs unless the practice is encouraged by AASHTO, FHWA, and/or others that typically establish guidelines for hydraulic engineering in the civil engineering community. (Department of Transportation, Virginia)

- I suggest that you contact the Federal Highway Administration (FHWA) for confirmation that the 500-year estimate is used routinely in scour computations for bridge design. Based on my experience with that design process, there is a definite need to retain the 500-year estimate. I am not aware of any routine use for the 1000-year estimate. (Dept. of Environmental Protection, Pennsylvania)
- 500-year precipitation depths for various durations are sometimes used in hydrologic models to estimate flood flows for computation of flood profiles that are then used to produce flood hazard maps for the FEMA flood insurance/mapping program. (Southeastern Wisconsin Regional Planning Commission)
- …it will be very beneficial to publish more information about the uncertainty such as coefficient of variation in addition to the confidence intervals. So the designers would know how much risk/uncertainty is involved in the 500-year and 1000-year estimates. These uncertainties such as coefficient of variation can be used for the uncertainty and risk analyses. (Flood Control District, Arizona)
- From my experience, hydrologists and engineers do use the 500-year estimates. For example, FEMA uses them to delineate Zone X flooding, and engineers use them to evaluate levels of protection offered by flood control dams. I have observed that the level of uncertainty tends to be ignored across the board. Because the information is readily available and is presented in the same manner as the other data, the higher frequency events are being accepted with no distinction in confidence from the lower ones. This is particularly troublesome in the arid southwest where the inherent lack of rainfall data is already problematic. The Arizona Floodplain Management Association's fall conference is November 8-9, and I'd like to bring this up for discussion there. I realize it is past your comment cut-off period, but if I collect any useful information from the members, I'll pass it on to you. (Private consultant, Arizona)
- For urban drainage applications, a “check storm” is used to assess hazard potential at critical locations (e.g., underpasses, intersections, etc.), and typically the 100-year storm is used for this purpose. The Alaska Highway Drainage Manual stipulates that designers of bridges and bottomless structures consider a “superflood” event and assess the associated flood hazards. Roadway overtopping potential is also evaluated at culvert crossings as well. ADOT&PF defines a superflood as the 500-year flood or 1.7 times the 100-year flood, whichever is less. I have not personally used 500-year or 1000-year precipitation information for generating peak flow estimates, but others may have. I suspect that most hydraulic engineers will refer to the USGS Water-Resources Investigations Report 03-4188 Estimating the Magnitude and Frequency of Peak Streamflows for Ungaged Sites on Streams in Alaska and Conterminous Basins in Canada for discharge estimates for medium to large basins. (Department of Transportation & Public Facilities, Alaska)
- We at the Canyonlands Research Station, USGS, Moab, UT, use the 500 yr frequency estimates for our work testing the characteristics of water erosion on sandy soils of the Colorado Plateau. We use a rainfall simulator to measure infiltration and runoff on soils of varying degrees of soil disturbance/soil development subjected to rainfall intense enough to cause runoff, but not so much as to be outside the realm of reality. We use the very low frequency intensities to set outer limits on amounts of soil erosion we might expect from different soils. (U. S. Geological Survey, Utah)
- In response to the email below soliciting comments, I would like to offer the following: I have been a practicing civil engineer since 1985, and since 1996 exclusively in the area of hydrology and hydraulics. I have not been involved in, or been aware of, any need for 1000-year precipitation frequency estimates. However, in my opinion, there is a significant and ongoing need for 500-year estimates. I can think of two prominent examples: First, FEMA and others producing flood mapping studies and plans will often include estimates of not only the 1% annual chance flood (100-yr), but also the 0.2% annual chance flood (500-yr). Second, FHWA guidance on designing bridge foundations to withstand predicted scour during storm events requires estimates of both 100-yr and 500-yr scour depths. I think that continued development of 500-yr precipitation frequency estimates is justified in view of the above practices by US Federal government agencies. In addition, I would say that the trend in the industry is to provide more robust designs for public infrastructure, not less. Finally, I would bring to your attention many relatively recent flood events that exceeded a 100-yr return frequency: April 2007 (New Jersey); September 1999 (Tropical Storm Floyd, NJ); July 2004 (Burlington County, NJ, approx 1000-yr event); June 2006 (Upper Susquehanna River, NY, > 500-yr event). Given the above, I believe there is a well-demonstrated need for 500-yr precipitation frequency estimates, but not 1000-yr. Thank you for the opportunity to provide some input. Thank you also

for the invaluable data that NOAA provides to the engineering community. (Private consultant, North Carolina)

- FEMA Flood Insurance Studies and Flood Insurance Rate Maps include an estimated flood extent for the 500-year event. If you do not publish 500-year precipitation frequency estimates the study contractors will do it case by case. It would be better to have a standardized estimate from HDSC. (Private consultant, Ohio)
- …we use the 500-yr recurrence interval precipitation estimate to determine discharges and flood levels of 0.2% probability (500-year) flood events for FEMA Flood Insurance Studies and related analyses and design. We feel the 0.2% probability (500-year) flood event is an important benchmark to evaluate risk for extreme flood events that are expected to exceed the design capacity of a community's infrastructure. Additionally, the 0.2% probability (500-year) flood event can be used as a broad generalization of flood risk under unknown circumstances, such as future conditions or debris blockages. I am unaware of anyone in our office using the 1,000-yr recurrence interval precipitation estimate. [Our office] specializes in the planning, design, and construction management of local government and private infrastructure projects. Our specialties include flood protection, stormwater, wastewater, environmental management, recreation, and transportation. (Private consultant, Indiana)
- I would suggest that you contact the U.S. Nuclear Regulatory Commission or the Department of Energy to see if such information is necessary to have for long-term spent nuclear fuel storage safety and environmental evaluations (e.g., Yucca Mountain). Such agencies may have a need for such information. I'm not sure who you would contact in those agencies, however, but hope this info helps. (Private consultant, Massachusetts)
- We do not use 500 yr or 1000 yr precipitation frequencies for design at Mn/DOT. I have occasionally compared a specific storm event to the larger precipitation frequency estimates to provide a sense of perspective, so I would recommend keeping at least the 500 year. Of course one hopes that people understand the potential inaccuracies associated with any number they use. (Department of Transportation, Minnesota)
- In Arizona the 500-yr event peak discharge is being used to design bridge superstructures and foundations (scour analysis). The maximum even for sizing the opening is the 50-yr. The 1000-yr is only used for checking flooding. So this answers the question regarding whether this event is being used. As for its accuracy, we are using what NOAA 14 spits out at its face value. Just for info. (Member of StormTalk Forum, Arizona)
- The extreme events are sometimes used by defense attorneys to illustrate that the storm that caused damage to the plaintiff's property was highly unusual. But from a practical design standpoint, the only time a 500 year storm event is used in design might be for a major dam project to predict overtopping. (Private consultant)
- Estimates of the 500-year precipitation are needed as Congress has before it recommendations to increase the required level of flood protection from the 100-year flood to the 500-year flood. The Association of State Floodplain Managers (ASFPM) has two public policy white papers making this recommendation. In watersheds without stream gage information, precipitation data is used to make flood estimates in hydrologic models. So the 500-year precipitation estimates are vitally important as the push for higher standards for flood protection advance. The science needs to be available to support the public policy changes. If there are concerns about the quality of 500-year and 1,000-year precipitation estimates, then the case needs to be made that research money is needed to be able to answer the question of what are the best available data for determining the 500-year precipitation frequency estimates and the 500-year flood. (American River Watershed Institute, California)
- I think publication of 1000-year estimates is not a good idea, as records are simply not long enough to support them. The same could be said for 500-year estimates. However, bridge scour evaluations are being done for 500-year floods, and there needs to be some basis for them. I think the use of 500-year events for bridge scour is to some extent a knee-jerk reaction to some recent (last 20 yr or so) bridge failures, but it is current policy nonetheless. Therefore, I recommend that publication of those estimates be continued, but that

users of them be warned that the uncertainty associated with them is very large. (University, Alabama)

- My opinion is that the 500-yr precipitation events are useful. FEMA includes the 500-yr flood in their flood plain mapping efforts. In Illinois, we usually seem to be extrapolating the Illinois State Water Survey Bulletin 70 precipitation amounts to estimate the 500-yr. Having a NOAA 500-yr estimate would result in a more uniform estimate of the 500-yr across watersheds. I am not aware of anyone using 1000-yr precipitation events. For extreme events, the modeled frequencies are the 100-yr, then either the 200- or 500-yr, and then the PMF or fractions of the PMF. My preference would be for there to be 200- and 500-yr precipitation event estimates prepared by NOAA. (Private consultant, Illinois)
- FEMA Flood Studies include the 500-year flood. For that reason I think the 500-Year rainfall estimates are important. Dam design utilizes the Probable Maximum Precipitation (PMP). I don't recall having ever used the 1,000-Year rainfall estimate. (Private consultant)

B) Use and/or support publishing 1,000-yr estimates.

- I have used PMP for some dams and all slurry impoundment dams once only in 1980s, otherwise mostly we use 100 yr. flood. 1000 yr. or PMP is only used in very rarely in special cases only where hazard due to dam break can wipe out a community or cause devastation. (Private consultant)
- When the level safety becomes an increasing concern, the 500 and 1000-yr events are the legitimate choice. How can we assess the risk of flood when the 1000-yr event is the design event? This is a very complicated question. Statistically, the 1000-yr rainfall depth can be determined by the distribution curve. But, there is always a question as to if such a highly extreme event can be represented and predicted by the 20 to 30-yr sample data. There are good reasons why we separate PMP from the frequency-duration rainfall events. In practice, our concern is the PMF. It does take both rainfall depth and tributary area to produce runoff. Rainfall depth decays with respect to the tributary area. Consider the nest structure for the rainfall distribution. The intense portion happens to a point area (say 5 square miles), rather than the entire watershed area (say 500 squire miles). Even though we can produce the 1000-yr rainfall depth by a statistical method, we are still facing the basic question as to how to apply such a extreme point rainfall value to a large tributary area or how to define the depth-area reduction. In general, thunder storm events happen with a short duration while an extremely large flood may come from a long event. A short storm may only cover the lower valley area and a long event can cover the entire watershed as the tributary area. A 1000-yr event presents a challenge as to how to conduct the storm centering by which we can define the tributary area under the storm. In other words, the tributary watershed boundary is not always the same when dealing with 1000-yr or PMP events. The above is my penny thoughts of my experience when I worked with 200 to 1000 square miles watersheds in the SW Nevada Valley. (University, Colorado)
- In an earlier email, we were posed with the question of whether to continue to show the 500-year and 1000-year rainfall information or not. While it is only our opinion, I appreciate having the information available. This information can be difficult to find, but more importantly, I believe it gives one a good estimate of greater storm events. As long as they are not assumed to be more accurate than they really are, I see no harm in having the data. I hope it remains on your website. I also hope it finds greater usage in the future among engineers and review agencies. Specifically, I believe there area instances where the 500-year storm event would be better than the 100-year storm event for many engineering usages. To not have the information available may become a "reason" that the smaller storm event would be used, and thereby placing people at greater risks. (Private consultant, Tennessee)
- I'd be interested in seeing precipitation estimates with an associated description of the uncertainty -- either a probability distribution or a confidence interval. Is this being considered? (U. S. Army Corps of Engineers)
- For most Flood Insurance Studies and Flood Damage Reduction Studies, we have to provide 500-year flood profiles at a minimum with some Corps of Engineer Districts computing 1000-year or greater. In the past we would extend by hand the frequency rainfall curves to obtain those values. By having the NWS determine these higher frequency rainfall values, this eliminates the uncertainty of extending these curves ourselves, thereby adding some uniformity from District to District. Therefore, LRL would prefer that the NWS

continue providing these precipitation frequency estimates. Thanks for all of your great work on developing Atlas 14. (U. S. Army Corps of Engineers)

- Thanks for keeping me up to-date on these issues. In general, a 500-year discharge is used for planning purpose (sometimes FEMA require it and sometime doesn't. DSOD(Division Safety Of Dams) may require the analysis for more than 1000 -year discharge. The important point is that a 1000-year precip data may not produce a 1000-year run-off volume at the outlet of the watershed. For a given watershed, it is very important to have a long term data for the relation between the stream gage and precip data. (Private consultant)

- Although perhaps a disclaimer should be emblazoned on the data, it is still your best estimate. FEMA's HAZUS program is currently able to predict damages up to the 1000yr event and typically unusual flood events are related back to a high yr flow. Floodplain and watershed managers are debating what is a appropriate level of protection 100yr or 500yr flood events which is determined ultimately by the precip freq. Before you give it up as nearly useless you may want to seriously reach out to the engineering community that undertake the design of infrastructure. (Bureau of Recovery and Mitigation, Pennsylvania)

- I did not know that you were doing this. I know that California DWR has up to 10,000 year point precip estimates for various durations, but this is the first I had heard that NOAA has published 1000-year data…. The California data are useful for establishing a "comfort" zone with respect to projects affected by floods. It is a relevant number to consider in evaluating safety of dams, at least on a preliminary basis. Of course you have to state the distribution assumptions and some measure of uncertainty limits.

  I recommend keeping the 1000-year data. Not that it has much application in storm sewer design but it is important with respect to dam safety issues and major areal flooding issues, such as multi-basin convergent flooding. Sometimes it is a useful measure to consider in design of dam safety features, as one risk factor, possibly among others, such as a PMP estimate. (Private consultant, California)

- I realize that the 1,000 year analyses are fraught with problems and uncertainties, but I still encounter people who need them -- in many cases, for administrative reasons ("laws require..."). On way or another, someone is going to estimate those. It may go the way of PMP -- opening up opportunities for the private sector to move in. Instead of "site-specific analyses" we may see "return period specific" ones. My sense would be that for consistency the agency that does the 10-, 25-, 100-year etc. should also do the 1,000-year analyses. (University, Oregon)

- We use the extreme events when modeling watersheds for different frequency storms. We look at the entire range of frequencies (1 yr to 1000 yr and up to the PMF) to see the affects of all storms on the watershed. Although there is some uncertainty with the 1000 yr event, it still gives you an indication on what the 1000 year or an extreme event will do on your watershed model. (U.S. Army Corps of Engineers, Great Lakes and Ohio River Division)

- I have mixed thoughts about using and not using the 500- and 1000-year estimates. Some jurisdictions require use of estimates of such rare events, although I think fractional or full PMP estimates might be better suited for such estimates. Nonetheless, we do still have some requirements for them. I would prefer using your estimates over having to construct my own. I suggest you keep them until such a time as it becomes clear they are not required by regulators or reviewers. (Private consultant)

- The Fresno Metropolitan Flood Control District provides flood control and urban storm drainage to the Fresno-Clovis area in Central California. While we do not use 500 and 1,000 year frequencies for design, we do find them useful in that they provide some perspective on the statistical and historical determination of the amount of rainfall in these extreme events. However, we also recognize that these frequencies are problematic to accurately define. Our vote would be to continue the 1,000-year event estimation.

  The Fresno Metropolitan Flood Control District has occasionally used the 1000 year estimate. This information is useful when making improvements and/or analyzing the performance of the Corp of Engineers Flood Control Facilities. (i.e. - The Redbank and Fancher Creeks Project.) n 1993 when we evaluated alternate outlet/spillway improvements for the Alluvial Drain Detention Basin the 1000 year estimate was used. In particular, The Basin Maximum Storm was determined by trial and error runs of the HEC1 model using different total rainfall until the Basin High Water nearly equaled Elevation 389.3. The recurrence interval of the storms was determined using rain gage data from the California Department of Water Resources Bulletin 195. The 96 hour rainfall for the 200 year, 1,000 year and 10,000 year recurrence intervals were plotted against the normal annual rainfall for each of the gages in the area surrounding the Alluvial Drain watershed and curves drawn through the points of equal recurrence frequency. The point of the normal annual rainfall and Basin Maximum Storm was plotted on the same graph and compared to the curves. The recurrence interval was estimated by interpolating the position of the plotted point from the curves. For District staff, this information is beneficial and used from time to time. We would like to see this information updated and maintained. (Flood Control District, California)

- I have not used the 1,000-year precipitation frequency estimates published by NOAA. We have a 1,000-year duration frequency depth curves, but I don't know what sources my predecessor used to create it. It could be he used NOAA references. If we were to update our D-F-D curves, and relied on NOAA 1,000-year precipitation frequency estimates, we would be out of luck. If the design criteria from state and federal agencies calls for the calculation of the 1,000-year precipitation (or greater) you should keep estimating it. We were recently told by the California Division of Safety of Dams to use the 80,000 year storm for a dam on the relatively small (11 square mile) watershed. The related e-mail string is pasted below as proof. Our wonder is how different would the 80,000 year storm be from the PMP? Why be so specific when the uncertainty is so high for such very rare events. Some dialogue between the meteorologists and engineers/hydrologists should occur to get a clear handle the reasonableness of design frequencies. The fact that NOAA recognizes the "severe uncertainty associated with computing such extreme events" shows that "splitting hairs" over rare events is close to ridicules or possibly foolish. (Flood Control District, California)
- The 500 and 1,000 year precipitation events are used commonly for the design of spillways and other flood control measures. This information is routinely utilized by civil engineers in the planning and operation of canals, spillways, flood walls, and other hydraulic structures. The Corp of Engineers, FEMA, and Bureau of Land Reclamation are among the Federal agencies that utilize the information in the publication of standards and design guidelines. The 500 year return period appears in some of the literature as equal to 1/2 the PMP (probable maximum precipitation) and the 1,000 year return period as the PMP. In Connecticut the Department of Environmental Protection, the agency that regulates most water use activities, requires the development of the 500 and 1,000 year return period precipitation to either design new or check old hydraulic facilities. The Connecticut Department of Transportation utilizes the information to design major stream crossings. This extreme event data appears to be also utilized in dam break planning to determine safe evacuation routes, etc. While the returns may be subject to error, it is far better to have a consistent approach that has a basis in the sciences than to allow each agency to develop there own procedures which are more likely to be just as flawed if not more so than what is being prepared and published. I have found them useful in predicting extreme spillway and river flow events. Please note that FEMA uses the 500 year return frequency for flood forecasting in its Flood Insurance Studies. The 1,000 year return event is utilized in spillway design. While they may have large potential error, they do provide a consistent approach. Almost forgot to add that the US Army COE utilizes the estimates for flood control projects as the extreme storm. The same is true of the Bureau of Reclamation in its dam and flood control projects. A lot of the published material references old Weather Service information. You may find that there are more agencies interested, but are not aware of where the information has gotten to on the web sites. It can be a thankless task trying to find some of it. (Local government, Connecticut)
- I have used 500 year event data for critical public facilities such as schools, fire stations, public safety information centers, etc. I expect this is a common application. The 500-year event is also used for design of critical features on some solid waste landfill covers. I have used 1000-year event information for designs of erosion protection hazardous waste landfills, particularly for those landfills that have included disposal of low level nuclear materials. I understand that some uranium mine tailings areas require have designs that have erosion resistance to damage from 1000-year events. You may find more information by contacting personnel at one of the Department of Energy national laboratories (Los Alamos, Sandia, Lawrence Livermore etc.) or the US Nuclear Regulatory Commission. (Private consultant)
- We still use these extreme rainfall events to do runoff modeling for small dams and detention structures.

(Private consultant, California)

- I am submitting comments on the 1,000-year precipitation frequency estimates on behalf of the NWS Central Region. We would like to see the HDSC continue to publish the 500-year and 1,000-year precipitation frequency studies. There are customers in our region that use these studies as a frame of reference. Customers are not using them for engineering design or other water resources studies; however, they are using them to size up events and put events into perspective. Because they are using these events as an approximate benchmark, the greater uncertainty associated with extreme events is not a significant problem. The customer base ranges from media, hydraulic engineers and even the general public. A recent example where these studies have been applied in our region was the Jacob's Creek flash flood of 2003 (Kansas Turnpike) where the media widely published the 390-year return interval of the event. This event received national media attention, and the 500-yr and 1,000-yr studies were used as the basis for calculations that helped to communicate the rarity of that event. (NOAA/NWS, Central Region)
- If it is a tool to simply provide an unknown degree of conservatism up the frequency curve then fine, but we really should call it the 0.999-event to be recurrence interval vague and not seemingly claim that we as scientists/ statisticians have bitten off more than we can chew. Which I think we have claiming the "1000-year event". (U.S. Geological Survey, Texas)
- I use the 1000 year number to check against the PMP for a particular location. The results are relatively close. (U.S. Department of Agriculture, Tennessee)
- The Bureau of Reclamation uses the 1000-yr estimates in risk assessments for determining the safety of its dams. Engineers frequently need to use data that has a large uncertainty because that is all that is available and it is better than having nothing. Therefore, we would like to see these values to continue to be published. (U. S. Bureau of Reclamation)
- Although the 500 and 1000 year frequency estimates are uncertain, they are used when looking at situating hazardous materials or facilities in the area adjacent to the flood plain. Engineers doing site planning and development will need to have a source for the best values available and depend upon the government to provide these at the present time. They are also used for evaluating flood protection facilities for municipalities and individuals. (Private consultant)
- Here in Manitoba frequencies of this magnitude are being used. The province is in the process of constructing a major upgrade to the floodway around Winnipeg. This upgrade is designed for the 700 year event. The preliminary design process compared the upgrade to a storage option which had a 1,000 year level of protection. These are flood protection options for a city of 630,000 population with a flood risk from a major river basin. (Member of SWMM Forum, Canada)
- We use the 1000-year rainfall to estimate the Maximum Probable Flood for dam failure analyses and protection with mapping downstream. I have copied Larry Larson of the Association of State Floodplain Managers to see if this organization can give you more guidance. (Member of StormTalk Forum)
- The Flood Control District of Maricopa County would appreciate HDSC CONTINUING to publish the 1,000-year precipitation frequency estimates. We agree that there are large inaccuracies involved with these extreme frequency values, but we do use them for dam safety and rehabilitation studies. We believe that continuing to publish them with qualification narratives or disclaimers is appropriate. It is the best available information that we have for applications of this type and for checking the reasonableness of extreme precipitation analyses generated using known storms of record. …

  I responded yesterday for the Flood Control District of Maricopa County. I would like to add the following to my response: The 500-year precipitation frequency estimates are also valuable. Not only do we use these for our dam and levee safety program, but FEMA is considering requiring delineation of the 500-year floodplain for flood insurance purposes in the future. The District would like to see both continued to be published with appropriate comments regarding uncertainty. (Flood Control District, Arizona)
- We use the 500-year and 1000-year return periods for flood safety determinations, even if we do not design drainage systems for that. It is much better to have it published by a reputable agency since it prevents a lot

of unproductive discussion about the uncertainty of any results. (County government, Florida)

- I have used 1000-year data for Nuclear Regulatory Commission (NRC)-required analyses, and maybe EPA, depending on the quality of my recollection on who requested the analyses. They are about the only agencies out there that really want to know what happens at 1000-yr probabilistic extremes for weather related phenomena. I did a project that was a cap for nuclear-contaminated waste, and analyses of 1000-yr weather conditions were required. The thing is, if you get rid of the data, the end user is going to take the 500-yr data (or whatever is available) and try to extrapolate it to 1000-yrs anyway, which probably would be less uncertain than the methods that you use. I am not so sure there is any harm in your reporting of 1000-year data, with the proper caveats and disclaimers, and the probabilistic confidence data. I guess that goes for 500-yr data as well. I do like to see data myself, and I do understand the uncertainties inherent to the data (included the more frequent storm data as well). On the occasion that someone does want to use it for analyses, the NOAA-reported extreme data can be useful. I certainly would rather cite NOAA as my data source than myself as my data source. Also, sometimes actual rainfall exceeds 100-yr and 200-yr probabilistic models (for example, Hurricane Ivan), and at the very least, it is fun to try to place what the frequency of recurrence might be by comparison to your published data. (Private consultant)
- We still use the 1000 year precipitation frequency estimate in the design of spillway for dams under the jurisdiction of the State of California. The range of precipitation used in the design ranges from the 1000 year as a minimum to the PMP as the maximum. The selected design precipitation is based on the size of the dam and reservoir and downstream hazards. Please do not discontinue the publication of the 1000 year precipitation frequency estimates. (Division of Safety of Dams, California)
- I think there is always uncertainties in the assessment of hydrological processes. It is good if the uncertainty associated with the estimates are also included. So far the use of 1000-year precipitation frequency estimates, it has been widely used to estimate the Inflow Design Flood (IDF) for the construction/re-construction/upgrade works of dams around the world where flow data is scarce and/or to assess the basin response to intense rainfall event. Based on the consequence classification, the IDF can range from 100-year to 1000-year for low consequence dam, 1000-yr to PMF for high consequence dams and PMF for very high consequence dams (Dam Safety Guidelines of Canadian Dam Association, 1999). (Private consultant, Canada)
- I have not used such data till now, however access to such data seems to be very important for me for rainfall-runoff modeling as well as for comparison such values (1000-year rainfall and 1000-year flood) with assumed PMP and computed PMF. (University, Warsaw, Poland)
- Since our county has experienced some extreme events in recent history (Fort Collins flood of 1997 14.5" rain including 10.5" in 5 hours and the Big Thompson flood of 1976) a number of entities in this area have been interested in the 500 and 1000 year values. Most recently, the city of Fort Collins has taken these values (produced by local hydro consultants) for estimating water levels for hospitals and other essential activities that they feel need to have a greater than 100-year storm protection. (University, Colorado)
- Most of the engineers that I've spoken with generally don't use the 500- and 1000-yr as any criteria for their designs. However, these numbers get used whenever specific heavy rain events come through and folks (mostly media) want to use return interval info for the public. 500-yr and 1000-yr numbers are usually thrown in as extreme numbers since we (almost) never experience them. I would also state that return intervals are not widely understood, and we often try to translate from a return interval into a probability of occurrence on any given year. I'd don't necessarily think the 500- and 1000-yr event values should be removed (they do provide information), but if these values are not understood, it can provide mis-information. (State Climate Office, North Carolina)
- In California, the Division of Safety of Dams (DSOD) requires a minimum design storm with a return period of 1:1,000 years for the dams under their jurisdiction. Depending upon the height and volume of storage plus the potential damage downstream from failure, the design storm is increased based on a probability and risk assessment scale. The design storm for larger dams could have return period larger than 1:1,000 years but not to exceed the Probable Maximum Precipitation (PMP) from NWS HMRs. Since 1968, California has depended on the probabilistic storms derived and updated by Jim Goodridge using the Type III Pearson

Curve Distribution. However, Jim has retired and … it would be impossible for him to continuously update the study. Your office has demonstrated that your method of L-moments is more superior than the Pearson Type III Distribution. Your continuous publication of the 500-yr and 1,000-yr storm would benefit not only California which uses the probabilistic method of design storm for dams but other states who use the same or similar concept like the state of Washington. I would recommend that you continue with your studies and publication of the 500-yr and 1,000-yr storm. I am also aware of the difficulty or uncertainty with such extreme event but such uncertainty can always be qualified as a statement to warn the user. (Private consultant, California)

- I used them once to check on an extreme event back in Northern Indiana in July 2006. The rainfall amounts exceeded what you had for the 1000 year event…. I think that good data out to 1000 years would be a benefit to users. (NOAA/NWS)
- While there is probably a good deal of uncertainty in determining what the 1,000 year rainfall event amount is, it certainly is worth the effort to continue doing this. Over the years it seems the design event being used for designing hydraulic structures has been changing. Usually requiring the use of a larger event. People used to design for a 50-year event, now designing for the 100-year event is fairly common, and soon designing the 500-year will be more common. FEMA has been showing the water surface elevation for the 500-year flood in its' Flood Insurance Studies since they were first published. FEMA still continues to show 500-year water surface elevations in its Flood Insurance Studies. For some of these studies the information for the 500-year event (as well as for other events) was developed using hydrologic models. These models require a rainfall amount for the return event being modeled. Without a rainfall amount, it might be impossible to determine what the 500-year water surface elevation is. FEMA's benefit cost analysis methods use information from the 500-year event in the determining the expected future damages. Therefore, for communities that use hydrologic modeling to determine the 500-year water surface elevation, they will still need at least 500-year rainfall amounts. FEMA is considering moving towards requiring that levees be designed for the 500-year event. Probably most of this future analysis will be done using hydrologic models, which will require a 500-year rainfall amount. There also has been some discussion about requiring some levees be designed for even more extreme events like a 1,000-year flood. Some communities require that critical facilities be elevated to or above the 500-year flood. Most watercourses do not have stream gauges on them, therefore the elevation of the 500-year event is probably be determined by a hydrologic model. The State of California is now requiring that levees be designed for the 200-year event. The HDSC should continue to determine 500-year and 1,000-year precipitation values. The floodplain management community and the engineering community will be increasing their use of these values in the coming years. (Flood Control District, Arizona)
- I see a sort of value in 1000-year precipitation estimates - for putting other extreme events and lesser events in perspective. Dam safety and dambreak analyses use extreme projections, and it's good to have some sort of data to check against FEMA 500-year flood / flow estimates. (County Water Programs, Washington)
- The 500-year rainfall is definitely needed by FEMA to estimate the 500-year flood for flood insurance studies and by FHWA for bridge scour studies. There are at least two Federal agencies that use the 500-year flood in their programs. There is a lot of talk about building levees and flood protection structures to higher level of protection than the 100-year and the 500-year, no matter how certain, is useful for planning purposes and realizing that flood larger than the 100-year event occur. Executive Order 11988 states that Federal agencies should use the 500-year to evaluate critical actions in the floodplain. A critical action is defined to include any activity for which even a slight chance of flooding is too great. So Federal agencies are encouraged to use the 500-year when siting property in or near the floodplain. So I think there is a strong case for keeping the 500-year rainfall. I see no problem with keeping the 1,000-year rainfall as well to illustrate that large rainfall events can occur although the purposes for the 1,000-year event are not nearly as clear as for the 500-year event. (Private consultant, Virginia)
- My opinion (generally shared by others at USBR) is that the NWS should continue to publish these estimates. In addition, NWS should publish confidence intervals on those estimates on the PFDS and in reports. These 500- and 1,000-year estimates ARE being used by Reclamation for conducting dam safety risk analyses and assessments. These estimates can also be used to drive rainfall-runoff models for FEMA floodplain studies, as FEMA requires 500-year estimates. Reclamation also utilizes much of the published

estimates in your reports (e.g. Volume 1 - Semiarid Southwest) to extrapolate the RGFs to smaller AEPs, such as 1/10,000 and 1/100,000. Note that in nearly all cases described and published by Hosking and Wallis (1997), they present results to F=0.999 (AEP=1/1,000). They also present RMSE and bias. You can do the same thing. Many other investigators have published even more remote quantiles. For example, see Schaefer (1990, WRR) where he published estimates to 10,000 years. More recently, Mel has worked closely with Reclamation (as well as USACE) to conduct regional precip frequency (using L-moments) for dam safety, and estimate 24-hr and 72-hour distributions including 100,000-year quantiles. See for example (if you don't already have these): RD-48B, Appendix B - Precipitation Magnitude-Frequency Characteristics for the American River Watershed http://www.hec.usace.army.mil/publications/ResearchDocuments/RD-48B.pdf RD-48C, Appendix C - 72-Hour Precipitation-Frequency Relationship and Uncertainty Analysis for the 1860-mi2 American River Watershed http://www.hec.usace.army.mil/publications/ResearchDocuments/RD-48C.pdf

Reclamation requires studies such as these for our dams. Thus, it is imperative that you continue to publish extreme precipitation quantiles. Reclamation also oversees dams for the Department of Interior (FWS, BIA, NPS). We already use risk analysis and hydrologic risk techniques to assess USBR dams. We are now beginning to use risk analysis to assess these other dams. Many of these non-USBR dams are smaller dams, and, by having 500-year and 1,000-year precip frequency estimates published, we have a ready tool to assess the safety of these dams.

You asked in your message about 'understanding' of the estimates. We do have a clear understanding of these estimates. What would be more helpful is if you did publish confidence intervals for the estimates. What is ideal for these confidence intervals is that you would publish a full suite of probabilities, so that the user could select the confidence limit (or interval width) of their own choosing for their particular problem. For example, in seismic hazard analysis it is common to publish the median (50%), 16% and 84% percentiles for a particular quantile. I suggest you do the same, for discrete percentiles. This could be typical ones, such as 2.5, 5, 10, 16, 50, 84, 90, 95 and 97.5%, corresponding to 95, 90, 80, and 68 percentile confidence interval width. Thus, the user could get nearly the whole pdf for a given quantile (as suggested to you by Ezio Todini), and be able to select the risk appropriate for their problem. We could then also see if the pdf is nonlinear - e.g. how close the median estimate is to the model (best) estimate. In order to potentially improve the estimates, here are some ideas for you to consider as your study techniques evolve. Perhaps you are already implementing these concepts. First, you should perform studies of bias and RMSE of the estimates via monte-carlo simulation. Do some simulation for selected regions as part of your studies. Hosking and Wallis (1997, p. 93) have clear guidance how this is done. You should also do a reasonable job at estimating the spatial cross-correlation to examine the effects of intersite dependence. This will help tell you how much 'independent' data there are for potential extrapolation. In addition, you should examine record length effects. See Hosking and Wallis 1997 sects. 7.5.5 and 7.5.6 for ideas. There are existing techniques to do this, as you know.

One additional refinement you might possibly consider is to combine the 'best fitting' RGF distributions (say top 3 or 4... such as GEV, GPA, GNO, LP3) and weight them to produce a final estimate, rather than relying on a single distribution. This can be done using concepts similar to likelihood function weighting, but using the lmoms results. In this way, you slightly increase (in general) the uncertainty of a quantile by including this model uncertainty. In many cases sampling uncertainty overwhelms model uncertainty. But, as your concern is with extrapolation, the model choice (say GEV) completely dictates the relationship. Relaxing this assumption helps portray more 'realistic' uncertainty to the user. A simple way to do this directly is if you agree with the approach argued by Hosking and Wallis 1997 sect 5.2 (p. 78-83), you could use the Z score to do the weighting. That is, if you believe in a Z in the first place, and with cross-correlated data. You should also publish the 'final' RGF index grids after your CRAB procedure. Currently you do not do this; Rich Stodt and I have had several conversations with Tye about obtaining these grids as they would help us extrapolate your published relationships to smaller AEPs. What was not clear to me in your message was this term "severe uncertainty". What exactly do you mean by "severe"? Is 'severe' a standard error greater than (say) 300%? Is it a model with a large negative (positive?) bias for a particular quantile? Please consider clarifying terms such as these if you use them in your precip frequency publications. If you choose not to publish the 500-year and 1,000-year estimates, we will continue to use what you publish - the data sets, regions, and RGFs - to derive our own estimates. Currently, your existing methods meet some, but do not quite meet all of our dam safety needs. We would like to continue working with you to estimate extreme precipitation quantiles. (U.S. Bureau of Reclamation)

- I have polled our field offices and received a variety of opinions on this proposal. There is consistency in the use and application/need for the 500-year precipitation dta. Currently there is limited use of the 1000-year dta nut our researchers feel that it does provide value to the hydrologic community of practice. My understanding is that new L-moments methodologies allow a fairly simple extrapolation to the 100-year so I question how much effort is saved to discontinue it. Based on the input I received the 500-year is asolutely critical and we need the weather service to continue to provide it and we would like to see precipitaion estimates provided up to 1000 yr precipitation estimates. This really needs to be done for the whole country, and right now it is only available for the eastern half. The uncertainty of the estimates is certainly a question but it still beats no estimate at all. These estimates are crucial to hydrologic modeling for many purposes. Including: Dam safety PRA (we use this data to make inflow frequency curve estimates); Levee design and PRA analysis; general flood damage reduction studies; and the design and analysis of many other hydraulic structures. In my opinion the weather service is providing a valuable service to the nation and should expand these products instead of reducing them. Please contact me with any questions. (U.S. Army Corps of Engineers)

- You will find responses below from two of our senior hydrologists regarding the need for 500 and 1,000-year precipitation frequency estimates. In summary:
  1. The Corps (and many others) use 500-year precip for hydrologic analyses related to FEMA's National Flood Insurance Program (FISs). The 500-yr return interval (0.2 percent exceedance) flooded outline is shown on FEMA's FIS maps.
  2. The Corps does not use 1,000-yr precipitation per se. However, we use precipitation values that are above the 500-yr values when we develop the Standard Project Flood (SPF). The SPF analysis is necessary for the design of hydraulic structures the failure of which would severely impact human safety and property. Many dams are designed for the SPF as are, for example, the super critical flow channel at Chaska, MN. We do not assign a frequency to the SPF due to the uncertainty of frequency estimates that far exceed recorded periods of record. Bottom line, analyses of rainfall totals above the 500-yr are conducted. The studies behind the Engineering Manual which describes how to develop an SPF analyzed extreme precip events throughout the U.S. (U.S. Army Corps of Engineers)

- Precipitation estimates for very rare events are often used in rainfall-runoff modeling to estimate flood peak discharges, flood hydrographs and runoff volumes where there is the potential for loss-of-life and/or extensive property damage from flooding. Rainfall-runoff modeling for extreme storms is often conducted in the dam safety community to assess the adequacy of spillways and other hydraulic structures. Estimates of the 500-year and 1,000-year events would be welcomed by State and Federal agencies and engineering firms that routinely conduct flood analyses for dams. There are over 80,000 dams in the National Inventory of Dams in the US. Estimation of 500-year floods via rainfall-runoff modeling is sometimes conducted for projects associated with FEMA 500-year flood plain designations. Likewise, issues related to urban flooding often involve estimation of rare floods beyond the 100-year flood.

  You mentioned the "severe uncertainty" in estimating 500-year and 1,000-year precipitation. The regional precipitation-frequency methods now in place provide for a dramatic reduction in the uncertainty of estimating rare quantiles. At-site methods used in TP-40 and NOAA Atlas #2, resulted in acceptable confidence in estimation of the at-site mean, reduced confidence in the at-site variance and little to no-confidence in the at-site skewness. Given the at-site methods and the short record lengths commonly available at the time of TP-40 and NOAA Atlas #2, 50-year and 100-year estimates were made with considerable uncertainty, particularly at locations distant from a representative precipitation gage. By comparison, properly conducted regional L-Moment analyses with large datasets that focus on preserving the spatial variation of regional L-Cv and L-skewness typically result in high confidence in the estimate of L-Cv and acceptable confidence in L-Skewness. Likewise, large regional datasets allow for selection of a probability distribution that is sufficiently close to reality that the choice of the distribution is often not a major source of uncertainty at the 500-year and 1,000-year levels. Reasonable estimates of 500-year and 1,000-year precipitation can be achieved when care is taken in assembling homogeneous regions, properly dealing with boundaries between regions, and paying particular attention to spatial mapping of the at-site means, regional L-Cv and L-skewness. The recently completed precipitation-frequency studies for the States of Washington and Oregon, (MGS Engineering, Oregon Climate Service, JR Wallis) provide examples of the type of regional L-moment procedures that are capable of producing reasonable estimates of 500-year and 1,000-year precipitation in mountainous terrain. Information on the magnitude of uncertainties for rare precipitation estimates would allow users of the information to determine how those uncertainties would be utilized in a specific study. Practitioners in rainfall-runoff modeling for extreme storms and floods would much prefer to have estimates of rare precipitation events along with information on uncertainties rather than no estimates at all. The demand from community planners and citizen groups for information on rare floods and rare storms will continue to grow as development continues to occur in our communities. (Private consultant)

- We definitely use the 500-yr rainfall as it is part of our defined analysis of the most economically beneficial flood damage reduction project. We analyze a whole range of frequencies up to and including the 500-yr flood event! The level of protection that has the most benefit to cost ratio for a given flood-prone location is given the label of the "NED" or National Economic Development Plan. 1000YR - We don't typically use the 1,000 year return period rainfall, although sometimes its nice to know what an estimate might be. In our District, most of us realize that extending a frequency curve out this far has no basis upon the physical ability of the atmosphere to produce such an event. It is simply an extension of the curve. The value could be misused by some less informed scientists. Its not the end of the world to lose this value…but it's a nice thing to look at when your considering risk. (U.S. Army Corps of Engineers, California)
- We have recently had a desire to calculate the return period of a regional storm event. The purpose was to determine the return period of the storm required to fill up a SWM pond under a given set of conditions. We are still deciding what the most realistic way of looking at the return period is. One of the ways we used was to draw a straight line through the calculated 50 yr and 100 yr rainfall volumes, and extend it out to the volume we needed. Another way was to plot all the annual rainfalls on semi log paper (in the same way we determine the 2-100 yr storms), and again extend it far beyond the range for which we have data. The result of the latter method made our storm event very unlikely (very high return period), but that may simply be the case for that rainfall on any particular spot (though it happens more often within an entire province). I think the Environment Canada may be looking at some of the same large return frequency calculations. It may be worth contacting their weather office http://www.msc-smc.ec.gc.ca/contents_e.html. (Private consultant)
- There certainly is a need for such estimates for high value structures whose destruction by heavy rain would result in large loss of life and economic losses. However, poor quality estimates, and out of date estimates using shaky techniques are actually a huge negative. Do you have the resources/people to continue to do a proper job of it?...

  From Monte Carlo experiments with the big datasets used in our regionalizations very little of the uncertainty in quantile estimates comes from the l-cv, l-skew or distribution choice, most comes from variation associated with estimates of the mean so your densities are relatively easy to assess. All of this work is based upon the assumption of a stationary climate, but h is not 1/2 so its hard to see how one justifies a 30 year normal although NOAA loves it and updates every decade. But updating these regional l-cvs l-skews and densities would be a huge chore on a decadel basis. how about just doing them on case by case basis for the really important projects? (University, Connecticut)
- … I have often counseled that cities need to think about 1,000 year events - that doesn't mean they should make investments that would reduce 1,000 year damages to zero, just that they should think about what they would do before they have to respond in an emergency. It is akin to traditional Corps of Engineers planning that uses the probable maximum flood to make sure new levees won't cause catastrophes that wouldn't occur without the levees. So I support the development of 1,000 year estimates, and using the l-moment analysis that you and Jon Hosking applied in the National Drought Atlas gives a useful estimate from a stationary climate perspective - not a bad start for the sort of "what would we do" planning I advise. The problem is that most governments don't plan for even lesser events. For example, the New York Times has been running articles on the drought affecting Atlanta. Unlike western cities, Atlanta has few sources of water (essentially no ground water) and most is used for urban use (in the west, 80-90% is used for low economic value

agriculture, so the potential is there to save the cities by using water where it has more value). When Atlanta runs out of water, it runs out of water. Fifteen years ago I participated in a regional study that showed that Atlanta was at risk during a recurrence of the 1930s drought; this was not a small academic study, but a multi-million dollar, multi-year study that led to the first interstate water compact in the southeast, signed by President Clinton and the three governors after being passed by the US Congress and three state legislatures. This is what was reported in yesterday's NY Times:

(Atlanta's) projections, they say, are based on an outdated estimate of water availability, provided by the state, that does not take into account climate change. Pat Stevens, chief environmental planner for the Atlanta Regional Committee, which provides employees to the water district, said the plan was being revised and the requirements would tighten. "You can't just do this overnight," Ms. Stevens said. "Otherwise, you will close businesses. We will out-conservation California," she added. "But, you know, it takes time." In January, the Legislature will consider a proposal to expand the planning process statewide. State officials defend their response, saying the drought got very bad very quickly. Ms. Stevens and the state officials were heavily involved in our study fifteen years ago that showed Lake Lanier going dry, no climate change needed. The interstate compact expired because the governors of Alabama, Florida and Georgia did not agree to extend it (there was a sunset clause, and they had to agree each year that it was worthwhile to continue to plan together). This morning the Times ran this piece:

Wednesday October 24, 2007. Gov. Sonny Perdue ordered North Georgia businesses and utilities to cut water use by 10 percent to conserve more of the state's dwindling water supply during an epic drought. Mr. Perdue called the order a "first step" to reducing water use and encouraged residents to treat their drying lawns and dirty cars as a "badge of honor." The cuts apply to the 61 North Georgia counties that were declared to have a Level 4 drought last month. With a dry winter in the forecast and fewer than 80 days of stored water left in Lake Lanier, the North Georgia reservoir that supplies water to about three million people, Mr. Perdue warned that more restrictions could be on the way. (Private consultant, retired USACE)

- I would not discontinue the estimation of such low frequency precipitations, but I would investigate on the possibility of assessing and publishing their probability density. It is certainly true that if you provide an estimate of the 1,000-year precipitation estimate it will inevitably result into a highly uncertain value. Nonetheless, if you associate to this value (considered as the expected value) an estimate of its probability density, you will be able of marginalizing away most of the uncertainty associated with the mentioned value in any technical or economical estimate.

  … I have the feeling that there is a general misunderstanding on the terms return period and uncertainty. The so called 1000 year return period flood is nothing else than the upper quantile 1/1000 which large estimation uncertainty is unavoidable. This is why this uncertainty, whatever large, must be evaluated and "marginalised", namely used to compute the expected value. For instance, if damages occur when the discharge is higher than 3000 m3/s and the one in a thousand years flood has been estimated 2500 m3/s, if this value is used by interpreting it as a deterministic value one may expect no damages at all, while, given its large uncertainty, the expected value of damages (obtained by integrating the product of damages time the pdf of the 1/1000 year estimate) is obviously non zero and can be large indeed. I know that engineers do not master this concept, but this is the only way for reducing the effect of uncertainty. I found more interesting the question on the effects of climate changes in terms of non-stationarity. One must handle these non-stationarities, maybe via possible future scenarios that modify the stationary estimates, but this does not mean that we must abandon the stationary flood frequency estimation, provided that, as mention earlier, one accounts for the estimation uncertainty. (University, Italy)

- What is needed is further work assessing the accuracy of estimates of extraordinary floods/precip events. There is surely a need for such estimates, such as the 1000 year precip event. We have been working on this problem recently within the context of envelope curves of flood discharges. I would like to refer you to a recent paper (attached) which shows a method for determining the return period of a PMF type event or other extraordinary event. Vogel, R.M., N. C. Matalas, J.F. England and A. Castellarin (2007), An assessment of exceedance probabilities of envelope curves, Water Resour. Res., 43, W07403, doi:10.1029/2006WR005586.

  Such an approach may be usefully applied to rainfall events as well to assess our knowledge of the upper tail. There is certainly a need to further understand the frequency behavior of extreme events before reporting extreme statistics such as a 1000 year event. Has anyone compared the ability of various distributions for their ability to estimate the 1000 year annual maximum rainfall? I know that the new NOAA atlas looked at smaller events, but were any experiments focused on the extreme tail? (University, Massachusetts)

- …To add to the fray an issue is the nonstationarity in these estimates if they are based purely on 20th century data. How would one factor in anthropogenic climate change -- if predictions of the drying of the subtropics and of enhanced intense storms in the higher latitudes are correct within the limits of uncertainty we consider, then some thought has to be given to that. I am not suggesting that a GCM based approach to this problem be pursued. It will likely be abortive. Merely suggesting that the uncertainty in the estimate is not only based on the sample size relative to the return period. It is mechanistic, and we can't quite address that -- so even if the number is a benchmark for an extreme state, some thought as to what one wants to say needs to be given. (University, New York)
- I find the progressive trend in the use of extremes in planning is away from mechanistic decisions based on expected value towards messier collaborative assessments of multiple scenarios with differing assumptions. The emphasis shifts from, "what is the best estimate of the 1,000 year flood or drought" to "what's the range of extreme events that we need to consider as boundary cases because we can't dismiss them as uncharacteristic of this region". In climate change analysis on the recent Lake Ontario water levels study, we used four GCM scenarios and generated water supply sequences from them because the only thing we know for sure about climate change predictions is that you can't pick one and base all your plans on it. The messy approach can handle some uncertainty in the estimation of rare events from a stationary climate, too. Just to be clear, we still need the traditional extreme stationary estimate to do even the messy analysis. During the Atlanta study, we once had >15 inches of rain in one day, probably more than the 1,000 year event in Las Vegas by any estimate. (Private consultant, retired USACE)
- Let me add to the comments so far: I have serious doubts about calculating 1000 year return periods based on a relatively short period of record. The confidence bands will be enormously wide to render the numerical result essentially meaningless. Based on my long experience with user communities, a 1000 year return period would likely be grossly misused in decision making. I am also against 500 year return periods for the same reasons. Confounding the issue is the nonstationarity of climate. While natural climate change has and will occur all the time, the nature of the change in the future is still far from certain. Add in the anthropogenic influences, and the situation becomes very murky. I like the ensemble approach of looking at possible scenarios and coming up with a rational decision based on imprecise guesses. While I have difficulty with fuzzy statistics and logic, I don't see any other choices. As … so eloquently related with the Atlanta story, even the rational ensemble approach is often compromised by the politics of the day. … My feeling is not to portray longer than 100 year return periods. So, I welcome your thoughts. (Private consultant, retired NCDC)
- I think our differences are small. I would not use 1000 year estimates alone to do expected values or risk assessments, for the reasons you and others have said. And the Atlanta situation (or Devils Lake, or many others) shows that even good information can be ignored or misused. The ensemble approach, that uses lots of information in well ventilated debates is more likely to lead to good decisions, especially if there is an adaptive component that lets you learn and adjust. But I do think a 1000 year estimate can be helpful in an ensemble approach for guessing at reasonable boundary conditions. It's no flakier or less useful than a lot of climate change hydrology, which is de rigeur these days. For example, in the King William reservoir controversy, the city of Newport News, VA made a case for a new reservoir based on what many thought were exaggerated predictions of future demand. But by habit, they had estimated safe yield using historic streamflows, about 60 years as I remember. Virginia is celebrating the 400th anniversary of Jamestown and some historian believe that an extreme drought wiped out the initial settlements. So a prudent planner should consider that there will be a drought worse than the 1950s, but how much worse? With some prompting, the city consultant cobbled together synthetic streamflow data from fragmentary 1800s data, and these supplies were much smaller than the 20th century flows. I compared precipitation and streamflow data from the 20th century droughts to the 1000 year recurrence interval, 5 year duration precipitation depths from the Electronic NDA Jim developed, and it suggested to me that their made up drought streamflow volumes were even drier than a 1000 year drought, but not crazy as a boundary condition. As a boundary condition, it didn't matter whether it was a 500 year or 2,000 year drought; it was a reasonable guess at a worse case for this part

of the country, still wetter than recorded droughts on many western streams with the same drainage area. I agree this can be misused. No sense trying to justify a supply of water big enough to survive a drought like this without use restrictions, because the damages, whether multiplied by .005 or .0005 are not going to justify present day expenditures or environmental damage. But a good planner might say, OK, if it comes to this, we close the pulp mill or we work with other cities to share emergency pumping capacity and we talk to the Corps now about permits to lay pipes across wetlands. (Private consultant, retired USACE)

- We do need to consider the probability of very rare events, events whose return periods are considerably greater than 100 years. However, it is not clear where we should draw the line on how large a return period, T, we should consider. The standard error of the T-year event offers some guidance in this regard. In addition to the standard error, we need to measure our degree of confidence in the usefulness of the T-year event. If we have very little confidence in our estimate of the T-year event, we would not be inclined to use the estimate in practice. Our confidence is higher if our T of interest is within our historical experience than if it is outside that experience. Degree of experience relates to our knowledge base. If an estimate of the T-year event is based on the assumption of stationarity and our experience indicates that climate change has altered the hydrometeorologic setting, then how much confidence do we have in using the estimate in practice? If our estimate of the T-year event is effectively based on the assumption that the right tail of a distribution function is unbounded, but our experience based on physical considerations strongly suggests otherwise, then how much confidence do we have in using the estimate in practice? As we consider larger Ts, our historical experience diminishes and consequently so does our degree of confidence.

  In considering very rare events, we should give some thought to philosophic approaches to estimating probabilities besides those of relative frequency and degree of belief. The notion of degree of confidence might be viewed philosophically in Keynesian terms of probability. In those terms probability is conditioned on evidence. Very briefly, as new evidence (historical experience) emerges, the former probability is not improved, but rather a new relation between propositions is established. I'm not suggesting that this probabilistic view is hydrometerologically meaningful, though it may be. I mention it to illustrate that in dealing with very rare events we might benefit more from a philosophic perspective on probability than on what our conventional view allows. (U.S. Geological Survey)