RISK-BASED ANALYSIS IMPLICATIONS FOR FLOOD PLAIN MANAGEMENT

by

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INTRODUCTION AND BACKGROUND

The foundation for application of risk-based analysis to Corps flood damage reduction studies was presented and discussed at a seminar held in Monticello, Minnesota in 1991 (HEC, 1991). The issue that gave rise to the seminar was that of levee freeboard, a well established engineering allowance for uncertainty in the stage of the design flood. A conclusion of seminar participants was that explicitly quantifying and subsequently integrating the uncertainty associated with various aspects of flood project studies into the analysis would provide improved project decision making as well as resolving the freeboard issue. In a nutshell, project features like levee freeboard would be abandoned in favor of explicit quantification of likely values and the associated probabilities. Draft guidance in application of risk-based was issued to Corps field offices later that year. Final guidance in the form of Engineer Regulations and Engineer Manuals have emerged in subsequent years (USACE 1996a and USACE 1996b).

One consequence of application of risk-based analysis is that more information is available about expected flood levels, flood level uncertainty, and project performance. Also, some traditional information is no longer developed. For example, it is no longer possible to assign a single value to the conventional performance index (level-of-protection) of flood damage reduction projects. Instead, expected values, conditional probabilities, and other like information are substituted. For Corps application in flood damage reduction project formulation, evaluation, and selection, these changes lead to more informed decision making. While project selection policies have not changed, better and more complete economic and engineering performance information is developed. The rub comes in that regulatory actions need explicit and non-controversial, criteria for which data is relatively easy and straight-forward to develop. The adoption of risk-based analysis by the Corps is criticized as upsetting the traditional regulatory system related to flood plain management.

The objective of this paper is to explore the relationship of risk-based analysis and flood plain management with the view to sharpening understanding of the issues and presenting the present flood plain management accommodation of risk concepts by the Corps. In this context, this paper is limited to issues related to flood risk data, flood plain delineation, Federal Emergency Management Agency (FEMA) certification, and Corps flood damage reduction project studies.

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THE ISSUES

The following table presents a summary of the issues related to risk-based analysis and flood plain management.

Table 1
Issues Related to Risk-Based Analysis and
Flood Plain Management

Issue Topic	Historic Context	Risk-based Context
Flood Risk Data, Presentation	Flow, stage, exceedance probability - tabulations	RBA[1] explicitly quantifies/ applies uncertainty in data
Flood Plain Delineation	Median probability flow - stage, Corps Ex. Prob. Q/S[1]	Near same; FEMA median prob., Corps RBA - Ex. Stage
Flood Project Benefits	Stage, flow, damage - integration for EAD[1]	Explicit uncertainty, better EAD; EAD distribution
Flood Project Performance	Level-of-protection, capacity exceedances	Expected exceedances, conditional probability
Flood Project Selection	Acceptable alternatives, net expected benefits	Same, improved estimate of net expected benefits
FEMA Levee Certification	Median flow, stage plus freeboard	Same, RBA - refined reflection of performance

[1]RBA - Risk-based analysis; Q/S - flow/stage; EAD - Expected annual damage.

FLOOD RISK DATA

Flood risk data are developed from hydrologic and hydraulic studies that determine flow-exceedance frequency, flood profile/stage, and areal extent of flooding. The basic information is extracted from historic flow records and applied in flow-frequency analysis and rainfall-runoff and river hydraulics calculations. The basic information is the same between contexts, the analysis is similar except that RBA explicitly quantifies uncertainty in stage and flow so that the resulting stages computed for flood risk tabulations and presentations includes the interaction between flow and stage uncertainties. RBA develops expected stage whereas the historic analysis can yield median probability stage as well as approximately the expected stage.

FLOOD PLAIN DELINEATION

Flood plains are delineated by intersecting water surface elevation profiles, normally computed from river hydraulics models, with terrain maps. Flood plains delineated for FEMA flood insurance purposes are based on flow for the base flood (1% median probability event) and computed flood elevation for that flow. This is the standard policy no matter who delineates the flood plain (e.g. the Corps) since they are being delineated for FEMA mission purposes. Flood plains delineated by the Corps for flood benefit calculations in support of project studies are based on expected flood stage, either from flow developed using ‘expected probability’ and computed flood elevation for that flow, or expected flood stage directly as results from RBA. For all practical purposes, the expected flood stage as results from RBA and the flood stage resulting from computing flow via ‘expected probability’ then computing stage, are the same.

The application of risk-based analysis does not change the fact that FEMA and the Corps compute and delineate flood plains differently for reasons attributed to agency mission differences. FEMA takes the position that computing and delineating flood plains for the ‘median probability’ flood stage is appropriate for their flood insurance mission, and the Corps takes the position that ‘expected probability’ flood stage is appropriate for their mission for flood project studies. RBA simply results in expected stage due to incorporation of uncertainty directly in the analysis, and the result is in-effect, the application of ‘expected probability’ concepts. RBA neither solves nor further aggravates the differences in the two agencies viewpoints. Data in Table 2 introduced later contains information illustrating these differences.

FLOOD PROJECT BENEFITS

Flood damage reduction projects developed by the Federal government are subjected to an economic analysis to determine whether the proposed investment of public funds will yield positive national economic development benefits. Although there are some other complexities and issues, the basic approach of the analysis is to compute EAD for the flood plain to be protected, first without the project in place, then with the proposed project in place, and subtract the results to determine the expected damage reduction benefits. In the historic context , the EAD was computed by the Corps by forming for the condition of interest, an annual damage-exceedance probability function that is then integrated to compute the expected value of annual damage. This value is often referred to as average annual damage. Technical studies supporting this analysis include for each alternative of interest, developing flow-exceedance frequency functions via statistical analysis or rainfall-runoff models, stage flow relationships via water surface profile computations, and elevation damage relationships from flood plain structure inventories and flood vulnerability studies. The Corps applies ‘expected probability’ in the computation of the flow-exceedance frequency function development.

In RBA, the basic data are the same but additional data are developed for the basic relationships, and the integration to compute expected value is done by Monte Carlo sampling rather than simple graphical or numerical integration. The fact that RBA involves explicit quantification of uncertainties in the relationships is quite significant. The uncertainties must be derived (USACE, 1996) and incorporated in the expected value computations.

The outcome is that RBA estimates expected damage reduction benefits that are both different than the historic context (though not dramatically so), and improved. In addition, the uncertainty in potential flood project damage reduction benefits is explicitly computed for use in project formulation and selection decisions. The inclusion of uncertainty in the EAD computations typically results in higher EAD values (Davis, 1991). The difference (e.g. damage reduction benefits) is usually, though not always, somewhat greater than the corresponding EAD computed in the historic context. Much debate about EAD computations with uncertainty is documented in the literature (NRC, 1995; Beard, 1997; Goldman, 1997; Stedinger, 1997).

For the discussion here, the view is that computing EAD and thus flood project benefits by application of RBA yields an improved estimate and provides valuable additional information about the uncertainty of potential project benefits.

FLOOD PROJECT PERFORMANCE

From a risk perspective, flood project performance was historically characterized by the concept of 'level-of-protection' (LOP). The LOP is the annual exceedance probability (often expressed as return interval in years) of the flood event resulting in incipient damage for the flood plain of interest. While there is some variation in interpretation of incipient damage in unprotected flood plains, it is most often taken as the flood event for which the stage just begins to cause significant damage; and for protected flood plains, it is the flood event that just begins to exceed project capacity.

Level-of-protection as a performance index is justly criticized because it only captures the exceedance probability of incipient flooding and does not capture other issues associated with project capacity exceedance. Nor does it reflect the uncertainty associated with flooding. It is widely used because it is simple and understandable (e.g. project provides 100 year protection). It is a matter of debate whether it illuminates or obscures the risk associated with flooding.

In RBA, there is less tendency to characterize project performance with the LOP because a richer set of information is available about risk performance - expected exceedances and conditional non-exceedance probability. While inverting the expected exceedances will yield an LOP looking number, it is more appropriately described as the average recurrence interval of flood exceedances.

The added information provided by RBA, conditional non-exceedance probability (referred to herein as simply conditional probability), has proven to be another useful descriptor of flood project performance. For example, we can now quantify the following: given that a 1% chance flood event occurs, what is the chance that it will exceed a given stage (e.g. top of levee). Similar information associated with other flood events is also easily developed. The fact that there is uncertainty about the ability of a flood project containing an event of interest was acknowledged in the past but was not here-to-fore quantified. Presenting conditional probability information up front is both informative (we know more about project performance) but also disquieting to those who prefer to assume that knowledge about project performance is more absolute. Some express the view that the additional information complicates decision making and is therefore not good. While we believe this information can and will contribute to better understanding of project performance, flood professionals need to develop improved means of communicating risk concepts and information to local officials and flood threatened communities. Table 2 presented later, contains tabulations depicting information about performance characterized by conditional probability.

Other descriptors of flood project performance are needed such as residual damage (a series of single values) from floods; or floods, that exceed project capacity; or the expected residual damage resulting for all possible exceedances. Also, another measure of performance is difference in population at risk with and without the proposed project. RBA output is complementary with these additional performance descriptors.

FLOOD PROJECT SELECTION

The flood project development process includes the following steps: formulate likely alternative solutions, evaluate economic and other performance measures, array acceptable alternatives, and select the alternative that maximizes net national economic development (NED) benefits from the acceptable array. Local agencies may opt for larger/different plans (however they must pay the full cost of the increment over the NED plan) or smaller/different plans provided the Corps concurs that performance is acceptable. There is no cost share penalty for local preference of smaller (than NED) projects. A view has been expressed (it is not policy) that if local agencies select a plan that is smaller/different (and thus lower NED benefits), then they should contribute a higher percentage of costs since full NED benefits are not realized.

In the historical context, formulation and selections decisions were made on information presented as best estimates and derived expected values. In the RBA context, decisions continue to be based on expected values, but the values are improved estimates because uncertainty has been quantified and incorporated directly in the analysis. This is particularly the case for economic benefit estimates, as discussed previously. Not only is the expected value estimate improved, but the uncertainty in the expected value is quantified. In principle then, selection among the alternatives considering economic performance could consider degree of certainty in net benefits, perhaps favoring an alternative with lower expected benefits but less uncertainty over another alternative with higher expected benefits but also greater uncertainty.

A criticism voiced against RBA, particularly for levee projects, is that it would result in projects with lower protection levels, ostensibly because freeboard is no longer a feature, or that certification for the FEMA base flood would occur at lower elevations. (The certification issue is discussed in the next section.) Examination of Table 2, presented later, reveals no relationship between the FEMA certification elevation and the NED plan. The situation is just the contrary. As mentioned earlier, computed expected benefits are typically higher when using RBA (it stands to reason that greater uncertainty would result in higher expected values), than in the historical context. The tendency therefore is for the NED alternative to be larger (provide more protection) with RBA over the NED alternative in the historical context.

LEVEE CERTIFICATION FOR THE NATIONAL FLOOD INSURANCE PROGRAM

The consequence of the Corps adopting risk-based analysis for flood studies creates an interesting situation when levees are involved. Freeboard, a vertical levee height added to the design flood stage, was historically included to account for uncertainties in flood stages and levee embankment geotechnical performance. The amount of freeboard was normally a fixed amount, typically three feet, that was not varied to reflect uncertainties. With risk-based analysis, freeboard is no longer a feature since the uncertainties previously allowed for are now explicitly included in the levee sizing analysis. Also, no longer is there only a single valued representation of flood potential (for example 'the 100-year flood') since risk-based analysis more accurately reflects the uncertainty involved in flood estimates. Therefore, an issue associated with application of risk-based analysis is that of levee 'certification,' an important concept in administration of the National Flood Insurance Program of FEMA. The published FEMA policy for certification of a levee for protection against the regulatory flood (normally 100-year) includes freeboard in the criteria. This apparent inconsistency in the respective agency's perspectives regarding levees was the subject of discussions beginning in 1993 and continuing to the present. A detailed discussion of FEMA levee accreditation procedures is provided by (Gutherie et. al, 1991).

The discussions between FEMA and the Corps leading to the adopted policy dealt with the ramifications of acknowledging uncertainty, the need for continuity with past FEMA certification policy, and the desire to improve regulatory decision making. In broad terms, the alternative policies considered were:

a. Ignore risk-based analysis and continue with existing FEMA policy as published in CFR.

b. Base certification on expected flood elevation compared to top of levee elevation.

c. Adopt a conditional non-exceedance frequency target (e.g. 85% reliability) and base certification on comparison with top-of-levee elevation.

d. Devise comprehensive policy that incorporates continuity with existing FEMA policy and makes use of risk-based analysis results.

The policy adopted by the Corps, and concurred in by FEMA, is alternative d. It ensures that application of risk-based analysis is complementary with flood insurance program administration needs. The Corps policy was transmitted to the field by letter dated 10 April 1997 and is appended to this paper. Briefly, the policy is: when RBA data are not available - use existing FEMA levee certification policy; when RBA data are available, certify if have protection to at least 90% conditional non-exceedance probability flood stage (may be higher than existing FEMA policy would require) but protection need not be greater than flood stage corresponding to 95% conditional non-exceedance probability (may be lower than existing FEMA policy would require).

Data for a number of Corps studies provide information upon which to examine ideas and policies. Table 2 is an abbreviated version of the table that was the focus of much of the late-stage discussions between FEMA and the Corps leading to the policy adopted.

Table 2 is rich with information depicting the impact and implications of the adopted policy - it is worthy of study. For example, applying the adopted policy for the 13 stream/levee circumstances tabulated results in the following governing certification elevations: four by existing FEMA policy; four by the lower bound in Corps policy (levee would have to be higher than existing FEMA policy); and five by the upper bound in Corps policy (levee could be lower than existing FEMA policy). Also, of the eleven streams with NED plan elevations noted, there is no relationship between the FEMA certification elevation and the NED elevation; nine would be certified to FEMA with seven governed by existing FEMA policy and two by the lower bound of the Corps policy; and two would not be certified.

CONCLUSIONS

Concluding observations are:

> Application of RBA by the Corps has implications for flood plain management.

> The basic data required to perform RBA is the same as for the historic context; additional analysis is required to quantify uncertainty in flow and stage; and additional information is available for communicating about flood risk to responsible agencies and flood plain occupants.

> RBA does not materially impact the positions of FEMA and the Corps with respect to flood plain delineation - mapping for the FEMA flood insurance program is based on the median probability flood and mapping for Corps flood project studies is based on expected flood stage, just as the respective agency positions were before RBA.

> RBA improves flood damage reduction project benefit estimates and develops additional benefit uncertainty information for use in project selection decisions.

> Flood project performance information is improved with RBA by replacing level-of-protection with expected exceedances and adding conditional non-exceedance probabilities. Communicating performance information requires additional attention by Corps professionals.

> Flood project selection with RBA is very similar to the historic context in that the information and process are the same, but the information available are improved estimates and more complete.

> FEMA levee certification by the Corps has been substantially impacted by RBA. A policy has been developed and adopted through discussions with FEMA wherein the application of risk-based analysis is complementary with flood insurance program administration needs.

Table 2
Corps Levee Project Risk-based Analysis Data

General Information		Risk-based Analysis Data						
(1) Levee Project	(3) FEMA Cert. Elev. (Ft.)	(4) NED Plan Elev. (Ft.)	(5) NED Levee Expected Exceed.	(6) 1% Chance Expected Elev. (Ft.)	(7) Conditional % Chance Non-exceedance		(8) Elev. for Non-exceed. Freq. for .01 Event	
					FEMA (Col. 3)	NED (Col. 4)	90% Elev.	95% Elev.
1. Pearl R., Jackson, MS	44.6	47.0	1/770	41.8	97.6	99.8	43.4	44.0
2. American R., CA	49.1	52.0	1/230	47.1	91.9	94.4	48.5	52.3
3. West Sacramento, CA	32.2	33.5	1/670	29.6	99.9	>99.9	31.5	32.1
4. Portage, WS	798.3	797.0	1/10000	795.6	99.9	99.6	796.6	797.3
5. Grand Forks, ND	834.4	NA	NA	831.5	90.8	NA	834.3	835.2
6. Hamburg, IA	912.2	911.5	1/910	909.8	99.9	99.2	910.7	910.8
7. Pender, NE	1329.3	1330.0	1/380	1327.8	76.3	83.6	1330.9	1331.5
8. Muscatine, IA	560.8	561.5	1/330	558.8	90.1	94.4	560.8	561.7
9. Sny ILDD, IL	474.1	N/A	N/A	471.5	56.7	N/A	476.9	477.7
10. E. Peoria, IL	458.1	462.6	1/10000	458.3	45.3	99.5	460.7	461.2
11. Cedar Falls, IA	864.7	866.0	1/360	862.6	90.0	94.0	865.0	866.3
12. Guadalupe R., TX	57.9	56.8	1/110	56.5	87.2	76.9	58.4	59.5
13. White R., IN	715.0	713.2	1/250	712.3	98.0	86.0	713.5	713.9

Column Definitions: (3) 1% chance median discharge + 3.0 feet. (4) The NED plan levee elevation. (5) The expected annual exceedance probability of the NED levee elevation. (6) 1% chance expected elevation. (7) The % chance non-exceedance of a levee with the top elevation equal to that corresponding to the column noted given the 1% chance median annual event occurs. (8) The non-exceedance frequency elevation for 90% and 95% for the 1% chance median event.

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GUIDANCE ON LEVEE CERTIFICATION FOR THE NATIONAL FLOOD INSURANCE PROGRAM

1. **PURPOSE AND APPLICABILITY:** This document provides guidance to be used for certifying levees to the Federal Emergency Management Agency (FEMA) for their administration of the National Flood Insurance Program (NFIP). This guidance does not affect plan formulation and evaluation procedures. It is intended to provide a consistent methodology for levee certification by the Corps of Engineers. This guidance applies to all Corps District and Division offices. Note that levee certifications are provided to FEMA at the District/Division option and within available funds.

2. **BACKGROUND:** By letter dated 21 March 1996, FEMA, requested that the Corps review its criteria for levee certification in order to ensure consistency in administration of the NFIP by FEMA. This concern has arisen as a result of the Corps application of Risk-Based Analysis (RBA) in flood damage reduction project formulation studies. FEMA's policy requires that levees be structurally sound, properly maintained, and have at least 3 feet of freeboard above the 100-year flood profile elevations before FEMA will recognize that the levees provide protection from the 100-year flood. The FEMA requirements are fully explained in 44 CFR, Chapter 1, Part 65.10 of the Code of Federal Regulations. The FEMA requirements include data and analysis submission requirements for design criteria (freeboard, closures, embankment protection, embankment and foundation stability, settlement, interior drainage), operations plans and maintenance plans. 44 CFR Part 65.10 also states that in lieu of the structural requirements and data and analysis requirements, a Federal agency with responsibility for levee design may certify that a levee has been adequately designed and constructed to provide 100-year protection.

Levee certification for NFIP purpose can best be explained as follow. FEMA may request a "levee certification" from the Corps by letter directly to the Corps District office. The letter normally contains language such as:

> "...Please provide this office with current certification as to whether the design and maintenance of this levee are adequate to credit it with 100-year flood protection. Please note that such a statement does not constitute a warranty of performance, but rather the Corps current position of the levee system's design adequacy..."

3. **POLICY:** The Corps will continue to work with FEMA to ensure that Risk-Based Analysis provides improved information for levee certification decisions. The following guidance and decision tree should be used until further notice.

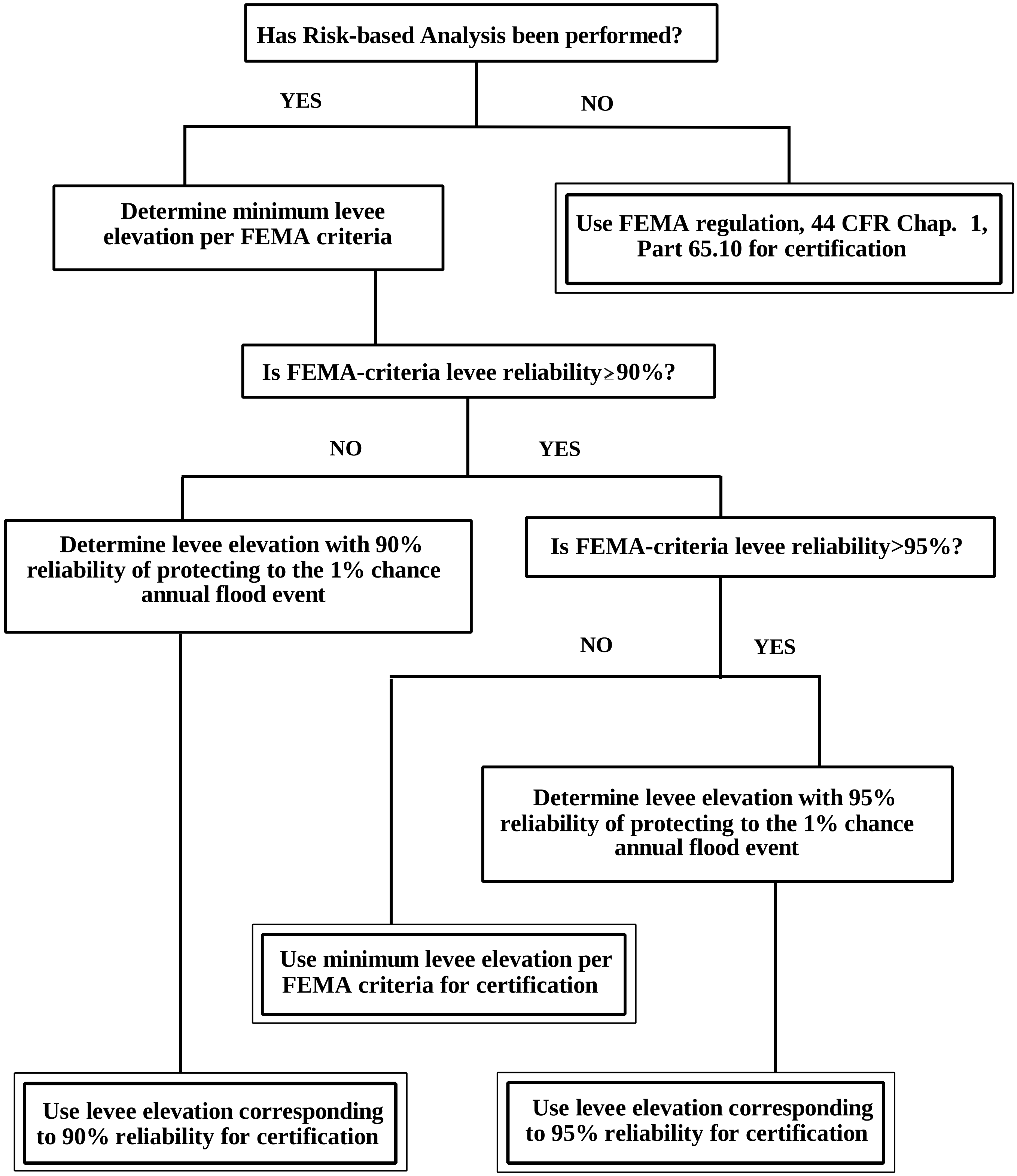
GUIDANCE ON LEVEE CERTIFICATION FOR THE NATIONAL FLOOD INSURANCE PROGRAM

a. **Existing Levees, No Risk-Based Analysis Available**: For certification purposes, the Corps should evaluate the levees based primarily on FEMA criteria contained in 44 CFR Chapter 1, Part 65.10 Thus, the general rule will be that if a levee will contain the median one percent chance flood, with three feet of freeboard, it should be certified as being capable of passing the FEMA base flood, as long as it is adequate based on a geotechnical and structural evaluation, as described below. Exceptions to the three feet of freeboard requirement may be pursued, based on the FEMA policy of permitting other Federal agencies responsible for levee construction to certify that levees will pass the FEMA based flood. Such exceptions should be based on careful evaluation of the hydrologic, hydraulic, structural and geotechnical uncertainties, and current levee conditions as discussed blow.

b. **Existing and Proposed Levees, Risk Based Analysis Available:** In these cases, output on project performance from the Risk-Based Analysis should be used to arrive at a decision regarding levee certification for FEMA. Existing and proposed levees will be certified as capable of passing the FEMA base flood if the levees meet the FEMA criteria of 100-year flood elevation plus three feet of freeboard, with two exceptions, as follows. When the FEMA criteria results in a "Conditional Percent Chance Non-exceedance" (Reliability) of less than 90% the minimum levee elevation for certification will be that elevation corresponding to a 90% chance of non-exceedance. When the FEMA criteria results in a reliability of greater than 95%, the levee may be certified at the elevation corresponding to a 95% chance of non-exceedance. For existing levees, the certification decision is also contingent upon a structural and geotechnical evaluation, as described below. For proposed levees, the geotechnical and structural issues are assumed to be accounted for during design and construction of the levees.

c. **Engineering Evaluation:** A geotechnical and structural evaluation will be used to determine the water elevation at which the levee is not likely to fail. In some cases, this water level will be the determining factor in the decision to certify the levee system. The procedures to be used in the evaluation of a levee system for NFIP levee certification should consist of an engineering evaluation to determine if the levee system meets the Corps design construction, operation and maintenance standards, regardless of levee ownership or responsibility. The District will examine available existing information and data, such as original design, surveys of levee top profile, levee cross-sections, records of modifications and changes, performance during past flood events, and remedial measures. It will also include a field inspection of the levee, structures, closure devices and pumping stations to evaluate the adequacy of maintenance. The engineering analysis should examine the project with respect to embankment stability, underseepage, through seepage, and erosion protection. Existence of closure devices will necessitate a review of the adequacy of flood warning time for the complete operation of all closure structures.

LEVEE CERTIFICATION DECISION TREE



FEMA Criteria = 1% chance median annual flood event plus three feet of freeboard
RELIABILITY = % chance non-exceedance given the 1% chance annual event occurs