DEPARTMENT OF THE ARMY
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Regulation
No. 1105-2-101

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Planning
RISK ANALYSIS FOR FLOOD DAMAGE REDUCTION STUDIES

1. Purpose. This regulation provides guidance on the evaluation framework to be used in Corps of Engineers flood damage reduction studies. It is jointly promulgated by Planning and Engineering.

2. Applicability. This regulation is applicable to all HQUSACE elements, major subordinate commands, districts, laboratories and field operating agencies (FOA) having civil works responsibilities. It applies to all implementation studies for flood damage reduction projects.

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

4. References.

a. ER 1105-2-100, Guidance for Conducting Civil Works Planning Studies.

b. EM 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies.

c. ETL 110-2-556, Risk-based Analysis in Geotechnical Engineering for Support of Planning Studies.

5. Background.

a. Risk and uncertainty are intrinsic in water resources planning and design. All measured or estimated values in project planning and design are to various degrees inaccurate. Invariably the true values are different from any single, point values presently used in project formulation, evaluation, and design.

b. The Corps develops best estimates of key variables, factors, parameters, and data components in the planning and design of flood damage reduction projects. These estimates are considered the "most likely" values. They are frequently based on short periods of record, small sample sizes, and measurements subject to error. Prior to risk analysis, sensitivity analysis had been the primary tool for considering uncertainty in project planning and design. Sensitivity analysis, however, frequently presumes that the appropriate range of values is identified and that all values in that range are equally likely. In addition, the results of this analysis are typically reported as a single, most likely value that is treated by some as if it were perfectly accurate.

This Engineer Regulation supercedes ER 1105-2-101 dated 1 March 1996.

c. Risk analyses can be advantageously applied to a variety of water resources planning and design problems. The approach captures and quantifies the extent of the risk and uncertainty in the various planning and design components of an investment project. The total effect of uncertainty on the project's design and economic viability can be examined and conscious decisions made reflecting an explicit tradeoff between risks and costs. Risk analysis can be used to compare plans in terms of the variability of their physical performance, economic success, and residual risks.

d. Budget constraints, increased customer cost sharing, and public concern for project performance are issues that must be addressed in the assessment of Federal water resources investments. Explicit consideration of risk and uncertainty can help address these issues and improve investment decisions.

5. Definitions. To describe effectively the concepts of risk analysis for flood damage reduction studies, this document uses the following terminology:

a. "Risk" is the probability an area will be flooded, resulting in undesirable consequences.

b. "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.

c. "Risk Analysis" is an approach to evaluation and decision making that explicitly, and to the extent practical, analytically, incorporates considerations of risk and uncertainty in a flood damage reduction study.

d. "Annual Exceedance Probability (AEP)" is the probability that flooding will occur in any given year considering the full range of possible annual floods.

e. "Residual Risk" is the flood risk that remains if a proposed flood damage reduction project is implemented. Residual risk includes the consequence of capacity exceedance as well.

6. Variables in a Risk Analysis. It is recognized that the true values of planning and design variables and parameters are frequently not known with certainty and can take on a range of values. One can describe, however, the likelihood of a parameter taking on a particular value by a probability distribution. The probability distribution may be described by its own parameters, such as mean and variance for a normal distribution, or minimum, maximum, and most likely for a triangular distribution. Risk analysis combines the underlying uncertainty information so that the engineering and economic performance of a project can be expressed in terms of probability distributions.

A variety of planning and design variables may be incorporated into risk analysis in a flood damage reduction study. 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. Other variables may be important for other types of projects. For example, in agricultural areas, seasonality of flooding and cropping practices may be important. The uncertainty of these variables may be due to sampling, measurement, estimation, and forecasting. For hydrologic and hydraulic analysis, the principal variables are discharge and stage. Uncertainty in 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. Uncertainty factors that affect stage might include conveyance roughness, cross-section geometry, debris accumulation, ice effects, sediment transport, flow regime, bed form, and others. For geotechnical and structural analysis, the principal source of uncertainty is the structural performance of an existing levee. Uncertainty in structural performance occurs due to a levee's physical characteristics and construction quality. Uncertainty in the operating performance of planned structures due to the difficulties related to locating and installing temporary barriers in a timely manner or variations in retention structure flood control operations may also be important considerations for certain flood damage reduction projects. In addition to uncertainty in the variables noted above, uncertainty arises from imprecise analysis methods (i.e. mathematical computations do not perfectly represent natural processes).

7. Policy and Required Procedures.

a. All flood damage reduction studies will adopt risk analysis as described herein. The risk analysis approach and results shall be documented in the principal decision document used for recommending authorization and/or construction. The types of documents involved are feasibility reports, general design memorandums, and general reevaluation reports. For reconnaissance phase, the proposed feasibility study risk analysis will be developed to the task level and included in the Project Management Plan. The plan 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 of overall economic and engineering performance. In cases where a general reevaluation report is proposed and standard freeboard assumptions or other engineering standards were used that are critical to sizing and/or performance of project features, a reformulation of the project using risk analysis, as described herein, shall be undertaken to determine the appropriate project for construction recommendation.

b. 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. Not all variables are critical to project justification in every instance. In progressing toward the ultimate goal, the risk analysis and study effort should concentrate on the uncertainties of the variables having a significant impact on study conclusions. At a minimum, the following variables must be explicitly incorporated in the risk analysis:

- the stage-damage function for economic studies (with special 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 and costs of production) will be key and should be used in the economic analysis;

- discharge associated with exceedance frequency for hydrologic studies;

- conveyance roughness and cross-section geometry for hydraulic studies; and

- structural and geotechnical performance of existing structures.

c. The Standard Project Flood (SPF) is defined in several legacy Engineer Regulation (ER) and Engineering Manual (EM) guidance documents. In the context of ER 1105-2-100 and risk analysis guidance, the SPF is no longer a valid design target, having been superceded by more current guidance. Instead, a full range of floods, including those that would exceed the SPF, is to be used in formulation and evaluation of alternatives. It is noted, however, in certain regions of the United States, there is a significant history of projects that were planned, designed, and constructed based on the SPF, and strong local identification with the concept continues to be prevalent. As a consequence, while current guidance on project formulation and selection governs, the SPF may have a useful role for application in risk analysis, 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.

d. The National Economic Development (NED) plan will be the scale of the flood damage reduction alternative that reasonably maximizes expected net benefits, (expected benefits less expected costs). It will be calculated explicitly including uncertainties in the key variables. Consideration of increments in project scale beyond the NED plan is permissible to improve project performance and to manage residual risks to people and property. Existing policy governing project increments beyond the NED plan must, however, be followed. Flood damage reduction projects may be part of a Combined NED/National Ecosystem Restoration (NER) Plan as described in ER 1105-2-100. Specific procedures for formulating and evaluating combined plans are described in Engineer Circular 1105-2-404.

e. The estimate of net NED benefits and benefit/cost ratio will be reported both as a single expected value and on a probabilistic basis for each planning alternative. The probability that net benefits are positive and that the benefit/cost ratio is at or above 1.0 will be presented for each planning alternative.

f. The flood protection performance will be presented. The risk analysis will quantify the performance of all scales of all alternatives considered for final recommendation. The analysis will evaluate and report residual risk, which includes consequence of project capacity exceedance. This requires explicitly considering the joint effects of the uncertainties associated with key hydrologic, hydraulic, and geotechnical variables. This performance will be reported in the following ways:

(1) the annual exceedance probability with associated estimates of uncertainty,

(2) the equivalent long-term risk of exceedance over 10-, 30-, and 50-years, and

(3) the ability to contain specific historic floods.

g. The distribution of residual flood damage and other relevant aspects of residual risks shall also be displayed. The residual risk shall be reported as the expected annual probability of each alternative being exceeded. For comparison purposes, the without-project risk in terms of the annual probability of flood damages occurring and the annual probability of other property hazards (fire, wind, etc.) will be displayed. Residual human health and safety risks will be displayed. To aid this display and to improve the understanding of the residual risk, inundation maps showing flood depths, should the project be exceeded, shall be provided. In addition, a narrative scenario for events that exceed the project design shall be provided. Both the inundation map and the narrative scenario shall 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, economic performance, and project costs. These increments contain differences in flood damage reduced, residual risk, and local and Federal project cost. It is vital that the local sponsor and residents understand these tradeoffs in order to fully participate in an informed decision-making process.

i. Special Guidance.

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

(2) Certification of levees must follow current guidelines described in the Federal Emergency Management Agency/USACE memorandum on Levee Certification for the National Flood Insurance Program. See CECW-CP for the current guidance, which describes levee performance criteria that must be reported when levee certification is requested.

(3) Project performance will be described by annual exceedance probability and long-term risk rather than level-of-protection.

(4) Analysis to assure safe, predictable performance of the project will be included. Such analysis will formulate features to manage capacity exceedence at the least damaging or other planned location. For levees and floodwalls, this may include providing superiority at pumping stations and other critical locations. The analysis of these features will consider their contribution to the project's performance and cost.

8. <u>Example Displays of Risk Analysis Results</u>. Appendix A, Tables A-1a through A-6 and Figures A-1 through A-8, to this regulation represents example displays of engineering and economic performance information. This information can be useful in aiding decisions by local

sponsors, stakeholders and Federal officials by helping to increase their understanding of the risk inherent in each alternative.

FOR THE COMMANDER:

1 Appendix
App A - Example Displays of Project Engineering and Economic Performance Results from Risk Analysis

JOHN R. MCMAHON
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Chief of Staff

Appendix A

Example Displays of Project Engineering and Economic Performance Results from Risk Analysis

Table A-1a: Expected Value and Probabilistic Values of EAD and EAD Reduced

	Expected Annual Damage ($'000)		Damage Reduced ($'000)		EAD Reduced that is Exceeded with Specified Probability ($'000)		
Plan	Without Plan	With Plan	Mean	Standard Deviation	0.75	0.50	0.25
20 foot levee	575	220	355	57	316	353	393
25 foot levee	575	75	500	77	451	503	555
30 foot 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

Table A-1b: Expected Value and Probabilistic Values of Costs

	Annual Cost ($'000)		Cost that is Exceeded with Specified Probability ($'000)		
Plan	Mean	Standard Deviation	0.75	0.50	0.25
20 foot levee	300	40	273	300	327
25 foot levee	400	45	370	400	430
30 foot 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

Table A-2: Expected Value and Probabilistic Values of Net Benefits

	Expected Annual Benefit and Cost ($'000)		Net Benefits ($'000)		Prob. Net Benefit is > 0	Net Benefit that is Exceeded with Specified Probability ($'000)		
Plan	Benefits	Cost	Mean	Std. Dev.		0.75	0.50	0.25
20 foot levee	355	300	55	68	0.80	8	54	99
25 foot levee	500	400	100	88	0.88	45	104	164
30 foot levee	570	550	20	116	0.55	-62	14	91
channel	375	300	75	74	0.83	19	72	120
detention basin	325	275	50	96	0.70	-17	50	113
relocation	355	250	105	63	0.97	62	100	145

Table A-3: Expected Value and Probabilistic Values of Benefit/Cost Ratios

Plan	Expected Benefit/Cost Ratio		Probability B/C > 1	B/C Ratio Value that is Exceeded with Specified Probability		
	Mean	Standard Deviation		0.75	0.50	0.25
20 foot levee	1.21	0.26	0.80	1.03	1.19	1.35
25 foot levee	1.28	0.24	0.88	1.11	1.26	1.43
30 foot levee	1.05	0.22	0.55	0.89	1.03	1.17
channel	1.26	0.27	0.83	1.06	1.24	1.41
detention basin	1.19	0.35	0.70	0.94	1.18	1.42
relocation	1.44	0.27	0.97	1.25	1.40	1.60

Table A-4: Performance Described by AEP and Long-term Risk

Plan	Annual Exceedance Probability	Long-term Risk (Probability of Exceedance Over Indicated Time Period)		
		10 Years	30 Years	50 Years
Without	0.250	0.94	1.00	1.00
20 foot levee	0.020	0.18	0.45	0.64
25 foot levee	0.010	0.10	0.26	0.39
30 foot levee	0.001	0.01	0.03	0.05
channel	0.015	0.14	0.36	0.53
detention basin	0.030	0.26	0.60	0.78
relocation	0.020	0.18	0.45	0.64

Alternative Display
Table A-4: Performance Described by AEP and Long-term Risk

Plan	Annual Exceedance Probability (AEP)	Long-Term Risk (Chances of Exceedance Over Indicated Time Period)		
		10 Years	30 Years	50 Years
Without	0.250	1 in 1.1	1 in 1.0	1 in 1.0
20 foot levee	0.020	1 in 5.5	1 in 2.2	1 in 1.6
25 foot levee	0.010	1 in 10.5	1 in 3.8	1 in 2.5
30 foot levee	0.001	1 in 100	1 in 33.8	1 in 20.5
channel	0.015	1 in 7.1	1 in 2.7	1 in 1.9
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

Table A-5: Annual Exceedance Probability Uncertainty

Plan	Annual Exceedance Probability (AEP)		AEP of Plan that is Exceeded with Specified Probability		
	Mean	Std. Dev.	0.75	0.50	0.25
Without	0.250	0.140	0.155	0.249	0.344
20 foot levee	0.020	0.016	0.008	0.017	0.029
25 foot levee	0.010	0.008	0.004	0.008	0.013
30 foot levee	0.001	0.003	0.000	0.001	0.002
channel	0.015	0.010	0.008	0.013	0.020
detention basin	0.030	0.021	0.015	0.025	0.040
relocation	0.020	0.015	0.010	0.019	0.030

Table A-6: Risk Comparison

Plan	Annual Exceedance Probability
Without	0.250
20 foot levee	0.020
25 foot levee	0.010
30 foot levee	0.001
channel	0.015
detention basin	0.030
relocation	0.020
Comparable Property	
Fire Damage	0.001
Wind Damage	0.005
Earthquake	0.001

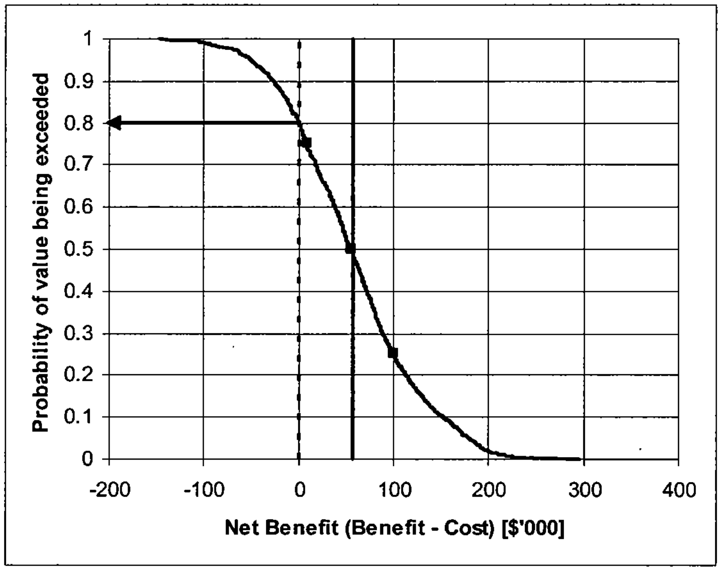

Figure A-1. Cumulative Distribution Function of Net Benefit for 20' Levee

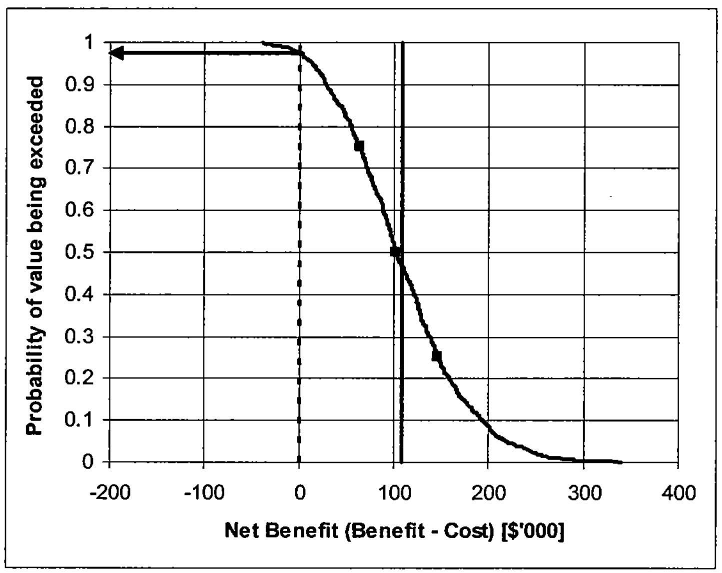

Figure A-2. Cumulative Distribution Function of Net Benefit for Relocation

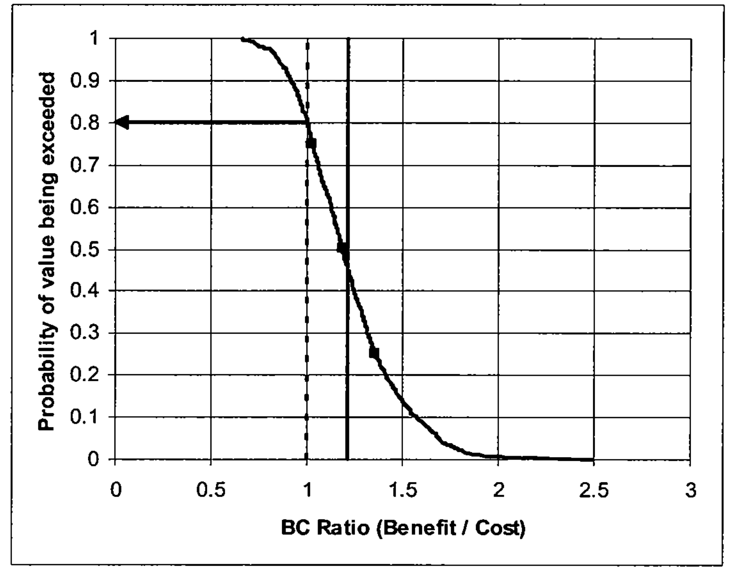

Figure A-3. Cumulative Distribution Function of BC Ratio for 20' Levee

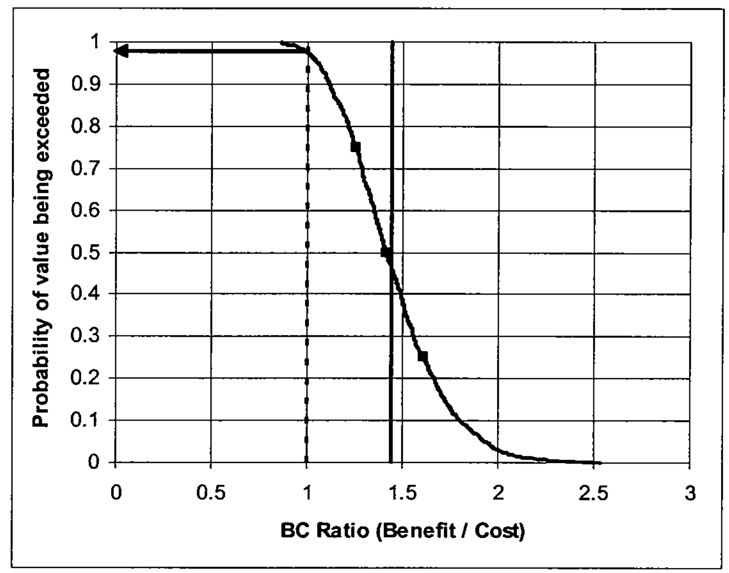

Figure A-4. Cumulative Distribution Function of BC Ratio for Relocation

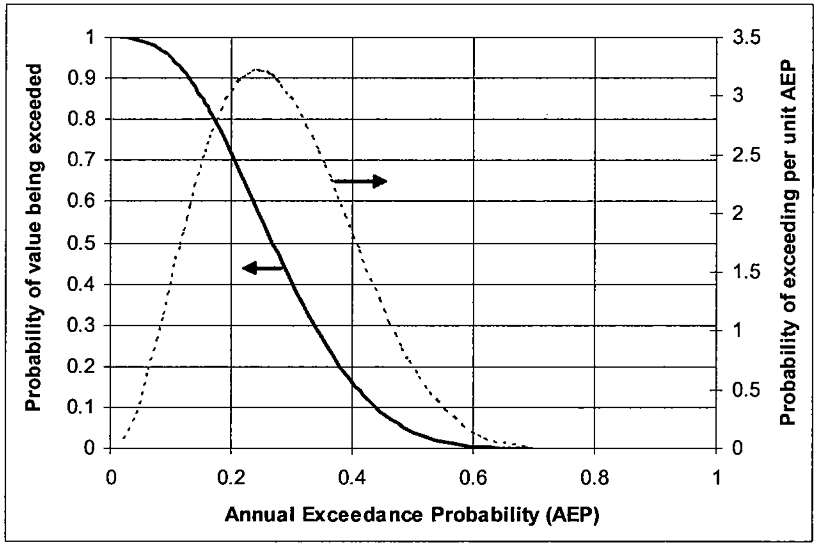

Figure A-5. Distribution Functions of AEP for Without Project

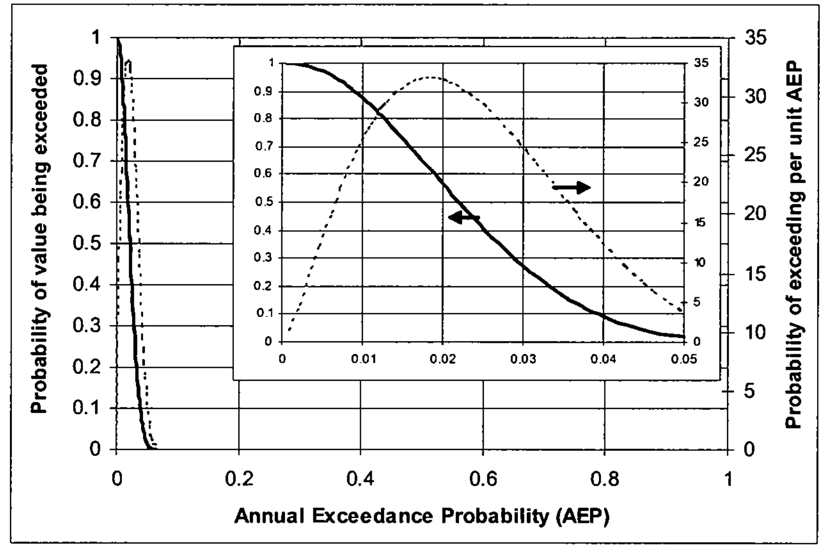

Figure A-7. Distribution Functions of AEP for Relocation

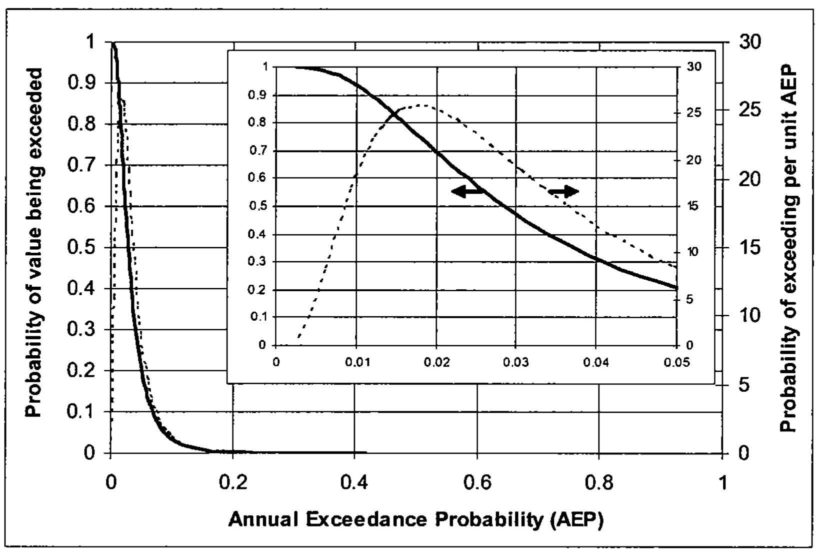

Figure A-6. Distribution Functions of AEP for 20' Levee

Should the levees protecting My City south of the Your River be threatened, residents could attempt to move to nearby higher ground. The depth of flooding in the protected neighborhoods in this area would generally not exceed that at the river's edge although a few areas would experience flooding of more that 10 feet. New Town, other 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. 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 fair coin and getting heads.

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

Figure A-8. Example Scenario