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RISK ASSESSMENT FOR FLOOD RISK MANAGEMENT STUDIES

15 July 2019

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DEPARTMENT OF THE ARMY ER 1105-2-101
U.S. Army Corps of Engineers
Washington, DC 20314-1000

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Regulation
No. 1105-2-101 15 July 2019

Planning
RISK ASSESSMENT FOR FLOOD RISK MANAGEMENT STUDIES

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1. Purpose. This regulation provides guidance on risk assessment requirements for flood management studies including but not limited to feasibility studies, post-authorization changes, general reevaluation studies, dam and levee safety studies, and major rehabilitation studies. This regulation is jointly promulgated by Planning and Engineering. The risk framework is a decision-making process that comprises three tasks: risk assessment, risk communication, and risk management, which can be advantageously applied to a variety of water resources management problems. These requirements are part of a broader decision-making process that includes similar assessments for risks to the natural environment as well as the social and cultural well-being of people potentially impacted by flood management activities.

2. Applicability. This regulation is applicable to all U.S. Army Corps of Engineers Headquarters (HQUSACE) elements, major subordinate commands, districts, laboratories, and field operating agencies having civil works responsibilities. This regulation applies to all implementation studies for flood risk management projects: riverine and coastal.

3. Distribution Statement. Approved for public release, distribution is unlimited.

4. References.

a. Engineer Regulation (ER) 5-1-11, U.S. Army Corps of Engineers Business Process. (https://www.publications.usace.army.mil/USACE-Publications/Engineer-Regulations/)

b. ER 1105-2-100, Guidance for Conducting Civil Works Planning Studies. (https://www.publications.usace.army.mil/USACE-Publications/Engineer-Regulations/)

c. ER 1110-2-401, Operation, Maintenance, Repair, Replacement, and Rehabilitation Manual for Projects and Separable Elements Managed by Project Sponsors. (https://www.publications.usace.army.mil/USACE-Publications/Engineer-Regulations/)

d. ER 1110-2-1156, Safety of Dams – Policy and Procedures. (https://www.publications.usace.army.mil/USACE-Publications/Engineer-Regulations/)

e. Engineer Manual (EM) 1110-2-1619, Risk Assessment for Flood Risk Management Studies. (https://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/)

f. Engineer Pamphlet (EP) 1110-2-8, Explaining Flood Risk. (https://www.publications.usace.army.mil/USACE-Publications/Engineer-Pamphlets/)

g. Specific Measurable Attainable Risk Informed Timely (SMART) Planning Guide (https://planning.erdc.dren.mil/toolbox/smart.cfm)

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*This regulation supersedes ER 1105-2-101 dated 17 July 2017.

h. U.S. Army Corps of Engineers (USACE), Hydrologic Engineering Center, 2010. "Flood Damage Reduction Analysis (HEC-FDA)," Version 1.2.5. Davis, CA. (http://www.hec.usace.army.mil/software/hec-fda/)

i. National Research Council, 1995. "Flood Risk Management and the American River Basin: An Evaluation." Washington, DC: National Academy Press. (https://www.nap.edu/catalog/4969/flood-risk-management-and-the-american-river-basin-an-evaluation)

j. "Transforming the Corps into a Risk Managing Organization," 26 November 2007. Contributing Authors: Dr. David Moser, USACE, Institute for Water Resources; Todd Bridges, USACE, Engineer Research and Development Center; Steven Cone, USACE, Institute for Water Resources; Yacov Haimes, University of Virginia; Brian K. Harper, USACE, Institute for Water Resources; Leonard Shabman, Resources for the Future; and Dr. Charles Yoe, College of Notre Dame. (https://www.iwrlibrary.us/document/4480fdb1-7f94-43fb-eb62-37f19a9edd84)

k. "USACE Resilience Initiative Roadmap 2016," 16 May 2016. (http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p16021coll6/id/1617#img_view_container)

l. U.S. Army Corps of Engineers, Risk Management Center, Best Practices in Dam and Levee Safety Risk Analysis. (https://www.usbr.gov/ssle/damsafety/risk/BestPractices/Chapters/I-0-20150612.pdf)

5. Context. Since the enactment of the Flood Control Act of 1917, USACE has played a significant federal role in managing flood risk nationwide. Flood risk management is the process of identifying, evaluating, selecting, implementing, monitoring, and modifying actions taken to reduce and manage risk through shared responsibilities. Scientifically sound, cost-effective, integrated actions are taken to achieve flood risk management. Social, cultural, ethical, environmental, fiscal, political, and legal considerations are accounted for in the process. Still, USACE recognizes that more needs to be done to assess, manage, and communicate flood risks. In 2006, USACE established the National Flood Risk Management Program to advance the goals of flood risk identification, communication, response, and management services across all levels of government to save lives and reduce property damage in the event of floods and coastal storms. All flood risk managers must balance the insights of USACE's professional staff with stakeholder concerns for such matters as residual risks, life safety, reliability, resiliency, and cost while acknowledging that no single solution will meet all objectives, and tradeoffs must always be made. Resilience is inherent to flood risk management, and it is the overall ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover from adverse events, including the ability to avoid, minimize, withstand, and recover from the adverse effects of a flood. Resilience also refers to the capacity or ability of a project or system to absorb disturbance and still retain its basic function and structure. For example, project resilience measures for a levee embankment can be provided by various forms of surface

hardening, armoring, or resistance to overtopping scour. These measures provide a higher degree of predictability for levee performance.

6. Background.

a. No project or action that is proposed, evaluated, adopted, and implemented can completely eliminate or mitigate flood risks. Further, the information used to estimate flood risk, formulate and evaluate plans, and determine the results of the analyses is uncertain. All measured or estimated values in project development are to various degrees inaccurate—reflecting both inherent natural variability in flooding phenomena (e.g., cyclical rainfall patterns) and lack of knowledge in estimating various parameters (e.g., estimation of Manning's n-value) relevant to project works and their performance. Pursuing the management of flood risk within the risk framework is an explicit means of better understanding both the flooding and associated consequences, and the uncertainty in their estimation, and thus should support development of robust strategies for managing flood risk.

b. The risk framework is a decision-making process that comprises three tasks: risk assessment, risk communication, and risk management. Risk assessment is a systematic approach for describing the nature of the flood risk, including the likelihood and severity of consequences. Risk assessments are quantitative whenever possible; however, qualitative assessments may be appropriate for some activities. Risk assessment includes explicit acknowledgment of the uncertainties in the parameters used to compute risk. Risk management is a decision-making process in which risk-reducing and resilience-increasing actions are identified, evaluated, implemented, and monitored. The purpose of risk management is to take actions to effectively reduce and manage risks identified in the risk assessment. Risk communication is a collaborative exchange of information among the risk assessors and those who will use the risk assessment results and/or those who are affected by the risks and risk management actions. Open communication improves the understanding of the risks by all parties, and leads to improved risk assessments and risk management decisions and outcomes. Documenting the results of a risk assessment framework is an important part of the process, and examples are included in Appendix A. Clearly presenting the findings of the risk assessment will help inform discussions with sponsors, stakeholders, and others; however, documentation alone will not fully convey the highly technical nature of risk assessment results. Open dialogue will likely be required to ensure a sufficient and common understanding of the risk assessment and mitigation options leading to the selection of most appropriate actions.

c. A risk framework process can be advantageously applied to a variety of water resources management problems, including those involving flooding. The approach captures and quantifies the extent of the risk and uncertainty in the various project development components of an investment decision. The total effect of uncertainty on the project formulation and consequent performance related to life safety, economic, social, and environmental concerns can be examined and conscious decisions made reflecting an explicit tradeoff between risks, performance, and costs. Risk assessments can be used to compare plans in terms of their physical performance, economic success, residual risks, and impacts to life, health, and the environment, including their uncertainties.

d. Budget constraints for plan selection, increased partner cost-sharing, the public's interest in project performance, and concern for life safety as well as social and environmental matters must be addressed in the analysis of federal water resources investments. Explicit consideration of risk and uncertainty can help address these issues and improve investment decisions.

e. Risk is broadly defined as a situation or event where something of value is at stake and its gain or loss is uncertain. Risk is typically expressed as a combination of the likelihood and consequence of an event. Consequences are measured in terms of harm to people, cost, time, environmental harm, property damage, and other metrics. Choosing the appropriate risk metrics and actively using them in decision-making is critical to effective risk management in support of a vibrant economy, thriving ecosystems, and sustainable communities. Flood risk considers explicitly the performance consequences of subjecting people and property to the entire range of likely flood events, given risk management provided by any structural or non-structural measures. One commonly used metric of economic risk is expected annual damage (EAD) or average annual equivalent damage when computed on an annual basis over the period of analysis.

f. Flood risk can be conceptualized as a function of the hazard, performance, exposure, vulnerability, and consequences as depicted in Figure 1.

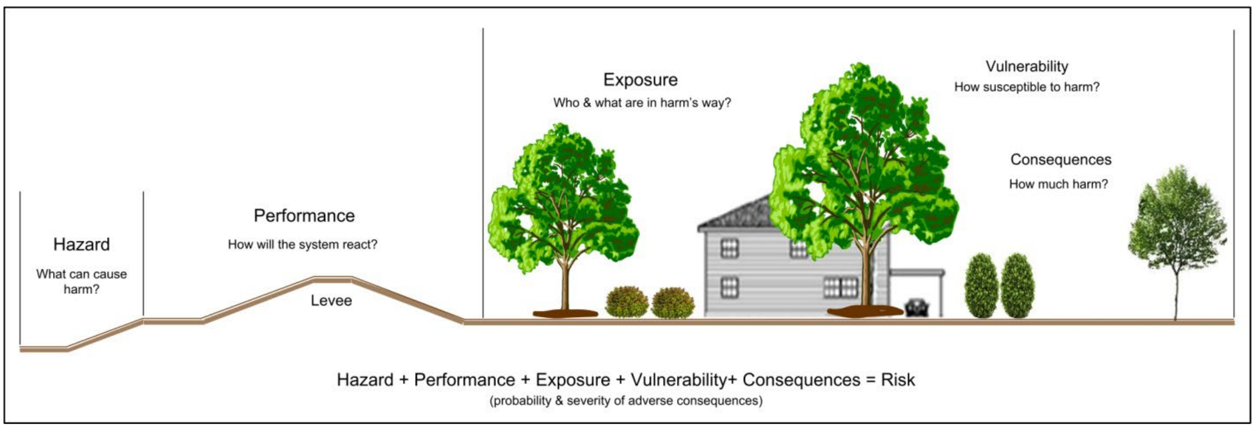

Figure 2: Risk conceptualized

(1) The "hazard" is what causes the harm: in this case, a flood. The flood hazard is described in terms of frequency, stage, velocity, extent, and depth.

(2) "Performance" is the system's reaction to the hazard. In Figure 1, performance refers to the system features and the capability to contain/manage the flood hazard for the full range of possible events and as a single event or load. In this regulation, this would be termed "system performance." Performance also refers to the metric that describes the capability of the system to accommodate a single event (Assurance; also Conditional Non-exceedance Probability, CNP) and the full range of events: Annual Exceedance Probability (AEP) and Long-Term Exceedance

Probability (LTEP). There are other definitions of performance in addition to system performance. Performance can also be described by levee breach from loading below the top of levee probability functions, the interior-exterior functions for leveed areas, unregulated-regulated transforms for reservoirs and diversions, and elevation-discharge functions (rating curves) for channels. These also would be considered "system performance." When the structural integrity of a system or system component is discussed, such as the fragility function, the reference would be termed "structural performance." When the economics of a system are discussed, the reference would be termed "economic performance" as expressed by EAD and EAD reduced.

(3) "Exposure" describes who and what may be harmed by the flood hazard. Exposure incorporates a description of where the flooding occurs at a given frequency and what exists in that area. Tools such as flood inundation maps provide information on the extent and depth of flooding; structure inventories, population data, crop data, and habitat acreage provide information on the population and property that may be affected by the flood hazard.

(4) "Vulnerability" is the susceptibility to harm human beings, property, and the environment when exposed to the hazard. Depth-damage functions, depth-mortality functions, and other similar relationships can be used to describe vulnerability.

(5) "Consequence" is the harm that results from a single occurrence of the hazard. Consequences are measured in terms of metrics such as economic damage, acreage of habitat lost, value of crops damaged, and lives lost.

(6) "Economic risk" is the combination of likelihood and harm to property, infrastructure, and other assets as well as economic systems (all measured in monetary terms). A common metric of economic risk is EAD.

(7) "Life loss consequence" is the determination of the population at risk and the estimated statistical life loss.

7. <u>Variables in a Risk Assessment</u>.

a. The true values of variables and parameters are recognized as important to project development decisions, are frequently not known with certainty, and can take on a range of values. The likelihood of a quantity or parameter taking on a particular value can be described by a probability distribution and the probability distribution may be described by its own parameters, such as mean and variance for a normal distribution. Quantitative risk assessment combines the information about the parameters with underlying uncertainty information within a computational model so that the engineering performance and associated consequences are determined on a statistical basis represented by a probability distribution. Consequences of interest include potential for life loss and economic losses and environmental impacts of a proposed project.

b. A variety of variables and their associated uncertainties may be incorporated into the risk assessment of a flood risk management study. For example, economic variables in an urban situation may include, but are not necessarily limited to depth-damage curves, structure values, content values, structure first-floor elevations, structure types, flood warning times, and flood evacuation effectiveness. Uncertainties in economic variables include building valuations, inexact knowledge of structure type or of actual contents, method of determining first-floor elevations, or timing of initiation of flood warnings. Other key variables and associated uncertainties include the hydrologic and hydraulic conditions of the system. Uncertainties related to changing climate should be addressed using the current USACE policy and technical guidance. Uncertainty in the likelihood of particular discharge and stage exists because record lengths are often short or do not exist where needed, and the effectiveness of flood flow regulation measures is not precisely known. Uncertainty in discharge also comes from estimation of parameters used in rainfall runoff computations, such as precipitation and infiltration. Examples of uncertainty factors that affect stage might include conveyance roughness, cross-section geometry, debris accumulation, ice effects, sediment transport, flow regime, and bed form. Uncertainty factors that affect the safety of human life include the number of routes of egress, time of day, distance to dry land, water temperature, number of multi-storied structures, demographics, and the existence and adherence to an emergency action plan. Not all variables are critical to project justification in every instance. To achieve the ultimate goal, the risk assessment and study effort should concentrate on the uncertainties of those variables having a significant impact on study conclusions and recommendations. SMART Planning Principles (Reference 4g) promotes balancing the level of uncertainty and risk with the level of detail of the study. The level of detail required to make planning decisions will grow over the course of the study, as the study team moves from an array of alternatives to a single recommended alternative. For technical details on how to address these uncertainties, see Reference 4b.

8. Policy and Required Procedures.

a. All flood risk management studies will adopt the risk framework as described herein. The risk framework approach and results of a risk assessment will be documented in the principal decision document. The types of documents involved include but are not limited to: feasibility reports, general and limited reevaluation reports, and project modification impact reports including water control manuals that reallocate storage requiring reauthorization, and design documentation reports. Project Management Plans (PMPs) will describe the methods to be used to quantify the uncertainties of the key variables, parameters, and components and the approach to combining these uncertainties into higher-level measures for determining overall engineering performance, life loss, and economic and environmental consequences (Reference 4b). In developing the PMP for a proposed feasibility study, the level of detail of a risk assessment will be developed to the task level and included in the PMP. In cases where a general reevaluation report is proposed and where deterministic assumptions including standard superiority assumptions or other engineering standards were used that are critical to sizing and/or performance of project features, a reformulation of the project using a risk assessment, as described in this regulation, will be undertaken to determine the appropriate project for construction recommendation.

b. The ultimate goal of a risk assessment is a comprehensive approach in which the values of all key variables, parameters, and components of flood risk management studies are subject to probabilistic analysis. Not all variables are critical to project justification in every instance. To achieve the ultimate goal, the risk assessment and study effort should evaluate the impact of various variables and their uncertainties, and concentrate on the variables having a significant impact on study conclusions. When a more detailed assessment is required, at a minimum uncertainty in the following variables and relationships must be explicitly incorporated in the risk assessment:

(1) Stage-damage functions from economic studies (with emphasis on structure first-floor elevation, depth-percent damage relationships, and content and structure values for urban studies). For studies in agriculture areas, other variables (e.g., time of year, crop type, costs of production) will be key and should be used in the economic analysis.

(2) Discharge-frequency functions from hydrologic studies (with emphasis on the record length or hydrologic modeling parameters).

(3) Stage-frequency functions from hydrologic/hydraulic studies (with emphasis on the record length). A stage-frequency analysis may be used when stage gage data is all that is available for a study and/or when there is no unique correspondence between flow and stage such as in locations highly controlled by backwater or tidal conditions or in the case of ice jam floods. Care should be taken in using this approach because in current analysis practice all uncertainties are collapsed into a single uncertainty as defined by the period of record.

(4) Regulated-unregulated transform function from reservoir regulation studies (with emphasis on operational uncertainties, inflow hydrographs, and rating uncertainties of outlet works).

(5) Stage-discharge functions from hydraulic studies (with emphasis on conveyance roughness and cross-section geometry).

(6) Stage-probability of failure or unsatisfactory performance functions (fragility curves, system performance probability curves) for mechanical, electrical, structural, and geotechnical performance of structures as defined in latest guidance.

(7) Stage-life loss function from life safety studies (with emphasis on rate and depth of flooding, population at risk, and emergency response plans).

(8) Stage-environmental impact considerations (emphasis on the key ecological and other factors impacting the environment).

c. Consistent with the Principles and Guidelines the National Economic Development (NED) Plan must be identified. The NED Plan is the alternative plan that reasonably maximizes net economic benefits consistent with protecting the nation's environment. NED will be calculated explicitly including uncertainties in the key variables specified in the risk register. Consideration of increments in project scale different from the NED Plan, as well as other plans preferred by the cost-sharing sponsor, may be considered. Flood risk management actions may be part of multi-objective plans as described in Reference 4b.

d. The estimate of net NED benefits and benefit/cost (B/C) ratio will be reported both as an expected (mean) value and on a probabilistic basis for each alternative. The probability that net benefits are positive and that the B/C ratio is at or above one (1.0) will be presented for each alternative.

e. The flood risk management performance of a plan will be presented for the system as a whole over the plan's given lifecycle and for each component that makes up that system. Typically, the system performance will reflect that of the "weakest" component. Reporting the performance of individual components may assist in the selection of future risk reduction measures, although consequences should be considered in these decisions as well. The risk assessment will quantify the performance, resilience, and risk of all scales of all alternatives considered in formulating the recommendation. The assessment will evaluate and report residual risk, which includes consequences of project performance or capacity exceedance. This assessment requires explicit consideration of the joint effects of the uncertainties associated with key hydrologic, hydraulic, and geotechnical variables and character of floodplain occupancy. This performance will be reported in the following ways (see glossary for definition of terms):

(1) AEP (metric, value, and designation of with/without performance) with associated description of uncertainty.

(2) LTEP over 10, 30, and 50 years.

(3) Assurance (also CNP) for the 0.2, 0.1, 0.02, 0.01, 0.004, and 0.002 events. Assurance can be computed using either a discharge-frequency or stage-frequency function.

(4) The Assurance (also CNP) for specific historic floods.

(5) Economic average annual and single event damage, potential life loss, and environmental conditions and impacts as required by ER 1105-2-100 (Reference 4b).

(6) Qualitative and quantitative statement of residual, transformed, and/or transferred risk (paragraph 8g).

f. An assessment of potential life loss, economic, and environmental damage for the without condition, along with all proposed alternatives is required. For studies where life loss plays a significant role in formulating and evaluating alternatives, and selecting the recommended plan, a quantitative assessment of life loss will be performed using accepted USACE methods and tools. As with the economic damage assessment, explicit consideration of the effects of the uncertainties associated with key input variables is required. Key input variables in the life loss estimate include, but are not limited to: warning time, warning effectiveness (both how quickly a warning spreads among the population at risk (PAR) as well as the response to a warning by PAR), flood arrival time, and fatality rate thresholds.

g. The probability distribution of residual flood damage and other relevant aspects of residual risks (transformed or transferred) will also be displayed. Residual flood risk is the flood risk that remains after a proposed flood risk management project is implemented. Residual risk includes the consequence of capacity exceedance as well as consideration of project performance, robustness, and resiliency. Transformed risk is a risk that emerges or increases as a result of mitigating another risk. Conceptually, a transferred risk relocates risk or increases risk from Region A of a system to Region B of the system as a result of action taken in Region A. The nature of the risk of flooding is different with a levee versus without a levee. A levee reduces the likelihood that existing improved property will be flooded but can often encourage new development, which can lead to an overall increase in risk if not managed effectively through proper land use and building codes. A levee may transform the flood risk from gradual and observable long before action is necessary to sudden and catastrophic. The residual risk, including transformed and/or transferred, will be reported as the expected annual probability of each alternative being exceeded with consideration of unsatisfactory project performance and the associated consequences. For comparison, the without-project risk in terms of the annual probability of flood damage occurring and the annual probability of other property hazards (fire, wind, etc.) will be displayed. To aid this display and to improve the understanding of the residual risk, inundation maps will be provided showing flood depths should the project be exceeded. A narrative scenario for events that result in flooding will be provided (see Figure A-5 for an example). An emergency action plan or community preparedness plan should also be presented as required by ER 1110-2-401 (Reference 4c). The impacts to residual human health, safety risks, and the environment should be discussed. Both the inundation map and the narrative scenario will be provided for each alternative considered for final selection.

h. All project increments comprise different risk management alternatives represented by the tradeoffs among engineering performance, project cost, economic and environmental resilience, and life loss consequences. These increments contain differences in flood damage reduced, residual risk, local and federal project cost, impacts to the environment, and life loss. USACE must effectively communicate to local sponsors and residents so they understand these tradeoffs and can participate fully in informing the decision-making process.

i. Many existing USACE projects were authorized and/or designed to the Standard Project Flood (SPF). The SPF is defined in several legacy ER and EM guidance documents, but the SPF is no longer a design target. USACE policy (Reference 4b) states that risk analysis (now risk framework) is to be used, to include the evaluation of a full range of floods (including those that would exceed the SPF) that will be used in the formulation and evaluation of alternatives. Comparing performance of the NED Plan and other candidate plans, given the occurrence of the SPF event, (a rare but historically understood flood event) can play a useful role in the assessment of residual risks to inform the decision-making process. As a consequence, while current guidance on project formulation and alternative selection governs, the SPF may have a useful role for evaluating residual risks, for comparing new project proposals with nearby existing projects that were based on the SPF, and as a check and validation of floods computed from statistical frequency analysis.

j. Special Guidance.

(1) The use of explicit freeboard or similar buffers to account for hydrologic, hydraulic, geotechnical, and other uncertainties will no longer be used for levee planning and design. Similarly, the use of freeboard to account for the same uncertainties will no longer be used in channel planning and design.

(2) Risk assessments for dams and levees must also follow other applicable USACE policy guidelines, such as Reference 4d.

(3) Evaluation of a levee system for the National Flood Insurance Program must follow current USACE policy and guidelines.

(4) Project performance will be described by AEP (metric, value, and description of with/without performance) with uncertainty, Assurance (also CNP), and LTEP. The array of all performance indices should be displayed on a system-wide basis and on individual components that make up the system. EP 1110-2-8 (Reference 4f) describes techniques in effectively communicating flood risk to local officials and the public. A legacy term, Level of Protection (LOP) was used as a performance index and a levee design concept that was founded on the principle of providing a high degree of Assurance that the levee system component would neither breach nor overtop when loaded with a specific recurrence interval flood (e.g., providing a 75-year LOP if it could contain that event with 90 percent level of Assurance). The recurrence interval of the flood hazard for this design principle was then used as an expression of the performance of the levee system. The term is no longer used as it did not include residual risk or structural performance. LOP should not be used to judge a set of alternatives or to target a specific project size.

(5) Economic analyses will compute the NED Plan utilizing benefits at the mean of the probability distribution consistent with ER 1105-2-100. Once the NED (or other Federally Recommended Plan) has been identified, project performance will be communicated in multiple ways, including but not limited to: AEP, LTEP, and Assurance (CNP) over a variety of flood events as shown in the Table 1, to include at least the 2%, 1%, and 0.4% annual exceedance events. When it is necessary to communicate performance in simpler terms for this plan, then the exceedance probability at which the project performs with 90% Assurance must be used in feasibility, design, and in communications with the public. Performance for a project having the example data in Table 1 may be communicated as: "Given irreducible uncertainties inherent in flood frequency analysis, the NED Plan will pass the 2% event with 90% assurance." This is consistent with standard engineering practice and with the risk expectations of the public.

Table 1
Project Performance: AEP, LTEP, and Assurance

Plan	**Annual Exceedance Probability**		**LTEP**			**Assurance by Event**				
	Median	**Expected**	**10-yr period**	**30-yr period**	**50-yr Period**	**10%**	**2%**	**1%**	**0.4%**	**0.2%**
NED Plan	0.019	0.018	17%	44%	62%	95%	90%	78%	8%	1%

(6) Project performance documentation will also include an assessment to demonstrate the extent to which the proposed project can achieve an economical, resilient, and predictable system including risk management of events exceeding capacity. Project features and alternatives, including superiority and resiliency measures, should be considered in the formulation to reduce and manage residual life safety risks associated with capacity exceedance (or unacceptable performance) against catastrophic economic and/or life loss scenarios. Economic, environmental, and other benefits derived from these resiliency features will be included in the alternative evaluation. For levees and floodwalls, this assessment may include providing superiority at pumping stations and/or other critical locations. Superiority in overtopping, providing higher levees at all points except where initial overtopping is desired, is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Interior slope and toe erosion protection should also be considered to address flood conditions exceeding containment capacity. The assessment of these features will consider their contribution to the performance, consequences, residual risk management, and cost of the project.

9. Example Displays of Risk Assessment Results. Appendix A presents several tables and figures that summarize uncertainty information in various ways, and highlight not just the probability distributions, but further interpretations of those uncertainties that can be used in decision-making. To report the probabilistic outputs described in paragraphs 8d and 8e, a selection of the tables and figures in Appendix A, along with an accompanying textual explanation, should be chosen to communicate uncertainty information. This information can be useful in aiding decisions by local sponsors, stakeholders, and federal officials by helping to increase their understanding of the uncertainty inherent in each alternative and determining ways to address residual risks and increase specific and overall resilience.

FOR THE COMMANDER:

2 Appendices
(see Table of Contents)

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Appendix A
Example Displays of Project Engineering and Economic Performance

Results from Risk Assessment

To report probabilistic outputs, a selection of these tables and figures, along with an accompanying textual explanation, should be chosen to communicate uncertainty information. This information can be useful in aiding decisions by local sponsors, stakeholders, and Federal officials by helping to increase their understanding of the uncertainty inherent in each alternative.

A-1. Table A1 contains the EAD for the without-project condition and the with-project condition for each alternative. The computed values of EAD are uncertain, and their probability distributions, resulting from the risk and uncertainty assessment described in this ER, are represented in various ways. The values of EAD reported are each the mean of the probability (uncertainty) distribution of that alternative. The damage reduced (without-project minus with-project EAD) is reported with more information about its probability (uncertainty) distribution. In addition to the mean, the standard deviation and the quartiles of the distribution are included. The standard deviation describes the width of the probability distribution. The quartiles are the values of the probability distribution with cumulative probabilities of 25, 50, and 75 percent—meaning there is the specified likelihood that the value will be greater than the quartile, so these values describe both the width and the asymmetry of the probability distribution. There is a 50 percent chance that the actual value of damage reduced is between the 0.25 and 0.75 quartiles. The 0.5 quartile is the median estimate, meaning there is a 50 percent chance the actual value is greater, and 50 percent chance it is less. The median differs from the mean when the probability distribution is asymmetrical.

Table A1
Expected value and probabilistic values of EAD and EAD reduced

	EAD ($1,000)		**Damage Reduced ($1,000)**		**Uncertainty in EAD Reduced; Probability Distribution Quartiles ($1,000)**		
Alternative	**Without Alternative**	**With Alternative**	**Mean**	**Standard Deviation**	**0.75**	**0.50***	**0.25**
20-ft (6-m) levee	575	220	355	57	316	353	393
25-ft (8-m) levee	575	75	500	77	451	503	555
30-ft (9-m) levee	575	5	570	98	502	573	626
Channel	575	200	375	65	328	370	415
Detention basin	575	250	325	93	263	325	388
Relocation	575	220	355	61	313	353	396

* The 0.5 quartile is the median estimate; it differs from the mean when the probability distribution is asymmetrical.

A-2. Table A2 provides the same information about annual cost as Table A1 provides for damage reduced.

Table A2
Expected value and probabilistic values of costs

Alternative	Annual Cost ($1000)		Uncertainty in Cost; Probability Distribution Quartiles ($1000)		
	Mean	Standard Deviation	0.75	0.50	0.25
20-ft (6-m) levee	300	40	273	300	327
25-ft (8-m) levee	400	45	370	400	430
30-ft (9-m) levee	550	60	510	550	590
Channel	300	30	280	300	320
Detention basin	275	10	268	275	282
Relocation	250	20	237	250	263

A-3. Figure A1 contains a summary of the expected (mean) values of benefits (damage reduced) and Costs, and more probabilistic information about the Net Benefits (benefits minus costs). The probability distribution of net benefits is described by the expected (mean) value, the standard deviation, and the quartile values, as described in Table A1. In addition, the probability that net benefits are in fact greater than zero is included. The graphs display the entire cumulative probability distribution of net benefits for two of the alternatives (25-ft (8-m) levee, Relocation), with markers for the quartiles, a solid vertical line for the mean, and a horizontal arrow

Plan	Expected Annual Benefit and Cost ($1000)		Net Benefits ($1000)		Prob. Net Benefit is > 0	Net Benefit that is Exceeded with Specified Probability ($1000)		
	Benefits	Cost	mean	std. dev		0.75	0.5	0.25
20 foot levee	355	300	57	68	0.80	9	54	100
25 foot levee	500	400	104	88	0.87	47	106	166
30 foot levee	570	550	21	116	0.58	-57	24	94
channel	375	300	73	74	0.83	18	70	118
detention basin	325	275	53	96	0.70	-17	51	113
relocation	355	250	107	62	0.97	63	102	146

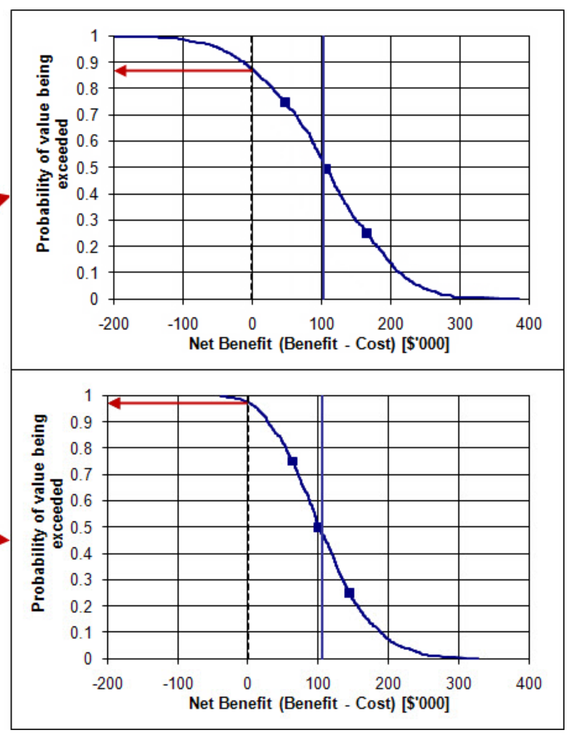

Figure A6. Expected value and probabilistic values for net benefits noting the probability that Net Benefit is greater than zero. Notice the inter-quartile range (the horizontal distance between the 0.75 and 0.25 quartile) is wider for the 25-ft (8-m) levee alternative than for the Relocation alternative. This difference demonstrates the greater uncertainty in the net benefits. Table A1 and Table A2 show greater uncertainty in both the damage reduced and the cost of the 25-ft (8-m) levee alternative, leading to greater uncertainty in the net benefits.

A-4. Figure A2 contains the same probabilistic information for the B/C ratio as Figure A1 displays for the net benefits. For actual reporting purposes, each graph should be labeled to include the name of the alternative plan (not shown here and subsequent figures).

	Expected Benefit/Cost Ratio			B/C Ratio Value that is Exceeded with Specified Probability		
Plan	Mean	Standard Deviation	Probability B/C > 1	0.75	0.5	0.25
20 foot levee	1.18	0.26	0.80	1.03	1.19	1.35
25 foot levee	1.25	0.24	0.87	1.11	1.27	1.43
30 foot levee	1.04	0.22	0.58	0.90	1.04	1.18
channel	1.25	0.27	0.83	1.06	1.24	1.41
detention basin	1.18	0.35	0.70	0.94	1.18	1.42
relocation	1.42	0.26	0.97	1.25	1.41	1.60

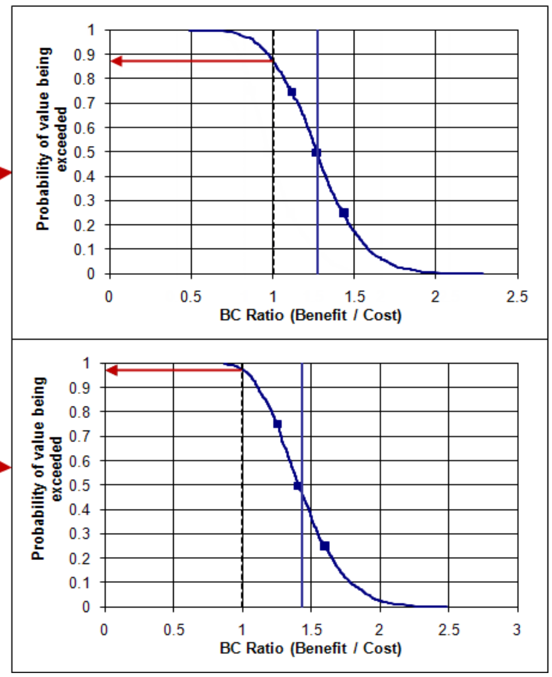

Figure A7. Expected value and probabilistic values for B/C ratios

A-5. The Relocation alternative has the highest mean net benefit, closely followed by the 25-foot (8-m) levee alternative. The range of benefits and costs associated with the Relocation alternative is also substantially smaller than the range seen with the 25-ft (8-m) levee alternative as seen in the standard deviation and the inter-quartile range (difference between 75 and 25 percent quartiles). Also, the Relocation alternative has the largest probability of net benefits being greater than zero (or, B/C ratio being greater than one.) Further note that the mean is not equal to the 50 percent quartile (the median), which a result of the distribution not being symmetrical.

A-6. Benefits divided by costs produce B/C ratios. From this, the probability of maintaining a B/C ratio greater than one is of interest. This example shows that the Relocation alternative has a probability of 97 percent of the B/C ratio being greater than one, while the probability of the

25-ft (8-m) levee alternative has a probability of 87 percent of the B/C ratio being greater than one. At this point only economic justification has been determined.

A-7. Table A3 and Table A4 present the expected or mean AEP and LTEPs computed for each alternative. The LTEP is the likelihood of exceedance at least once in the specified period and is computed as $1 - (1 - AEP)^N$, where N = number of years. Table A3 shows the LTEPs in the standard manner, and Table A4 displays LTEP in terms of return periods and odds.

Table A3
Performance described by AEP and LTEP

Alternative	Mean AEP	LTEP (Probability of Exceedance Over Indicated Time)		
		10 Years	30 Years	50 Years
Without	0.250	0.94	1.00	1.00
20-ft (6-m) levee	0.020	0.18	0.45	0.64
25-ft (8-m) levee	0.010	0.10	0.26	0.39
30-ft (9-m) levee	0.001	0.01	0.03	0.05
Channel	0.025	0.22	0.53	0.72
Detention basin	0.030	0.26	0.60	0.78
Relocation	0.020	0.18	0.45	0.64

Table A4
Performance described by AEP and LTEP (alternative display)

Alternative	Mean AEP	LTEP (Probability of Exceedance Over Indicated Time)		
		10 Years	30 Years	50 Years
Without	0.250	1 in 1.1	1 in 1.0	1 in 1.0
20-ft (6-m) levee	0.020	1 in 5.5	1 in 2.2	1 in 1.6
25-ft (8-m) levee	0.010	1 in 10.5	1 in 3.8	1 in 2.5
30-ft (9-m) levee	0.001	1 in 100.5	1 in 33.8	1 in 20.5
Channel	0.025	1 in 4.5	1 in 1.9	1 in 1.4
Detention basin	0.030	1 in 3.8	1 in 1.7	1 in 1.3
Relocation	0.020	1 in 5.5	1 in 2.2	1 in 1.6

A-8. AEP and LTEP are useful tools to explain the residual probability of flooding for an alternative. AEP can represent the probability of any event equaling or exceeding a specified stage in any given year. With levees present, the stage would be the top of levee or effective top of levee as specified by the geotechnical fragility curves; therefore, AEP represents the probability of water getting into the interior area of the levee in any given year. In the software HEC-FDA (Reference 4i), for non-leveed reaches the target stage is determined by the exceedance of a percentage of the mean damage associated with a specified event (e.g., the 1 percent AEP event). The without-project and the relocation project have different AEP values although the hydrology and hydraulics remain the same. LTEP is a way of describing the probability of flooding over a long period of time, for instance, the project's lifecycle or the life of a typical mortgage. As Tables A-3 and A-4 show, percentages or odds can be used to describe the chance of flooding. As shown in Tables A-3 and A-4, the 30-ft (9-m) levee alternative has the lowest AEP and LTEP of 1 in 20.5 over 50 years.

A-9. Figure A3 presents the resultant probability (uncertainty) distribution of the AEP, described by the mean value, the standard deviation, and the quartile values. The standard deviation describes the width of the probability distribution. The quartiles are the values of the probability distribution with cumulative probabilities of 25, 50, and 75 percent—meaning there is the specified likelihood that the value will actually be greater than the quartile, so these values

Plan	Annual Exceedance Probability (AEP)		AEP of Plan that is Exceeded with Specified Probability		
	mean	std. dev.	0.75	0.5	0.25
Without	0.250	0.140	0.187	0.268	0.362
20 foot levee	0.020	0.016	0.007	0.016	0.029
25 foot levee	0.010	0.012	0.005	0.010	0.019
30 foot levee	0.001	0.005	0.001	0.001	0.003
channel	0.025	0.010	0.008	0.013	0.020
detention basin	0.030	0.021	0.014	0.023	0.038
relocation	0.020	0.015	0.014	0.021	0.030

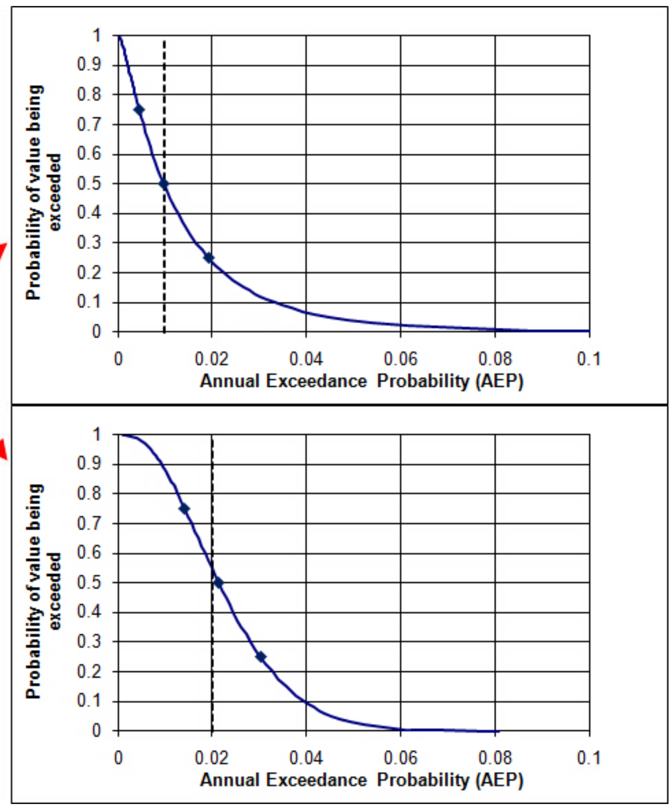

Figure A8. AEP uncertainty

describe both the width and the asymmetry of the probability distribution. There is a 50 percent chance that the actual value of damage reduced is between the 0.25 and 0.75 quartiles, while the 0.5 quartile is the median estimate, meaning there is a 50 percent chance the actual value is greater, and 50 percent chance it is less. The median differs from the mean when the probability distribution is asymmetrical.

A-10. As with any risk assessment, not only is the mean of an uncertainty distribution important, the entire probability distribution for the metric should be considered and compared. A comparison of the mean AEP for each alternative and the 50 percent quartile, or a look at all three quartiles, makes it apparent that the distributions of AEP may not be symmetrical. Figure A3 displays the entire cumulative probability distribution of AEP for two of the alternatives (25-ft (8-m) levee, Relocation), with markers for the quartiles and a dotted vertical line for the mean. The plots in Figure A3 provide information that summarizes the uncertainty. For example, the 25-ft (8-m) levee alternative clearly offers higher performance when considering the mean AEP and the three quartiles, but it also has a longer "tail" so it has a greater chance that the AEP could be much higher. The Relocation alternative has a shorter tail, and so has less chance that AEP could be much higher. Another way to understand the uncertainty is if considering the likelihood the AEP is actually greater than 2 percent, for the 25-ft (8-m) levee alternative, the chance is 22 percent, and for the Relocation alternative, the chance is 55 percent that AEP is greater than 2 percent.

A-11. Table A5 presents the mean AEPs for each alternative along with AEPs of other possible natural disasters in the area of interest. Evaluating risk associated with an area can be hard unless compared to events that people can more readily understand.

Table A5
Probability comparison

Alternative	**AEP**
Without	0.250
20-ft (6-m) levee	0.020
25-ft (8-m) levee	0.010
30-ft (9-m) levee	0.001
Channel	0.025
Detention basin	0.030
Relocation	0.020
Comparable Probability	
Fire Damage	0.003[1]
Wind Damage	0.005[2]
Earthquake	0.001[2]

[1]Average 2002–2010 based on home structure fires National Fire Protection Association and U.S. Census housing unit data.
[2]Annual probabilities for other hazards are region specific. Values provided here are for illustrative purposes only.

A-12. Figure A4 contains the Assurance (also CNP) levels, for each alternative for various exceedance probabilities. These values describe the estimated likelihood that the project can prevent damage at the specified exceedance probability. The Assurance is based on the uncertainty in the actual flow and stage associated with a given exceedance probability event, as well as the geotechnical performance of the project.

Plan	Conditional Non-Exceedance Probability					
	0.2	0.1	0.02	0.01	0.004	0.002
Without	0.35	0.25	0.1	0.01	0.0001	0.000001
20 foot levee	0.75	0.55	0.25	0.01	0.001	0.00001
25 foot levee	0.95	0.9	0.35	0.25	0.002	0.0001
30 foot levee	0.99	0.99	0.95	0.9	0.3	0.0002
channel	0.85	0.73	0.3	0.15	0.001	0.00001
detention basin	0.75	0.55	0.25	0.01	0.001	0.00001
relocation	0.35	0.25	0.1	0.01	0.0001	0.00001

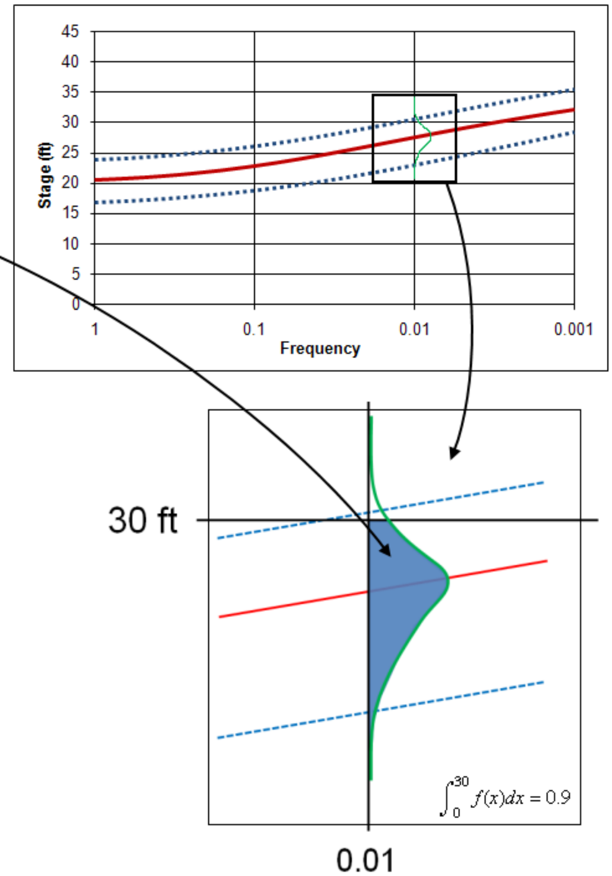

Figure A9. Assurance (also CNP)

A-13. To capture Assurance (also CNP), the upper graphic in Figure A4 shows the uncertainty in the stage versus frequency (exceedance probability) relationship. That probability (uncertainty) distribution is then compared to the target stages associated with each alternative to provide Assurance (also CNP). The lower graphic in Figure A4 shows the probability (uncertainty) distribution of stage for the 1 percent chance event and compares it to the top of levee stage for the 30-ft (9-m) levee alternative. The area under the Probability Density Function) curve is summed to determine the probability of not exceeding the target stage (i.e., the non-exceedance probability, conditioned on the occurrence of the 1 percent event).

A-14. Table A6 presents life loss estimates for each alternative of the study area. A quantitative assessment of life loss will be required for risk assessment associated with alternatives. To completely discuss the transference and transformations of risk, the changes in life loss associated with all frequency events for each alternative must be discussed. Although there may be significant decreases in economic losses and life risks for the lower frequency events, there may be significant increases for the same alternatives at the higher frequency events. The probability of flood occurrence times the consequence yields the overall risk reduction, transformation, and transfer that are going on within the system. A narrative scenario for events that result in flooding will also be provided, and an example is provided in Figure A5.

Table A6
Life loss

Alternative	Expected Life Loss	Probable Life Loss for a Given Event		
		100 Years	250 Years	500 Years
Without	3.700	5.300	8.900	22.000
20-ft (6-m) levee	1.400	6.000	10.500	28.000
25-ft (8-m) levee	1.000	8.500	12.300	33.000
30-ft (9-m) levee	0.850	0.300	14.000	56.000
Channel	2.500	4.300	7.100	18.000
Detention basin	1.500	3.100	4.100	13.000
Relocation	0.010	0.250	0.850	1.200

Should the levees surrounding My City south of the Your River be loaded by floodwaters, residents could attempt to move to nearby higher ground. The depth of flooding in the neighborhoods in this area would generally not exceed that at the river's edge although a few areas would experience flooding of more than 10 feet. New Town, on the other hand, is ringed by levees so that residents trying to leave the area would have to find their way across the main highway system to areas of higher ground. Limited routes of egress would make this difficult and thus negatively impacting life safety. Moreover, because New Town is in a depression, a third of the area would flood to depths over 10 feet. Some areas would flood to as much as 35 feet. Because of the lengthy duration of flooding and the lack of natural drainage from this area, flood water would likely remain in New Town for 2 weeks or more. With the proposed levee, New Town is subject to a 1 in 100 chance of being flooded in any year but a 1 in 2.5 chance in 50 years. Therefore, the probability of a catastrophic event within the lifetime of most residents is nearly the same as flipping a coin and getting heads. An emergency action plan (EAP) has been developed for the communities including response training exercises. Additionally, the low areas contain many acres of environmentally valuable wetlands that would be severely damaged from high velocities generated from a levee failure. Resiliency measures could be considered for each of these communities. These measures address the ability to avoid, minimize, withstand, and recover from the adverse effects of a flood. For example, both communities have developed and implemented EAPs including response training exercises. An EAP speaks to the ability to avoid or minimize damage to structural inventories or reduce the population at risk. Resiliency measures for a levee can be provided by adding superiority increments to the levee in higher hazard areas and surface hardening in planned levee overtopping reaches adjacent to low hazard areas. Resiliency provides a higher degree of predictability for levee performance that can be useful for floodplain managers and project operators.

SOURCE: Adapted from: National Research Council. 1995. Flood Risk Management and the American River Basin: An Evaluation. Washington, DC: National Academy Press.

Figure A10. Example scenario

Glossary

Abbreviations and Terms

To describe effectively the concepts of a risk framework for flood risk management studies, this Engineer Regulation uses the following terminology:

AEP	Annual Exceedance Probability
B/C	Benefit/Cost
CNP	Conditional Non-Exceedance Probability
EAD	Expected Annual Damage
EAP	Emergency Action Plan
EC	Engineer Circular
EM	Engineer Manual
EP	Engineer Pamphlet
ER	Engineer Regulation
FEMA	Federal Emergency Management Agency
HEC-FDA	(used in reference h. on page 1)
HQUSACE	U.S. Army Corps of Engineers Headquarters
LOP	Level of Protection
LTEP	Long-Term Exceedance Probability
NED	National Economic Development
PAR	Population at Risk
PMP	Project Management Plan
SPF	Standard Project Flood
USACE	U.S. Army Corps of Engineers

Definitions

Annual Exceedance Probability (AEP)
The probability that a certain threshold may be exceeded at a location in any given year, considering the full range of possible values, and if appropriate, incorporation of project performance. A threshold consists of a metric and a value, and must be specified for each use of AEP. If system performance is considered, then performance should be explicitly accounted for in the description of AEP; similarly, if system performance is not considered then it can be omitted in the description of AEP. Examples of threshold metrics include the stage, flow, surge, and floodplain or flooding extent, and corresponding values may be stated in feet, cfs, depth, etc. Examples of locations include a consequence area index point, a specific grid cell, or a fragility curve location (also referred to as system response probabilities). An example statement of AEP without performance is: "The boundary of the Federal Emergency Management Agency (FEMA) 100-year floodplain has a 1 percent AEP, and the entire FEMA 100-year floodplain corresponds to the aerial flooding extent where flood depths are greater than 0 feet." An example of AEP with performance is: "The resultant AEP with a depth greater than 0 feet at location XX is 1% while taking into account levee performance."

Assurance
The probability that a target stage will not be exceeded during the occurrence of a flood of specified exceedance probability considering the full range of uncertainties. Term selected to replace "conditional non-exceedance probability" (CNP).

Conditional Non-Exceedance Probability (CNP)
See Assurance.

Consequence
The harm that results from a single occurrence of the hazard. Consequences are measured in terms of metrics such as economic damage, acreage of habitat lost, value of crops damaged, and lives lost.

Economic Risk
The combination of likelihood and harm to property, infrastructure, and other assets as well as economic systems all measured in monetary terms. A common metric of economic risk is expected annual damage (EAD). EAD is the result of integrating the damage-probability functions.

Expected Annual Damage (EAD)
EAD is the expected value of storm damages in any given year. Expected annual damage is calculated by computing the area under the damage-frequency curve using a lifecycle approach. Expected annual damage is calculated for the with- and without-project conditions. The difference between the with- and without-project expected annual damage represents the benefit associated with the with-project alternative.

Exposure
Describes who and what may be harmed by the flood hazard. Exposure incorporates a description of where the flooding occurs at a given frequency, and what exists in that area. Tools such as flood inundation maps provide information on the extent and depth of flooding; structure inventories, population data, crop data, and habitat acreage provide information on the population and property that may be affected by the flood hazard.

Hazard (flood)
The “hazard” is what causes the harm, in this case, a flood. The flood hazard is described in terms of frequency, stage, velocity, extent, and depth.

Level of Protection (LOP)
LOP is used as a performance metric and a levee design concept that was founded on the principle of providing a high degree of Assurance that the levee system component would neither breach nor overtop when loaded with a specific recurrence interval flood (e.g., providing a 75-year LOP if it could contain that event with 90 percent level of Assurance). The recurrence interval of the flood hazard for this design principle was then used as an expression of the performance of the levee system. The term is no longer used as it did not include residual risk or structural performance. LOP should not be used to judge a set of alternatives or to target a specific project size.

Long-Term Exceedance Probability (LTEP)
The probability of capacity exceedance during a specified period. For example, 30-year exceedance probability refers to the probability of one or more exceedances of the capacity of a measure during a 30-year period; formerly long-term risk. This accounts for the repeated annual exposure to flood risk over time.

Project Performance
The system’s reaction to a hazard. Performance refers to the system features and the capability to accommodate the flood hazard as a single event or load. In this manual, this would be termed “system performance” (also termed “engineering performance”). Performance also refers to the metric that describes the capability of the system to accommodate a single event (Assurance, also CNP) and the full range of events (AEP and LTEP). In that light, in addition to the levee failure probability functions, performance can also be described by the interior-exterior functions for leveed areas, unregulated-regulated transforms for reservoirs and diversions, and elevation-discharge functions (rating curves) for channels. These too would be considered “system performance.” When the structural integrity of a system or system component is discussed, such as the fragility function, the reference would be termed “structural performance.” When the economics of a system is discussed, the reference would be termed “economic performance.” The performance of an item is described by various elements, such as flood risk management, reliability, capability, efficiency, and maintainability. Design and operation affect system performance.

Probability Distribution
A relationship that describes the likelihood of each possible value of a random variable.

Residual Risk
The flood risk that remains in the floodplain after a proposed flood risk management project is implemented. Residual risk includes the consequence of capacity exceedance as well as consideration of project performance.

Resilience
As per Executive Order 13653, "Preparing the U.S. for the Impacts of Climate Change," resilience is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

Risk
The likelihood and severity of adverse outcomes; for this ER the focus is on the risk from flooding. Risk is often measured as potential or mean life loss, property damage, and/or ecosystem losses and may also include uncertainty over the benefits to be gained from a proposed or actual action taken. Usually, both the likelihood and the consequence are to some degree uncertain.

Risk Assessment
A systematic approach for describing the nature of the risk, including the likelihood and severity of consequences. Risk assessments can be qualitative, semi-quantitative, or quantitative. Risk assessment includes explicit acknowledgment of the uncertainties in the flood risk.

Risk Communication
A two-way exchange of information between risk assessors and those who will use the risk assessment results or those who are affected by the risks and risk management actions. Open communication improves the understanding of the risks by all parties and leads to improved risk assessments and risk management decisions and outcomes.

Risk Framework
A decision-making process that comprises three tasks: risk assessment, risk management, and risk communication.

Risk Management
A decision-making process in which risk reduction actions are identified, evaluated, implemented, and monitored. The purpose of risk management is to take actions to effectively reduce and manage risks identified in the risk assessment.

Robustness
The ability of a system to continue to operate correctly across a wide range of operational conditions with minimal damage, alteration, or loss of functionality, and to fail gracefully outside of that range; the wider the range of conditions allowing for good performance, the more robust the system.

Safety
Thought of as the condition of being free from danger, risk, or injury. However, safety is not something that can be absolutely achieved or guaranteed. Instead, safety is the condition to

which risks are managed to tolerable levels. Therefore, safety is a subjective concept based upon individual perceptions of risks and their tolerability.

Superiority
Superiority simply means providing higher levees at all points except where initial overtopping is desired. Superiority is an increment of the levee height that increases the likelihood that when the system approaches capacity, controlled flooding will occur at a specified overtopping section.

Transferred Risk
A result of an action taken in one region of a system to reduce risk, where that action shifts the risk burden to another region in the system. For example, if a levee is raised in one reach of a system, thus containing more flow and thereby reducing risk in that reach, that action then results in increased flow downstream to another reach of the system. Risk has been "transferred" from one location to another.

Transformed Risk
New risk of flooding that emerges or increases as a result of mitigating another risk. The magnitude and nature of the risk of flooding is different with a levee compared with conditions without a levee. A levee reduces the likelihood that originally protected property will be flooded but may set the stage for development that puts new property at risk. A levee transforms the flood risk from one that may be gradual and observable before emergency action would be necessary for the originally protected properties to flood risk that may be sudden and catastrophic.

Uncertainty
Uncertainty is the result of imperfect knowledge concerning the present or future state of a system, event, situation, or (sub) population under consideration. Uncertainty leads to lack of confidence in predictions, inferences, or conclusions. It is important to distinguish uncertainty that results from a lack of knowledge from the uncertainty that results from natural variability.

Knowledge Uncertainty
Lack of knowledge regarding the true value of a quantity. Uncertainty is a consequence of reliance on limited data and on conceptual and mathematical models. This category of uncertainty is formally labeled epistemic uncertainty. Uncertainty is a measure of imprecision of knowledge of parameters and functions used to describe the hydraulic, hydrologic, geotechnical, and economic aspects of a project plan.

Natural Variability
The distribution or spread of values within a natural "population" or data set. This array of possible values in a population is caused by the inherent randomness of natural or social systems and is formally labeled aleatory uncertainty. The values in the statistical population have some probability distribution, and only limited knowledge of the entire statistical population and the probability distribution may exist. Sometimes variability is classed as a type of uncertainty although generally it should not be confused or interchanged with uncertainty as defined above.

Variability is the notion that there is a range of possible values that will occur and not the lack of knowledge about that range or the distribution of those values.

Vulnerability
The susceptibility of harm to human beings, property, and the environment when exposed to a hazard. Depth-damage functions, depth-mortality functions, and other similar relationships can be used to describe vulnerability.