Extreme Flood Concepts, an Historical Perspective

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BIOGRAPHICAL SKETCH

Mr. Darryl W. Davis has forty-one years of experience in the water resources field; the past thirty-six years with the U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA; the last seventeen years serving as the Director. Areas of technical specialty include: Surface water hydrology, river hydraulics, water resources planning, risk analysis, dam safety, system optimization, hydropower, flood damage computations, cost-benefit analysis, Floodplain management, water control management, and management of trans-basin international river systems. Prior employment includes: California DWR during development of the State Water Project; and private consultant working in Asia, Africa, and the Middle East.

Darryl has a B.S. degree from California State University, Fresno, CA and holds an MS degree from Stanford University. He is a registered PE in California, member of several professional societies, founding Trustee and Diplomate in the American Academy of Water Resources Engineers, associate editor for two technical journals, and author/co-author of about 50 technical papers and 20 major reports. Mr. Davis was the Institution of Engineers - Australia Eminent Speaker in 1993, in 2003 was named one of the top ten US Federal engineers, in 2005 was selected for the Julian Hinds award and lecture by the American Society of Civil Engineers, in 2006 was chosen for the Floodplain Management Association 2006 Distinguished Service Award, and in 2007 was selected for the California Water and Environmental Modeling Forum's Career Achievement Award.

Darryl retired from Federal service in May 2006. He now serves part-time as Senior Advisor, Water Resources Engineering, USACE Institute for Water Resources, Washington, DC, focusing at the national-level on dam and levee safety policy and flood risk management.

ABSTRACT

The concept of what constitutes an 'extreme flood' depends on the perspective of those developing or espousing their application. In early times, the concept was generally associated with the largest floods that had occurred locally or at least within the nearby region. Over time, great floods impacted the nation, policies for national investment in water management infrastructure evolved, and the desire to wisely manage the nation's floodplains stimulated the need for more refined and purpose-specific definitions of and methods for estimating extreme floods. Players in this arena include a better informed public and stakeholders, policy makers, hydrologic scientists, engineers, statisticians, and the occasional soothsayer. This presentation will offer a working definition of 'extreme floods', highlight notable flood, legislation, and policy happenings that have resulted in major focus on particular concepts of extreme events, and conclude with some reflections on current ideas and thoughts on the way forward.

Extreme Flood Concepts, an Historical Perspective

- By: Darryl W. Davis, Senior Advisor, USACE Institute for Water Resources, Davis, CA
- For: 2007 California Extreme Precipitation Symposium, April 13, 2007, Sacramento, CA.

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This presentation will offer a working definition of ‘extreme floods’, highlight notable flood, legislation, and policy happenings that have resulted in major focus on particular concepts of extreme events, and conclude with some reflections on current thinking and ideas on the way forward.

Outline of Presentation

- What are extreme floods and why estimate?
- Early ‘design floods.’
- Impact of 1927 Mississippi flood.
- 1936 flood control act and economic analysis.
- ‘Safe’ dams, (PMF).
- Circa 1955 design flood (SPF) and others.
- Principles and Guidelines (P&G).
- NFIP and the inevitable Bulletin 17B (1980’s).
- USACE and risk analysis.
- Lessons from Katrina/New Orleans.
- Reflections: Today and way forward.

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Extreme Floods

- Perspective for this discussion: Usually large floods that we have not yet experienced nor recorded.
- Why estimate?
  - Assess vulnerability of floodplains.
  - Measure effectiveness of protection systems.
  - Perhaps target as the ‘design flood’ for new or upgraded projects or regulations.

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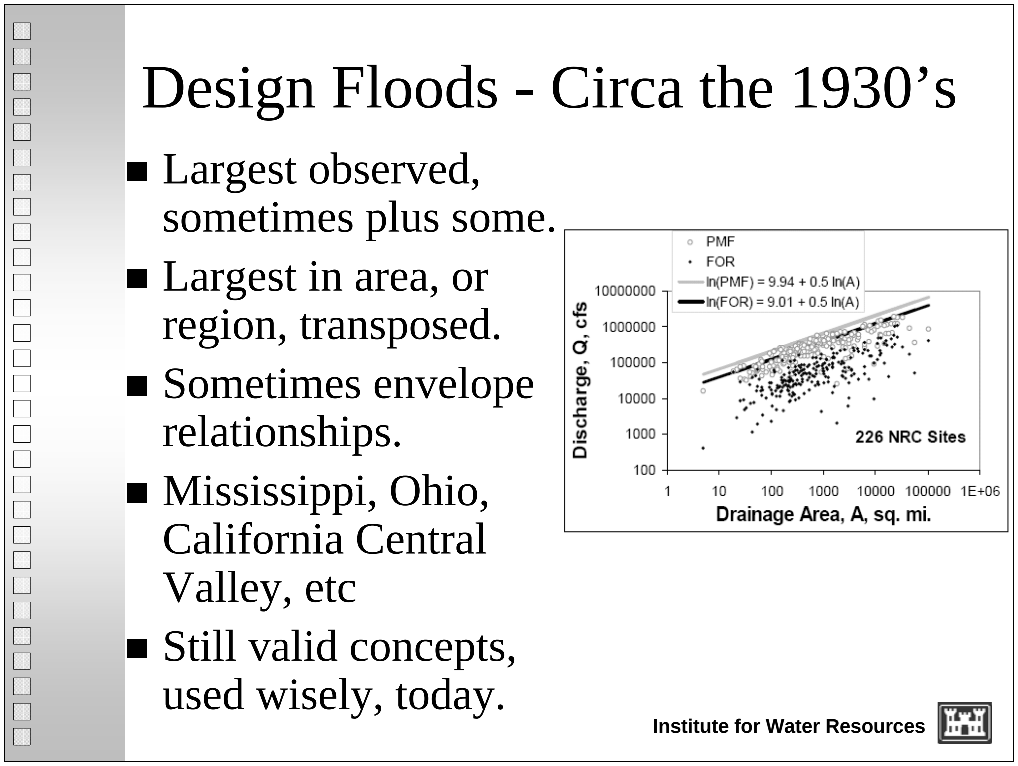
Several definitions of extreme floods can be found in the literature. For example, the Federal Emergency Management Agency defines an extreme flood as the .2% chance exceedance (500-year flood). For others, they are just plain big floods.

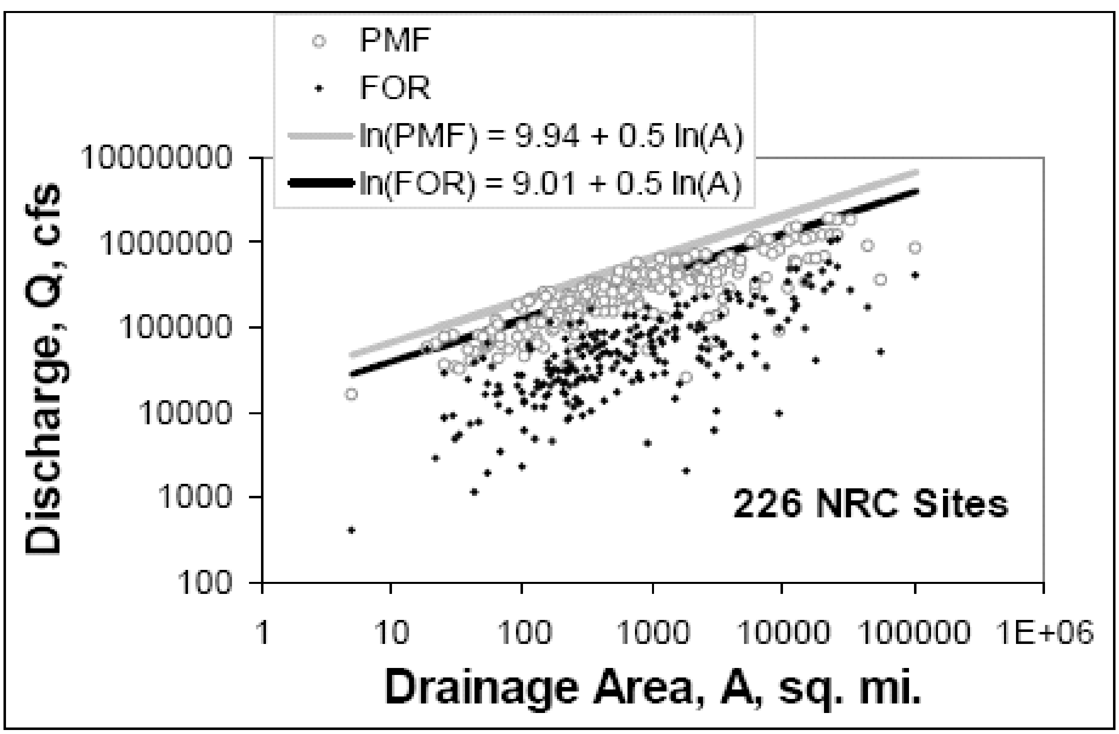
Here, the objective is to focus on floods that are extreme from the perspective that they generally have not been observed, must be estimated by some analytical or other means, and have a very relevant intended use or purpose for some organization or institution.

With the growing debate over what should constitute a ‘design flood’ for the nation, and the State for that matter, this definition has been posited.

By way of further explanation, the intent of this ‘historical’ perspective is to make note that there is an interplay between the science of estimating extreme floods, and the use to which they are likely to be put. Some notable flood events, legislation, and institutional policies are woven into the discussion.



Such plots, presented in a variety of forms ranging from the plot depicted (peak flow in cfs vs. drainage area in sq mi, to normalized peak flow (cfs/sq mi) vs. some parameter (or location) of interest. The curves serve as a general view of extreme floods and can serve as a check on a particular computation. Note: PMF=computed Probably Maximum Flood; FOR is Flood of Record, and NRC is Nuclear Regulatory Commission.



The ‘Rising Tide’ – Impact of the Great Mississippi Flood of 1927

- Flood devastated lower states, shocked the nation.
- Fostered legislation establishing Federal interest in floods.
- Called to question, ‘levees only’ protection.
- ‘Project Flood’ (1928 Jadwin Plan), early ‘system design flood’ concept that continues today.

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The Great Flood of 1927 on the Mississippi River is chronicled by John Barry in ‘Rising Tide.” The book is an exhaustively detailed discourse on the flood, its impact on the cities, infrastructure, and people of the Mississippi Valley, and the consequent response by the Federal government that some say was the initial foot-in-the-door for greatly expanded Federal authority.

Chronicled is the struggle that existed in the engineering community, mostly USACE, over the ‘levees only’ policy of the times, and a more broad look at managing floods. Obviously the ‘levees only’ lost on this one!

In response the question “What should we design for?”, the ‘Project Flood’ as it was called at the time, was conceived and developed, intended to be a flood so big (but scientifically based) that protection against such would render the floodplain ‘safe.’ This is perhaps the first, or at least one of the earliest, of the ‘design flood’ notions that are prevalent throughout the US with the basic idea surfacing again today.

Flood Control Act of 1936

- Established Federal interest conclusively.
- Benefits – whomever accrue, exceed costs.
- Save & hold harmless.
- Local costs for lands, easements, and rights of way.
- Concepts later refined in ‘Green Book’, P&G.

“Section 1. **It is hereby recognized that destructive floods upon the rivers** . . . **constitute a menace to national welfare**; . . . . **is a proper activity of the Federal Government in cooperation with States, their political sub-divisions and localities thereof**; . . . “

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DECLARATION OF POLICY (1936 Flood Control Act)

“Section 1. It is hereby recognized that destructive floods upon the rivers of the United States, upsetting orderly processes and causing loss of life and property, including the erosion of lands and impairing and obstructing navigation, highways, railroads, and other channels of commerce between the States, constitute a menace to national welfare; that it is the sense of Congress that flood control on navigational waters or their tributaries is a proper activity of the Federal Government in cooperation with States, their political sub-divisions and localities thereof; that investigations and improvements of rivers and other waterways, including watersheds thereof, for flood-control purposes are in the interest of the general welfare; that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries including watersheds thereof, for flood-control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected.

“until States, political sub-divisions of, or other responsible local agencies have given assurances satisfactory to the Secretary of War that they will (a) provide without cost to the United States all 1ands, easements, and rights of way necessary for the construction of the project except as otherwise provided herein; (b) hold and save the United States free from damages due to the constructed works; (c) maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of War: Provided, .. “

Safe Dams, the PMF, and Others

- Failure of dam due to overtopping likely to be catastrophic.
- Concept of ‘probable maximum’ – physical/met–ologic-based took root.
- National Academy of Science – can’t assign frequency.
- Paleo estimates and Monte Carlo modeling emerging as ‘bounding’ estimates.

“The PMP . . is the greatest depth of precipitation, that is theoretically possible for a particular area . . .
The PMF is the flood from the most severe combination of critical meteorological/hydrologic conditions that are reasonably possible. . . .”

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As the nation (and the world for that matter) began to build great dams, at the US Federal level stimulated by the ‘Reclamation Act in 1906 and the Flood Control Act in 1936, engineers and atmospheric scientists grappled with sizing reservoirs and spillways to address the question of safety from extreme floods, floods so big they would not expect to be exceeded. These needs gave rise to the concepts of Probably Maximum Precipitation (PMP) and consequent, Probably Maximum Flood (PMF).

“The PMP is the greatest depth (amount) of precipitation, for a given storm duration, that is theoretically possible for a particular area and geographic location.

The Probable Maximum Flood (PMF) is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.” – from USACE Manuals.

Because the frequency of such an extreme flood is of interest for many purposes, including risk-informed dam safety matters – of great concern today, the National Research Council of the National Academy of Science was asked to answer the question “What is the probability of the Maximum Probable Flood.” Their answer was that it is not theoretically possible to place a recurrence interval on the PMF. In the absence of a theoretical basis, dam safety and other policy makers generally assign the probability of the PMF to be about 10^{-5} to 10^{-6}.

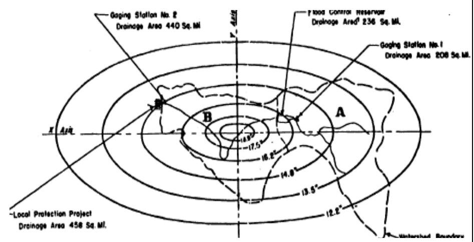
Because there is believed to be some physical bounds to extreme floods, and that there may be some evidence of such in geologic time, researchers have devised methods referred to as “Paleo Flood Hydrology’ wherein large historic floods are dated by examining the geology of floodplains, noting ancient deposits and aging such deposits through carbon dating or other means. Such methods are generally thought valid for the Holocene Period (the recent 10,000 years), believed to be a time of climate stability.

Also, there has arisen modeling approaches wherein factors involved in computing extreme floods, such as precipitation observed on a regional basis, and watershed descriptors, are assembled in a Monte Carlo modeling simulation to compute extreme floods.

These approaches offer promise to improve estimates of extreme floods but are not yet widely accepted nor applied.

Circa 1950's – Standard Project Flood (SPF), other 'design floods'

- USACE desired 'goal' for urban flood projects.
- Physical/met based; ~ ½ PMF – no frequency.
- East of Mississippi – standard method; West, some adaptation/transfer.
- Projects must still be economically justified.
- Alive/well, role as goal softened to comparison.



"..discharges that may be expected from the most sever combination of meteorologic and hydrologic conditions that are considered reasonably characteristic of the geographical region involved, excluding extremely rare combinations." (USACE)

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The Standard Project Flood was adopted by USACE in the mid-1950's as a national standard to provide essentially a reference event to target for providing protection of major urban areas. Since the PMF was generally acknowledged as an impractical goal, a lesser but still rare goal was desired.

Given the caveat that flood damage reduction projects must be economically justified, not all urban projects were able to be sized for SPF protection.

USACE Engineer Manual (**EM 1110-2-1411**) provides guidance on development and use of the SPF. Excerpt from the EM:

(2) Represent the flood discharge that should be selected as the design flood for the project, or approached as nearly as practicable in consideration of economic or other governing limitations, where some small degree of risk can be accepted but an unusually high degree of protection is justified by hazards to life and high property values within the area to be protected. Estimates completed to date indicate that SPF flood discharges are generally equal to 40 to 60 percent of "maximum probable" floods for the same basins.

While the role of the SPF as a concerted target for flood projects has softened with the advent of later Federal policy of investment economics and providing local stakeholders stronger voice, the SPF remains a valid reference point for comparing and judging the vulnerability of urban areas to devastating floods. While not assigned a frequency, subsequent analysis often finds the SPF to be in the range of 200 to 500-year recurrence interval. As frequency analysis has matured, the tendency has been to substitute the '500-year' event for the SPF for this comparison and reference role.

Circa 1980's – Principles and Guidelines (P&G)

- More precisely defined Federal interest; defined NED and Max Net Benefits., environmental account.
- Emphasizes alternatives, cost sharing, risk and uncertainty.
- Some say let economics reign, lessened force of 'design flood' concept.
- Projects presumed 'safe'.

Table 2.4.17—1 Summary of Annualized NED Benefits and Costs for Alternative Projects
[Applicable discount rate: ——]

Project benefits and costs	Alternatives 1	2	3	X
Flood hazard reduction benefits:				
Inundation:				
Physical				
Income				
Emergency				
Total				
Intensification				
Location:				
Floodplain				
Off floodplain				
Total				
Total Flood Benefits				
Benefits from other purposes				
Total project benefits				
Project costs				
Net benefits				

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Federal agencies undertake water resource investments for such measures as dams or levees within the broad confines of the Principles and Guidelines – P&G (WRC, 1983). The P&G generally requires that Federal projects contribute to national economic development, which means that they must be economically justified because benefits exceed costs. USACE has planned and constructed many of the nation's major flood damage reduction and coastal protection projects, including the majority of levee systems protecting major urban area in the US.

USACE implementation of the P&G requires that flood damage reduction projects be planned and designed so that the project scale maximizes the net national economic development (NED) benefits. However, other considerations can suggest projects larger or smaller than the NED-maximizing project. For example, levee heights are often compared to that which would satisfy the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) base flood level for excluding the floodplain from mandatory flood insurance. (This NFIP base flood (100-year) protection level is often mistaken by local communities as the Federal standard for urban flood protection. In fact, there is no Federal standard for flood protection.) In those urban settings where these principles suggest levee height less than NFIP base flood protection, the heights are generally increased to that level so that the levees may be certified for NFIP purposes. The resulting project must still be economically justified and the local sponsor may be required to pay the cost for the increment of levee height between the NED project and the NFIP base flood protection project. For non-Federal levee projects, the target selected by local agencies and the private sector is often simply to provide protection from the NFIP base flood so that the levee system may be certified and the protected floodplain is free of development controls.

From "**USACE Experience in Implementing Risk Analysis for Flood Damage Reduction Projects",** Darryl Davis, Beth A. Faber and Jery R. Stedinger (in peer review for publication April/May 2007)

NFIP and Bulletin 17B – (Uniform Flood Frequency Method)

- By mid 1980's, many agencies performing frequency analysis: Feds – USGS, USACE, NRCS, NRC, IBWC; states, local districts, AE's.
- Reasons: More economic analysis; increased in standards and permitting; legal challenges.
- Big one: National flood insurance program – 100-year floodplain became a key factor.
  - Needed to map nation's floodplains; needed consistency for administering floodplain regulations and flood insurance.

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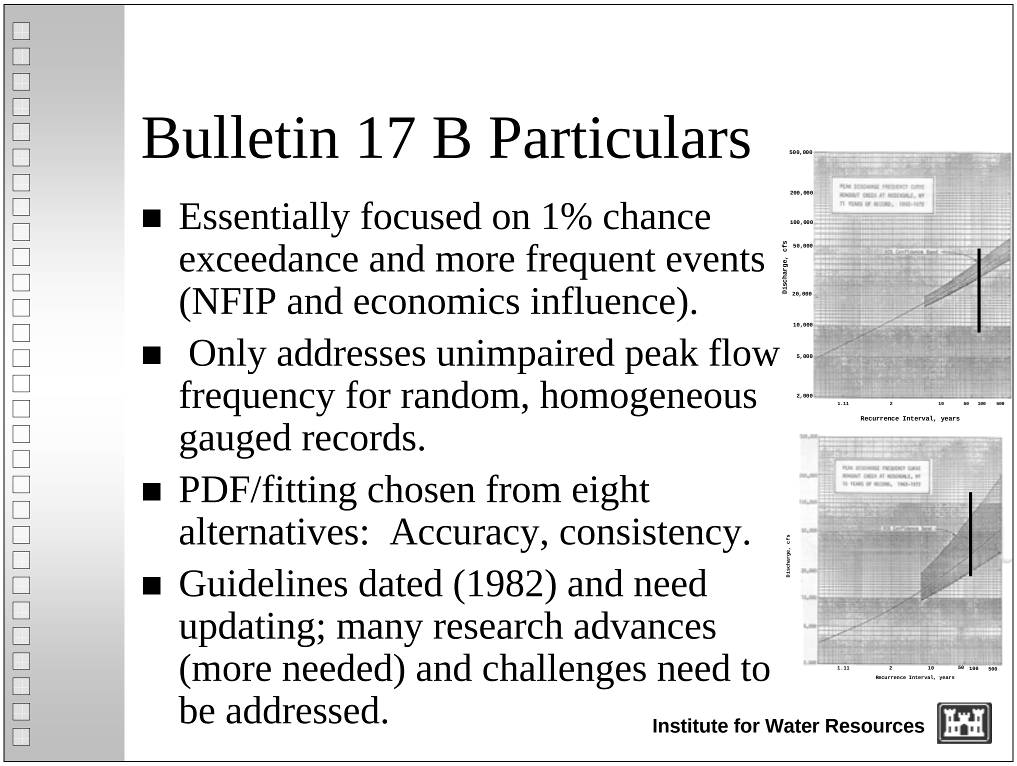
"The National Flood Insurance Program (NFIP) seeks to identify floodplains that are threatened by the 100-year event; flood insurance is mandatory for properties located within this zone if communities are to remain eligible for certain disaster relief programs. The mandatory insurance issue is a binary determination – either the floodplain property will be flooded by the 100-year flood or it will not. Floodplains flooded by the 100-year flood are subject to land use management provisions specified by FEMA (no development in the floodway, properties must be elevated for example). As would be imagined, there is strong interest by local community leaders to have their floodplains 'flood risk free' – e.g. not within the 100-year floodplain. If there is a flood damage reduction project associated with the floodplain, for example levees, then these projects must be found to provide the necessary level-of-protection for the floodplain to be mapped as protected. A technical finding that a levee may be 'certified' accomplishes this requirement. The regulation governing making the certification determination is published in the US Federal Register (Federal Register 1986)."

Excerpted from **"Is the Current Approach to Managing Flood Threats**

in the United States Sustainable?", by Darryl W. Davis**1**, PE, D.WRE, Senior Advisor, Water Resources Engineering (publication date is mid-May, 2007 as part of Environment and Water Resources Institute (EWRI) Congress, Tampa, FL Conference Proceedings).

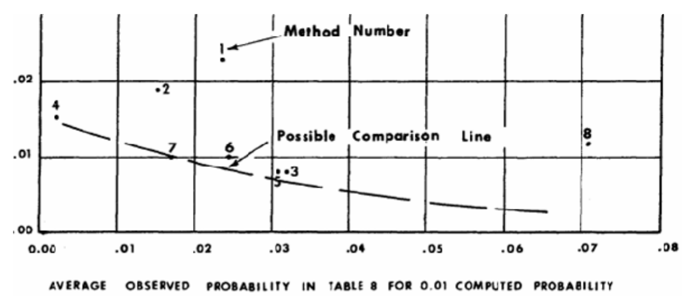
The NFIP together with the USACE need to perform economic analysis of proposed flood damage reduction projects are the dominant drivers behind application of flood frequency analysis, and are the impetus for the development and adoption of Bulletin 17B, *Guidelines for Determining Flood Flow Frequency*, US Water Resources Council, 1982.



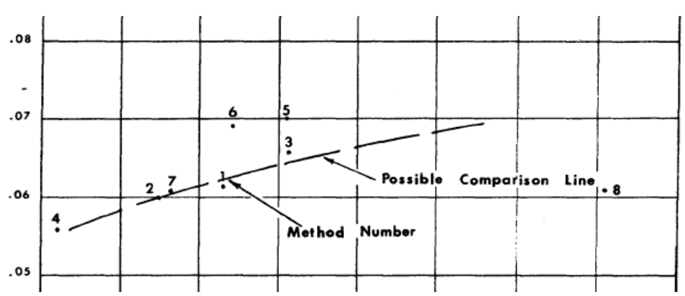
Candidate distributions, methods, and procedures selected from literature, natural long-record stations selected, eight distributions and alternative fitting techniques tested, several other stats methods examined.

Eight candidate distributions: Log Normal; Log Pearson III; Log Person III Regional Skew; Gumbel MLE; Gumbel BLIE; Log Gumbel; 2-parameter gamma; 3-parameter gamma.

300 stream flow stations, split-record analysis, various statistical accuracy, consistency, etc. tests. No. 7 is the 17B selected method.



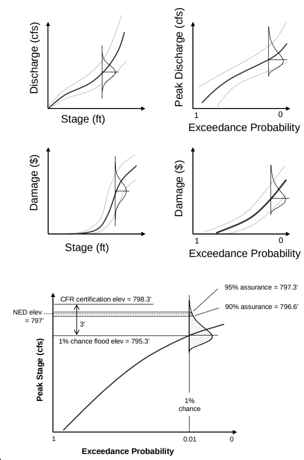
Accuracy



Consistency

USACE and Risk Analysis

- Response to call to better consider alternatives, reflect performance, and quantify risk and uncertainty.
- Fundamental principles: Quantify risk of flooding; quantify uncertainty in estimates; estimate and include residual risk in decisions.
- In context of extreme floods, RA as noted above, is an appropriate framework to embrace for project planning and evaluation and design flood selection.



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"<u>Principal purpose and themes</u>: The purpose of the 1992 USACE RA policy is to improve decision making and engender confidence in the project formulation/evaluation process by quantifying risk and disclosing uncertainty in key data and parameters. The fundamental tenants of the policy may be summarized as: 1) Make accurate and unbiased estimates of the probability and consequences of flooding, publish and communicate those findings, and make such information part of the deliberative process by the professionals and residents of the community; 2) acknowledge uncertainties associated with project performance, and quantify, publish, and communicate that information, making it a meaningful component of the deliberative process. (The key information items that must be addressed are the uncertainties in discharge-frequency, stage-flow, geotechnical and structural performance, project operations, and project costs and benefits); and 3) emphasize residual risk (probability and consequence of the exceedance of project capacity to public safety, lifeline security, and local and regional economic impact) by conducting residual risk analysis, and by documenting and communicating those findings to the project development deliberative process."

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Lessons from Katrina/New Orleans

- Floods can exceed even high ‘design flood’ standards; NO system designed for SPH.
- Protection systems can fail. Life risk elevated in importance.
- Failure to associate “risk” – chance of failing/consequences- of the protection system proved to be a mistake.
- Protection must function as integrated system.
- Need to revisit design process and standards; resiliency key.

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The many issues arising from Hurricane Katrina and the subsequent flooding of New Orleans were investigated by the Interagency Performance Evaluation Taskforce (IPET). The findings of the team were peer reviewed by a panel of experts appointed by the American Society of Civil Engineers. Further policy level overview review was conducted by the National Research Council of the National Academy of Sciences. Documents from the IPET investigations may be found at: (http://www.usace.army.mil/cw/hot_topics/): select IPET side link

Key actions/lessons from IPET:

➢Need to know and educate all on residual risk (failure probability and consequences)

➢Tendency for local officials to not really believe disaster will occur; risk viewed as a rather ethereal concept, discussed but not really embraced.

➢Design approach of defending against the ‘design flood’ without further consideration of overtopping/failure is a flawed concept. Design-in resiliency for levees/floodwalls. Reconstruction implemented resiliency concept.

➢Historic safety factors and deterministic design methods called into question; risk-based mode of analysis to be put forward and refined.

➢Never lose sight of components needing to be an integrated system.

Reflections: Today - Way Forward

- Projects reflecting high design floods of the past have degraded to barely 1% chance flood projects.
  - 'Just barely remove floodplain from NFIP.'
  - Consequence of national policy, primarily local cost sharing, NFIP, and to some degree, P&G.
- Katrina – designed for SPH; exceeded in many areas; can/will happen. Risk analysis adopted.
- Nation debating need for higher protection-level projects; 200-year, 500-year, SPF, others.
  - Need research to improve estimates of extreme floods, their frequency, and confidence in estimates.
- Feds not likely to invest in flood damage reduction projects not economically justified.

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Recommended Way Forward

- Estimate extreme floods by several methods/concepts: Historic and transposition; statistical methods (and variants); update SPF/PMF w/new data; Paleo and other ideas.
- Assess chance of flooding from each and consequences (residual risk), formulate plans accordingly.
- No matter choice, recognize capacity will be exceeded, thus plan project for its inevitable exceedance and develop companion emergency response plans.

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“While at the forefront of providing a comprehensive approach to managing flood threats in the mid-20th century, there is increasingly substantial evidence that the present approach of the United States is not sustainable from perspectives of public safety and economic and environmental consequences. Several observations can be made: (1) current floodplain management is unsustainable as flood damage is increasing, more lives continue to be threatened, and floodplain ecological functions degraded; (2) the nexus of Federal programs and local decision making coupled with cost sharing required for USACE projects are resulting in un-sustainable urban development in floodplains; (3) better synchronization of Federal, state, and local government policies and programs is required to stem the tide; and (4) optimal social investment in flood reduction requires a comprehensive and integrated perspective wherein levels-of-flood-protection, land use, and residual risk management are tailored to site-specific conditions.”

Abstract from: “**Is the Current Approach to Managing Flood Threats in the United States Sustainable?”,** by Darryl W. Davis, PE, D.WRE, Senior Advisor, Water Resources Engineering (publication date is mid-May, 2007 as part of Environment and Water Resources Institute (EWRI) Congress, Tampa, FL Conference Proceedings).