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USACE Experience in Implementing Risk Analysis for Flood Damage Reduction Projects

Darryl Davis[1], Beth A. Faber[2] and Jery R. Stedinger[3]

[1]Institute for Water Resources, USACE, Davis, CA; [2]Hydrologic Engineering Center, USACE, Davis, CA; [3]School of Civil and Environmental Engineering, Cornell University, Ithaca, NY

For about a decade now, the U.S. Army Corps of Engineers (USACE) has performed its flood damage reduction project development and improvements studies in an expanded risk analysis (RA) framework. This practice is a substantial change from policies and practices of the past, and was achieved despite significant impediments, both internal and external to the USACE. Sustaining the RA policy requires continued improvements in concepts and methods, as well as acceptance by the USACE professional Communities of Practice and the customers and stakeholders served by USACE. Hurricane Katrina and the devastation of New Orleans due to the failure of the protection system have brought increased attention by the nation to notions of risk and uncertainty in project performance. In this context, a broader embracing of RA in managing the nation's critical infrastructure may help sustain the implementation of these procedures within the USACE and the profession.

This paper provides a summary of the impetus for USACE adopting RA for flood-risk-reduction project evaluation and its consequent maturing and applications over the past decade. Several papers have been published that summarize concepts and applications (e.g. Dotson 1994, Burnham 1995, Davis 2003). The present state of the RA effort within the USACE is described and illustrated here with two key applications. External challenges and concerns about the USACE adoption of RA were significant and culminated in two formal reviews by the National Research Council of the National Academy of Sciences (National Research Council 1995, 2000); the National Research Council findings are summarized here. This paper outlines deficiencies and weaknesses in present policy and methods, summarizes research needs, and presents our perception of the way forward.

USACE Adoption of Risk Analysis Policy

It should not be surprising to informed observers that for a project-focused, action agency such as the USACE, the initial impetus for embracing a more formal framework for risk analysis for project development was stimulated by a specific project. Circa late 1980's/early 1990's, a levee project in the Northeast U.S. had been authorized by Congress for implementation, and USACE proposed the construction start in accordance with its normal budget cycle. The project was to take a few years to construct and was estimated to cost approximately $30 M. The "new start" failed to be included in budget legislation for that and the next year's budget cycle, but was again proposed in the following budget cycle – a common practice.

When the project was proposed again, however, there was a change in the cost estimate; the project was now to cost $45 M. A 50% increase in cost in just a few years (construction had not yet begun) was noteworthy and questioned by Office of Management and Budget (OMB) and USACE budget officials. The expectation among those questioning the cost increase was that there must be an increase in proposed project protection, or that some significant change in construction methods or materials had become necessary, and thus the cost increase.

The explanation by the engineers responsible for the project was that they had concluded that the freeboard criterion used for the project with the $30 M estimate was not appropriate; the freeboard had been

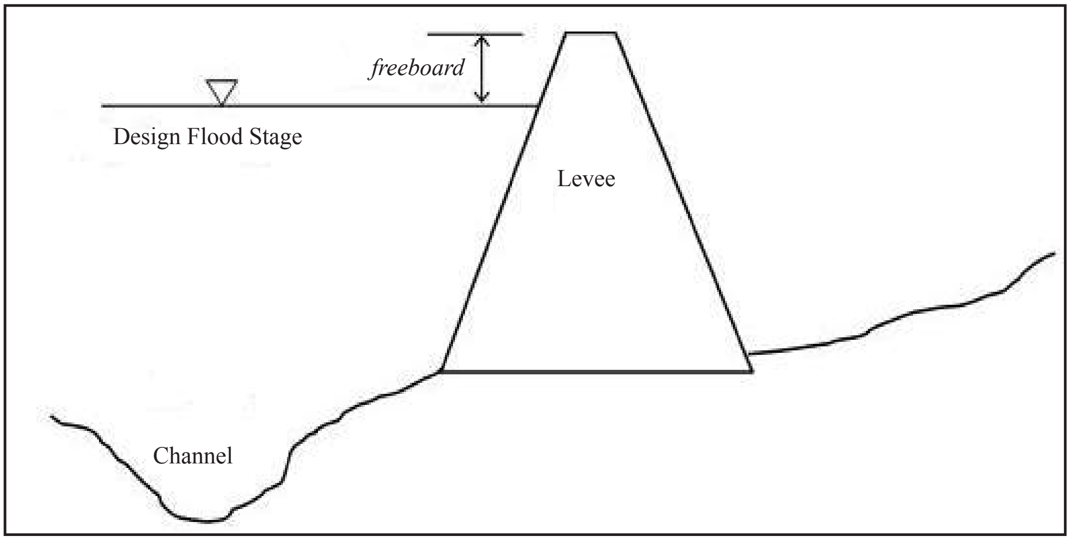

Figure 1. Conceptual description of levee freeboard.

increased, resulting in the increased cost.

By way of explanation, freeboard is an increment of height added to the design flood stage for a levee to account for uncertainty in the design flood stage and to provide a buffer for other engineering uncertainties. As this project illustrates, small increments of levee height can result in large increases in cost because a height increase translates to a substantial increase in the footprint of the levee, and thus significantly more material and right-of-way are required (Figure 1).

Further questioning of the engineers was met with staunch defense of the "design criteria" as needed to ensure project performance, and insistence that there was no creditable improvement in the project's expected performance and economic benefits. A stand-off ensued: budget and senior officials were adamant that an increase in levee height must result in more protection and benefits; the engineers insisted that the issue was simply a choice of design criteria.

In the late 1980s, freeboard and its contribution to project protection had been a point of contention for some time within the USACE with engineers maintaining that it is simply a design issue to ensure that the design flood can be contained, and economists and project formulation professionals arguing that some benefit (additional protection) should be credited for the increased height. A compromise was adopted wherein benefits would be taken for protection afforded by half the freeboard height (Moser 1991). That debate continued until the USACE adopted the expanded risk analysis procedures, as explained below.

The upshot of this dialogue was that future flood damage reduction project proposals forwarded through OMB were required to be cast in a risk and uncertainty framework. OMB, and analysts within USACE, pointed out to policy makers that RA concepts had been included in the Principles and Guidelines for Water and Related Land Resources – P&G (Water Resources Council 1983), and thus, ample precedent existed for specific policies to evolve, better representing uncertainties pertaining to project performance during the planning process. Moreover, the evaluation of flood risk reduction projects has always been an exercise in risk analysis, as the occurrence of large flood events is random and described probabilistically. At this time, new American Society of Civil Engineers model building codes included a form of probabilistic loading for structural analysis, and the time had simply come to modernize policy and methods for flood damage reduction.

The form of RA policy began to take shape during a seminar on levee freeboard held in August 1991 in Monticello, Minnesota. Two papers, (Davis 1991 and Moser 1991) proposed that instead of refining the economic justification of freeboard, the principles of risk and uncertainty analysis be adopted, thus eliminating the need for explicitly specifying a freeboard allowance. These proposals formed the basis for subsequent policy development. A policy advisory in the form of an Engineer Circular (draft Engineer Regulation) was sent to the USACE field offices shortly thereafter (1992) stating the primary components of the risk analysis policy. There was no accompanying technical guidance nor analytical tools and methods. This policy issuance generated reams of comments, literally, from USACE district and division offices. Few comments were supportive. Over the ensuing five years, concepts were sharpened, tools and methods developed, manuals and documentation prepared, and training sessions held. The formal documentation of the policy was a joint Engineer Regulation (ER 1105-2-101) issued by USACE Planning and Engineering directorates (USACE 1996a – updated and revised in January 2006), followed shortly thereafter by publication of an Engineer Manual (EM 1110-2-1619) (USACE 1996c). Technical and policy refinements were issued over the following ten years. ER 1105-2 101 stated that:

> The ultimate goal is a comprehensive approach in which the values of all key variables, parameters, and components of flood damage reduction studies are subject to probabilistic analysis.

Present State of Risk Analysis in the USACE

Decision Framework

Flood damage reduction projects are planned and constructed by Federal, state, and local government agencies, and private businesses. 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 areas across the U.S.

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 benefits; however, other considerations can suggest larger or smaller projects than the project that maximizes national economic development (Yoe and Orth 1996). For example, levee heights are often compared to that which would satisfy the Federal Emergency Management Agency (FEMA) National Flood Insurance Program base flood level for excluding the floodplain from mandatory flood insurance. This National Flood Insurance Program base flood, referred to as a 100-year protection level, is often mistaken by local communities as the Federal standard for urban flood protection (Davis 2007). In fact, there is no Federal standard for flood protection.

In those urban settings where these principles suggest levee height less than National Flood Insurance Program base flood protection, the heights are generally increased to that level so that the levees may be certified for National Flood Insurance Program purposes. The resulting project must still be economically justified and the local sponsor may be required to pay the entire cost for the increment of levee height between the National Economic Development project and the National Flood Insurance Program 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 National Flood Insurance Program base flood so that the levee system may be certified and the protected floodplain is free of development controls. (Levee certification is discussed again later in this paper.) It is important to note that project development principles and policies, such as maximization of national economic development, are not changed by USACE adoption of RA as the analysis framework for flood damage reduction projects.

Principal Purpose and Themes

The purpose of the 1992 USACE risk analysis policy is to improve decision making and engender confidence in the project formulation and 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, thus 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 deliberative project development process.

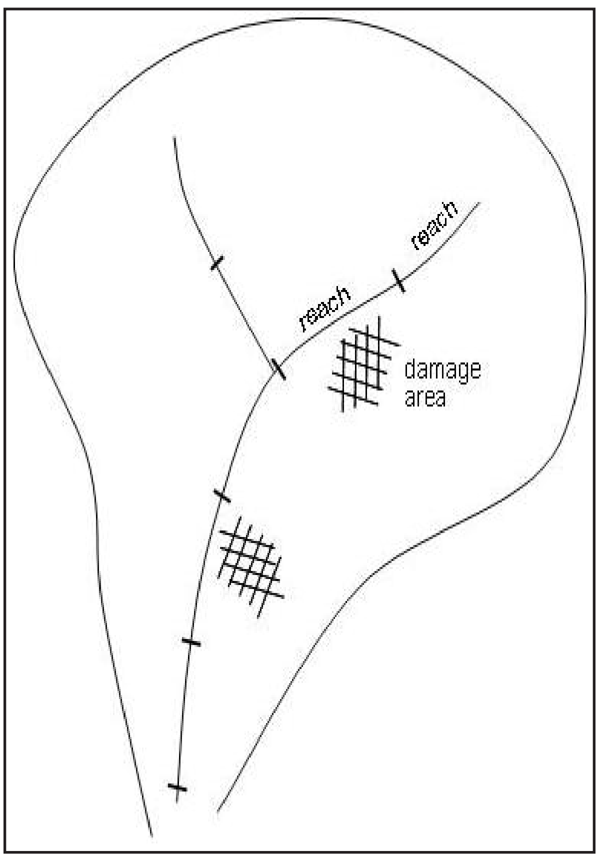

Figure 2. Floodplain parsed into reaches.

Implementing Risk Analysis in Project Studies

The way RA is implemented by USACE districts for project development studies is only modestly changed from past practice without RA. Historically, information is gathered and developed documenting the flood threat and properties at risk. The local community is engaged in better defining the objectives and offering potential solutions. The study floodplain is parsed into "reaches" to facilitate computations (Figure 2). For each reach, data are developed to quantify frequency of flooding and threatened properties. The approach for the analysis (in this example, a riverine reach) is to develop relationships between flow and frequency, stage vs flow, and stage vs damage. Flood damage reduction measures such as levees, floodwalls, relocation and evacuation, dams, and bypasses are formulated, their costs computed, and resulting changes to the above relationships defined. For alternative formulations, the relationships are conjoined to compute expected damage, damage reduced, and thus benefits. The overall output of the analysis for an alternative is 1) the project cost and benefits, and thus net benefits, and 2) the residual flood risk, typically annual exceedance probability with the project in place, and long-term risk, which can be compared to the "without–project" risk. Figures 3 and 4 provide illustrations of these analysis principles.

New USACE risk analysis procedures bring several elements of uncertainty directly into the analytical computations, resulting in a more complete and deliberate analysis of project costs and performance, and consequences of capacity exceedance. Instead of single-valued relationships described in Figures 3 and 4, the uncertainty in each is estimated and incorporated into the analysis, as illustrated in Figure 5. Again using the riverine setting as an example, uncertainty in the relationship between flow and frequency is estimated by developing confidence bands as prescribed in "Guidelines for Determining Flood Flow Frequency" (IACWD 1982) for analytical flow-frequency relationships, or invoking "order statistics" as documented in Engineer Technical Letter ETL 1110-2-537 (USACE 1997) for non-analytic frequency curves. For the stage-flow uncertainty, a variance in flood stage is estimated from several sources: historic floods,

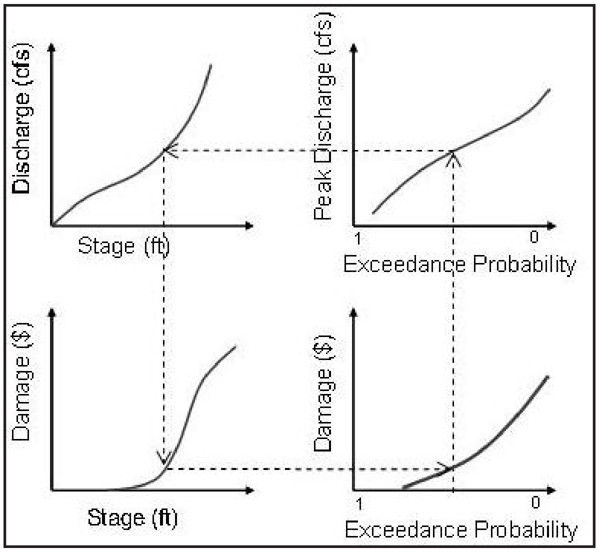

Figure 3. Conjoining of relationships between flow, probability, stage and damage.

high water marks, sensitivity analysis on hydraulic parameters, analysis of gauged rating data, or perhaps reference to published values. For the stage-damage relationship, parameters of structure first-floor-elevation, structure value, and damage fragility curves are sampled in a Monte Carlo framework to develop a function and its associated variance. Suggested methods for developing the uncertainty data are documented in EM 1110-2-1619. For structures such as levees that might be aged or in degraded condition, flood stage versus probability-of-failure relationships are developed by methods as suggested in "Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies" (USACE 1999).

Conjoining the evaluation functions to compute flood risk reduction performance (an uncertainty-weighted annual exceedance probability), expected damage, expected damage reduced, expected benefits, and ultimately, expected net benefits is again performed. With RA, instead of single estimates for these important decision parameters, probability density functions are developed. Information required for "without project" conditions and each proposed alternative (ER 1105-2-101) includes probability density functions of annual exceedance probability, benefits, and net benefits. The computations are performed in a Monte Carlo framework with computer software "HEC Flood Damage Analysis." The sampling and computation scheme is described in the Flood Damage Analysis User's Manual (USACE 1998).

Decisions about project scale and subsequent investment are essentially made as in the past, in an open, transparent, collaborative environment in which USACE engages the affected community, stakeholders, other Federal, state, and local agencies, and interested public and non-governmental organizations in a fluid give-and-take that is the essence of the U.S. democratic process. In the context of the present USACE risk analysis policy, the decision process can best be characterized as "risk informed" rather than be thought of as a formal risk-based decision process; there are not yet any

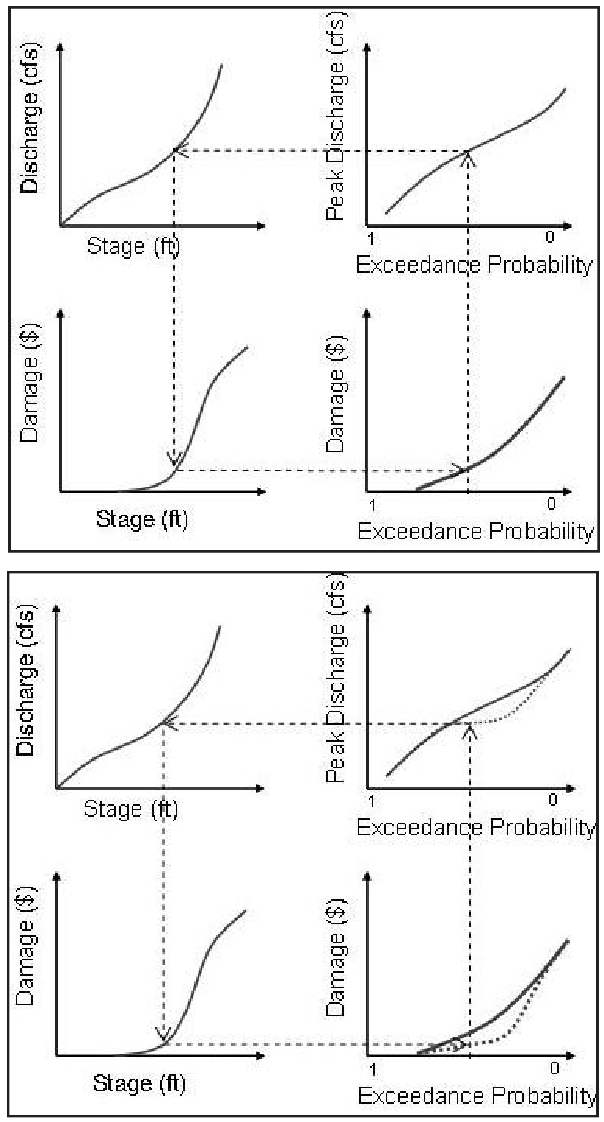

Figure 4a. Hydrology and Hydraulics relationships altered by presence of a reservoir.

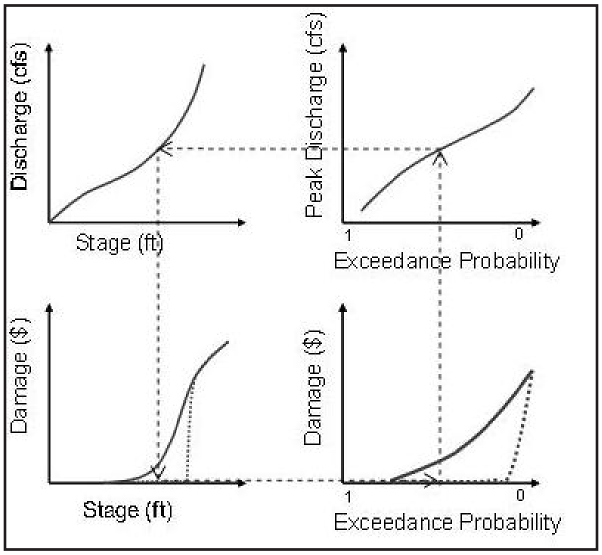

Figure 4b. H&H relationships altered by presence of a levee.

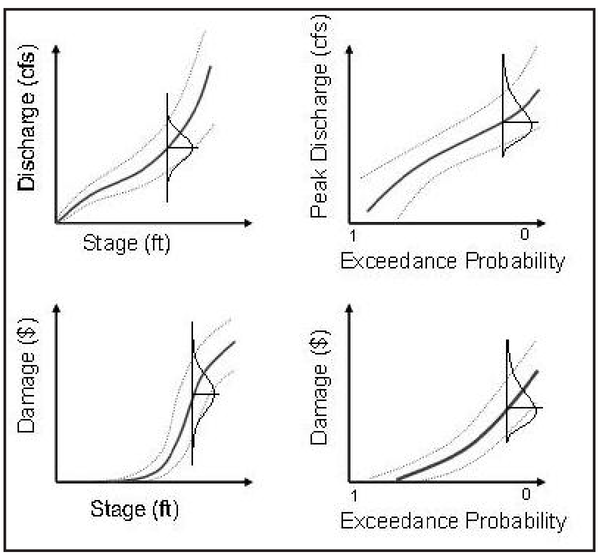

Figure 5. Uncertainty in flow, stage, damage and probability relationships.

prescribed risk-based decision criteria. As noted above, however, there are some clear boundaries as reflected in Federal law (environmental statutes, for example), regulations and policies (P&G and agency rules), and some notions fundamental to Federal investments such as public safety (project should improve public safety and not increase risk from flooding), equity (all citizens are treated in a balanced and fair manner), and requirement that project have multiple transparent beneficiaries (not enrich special interests).

USACE Risk Analysis and National Flood Insurance Program Levee Certification

FEMA administers the National Flood Insurance Program, a Federal program that seeks to stimulate wise floodplain land use decisions and create a fund to indemnify owners of properties in the floodplain from flood damage they might incur. The National Flood Insurance Program is described in various FEMA documents that may be retrieved from the website: www.floodsmart.gov. Flood inundation maps are an important component in administration of the National Flood Insurance Program. A key element in drawing flood maps, and hence setting insurance rates, is that of determining whether levees should be credited with protecting associated floodplains from the base (1 percent chance exceedance) flood. Levee certification is a technical finding that, for the floodplain in question, there is reasonable certainty that the levee protecting the area will contain the base flood. USACE recognized that their adopted risk analysis policy and methods had implications for floodplain management and associated FEMA levee certification and immediately engaged FEMA leadership in discussions. An approach to levee certification that embraced risk analysis was agreed upon between USACE and FEMA in 1996 and published in a policy letter to Corps of Engineers field offices (USACE 1996b). The essential elements of the 1996 risk-based levee certification guidance are: 1) Respect the elements and principles of CFR 65.10 (CFR 1986), FEMA regulations governing levee certification (e.g. demonstrate a degree of assurance of containing the base flood); 2) replace the fixed, minimum freeboard criteria components of the certification with a quantified conditional non-exceedance probability (referred to as "assurance") as follows: Use CFR 65.10 minimums provided that they achieve at least 90 percent assurance of containing the base flood (may require higher, stronger levees), but protection need not be greater than that providing 95 percent assurance of containing the base flood (so may certify for lower levees than CFR 65.10 minimums); and 3) to the extent possible, quantify and include uncertainty in the performance of the geotechnical and structural

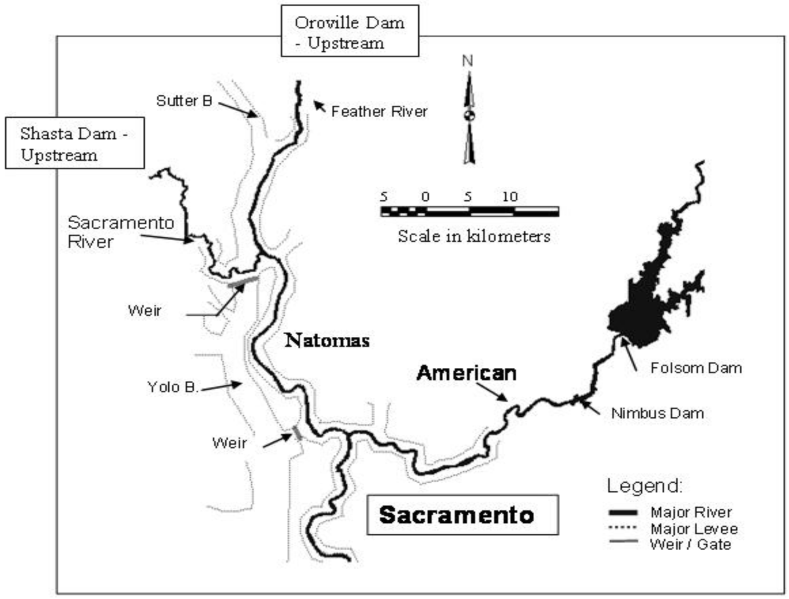

Figure 6. Sacramento River and American River Basins.

features of the levee system in the analysis. The risk-based levee certification policy has been in place in USACE since issuance of the policy letter in 1996.

The American River Example

An early application of the RA policy occurred during intensive studies and controversy involving the American River Project circa late 1990's (See also National Research Council 1995, Davis 2007). The City of Sacramento is located at the confluence of the Sacramento and American Rivers in central California and throughout history, has been vulnerable to floods from both Rivers. The Sacramento River and upstream tributaries are controlled by a series of dams and other protection works, but the flood threat from the American River remains serious (Figure 6). A record-setting flood in 1997 severely strained the system and highlighted again Sacramento's vulnerability to flooding from the American River, triggering new Congressional authorization of studies seeking to improve protection. An array of alternatives was studied ranging from new major upstream storage (Auburn Dam), to raising an existing dam (Folsom), to changes in operation for Folsom Dam as well as various combinations of storage increases and levee system improvements. Much of the controversy stemmed from strong opposition to and support for new upstream storage, namely Auburn Dam.

Due to the complexity of the hydrology of the area many large rivers draining steep Sierra Nevada watersheds with seasonal snow pack, as well as the complexity of operating the reservoirs and bypass facilities, there is significant uncertainty in how the existing system will perform, and how it would perform if various alternatives were implemented. The RA framework parsed the system into components for which inflow hydrology and associated uncertainty could be adequately reflected, project operations isolated, and downstream consequences of operation quantified. Many challenges were addressed to conduct a credible risk analysis of the system:

1. developing consistent system-wide inflow flood-frequency curves with uncertainty;
2. accurately representing reservoir operation rules with attendant uncertainty to develop regulated flow frequency curves;
3. adequately reflecting the integrity (or lack thereof) of the levee system with its associated uncertainty; and
4. computing economic benefits and associated uncertainty for the array of alternatives considered.

Table 1. Summary of American River Risk Analysis.

	Alternative[1]			
	No-Action Plan	Folsom Modification plan	Folsom Stepped Release Plan	Detention Dam Plan (Auburn)
Probability of Flooding per year[2]	1 in 67	1 in 153	1 in 169	1 in 500
Assurance of Passing[2]				
100-yr Flood (%)	31	83	87	99+
200-yr Flood (%)	5	43	48	94
400-yr Fl;ood (%)	1	12	22	73
Benefit Summary ($ Million US)				
First Cost ($ Million)	-	370-430	505-650	960-1000
Annual Cost	-	50	75	95
Expected Annual Benefit	-	125	130	200
Expected Annual Net Benefit	-	75	60	110

1. Alternative feature description, costs and benefits are based on 1998 data.
2. Performance parameters for each alternative are computed based on 1999 hydrologic parameters.

The approach taken and studies performed are documented in project reports and summarized in a paper presented at the International Commission on Large Dams in Beijing in 2000 (Eiker et al. 2000). Table 1 summarizes results from analysis of key alternatives, presenting the expected values for key performance parameters. Uncertainty information for these parameters was developed and reported in project documents but are not reproduced here.

This example contains an instance where the risk analysis information helped the Corps and other agencies better understand performance of a proposal coined the "Stepped Release Plan." This plan was carefully crafted by a local consultant to schedule the Folsom reservoir releases such that the operation precisely controlled the 200-year event (but not greater events) and thus would meet the local agency's performance goal. Before RA, the project would be characterized as providing the 200-year level of flood protection and would permit certification for the FEMA standard 100-year flood. Because this plan would release water almost exactly to the top of the levees, however, its "assured" protection characterization is questionable. In this plan, there is little margin for error and, therefore, uncertainty is an important factor. The RA results demonstrated the mis-characterization of the performance of the plan by producing a more accurate expected exceedance estimate (1 in 169), and demonstrating that the assurance of passing the 100-year FEMA flood (only 87 percent) was less than a sure thing. Without RA, the "brittle" nature of the alternative could have been argued, but its shortcomings would not have been quantified.

The application of risk analysis for this project was not without its problems and detractors. At the time (late 1990's) it proved difficult to adequately communicate the concepts of uncertainty and performance to decision makers accustomed to precise characterization of protection levels with no hint of uncertainty. In the decade since, some progress has been made, but communication of risk analysis findings is still a challenge. Another difficulty with using the risk analysis results occurred when a local Congressman twisted the statement of the conditional non-exceedance probability for one of the alternatives considered to be "having only a 60 percent chance of passing the 200 year flood" to achieve a political mis-direction. The Congressman sent out flyers to the populace characterizing the performance of this particular alternative as analogous to asking someone to board an airplane that had a 40 percent chance of crashing. Controversy still reigns with regard to flood protection for Sacramento. Auburn Dam remains in seemingly permanent limbo, plans are underway for a mini-raise of Folsom, and the levees are undergoing strengthening. Improvements to Folsom project operations are under study, including better use of forecasts. With all these measures successfully completed at some time in the future, Sacramento will still have less protection than did New Orleans when Hurricane Katrina struck.

The Portage, Wisconsin, Example

The application of risk analysis to a levee project in Portage, Wisconsin, is a counter example that illustrates how adopting a new policy is *not* always welcomed or necessarily successful in improving decision making. Briefly, USACE formulated a levee project for Portage following P&G policy of sizing the project to maximize national economic benefits National Economic Development subject to public safety and other governing policy. The National Economic Development levee height (797.0 ft) was compared to the new USACE levee certification criteria adopted for risk analysis (796.6 ft) and found to be sufficient to certify. USACE was prepared to issue the certification letter. However, the local sponsor was not satisfied that the levee should be certified since it did not meet the local State of Wisconsin or the National Flood Insurance Program CFR 65.10 freeboard criteria. The relevant information is listed in Table 2 and shown in Figure 7.

The circumstance reflected here is that of a stream with low variability and low uncertainty, requiring less ”buffer” than the CFR-required three feet to ensure (with a 90 percent level of assurance) 1 percent-chance protection based on risk analysis. The local sponsor objected sufficiently that the consequence was a call by Congress for the National Research Council of the National Academy of Sciences to review the USACE risk analysis policy. The positive outcome of the 1995 National Research Council review is summarized below.

None-the-less, the local sponsor persuaded Congress to authorize the levee project at the higher elevation than the NED plan (with 3 feet of freeboard), and it is what was ultimately constructed. One could view the application of RA in this situation as a failure in that the findings were dismissed. On the other hand, the role of the technical analyst, in this case USACE, is to inform decision makers in a balanced and unbiased manner, and let the democratic decision process proceed. Those involved were certainly better informed about the performance of the project than would have otherwise been the case.

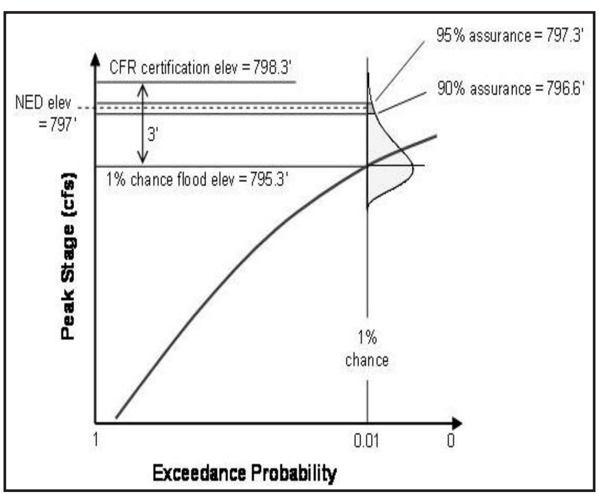

Figure 7. Relevant computed levee heights for Portage, WI (not to scale).

National Research Council Review Findings

Two National Research Council studies addressed the 1992 Risk and Uncertainty procedures. This paper’s third author served on both committees.

In 1994 a National Research Council committee was organized to review the USACE proposal for Auburn Dam on the American river. Because the newly developed RA procedures had been adopted for the redesign of that project, National Research Council committee found it necessary to comment on the approach. The committee concluded that the new procedures were an “innovative and timely development,” and that “the explicit recognition of modeling uncertainty should result in a better understanding of the uncertainty of flood risk and

Table 2. Portage, WI, Base Flood and Alternative Levee Certification Stages.

1% chance flood elevation	795.3
CFR Certification elevation	798.3 (1% chance plus 3 feet)
NED Levee elevation	797.0 (USACE recommended project)
90% CNP of 1% elevation	796.6
95% CNP of 1% elevation	797.3

damage reduction estimates." While the committee had a number of concerns about how risk and uncertainty were represented and reported, they were fundamentally very supportive.

More important to this discussion is the second National Research Council report (National Research Council 2000), which reflects the deliberations of a committee organized explicitly to provide a review of the new RA procedures. They too were very supportive, concluding that "the new techniques are a significant step forward and the Corps should be greatly commended for embracing contemporary, but complicated, techniques and for departing from a traditional approach that has been overtaken by modern scientific advances." However, the committee also provided a laundry list of issues that it felt needed to be addressed, including the vocabulary used to describe the computations better distinguishing between natural variability and uncertainty, the representation of hydrologic and other uncertainties including levee performance, and the methods used to combine uncertainties in different reaches into the overall distribution of project performance.

With respect to the levee certification issue, the 2000 committee found the competing representations of risk and uncertainty and their interaction with design and policy to be confusing. Eventually they recommended that "the federal levee certification program focus not upon some level of assurance of passing the 100-year flood, but rather upon "annual exceedance probability – the probability that an area protected by a levee system will be flooded by any potential flood." As clarification they added: "This annual exceedance probability of flooding should include uncertainties derived from both natural variability and knowledge uncertainty." The committee hoped this would provide a more nationally uniform level of flood protection. However, recognizing that this recommendation could not be implemented immediately, the 2000 committee suggested that: "Until the measure of annual exceedance probability is adopted as the key criterion for levee certification, the committee recommends that the Corps and FEMA set a single conditional non-exceedance probability for levee certification." Levee certification has proceeded according to this suggestion.

Both committees attempted to provide a discussion of the issues that would help the public and the engineering profession understand the advantages of the new methods, and what developments would allow the computations to be more accurate and reliable.

Current Deficiencies and the Way Forward

The USACE risk analysis policy for flood damage reduction is essentially the same today as when it was first issued in March 1996. The 2006 update of ER1105-2-101 was modest in adjusting terminology, clarifying issues, and improving the examples. There is belief among its advocates that decisions are now better informed and, thus, are expected to be better than before adopting the RA policy. That said, the wide-spread adoption of the policy and its application by USACE field offices continues to be a work in progress. Understanding of RA principles and techniques is not widespread. There has been loss of advocacy staff to retirement, normal staff turnover, and weakening of training and technical guidance support. An important development is the loss of senior-level oversight within the USACE that has come about as USACE downsized its headquarters and division offices. On the positive side, initiatives by USACE in the dam safety area that are framed in a risk analysis context have resulted in increased attention to and understanding of concepts of risk and uncertainty within the Corps. The recent catastrophe in New Orleans has lent renewed attention to flood risk, particularly in the coastal environment. This catastrophe has provided a window of opportunity to re-energize USACE effort to expand risk analysis procedures for flood damage reduction projects. A levee safety program begun in the aftermath of Katrina is developing new tools for levee safety assessment, also framed in an appropriate and expanded risk analysis framework.

A shortcoming or weakness in the current RA policy is its failure to address decisions in the face of risk and uncertainty (except in the case of levee certification for NFIP). Essentially, the policy directs that risk and uncertainty information be developed and considered in decisions, but does not suggest how to do so. Better policy and methodology guidance on what to do with information about the residual risk, uncertainty in project performance, and net benefits would aid decision-making in putting this information to use.

Methods and issues that need to be addressed for risk analysis procedures to move forward include:

- Improved integration and computational algo-rithms that can better reflect physical and logical upper bounds on functions to reflect reality when sampling the extreme tails of the probability distribution functions.
- Better tracking of each uncertainty's contri-butions to risk and uncertainty.
- New analytical methods and algorithms to better reflect the performance of levee systems as an integrated set of components (embankments, floodwalls, closure structures, pump stations, etc.).
- Better methods for estimating uncertainty for non-analytic frequency curves.
- Methods to incorporate other performance functions and their associated uncertainties.
- A more standardized vocabulary for risk analyses and improved vehicles for communication of concepts, methods, and results.

Summary and Conclusions

Here are three key issues that should be kept in mind with the adoption of an expanded and much more complete evaluation of project performance and related uncertainties.

1. Risk analysis removes hidden safety factors and lays open the assumptions of our analysis. Thus we need to make accurate and unbiased estimates of the probability of flooding and of exposure, and then communicate that information.
2. Risk analysis calls on us to honestly acknowledge the uncertainty associated with a project and its performance, and to expose, quantify, and communicate that information.
3. Risk analysis should emphasize the residual risk that remains after a project is completed. *Risk* includes both the probability of flooding and the consequences of such flooding, which depends upon the vulnerability of a community.

In that sense we think that the USACE effort to incorporate an expanded risk analysis framework is providing the critical tools the USACE and other agencies and professionals need to evaluate flood risk reduction projects in the 21st century.

Author Bios and Contact Information

Darryl Davis retired from USACE in 2006 where he had served for sixteen years as the Director of the Hydrologic Engineering Center. He is now a rehired annuitant-status, part-time member of the USACE Institute for Water Resources staff, advising in the areas of flood risk management, levee certification, and Dam Safety. Contact information: Institute for Water Resources, USACE, Davis, CA, 95616 Email: darryl.w.davis@usace.army.mil.

Beth A. Faber recieved her doctorate in civil engineering from Cornell University. Sonce then, she has worked for USACE at its Hydrologic Engineering Center for 8 years.She focuses on the use of risk analysis in planning and design decisions, and hydrologic frequency analysis. Contact information: Hydrologic Engineering Center, USACE, Davis, CA, 95616. Email: beth.a.faber@usace.army.mil.

Jery R. Stedinger has been a professor at Cornell University for 30 years during which time he took sabbaticals with the USACE and USGS. His research focuses on reservoir operations, risk analysis, and a wide range of topics related to stochastic hydrology and flood frequency analysis. Contact information: School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853. Email: jrs5@cornell.edu.

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