Chapter 3
Engineering Performance of Flood-Damage Reduction Plans

3-1. Overview

Economic efficiency, as measured by a plan's contribution to national economic development, is not the sole criterion for flood-damage reduction plan selection. The Water Resources Development Act of 1986 provides that plans should be evaluated in terms of (1) contribution to national economic development; (2) impact on quality of the total environment; (3) impact on well-being of the people of the United States; (4) prevention of loss of life; and (5) preservation of cultural and historical values. This chapter describes indices of plan performance that provide information for making such an assessment. In particular, indices described herein represent some aspects of the non-economic performance of alternative plans; this performance is referred to herein as *engineering performance*. The indices include expected annual exceedance probability, long-term risk, consequences of capacity exceedance, and conditional probability.

3-2. Expected Annual Exceedance Probability

a. Expected annual exceedance probability (AEP) is a measure of the likelihood of exceeding a specified target in any year. For example, the annual exceedance probability of a 10-m levee might be 0.01. That implies that the annual maximum stage in any year has a 1-percent chance (0.01 probability) of exceeding the elevation of the top of the levee. In the absence of uncertainty in defining hydrologic, hydraulic, and economic functions, annual exceedance probability can be determined directly by referring to the discharge-probability function and stage-discharge functions, or to the stage probability function. For example, to find the annual exceedance probability of a levee with top elevation equal to 10 m, one would refer first to the rating function to determine the discharge corresponding to the top-of-levee stage. Given this discharge, the probability of exceedance would be found then by referring to the discharge-probability function: This probability is the desired annual exceedance probability. Conversely, to find the levee stage with specified annual exceedance probability, one would start with the discharge-probability function, determining discharge for the specified probability. Then from the rating function, the corresponding stage can be found.

b. If the discharge-probability function and rating function are not known with certainty, then the annual exceedance probability computation must include uncertainty analysis. Either annual-event sampling or function sampling can be used for this analysis; the choice should be consistent with the sampling used for expected-annual-damage computation. Figure 3-1 illustrates how the annual exceedance probability can be computed with event sampling, accounting for uncertainty in the discharge-probability function, rating function, and geotechnical performance of the levee.

3-3. Long-term Risk

a. Long-term risk, also referred to commonly as natural, or inherent, hydrologic risk (Chow, Maidment, and Mays 1988), characterizes the likelihood (probability) of one or more exceedances of a selected target or capacity in a specified duration. Commonly that duration is the anticipated lifetime of the project components, but it may be any duration that communicates to the public and decision makers the risk inherent in a damage-reduction plan.

Long-term risk is calculated as:

$$R = 1 - [1 - P\,(X \geq X_{Capacity})]^n \qquad (3\text{-}1)$$

where $P(X \geq X_{Capacity})$ = the annual probability that X (the maximum stage or flow) exceeds a specified target or the capacity, $X_{Capacity}$; R = the probability that an event $X \geq X_{Capacity}$ will occur at least once in n years. This relationship is plotted in Figure 3-2 for selected values of duration n for annual exceedance probabilities P ($X \geq X_{Capacity}$) from 0.001 to 0.1.

b. Long-term risk is a useful index for communicating plan performance because it provides a measure of probability of exceedance with which the public can identify. For example, many home mortgages are 30 years in duration. With this index, it is possible to determine that within the mortgage life, the probability of overtopping a levee with annual exceedance probability of 0.01 is $1-(1-0.01)^{30}$, or 0.26. For illustration, such long-term risks can be compared conveniently with other similar long-term risks, such as the risk of a house fire during the mortgage period.

c. Likewise, the long-term risk index can help expose common misconceptions about flooding probability. For example, Figure 3-2 shows that the risk in 100 years of one or more floods with an annual

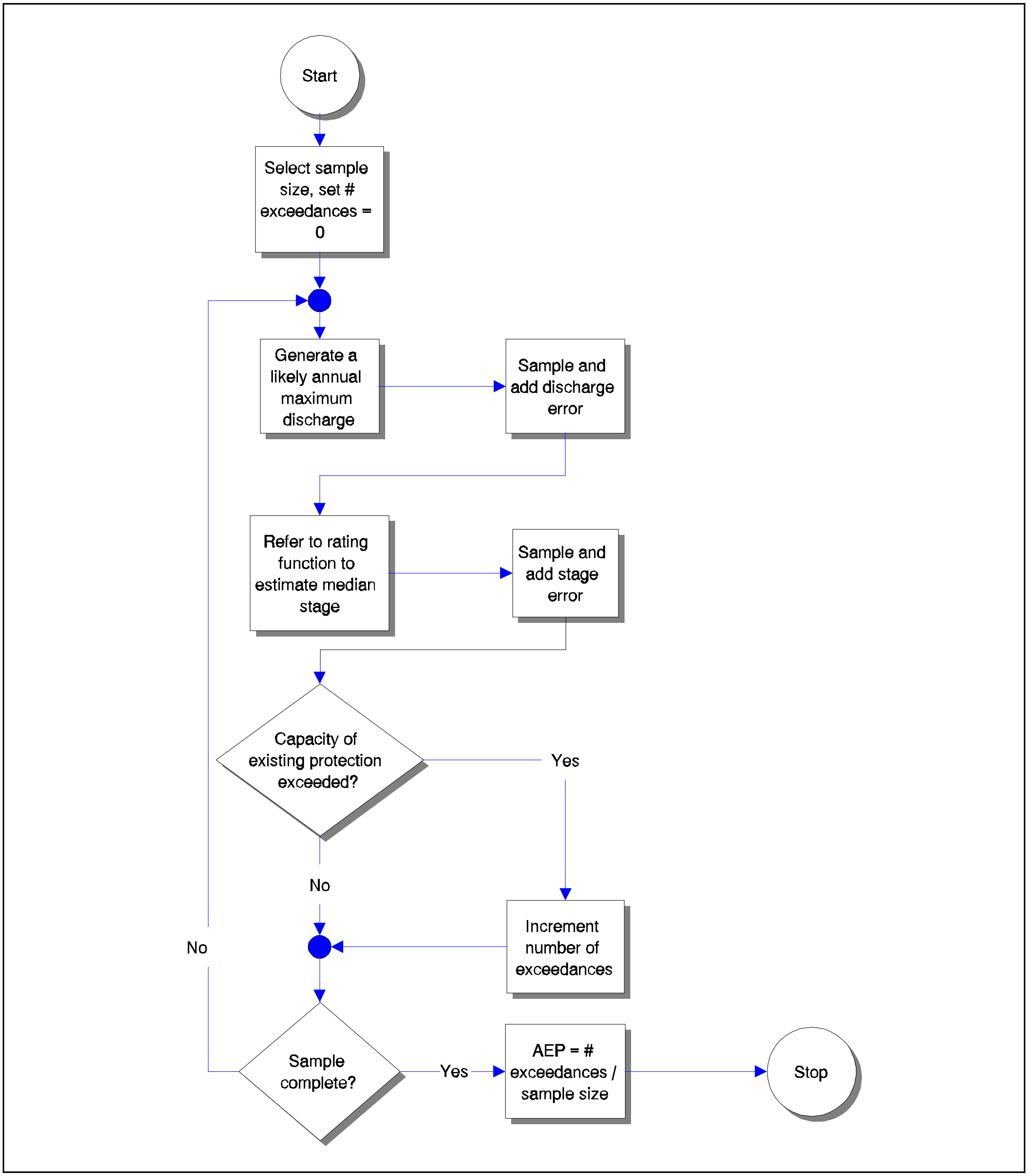

Figure 3-1. Annual exceedance probability estimation with event sampling

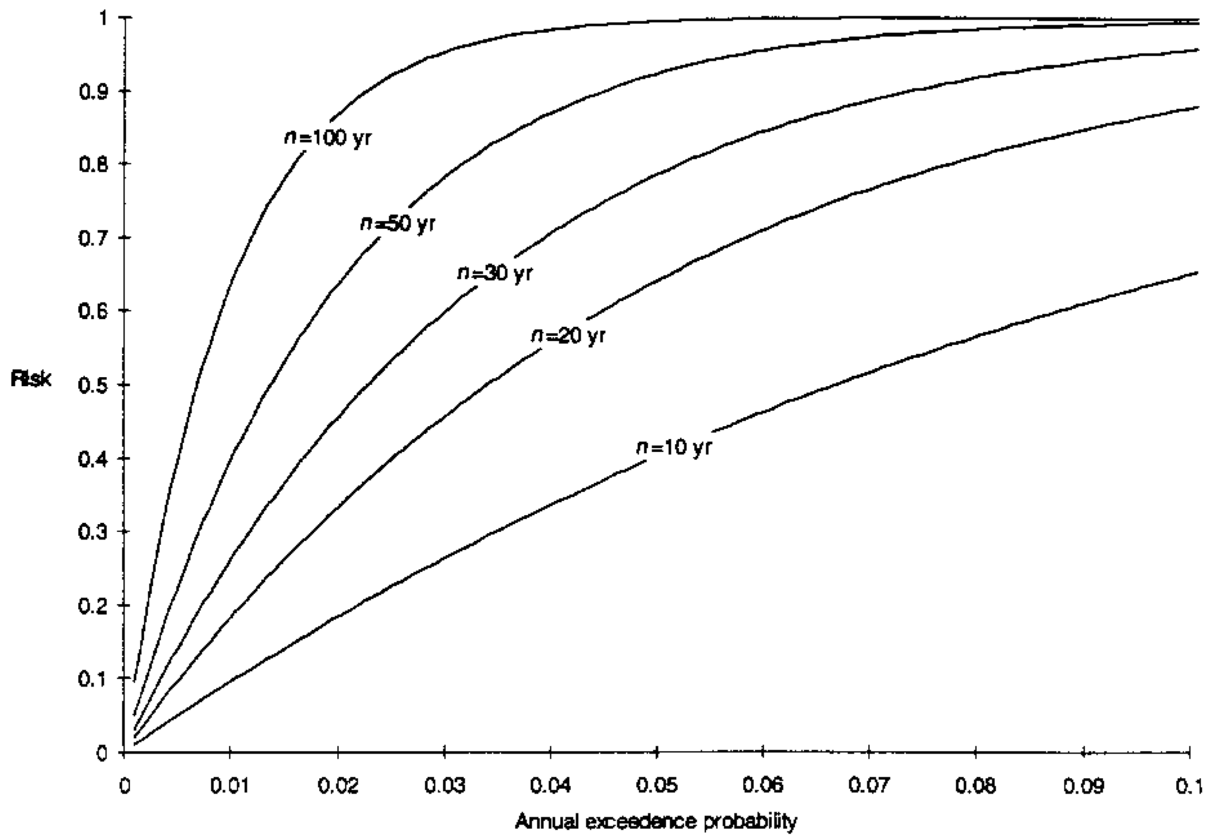

Figure 3-2. Long-term risk versus annual exceedance probability

exceedance probability of 0.01 is approximately 0.63. The complement is also true: The probability of *no* floods with annual exceedance probability of 0.01 is 1.00-0.63 = 0.37. That is, there is a 37 percent chance that no *floods* with a chance of exceedance of 1-percent or greater will occur within any 100-year period. Such information is useful to help the public understand the randomness of hydrologic events and to accept that it is not extraordinary that property in a regulatory floodplain has not flooded in several generations.

3-4. Conditional Annual Non-Exceedance Probability

a. Conditional annual non-exceedance probability (CNP) is an index of the likelihood that a specified target will not be exceeded, given the occurrence of a hydro-meteorological event. For example, the conditional non-exceedance probability of a proposed 5.00-m-high levee might be 0.75 for the 0.002-probability event. This means that if the plan is implemented, the probability is 0.75 that the stage will not exceed 5.00 m, given the occurrence of a 0.2-percent chance event. Conditional non-exceedance probability is a useful indicator of performance because of the uncertainty in discharge-probability and stage-discharge estimates. Evaluation of several events can provide insight as to how different measures perform. The assessment of a known historic event may assist local sponsors and the public in understanding how a project may perform.

b. Computation of conditional annual non-exceedance probability requires specification of:

(1) The performance target. This target commonly is specified as a stage, and it is commonly the maximum stage possible before any significant damage is incurred.

(2) One or more critical events. These should be selected to provide information for decision making, so the events chosen should be familiar to the public and to decision makers. These events can be specified in terms

of magnitude of stage, discharge, or annual exceedance probability. Reasonable choices include (1) the event with stage or discharge equal to the capacity of a flood-damage-reduction measure, such as the stage at the top of a proposed levee; (2) the stage or discharge associated with one or more historical events, and (3) events with familiar annual exceedance probabilities, such as the event with an annual exceedance probability of 0.01.

c. The method of computation of conditional non-exceedance probability depends on the form in which the target event is specified and the method of sampling used. In general, the computation requires repeated sampling of the critical event, comparison with the target, and determination of the frequency of non-exceedance. Figure 3-3 illustrates the computation for a levee alternative, using a critical event of specified annual exceedance probability. This figure assumes that the following are available: (1) discharge-probability function, with uncertainty described with a probability function; (2) rating function, with uncertainty described with probability function; and (3) geotechnical performance function. Conditional annual non-exceedance probability estimation with the critical event specified in terms of stage omits the discharge probability function uncertainties.

3-5. Consequences of Capacity Exceedance

a. EM 1110-2-1419 notes that "all plans should be evaluated for performance against a range of events." This includes events that exceed the capacity of the plan, for regardless of the capacity selected, the probability of capacity exceedance is never zero. No reasonable action can change that. A complete planning study will estimate and display the consequences of capacity exceedance so that the public and decision makers will be properly informed regarding the continuing threat of flooding.

b. The economic consequences of capacity exceedance are quantified in terms of residual event and expected annual damage. Residual expected annual damage is computed with the results of economic benefit computations; it is the with-project condition EAD (Equation 2-7).

c. Other consequences of the exceedance may be displayed through identification, evaluation, and description of likely exceedance *scenarios*. A scenario is a "particular situation, specified by a single value for each input variable" (Morgan and Henrion 1990). In the case of a capacity-exceedance scenario, specific characteristics of the exceedance are defined, the impact is estimated, and qualitative and quantitative results are reported. The scenarios considered may include a best case, worst case, and most-likely case, thus illustrating consequences for a range of conditions. For example, for a levee project, scenarios identified and evaluated may include:

(1) A most-likely case, defined by the planning team (including geotechnical engineers) to represent the most-likely mode of failure, given overtopping. The scenario should identify the characteristics of the failure, including the dimensions of a levee breach. Then a fluvial hydraulics model can be used to estimate depths of flooding in the interior area. With this information, the impact on infrastructure can be estimated explicitly. Flood damages can be estimated if assumptions are made regarding the timing of the exceedance and the warning time available. Review of historical levee overtopping elsewhere for similar facilities will provide the foundation for construction of such a scenario.

(2) A best case defined by the team to include minor overtopping without breaching. This scenario may assume that any damage to the levee is repaired quickly. Again, the impact will be evaluated with a hydraulics model. For evaluation of economic impact, loss of life, impact on transportation, etc., the timing of the exceedance may be specified as, say, 9 a.m.

(3) A worst case defined by the team to include overtopping followed by a levee breach that cannot be repaired. The breach occurs at 3 a.m., with little warning. Again, the same models will be used to evaluate the impact.

d. For each of the scenarios, the consequences should be reported in narrative that is included in the planning study report.

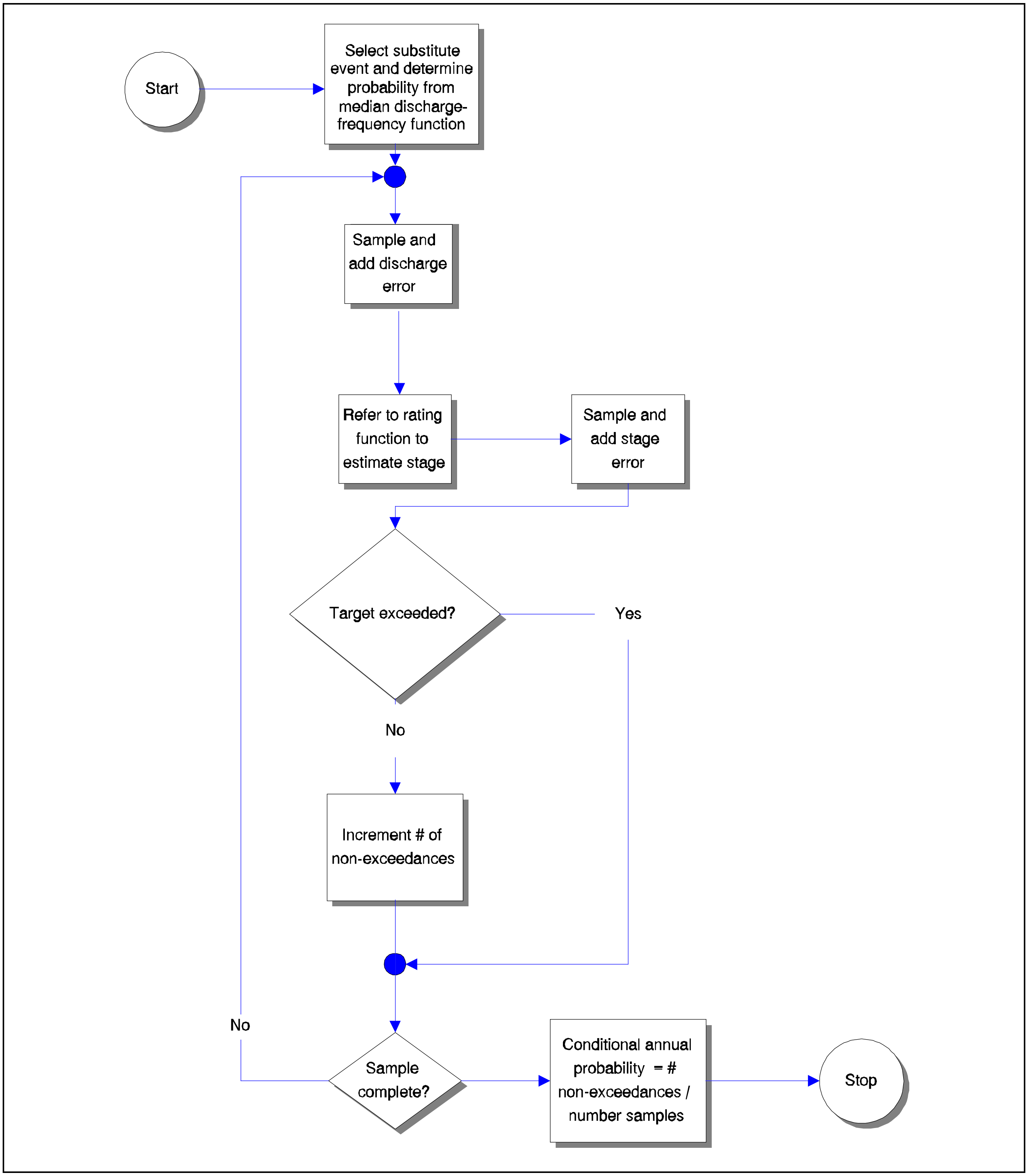

Figure 3-3. Conditional annual non-exceedance probability estimation with event sampling