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	Planning RISK-BASED ANALYSIS FOR EVALUATION OF HYDROLOGY/HYDRAULICS, GEOTECHNICAL STABILITY, AND ECONOMICS IN FLOOD DAMAGE REDUCTION STUDIES	
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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
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Regulation
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Planning
RISK-BASED ANALYSIS FOR EVALUATION OF HYDROLOGY/HYDRAULICS, GEOTECHNICAL STABILITY, AND ECONOMICS IN FLOOD DAMAGE REDUCTION STUDIES

1. Purpose. This regulation provides guidance on the evaluation framework to be used in Corps of Engineers flood control and flood damage reduction studies. It is jointly promulgated by Planning and Engineering and applies to Hydrology/Hydraulic, Geotechnical, Structural, and Economic evaluations.

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 control and flood damage reduction projects.

3. References.

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

b. Policy Guidance Letter No. 26, Benefit Determination Involving Existing Levees, 23 December 1991.

4. Background.

a. Risk and uncertainty are intrinsic in water resources planning and design. They arise from measurement errors and the inherent variability of complex physical, social, and economic situations. 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, measurements subject to error, and innate residual variability in estimating methods. Sensitivity analysis has 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.

c. Risk-based 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 risk and 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-based analysis can be used to compare plans in terms of the likelihood and variability of their physical performance, economic success, and residual risks.

d. Budget constraints, increased customer cost sharing and public concern for project performance and reliability 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. Risk-Based Analysis, for the purposes of this regulation, is defined as an approach to evaluation and decision making that explicitly, and to the extent practical, analytically, incorporates considerations of risk and uncertainty. 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. The approach combines the underlying risk and uncertainty information so that the engineering and economic performance of a project can be expressed in terms of probability distributions.

6. Variables in a Risk-Based Analysis**.** A variety of planning and design variables may be incorporated into risk-based 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, forecasting, and modeling errors. For hydrologic and hydraulic analysis, the principle variables are discharge and stage. Uncertainty in discharge exists because record lengths are often short or do not exist where needed, precipitation-runoff computation methods are inaccurate, and the effectiveness of flood flow regulation measures is not precisely known. 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 principle 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. These, in turn, influence the Probable Non-failure Point (PNP) and Probable Failure Point (PFP) required in the reliability assessment of existing levees.

7. Policy and Required Procedures.

a. All flood damage reduction studies will adopt risk-based analysis as described herein. The risk-based analysis approach and results shall be documented in the principal decision document used for recommending authorization and/or construction. This involves feasibility reports, general design memorandums, and general reevaluation reports. For reconnaissance studies, the proposed feasibility study risk-based analysis will be developed to the task level and included in the Project Study Plan (PSP). The PSP 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 and reliability. Some proposed projects may reach the Preconstruction Engineering and Design (PED) phase without employing risk-based analysis. In those cases where a reevaluation effort is proposed and standard freeboard assumptions or other engineering standards were used which are critical to sizing and/or performance of project features, a reformulation of the project using risk-based 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-based analysis and study effort should concentrate on the uncertainties of the variables having the largest impact on study conclusions. At a minimum, the following variables must be explicitly incorporated in the risk-based analysis: the stage-damage function for economic studies (with special emphasis on structure first floor elevation, depth-per cent 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 reliability of existing structures.

c. 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.

d. The estimate of NED benefits and costs will be reported both as a single expected value and on a probabilistic basis (value of the benefit and its associated probability) for each planning alternative. The confidence, in probabilistic terms, that net benefits are positive and that the benefit to cost ratio is at or above 1.0 and other selected values will be presented for each planning alternative.

e. The flood protection performance will be presented. The risk-based analysis will quantify the performance of all scales of all alternatives considered for final recommendation. 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 three ways:

(1) the expected annual probability of the alternative being exceeded,

(2) the equivalent long-term risk of exceedance over 10-, 20-, and 50-years using the binomial formula, and

(3) the conditional probability of non-exceedance of specified events.

Additionally, this performance should be described in terms of the percent chance of containing a specific historic flood should it occur.

f. 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.

g. 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.

h. Special Guidance.

(1) The term and concept of freeboard to account for hydraulic uncertainty will no longer be used in levee and floodwall projects. The term or concept of level of protection is no longer useful and will not be used in describing project performance.

(2) Analysis to assure safe, reliable, and predictable performance of the project will be included. Such analysis will formulate features to manage overtopping at the least damaging or other planned location, which provides superiority at pumping stations and other critical locations. The analysis of these features will consider their contribution to the project's performance, reliability, and cost.

8. Example Displays of Risk-based Analysis Results. Appendix A, Tables A-1 through A-8 and Figures A-1 through A-5, to this regulation represents example displays of engineering and economic performance information. This information can be useful in aiding decisions by local customers, local residents and Federal officials by helping to increase their understanding of the performance and residual risk inherent in each alternative.

FOR THE COMMANDER:

ROBERT H. GRIFFIN
Colonel, Corps of Engineers
Chief of Staff

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

Appendix A

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

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

Plan	Expected Annual Damage ($'000)			Probability EAD Reduced Exceeds Indicated Amount ($'000)				
	Without Plan	With Plan	Damage Reduced	0.95	0.75	0.50	0.25	0.05
20 foot levee	575.0	220.0	355.0	290.0	325.0	350.0	380.0	450.0
25 foot levee	575.0	75.0	500.0	370.0	435.0	490.0	550.0	690.0
30 foot levee	575.0	0.0	575.0	410.0	495.0	560.0	630.0	815.0
Channel	575.0	200.0	375.0	300.0	325.0	360.0	400.0	600.0
Detention Basin	575.0	250.0	325.0	200.0	260.0	300.0	330.0	450.0
Relocation	575.0	300.0	275.0	150.0	200.0	260.0	300.0	450.0

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

Plan	Expected Annual NED Benefit and NED Cost ($'000)			Probability Net Benefit Exceeds Indicated Amount ($'000)				
	Benefits	Cost	Net Benefits	0.95	0.75	0.50	0.25	0.05
20 foot levee	355.0	300.0	55.0	(25.0)	20.0	53.0	88.0	148.0
25 foot levee	500.0	400.0	100.0	(40.0)	35.0	91.0	152.0	280.0
30 foot levee	575.0	550.0	25.0	(155.0)	(60.0)	12.0	88.0	261.0
Channel	375.0	300.0	75.0	(30.0)	15.0	70.0	120.0	205.0
Detention Basin	325.0	275.0	50.0	(20.0)	18.0	50.0	75.0	150.0
Relocation	275.0	475.0	(200.0)	(300.0)	(250.0)	(210.0)	(170.0)	50.0

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

Plan	Expected Benefit/Cost Ratio	Probability B/C > 1	Probability Benefit/Cost Ratio Exceeds Indicated Amount				
			0.95	0.75	0.50	0.25	0.05
20 foot levee	1.19	0.86	0.92	1.07	1.18	1.30	1.52
25 foot levee	1.25	0.89	0.90	1.09	1.23	1.40	1.70
30 foot levee	1.05	0.57	0.72	0.90	1.02	1.16	1.47
Channel	1.25	0.84	0.90	1.05	1.22	1.39	1.65
Detention Basin	1.18	0.82	0.93	1.06	1.16	1.25	1.50
Relocation	0.58	0.00	0.37	0.47	0.56	0.62	0.89

Table A-4: Annual Performance and Equivalent Long-term Risk

Plan	Annual Performance (Expected Annual Probability of Design Being Exceeded)	Equivalent Long-term Risk (Probability of Exceedance Over the Indicated Time Period)		
		10 Years	20 Years	50 Years
W/O Project	0.250	0.944	0.997	1.000
20 foot Levee	0.020	0.183	0.332	0.636
25 foot Levee	0.010	0.096	0.182	0.395
30 foot Levee	0.001	0.010	0.020	0.049
Channel	0.025	0.224	0.397	0.718
Detention Basin	0.030	0.263	0.456	0.782
Relocation	0.100	0.651	0.878	0.995

Table A-5: Alternative Display of Annual Performance and Equivalent Long-term Risk

Plan	Annual Performance (Expected Annual Probability of Design Not Being Exceeded)	Equivalent Long-Term Risk (Chances of Design Being Exceeded Over the Indicated Time Period)		
		10 Years	20 Years	50 Years
W/O Project	0.750	1 in 1.1	1 in 1.0	1 in 1.0
20 foot Levee	0.980	1 in 5.5	1 in 3.0	1 in 1.6
25 foot Levee	0.990	1 in 10.5	1 in 5.5	1 in 2.5
30 foot Levee	0.999	1 in 100.5	1 in 50.5	1 in 20.5
Channel	0.975	1 in 4.5	1 in 2.5	1 in 1.4
Detention Basin	0.970	1 in 3.8	1 in 2.2	1 in 1.3
Relocation	0.900	1 in 1.5	1 in 1.1	1 in 1.0

Table A-6: Conditional Probability of Design Non-exceedance

Plan	Conditional Probability of Design Containing Indicated Event					
	10 %	4 %	2 %	1 %	.4 %	.2 %
20 foot Levee	0.990	0.920	0.450	0.100	0.015	0.000
25 foot Levee	0.999	0.990	0.900	0.440	0.075	0.010
30 foot Levee	~1.000	~1.000	0.999	0.985	0.870	0.600
Channel	0.800	0.600	0.350	0.050	0.000	0.000
Detention Basin	0.700	0.550	0.250	0.025	0.000	0.000
Relocation	0.500	0.100	0.015	0.000	0.000	0.000

Table A-7: Probabilistic Values for Population at Risk

Plan	Annual Probability that Population At Risk Equals or Exceeds Indicated Amount with Project				
	0.250	0.100	0.020	0.010	0.001
Without Project	500	1000	2000	2500	5000
20 foot levee	0	0	2000	2500	5000
25 foot levee	0	0	2000	2500	5000
30 foot levee	0	0	0	0	15000
Channel	0	0	500	2000	5000
Detention Basin	0	0	500	2500	5000
Relocation	0	500	1500	2000	4500

Table A-8: Residual Risk Comparison

Plan	Annual Performance (Expected Annual Probability of Design Being Exceeded)
W/O Project	0.250
20 foot Levee	0.020
25 foot Levee	0.010
30 foot Levee	0.001
Channel	0.025
Detention Basin	0.030
Relocation	0.100
Comparable Property	
Fire Damage	0.0010
Wind Damage	0.0050
Earthquake	0.0010

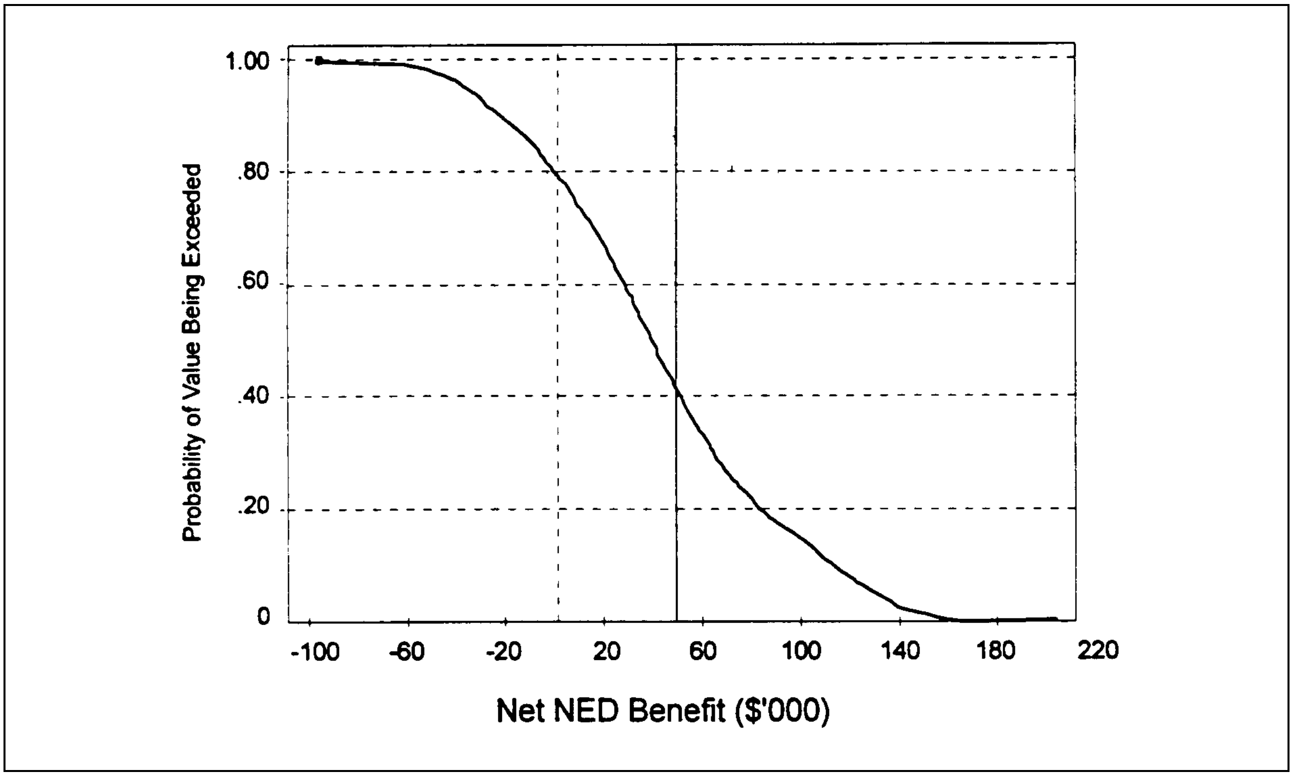

Figure A-1: Cumulative Distribution Function of Net Benefit for 20’ Levee

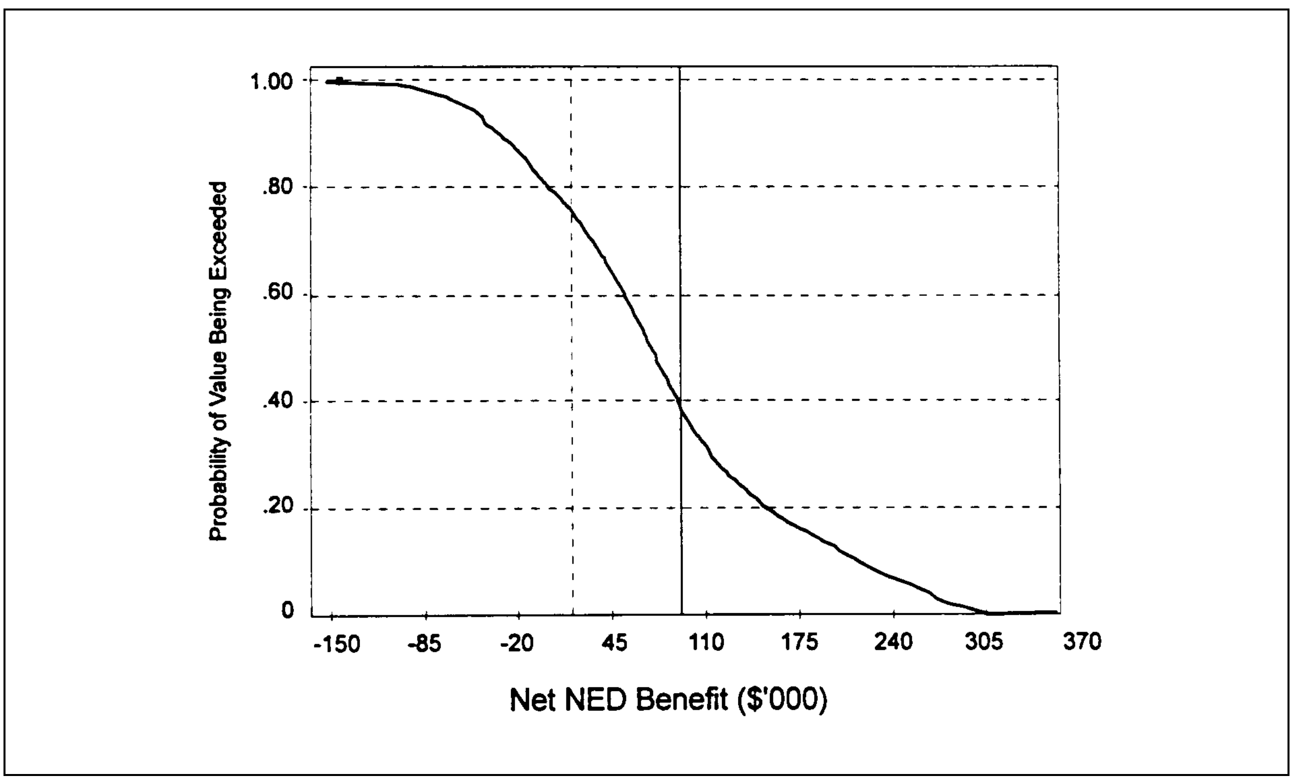

Figure A-2: Cumulative Distribution Function of Net Benefit for 25’ Levee

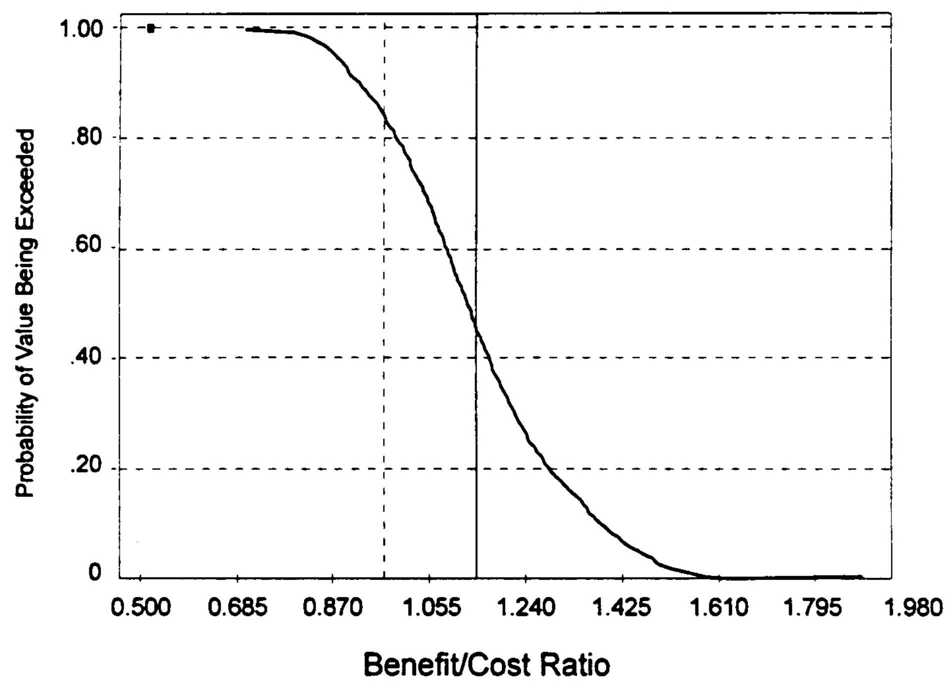

Figure A-3: Cumulative Distribution Function of Benefit/Cost Ratio for 20' Levee

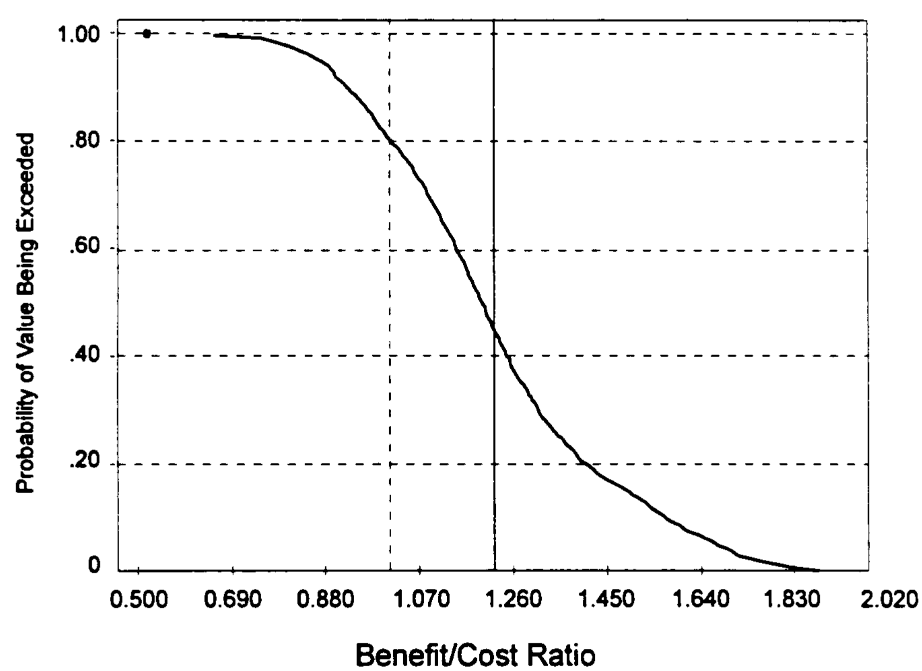

Figure A-4: Cumulative Distribution Function for Benefit/Cost Ratio for 25' Levee

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 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. 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 areas, 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-5: Example Scenario