Engineering and Design
CERTIFICATION OF LEVEE SYSTEMS
FOR THE NATIONAL FLOOD INSURANCE PROGRAM (NFIP)

Table of Contents

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

Technical Letter
No. 1110-2-570 12 September, 2007

Engineering and Design
CERTIFICATION OF LEVEE SYSTEMS
FOR THE NATIONAL FLOOD INSURANCE PROGRAM (NFIP)

1. **Purpose.** This document is applicable for all US Army Corps of Engineers (USACE) riverine, lake, and coastal levee and floodwall systems certification determinations. The purpose is to provide a consolidated document that will guide USACE procedures for levee/floodwall systems certification determinations in support of National Flood Insurance Program (NFIP) as administered by the Federal Emergency Management Agency (FEMA). This Engineer Technical Letter (ETL) will supplement and clarify existing policy, procedural and technical guidance; provide an overview of documentation requirements; outline an Independent Technical Review (ITR) process; and, summarize authority and funding mechanisms. Technical and procedural guidance in this ETL are intended solely for use in evaluation of existing and new levee systems in support of certification determinations by USACE for NFIP; it is not intended as design guidance.

2. **Applicability**. This ETL applies to all USACE commands having civil works responsibilities. It applies to existing and new levee systems. The finding to be determined is whether the levee system under study meets requirements for certifying that the system can be reasonably expected to provide flood protection from the up-to-date estimate of the one-percent annual chance exceedance flood.

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

4. **References.** See Appendix A

5. **Background**

5.a. Mapping for NFIP Purposes. The US Department of Homeland Security's Federal Emergency Management Agency (FEMA) is the federal agency responsible for administering the National Flood Insurance Program (NFIP). As part of the NFIP, FEMA develops Flood Insurance Rate Maps (FIRMs) to identify areas that may be subject to flooding, to determine flood insurance rates, and for flood plain management activities. Starting in 2002, FEMA embarked in a nationwide flood mapping program called the Map Modernization (Map Mod) Program. Through the Map Mod Program, FEMA will provide the nation with digital flood hazard data and maps, known as Digital Flood Insurance Rate Maps (DFIRMs) that are more reliable, easy to use, and readily available. As part of this process, FEMA is working with federal, state, and local agencies to ensure that the most up-to-date information possible is incorporated into this new digital product. FEMA recognized that many levees may have changed considerably or deteriorated since the current effective maps were published. As part of the remapping process, FEMA is verifying that all levees recognized as providing protection from the base flood meet the requirements outlined in Title 44 of the Code of Federal Regulations, Section 65.10 (44 CFR 65.10), *Mapping Areas Protected by Levee Systems*. Their current policy is formalized in Procedure Memorandum No. 34, *Interim Guidance for Studies Including Levees* (August 22, 2005).

5.b. Levee Certification. Levee certification is a technical finding that, for the floodplain in question; there is reasonable certainty that the levee system protecting the area will contain the base (1% annual chance exceedance) flood. The sole purpose of levee certification is to validate that areas protected from flooding by the levee in question may be shown on Flood Insurance Rate Maps (FIRMS) as protected from the 1% chance exceedance flood. The resultant map determines floodplain properties insurance rates, Federally-imposed floodplain management requirements, and other administrative features of the NFIP. Levee certification is only concerned with the levee system performance associated with the 1% chance exceedance flood event. Levee certification findings do not address nor are the findings concerned with public safety, performance of the levee system for floods other than the 1% event, nor risk to floodplain residents from floods that will exceed system capacity.

5.c. Levee Certification Roles and Responsibility. Before FEMA recognizes or *accredits* a levee system as providing protection from the 1% chance exceedance flood, the system must meet and continue to meet minimum design, operation, and maintenance standards as specified in 44 CFR 65.10. The community or other parties seeking accreditation of a levee is responsible for providing FEMA the data and documentation defined and outlined in 44 CFR 65.10. The design criteria outlined in paragraphs (b)(1) through (7) must be *certified* by a registered professional engineer or a Federal agency responsible for levee design. FEMA does not certify levee systems. The design criteria include, but may not be limited to, requirements for freeboard, closure devices, embankment protection, embankment and foundation stability, settlement, and interior drainage.

5.d. A note on Risk Terminology. The term 'risk' is used among professionals in various fields to convey a variety of concepts ranging from probability or chance of occurrence or exceedance, to uncertainty, to probability of occurrence or exceedance and consequences, and sometimes all of these. The general public tends to associate risk with the idea of chance of occurrence, most often something that is bad and to be avoided. The Dictionary.com definition of risk "*exposure to the chance of injury or loss; a hazard or dangerous chance*" is most consistent with the general public view. In its dam safety policies, and other USACE technical engineering guidance, risk is generally defined as the probability of occurrence and associated consequences, often expressed as a probability-consequence diagram. Note, however, various USACE official guidance documents and policy letters have 'risk' in their titles and these documents often address only probability of occurrence or uncertainty. For this document, the attempt has been to use the more accepted 'probability and consequences' definition for risk, but there are a number of places where using another term besides risk would likely result in more confusion than clarity. Hence, where possible, correct use of 'probability of occurrence or 'exceedance probability' or 'uncertainty' is used but in other instances, the more general term 'risk' is used for probability of occurrence and uncertainty without intending associated consequences.

6. **Policy Guidance**.

6.a. Policy Overview. USACE has issued several policy guidance letters, described below, specifically addressing levee certification for NFIP purposes. In the mid-1990s, USACE adopted a risk analysis approach for flood damage reduction project development. That policy, Engineering Regulation (ER) 1105-2-101, *Risk Analysis for Flood Damage Reduction Studies*, was updated in January 2006. In April of 1997, two policy letters addressing levee certification determinations were issued. The first letter, *Guidance on Levee Certification for the National Flood Insurance Program*, dated April 10, 1997, was issued to ensure consistency throughout USACE with the application of the policy to levee certifications. This letter was updated and reissued with the policy letter, *Guidance on Levee Certification for the National Flood Insurance Program – FEMA Map Modernization Program Issues*, dated June 23, 2006. The emphasis in this updated letter and attachments describes USACE policy in the area of freeboard criteria by providing a performance target that is statistically based, reflecting stream profile variability and uncertainty. The second policy letter, *Geotechnical Activities in Support of Levee Certification for Federal Emergency Management Agency (FEMA) Flood Insurance Purposes*, dated June 20, 1997, established that geotechnical analysis for levee certification determinations would continue to be based on traditional deterministic analysis. In the future, there will be transition from a solely deterministic approach to an integrated approach combining widely understood and accepted deterministic assessment procedures with appropriate risk analysis methodology once the risk approach is developed and finalized.

6.b. Authority and Funding Guidance. A policy letter, *Authority and Funding Guidance for USACE Levee Certification Activities*, dated August 15, 2006, outlines current authorities, programs, and funding mechanisms which are applicable to USACE in relation to performing or supporting levee certification determinations. Available funding sources for the purpose of levee certifications will vary district to district. In summary, the letter provides the following guidance:

6.b.(1) USACE will provide levee certification determinations for levees that it operates and maintains. Schedule of completion will be based on availability of project or operation and maintenance funds.

6.b.(2) Upon request, USACE has authority to provide levee certification determinations for levees in the USACE Inspection of Completed Works (ICW) Program. The certification determination may be funded via ICW funds if available. Otherwise, funding may be provided by the requester via Economy Act (Title 31, Subtitle II, Chapter 15, Subchapter III, § 1535 - agreements between Federal Agencies) or Support for Others (ER 1140-1-211 - agreements between USACE and state and local governments – must also involve Federal assistance from another agency).

6.b.(3) Upon request, USACE has the authority to provide levee certification determinations for levees in the USACE Rehabilitation and Inspection Program (RIP). This includes non-federal levees which meet USACE RIP criteria and have been accepted into the program and is currently in active status. The certification determination must be funded via Economy Act or Support for Others agreements.

6.b.(4) Upon request, USACE has authority to provide levee certification determinations for projects constructed by other Federal agencies. The certification determination must be funded via Economy Act or Support for Others agreements.

6.b.(5) Authority exists to perform levee certification determinations as part of a larger cost-shared project in the study or design phase. Project appropriated funds may be used.

6.b.(6) USACE does not have authority to perform levee certifications for non-Federal projects, which are not within a USACE program or part of an ongoing USACE study or project.

6.b.(7) USACE cannot initiate a cost-shared study for the sole purpose of levee certification.

6.b.(8) For any levee system, USACE may provide technical analysis support for a levee certification determination to be performed by others. Under the Floodplain Management Services Program (FPMS), USACE may provide support using full federal funding, if available, or accept voluntary contributions from state and local governments for the purpose of expanding the scope of services requested. A final levee certification determination may not be completed under the FPMS program. Technical support for a levee certification may also be provided by USACE via an Economy Act or Support for Others agreement.

6.c. <u>Waivers</u>. No waivers granting exemptions from the application of risk analysis to the hydraulic and hydrology evaluation for levee certification determinations will be issued. This refers to the replacement of a minimum freeboard requirement with a quantified assurance of containing the base flood. Any related previous waivers are no longer valid.

6.d. <u>Partial and Conditional Certification Determinations.</u> Levee systems are a collection of components that must function as a complete integrated system be effective. Certification will be based on a professional assessment of likely performance of the complete levee system when subjected to the 1% chance flood and the condition of the system at the time the certification determination is made. Thus, the concept of “partial certification” is not appropriate. In some instances, USACE may be requested to ‘certify’ that a particular aspect of a system will provide the necessary protection. In such an instance, USACE must be careful to provide their results in the context of the component in question meeting accepted design and operation standards but such finding is not to be interpreted as a ‘certification’ finding. The certification finding will be reserved for the levee system as a whole. ‘Conditional’ certification implies that something must be accomplished for the certification to be valid or that something must not happen in the future – such as additional rise of a closed basin lake. Thus, except for as provided in Title 44 of the

Code of Federal Regulations, Section 61.12 (44 CFR 61.12), *Rates based on a flood protection system involving Federal funds*, for insurance rates based on adequate progress towards construction completion, conditional certifications are not to be issued. The findings may be transmitted in a letter that indicates that when such conditions are satisfied, then a certification letter may be issued.

6.e. Maximum Period of Validity for Levee Certifications. Existing policy letters and documents do not specifically address the period for which a certification is to be considered valid. Through numerous deliberations, USACE has chosen 10 years as the agency maximum period of validity until a national standard is established. Letters of certification issued by USACE will include a statement that the certification is valid for a stated period not to exceed ten years. At any time prior to the ten years, it is at the district's discretion to revoke the certification should the district decide that levee system no longer meets certification criteria, such as with inadequate operations and maintenance or change in structural and geotechnical integrity or hydrologic and hydraulic conditions.

6.f. Flood Fighting and Levee Certification. Flood fighting activities are actions taken under emergency conditions that are required to attempt to keep the system from failing. Flood fighting will not be recognized as a measure that can be employed to ensure that a levee can be certified. If the system requires flood fighting to achieve base flood protection, the system cannot be certified.

7. **USACE Role in Levee Certification**.

7.a. Introduction. USACE has had and continues to have a major role in the planning, design, and construction of many levee systems throughout the Nation. Because of this, USACE, in many instances, will be looked upon as having a key role either in performing levee certification determinations or supporting levee certification determinations.

7.b. Levee Certification Determinations. The specific types of levee systems for which USACE has the authority to perform a levee certification determination are described in Section 6b. USACE will perform determinations for systems it operates and maintains if requested by a non-federal government entity with a vested interest, such as a county or local government. For all other levee systems, the process will begin at the request of a local sponsor. Each levee system is unique and USACE districts will work closely with their corresponding FEMA regional office and the local sponsor to determine the applicable authority, resources to perform the requested work, and timeframe. Each USACE district will assess each levee determination request and coordinate within the district to determine, based on the type of project, the applicable funding mechanism or combination of funding mechanisms. Below is a summary of the basic process and is presented in flowchart form in Appendix G.:

7.b.(1) Request is made by a local sponsor. These requests may come into various offices within a district, such as, Operations, Engineering, or Planning. Each district office should designate a single point of contact for requests and develop coordination SOPs. It is important for the district office that receives the request to coordinate with the other district offices that will be involved with the work.

7.b.(2) District determines type of system and which authority, if any, applies.

7.b.(3) District coordinates with FEMA regional office and local sponsor to determine scope of work and schedule. Scope and cost may be based upon availability of data and engineering analyses to be performed.

7.b.(4) District determines applicable funding mechanism. Should the work or part of the work be performed on a reimbursable basis, each district will follow its process to initiate the agreements under the applicable authority.

7.b.(5) District performs technical analysis. The district will develop an investigation strategy (see Section 8) based on the results of a data/literature search and on-site field inspection. The specific technical analysis scope will be based on a step-wise data collection process including design and construction documentation, O&M inspection procedures and inspection reporting, specific event performance records (see Section 9.c) and the levee certification field inspection (see Section 9.d.). The level of detail of technical analysis would then be dependent on the completeness of technical background available to demonstrate the robustness and structural soundness of the levee system. District may choose to coordinate with the FEMA regional office and local sponsor throughout the technical analysis process.

7.b.(6) District compiles documentation and completes a Levee Certification Report (LCR), as described in this ETL.

7.b.(7) District performs Independent Technical Review (ITR) of the LCR.

7.b.(8) District coordinates findings with the FEMA regional office and local sponsor.

7.b.(9) District provides final LCR and findings letter to FEMA regional office and local sponsor.

7.c. Technical Support. In certain instances, USACE may be engaged as a technical resource in support of a levee certification determination as follows:

- To provide existing information, such as, as-built drawings, mapping, geotechnical data, construction documentation plus previous and current inspection reports; or
- To perform specific technical analyses, such as, hydrologic and hydraulic modeling or slope stability and seepage analyses; or
- To review analyses performed by others if requested by a local sponsor in our program.

Districts have the flexibility to provide this support using appropriate in-house resources or on a reimbursable basis through an agreement under the Economy Act if the requester is another federal agency or the Support for Others program in accordance to 10USC3036(d). In addition, the Flood Plain Management Services (FPMS) program can be used to provide support for levee certifications either at 100% Corps funded based on availability of resources and district priorities or on a reimbursable basis through voluntary contributions. Districts will follow their local processes to initiate agreements under FPMS.

7.d. National Flood Risk Management Program. The USACE has established the National Flood Risk Management Program (NFRMP) to develop an integrated national flood risk strategy to improve public safety through a reduction in damage and suffering caused by flood and coastal storm events. The USACE Levee Safety Program is a key component of the NFRMP.

7.d.(1) The USACE Levee Safety Program emphasizes the role of levees to reduce risk and the need to educate the public of the risks associated with levee systems. One of the objectives of the program is to create a consistent risk-based framework to evaluate levees nationally and to prioritize actions to maximize risk reduction to the public. This program will also create a national levee inventory that will serve as a national source of information to facilitate and link multi-jurisdictional activities, which include flood risk communication, levee certification, levee inspection, floodplain management, and risk assessments.

7.d.(2) The objectives of the USACE Levee Safety Program are to protect public safety, reduce economic impacts, maximize cost effectiveness, develop reliable and accurate information, and build public trust and acceptance. In addition to a more robust inspection program, these objectives are achieved through the on-going development of a comprehensive and integrated estimation of risks across all features of a levee system, including an evaluation of the 1% annual chance exceedance event. The Levee Safety Program will be a crucial information resource to support levee certification determinations and to assist the public in making informed and comprehensive flood risk management decisions. Because of this, USACE will continue to have a key role involving levee systems with ensuring the most current levee information is synchronized and communicated to the public.

8. **Investigation and Evaluation Strategies.**

8.a. General. This section suggests a strategy for ensuring efficient and effective use of time and funds in seeking to make certification determinations. The scope of the investigations to support certification could vary widely depending on original design intent, age of project, dynamics of system or completeness of operations and maintenance documentation. Developing the level of study and documentation would in turn influence the cost of a system certification investigation. A key perspective that underpins strategies outlined in this section and the following section is that of system evaluation. A basic tenant of the system evaluation consists of determining whether the individual components and perspectives of hydrology, hydraulics and coastal floods containment, structural and geotechnical performance, mechanical and electrical requirements, operations and maintenance plans, and recent inspection results adequately pass their individual certification requirements. Also key to system evaluation is ensuring that interaction among the components will not result in possible failure, suggesting that a Failure Mode Analysis (FMA) approach may at times be useful. A discussion of FMA as applied to dam safety investigations is contained in *Dam Safety Risk Analysis Methodology,* US Department of Interior, Bureau of Reclamation, May 2003

8.b. Compile Existing Data. All available data will be collected including, but not limited to:

- operations and maintenance manuals,
- performance reports,
- engineering and design documents (including an assessment of the flood hazard, structure components, interior drainage components, geotechnical configuration and placement, etc),
- as-built drawings,
- surveys of top of protection,
- Flood Insurance Study text and maps,
- current hydraulic models,
- base maps showing cross-section locations, construction techniques and inspection reports,
- flood-fighting, maintenance, repair, modification, and rehabilitation records,
- annual and after-event inspection documentation, and
- permits for utility crossings.

Existing data would include current project condition as determined by a levee certification field inspection (see Section 9.d.) of all features and components in the system.

8.c. Initial Screening. Levee systems under study will be tentatively placed in one of three categories based on the data collected. The categories can be defined as: those clearly likely to be certifiable; those clearly likely to not be certifiable, and those levees requiring additional or more detailed engineering studies on which to base a determination. The initial screening should include a preliminary probability of failure and uncertainty of levee overtopping analysis as detailed in Paragraph 9.c.

8.d. Clearly Certifiable Systems. Project systems that have full documentation of system performance including engineering design, construction reports, operations and maintenance documentation and project performance demonstrating the capability of safely containing the 1% chance exceedance flood with significant margin for error can clearly be a certifiable system. To fit in this category the preliminary flood frequency and uncertainty analysis should show at least a 95% assurance of containing the 1% flood. The preliminary 95% assurance should give one the confidence that a more refined final analysis would meet the 90% assurance criteria. Additionally, preliminary geotechnical and structural assessments and related performance predictions must indicate a high likelihood of adequate performance for critical system components when subjected to the 1% chance exceedance flood. Such levee systems will typically be those designed for substantially higher levels of protection/design elevations. The process would then be to perform the field inspection to verify the documentation, perform a hydrology and hydraulic uncertainty risk analysis to verify adequate height to contain the 1% chance flood with 90% assurance, then consolidate the information in a Levee Certification Report (LCR) (see paragraph 10.a.), perform an Independent Technical Review (ITR) and prepare a Certification Letter.

8.e. Clearly Non-Certifiable Systems. Project systems that display significant or critical deficiencies in any particular area of project performance, system design performance prediction, or structural condition and therefore have obvious inability to contain the 1% chance exceedance flood should clearly be identified as a non-certifiable system. The process would then simply be to perform the field inspection to verify the documentation, perform a hydrology and hydraulics uncertainty analysis to verify inadequate height to contain the 1% chance flood with 90% assurance and/or perform appropriate geotechnical or structural analyses to illustrate critical deficiencies, then consolidate this information regarding those deficiencies in a Levee System Report, perform an ITR and prepare a letter documenting the negative findings.

8.f. Systems Requiring Additional Studies. Project systems that have partial or unavailable documentation to clearly demonstrate the capability of the levee system to contain the 1% chance exceedance flood with the necessary assurance, will require additional studies. The next section will provide guidance on the overall approach to parsing the levee system into assessable components which needs to be addressed. In other words, definition of reaches where the hydraulic and hydrology uncertainty analysis would be applied, how the hydrologic and hydraulic loadings would be integrated with elements subject to structural and geotechnical analysis, and other analyses related to a systems evaluation of performance.

9. **Technical Evaluation Guidance**.

9.a. General. FEMA guidelines for assessing the eligibility of a levee system for certification is based on several design criteria and approved operation and maintenance plans. Technical evaluations performed by the USACE for the purposes of levee system certification are aligned with these criteria. Note that while the CFR components continue to be relevant, design approaches and criteria have evolved from those that were applicable for the CFR publication date of 1984. Further USACE has more recently-adopted policies and perspectives re-emphasizing public safety that are appropriate to apply in USACE levee certification determinations. It is these up-to-date policies, engineering concepts and perspectives, and criteria that will be applied for USACE levee certification determinations and which are described in subsequent paragraphs. Major factors to be considered in technical evaluations include:

- O&M Plan
- Levee Certification Field Inspection
- Characterizing the flood hazard
- Capacity exceedance/failure criteria
- Freeboard (or equivalent levee assurance determination)
- Closure devices
- Embankment protection
- Seepage analysis
- Embankment and foundation stability
- Settlement
- Construction records and control testing
- Performance records
- Major maintenance and rehabilitation
- Interior drainage
- Residual risk and public safety

9.b. Overview the basis for certification determination. This section provides the overall approach used to define the flooding hazard including the elements that are relevant to assessing the 1% chance exceedance flood. These elements include the definition of the exceedance criteria, design and construction details, as-built and in-situ status for the full array of engineering assessment factors, operations and maintenance status and plans, residual risk and emergency response plans. Each section will provide a detailing of references and guidance documents and other sources of information and professional state-of-the-practice documents. This section will define overall method for combining levee system assessment elements to establish whether or not that system is certifiable.

9.c. Operations and Maintenance (O&M). One of the initial and final components of evaluation for certification is determining if the O&M of the system is adequate in order ensure the overall integrity and functionality of the levee system during the base flood event. An initial evaluation will help facilitate the identification of observable deficiencies and/or areas which may need further analysis to determine certification. The system under evaluation shall have an officially adopted operation and maintenance manual detailing specific actions and procedures. The manual shall include information such as frequency of O&M activities, provisions for periodic inspections (with no more than 1 year between inspections), and assignments of responsibility for the activities. All O&M activities shall be under the jurisdiction of a Federal or state agency, an agency created by Federal or state law, or an agency of a community participating in the NFIP. Sources of information to use during the evaluation may include O&M documentation, rehabilitation measures, and inspection reports. An additional tool to use for this evaluation is the USACE revised Inspection of Completed Works (ICW) inspection checklist in conjunction with the USACE publication, *Levee Owner's Manual for Non-Federal Flood Control Works*, March 2006, and subsequent publications of this manual. Any deficiencies identified need to be reviewed by the certification team to ensure the deficiencies will not prevent the system from providing protection against the base flood. For example, a project protecting to the .2% chance exceedance (500-year) level could have deficiencies and still provide protection against the base flood. This project could still be certifiable for NFIP purposes. As a final evaluation it may be appropriate to revisit the O&M evaluation after other technical analyses in order to verify that the system components are integrated in order to ensure operability during the base flood event.

9.d. Levee Certification Field Inspection. A levee certification field inspection or field visit will be conducted by an appropriately staffed team. The inspection team should be comprised of disciplines similar to the periodic inspection team under the ICW program. Previous O&M inspection reports (annual or periodic) may not be substituted for a levee certification field inspection but certainly could guide the focus or areas of concern. Part of the field inspection could confirm deficiencies or reveal repair have been completed on required maintenance items. However, the main purpose of the inspection is to collect pertinent information to support the certification determination or identify the areas which need further analysis. The field inspection should consider all aspects of the levee system and to its capability for containing the 1% flood.

9.e. Context of risk and uncertainty analysis for certification determination. USACE policy intent is to apply a probability and uncertainty analysis framework to levee certification determinations for all engineering elements. As of the publication date of this ETL, probability and uncertainty-based methodologies for the hydrology and hydraulics in riverine situations are more mature; elements of the certification determination exist and will be applied as outlined below. Probability of exceedance and uncertainty assessment methods for coastal, estuarine, and lake settings are less mature, are being developed currently, and should be cautiously applied to the greatest extent possible until they become more codified into engineering guidance. Probability of exceedance and uncertainty-based methodologies are under development and emerging for structural and geotechnical engineering elements but are not yet sufficiently mature for direct application in certification determinations. Thus, initially, the risk framework is applicable for only the flow and stage-chance exceedance (still-water-level-frequency) aspect of probability of exceedance and uncertainty assessment, and to a lesser degree other components. As methodologies for these and the remaining engineering assessment elements mature, they will be incorporated into future versions of this ETL, with an anticipated update and revision cycle of one to two years. To provide a vision of the way forward, each of the following technical sections describes the base certification methodology (probability and uncertainty-based for flow and stage-frequency, probability of exceedance and uncertainty based for some other elements, and deterministic for a number of other elements), summarize the status of developing probability of exceedance and uncertainty-based methods, and to varying degrees, outlines the expected future state when the methods mature.

9.e.(1) Risk-based methodologies for analyzing the full suite of engineering and operational elements of a levee system or dam are under development for application to USACE dam and levee safety assessments. These methodologies are expected to be adapted to levee certification determinations and made part of this ETL as they mature.

9.e.(2) Existing guidance for characterizing the storm surge and waves in lake, estuarine, and coastal settings is neither complete nor well organized. Many aspects are covered in sections throughout EM 1110-2-1100 (the Coastal Engineering Manual) and other guidance documents and information products; however, it is not organized well around the subject of flood hazard assessment. Therefore, it does not provide clear and concise, step-by-step, guidance for characterizing the hazard and frequency of flooding associated with storm surge and waves. And, based on work done by the Interagency Performance Evaluation Task Force (IPET) and in the Louisiana Coastal Protection and Restoration (LaCPR) study, certain aspects of the guidance were found to be deficient. Until guidance is updated and made more complete, and more effective, it is important to create awareness of certain aspects that are critical to levee certification (9.f.(5) and its sub-paragraphs, 9.f.(6), and 9.f.(7)), especially where current guidance is deficient.

9.e.(3) A probability of exceedance and uncertainty assessment approach for levee systems in coastal/estuarine settings is being refined, advanced, and applied as part of the LaCPR and Mississippi Coastal Improvement Project (MsCIP) projects, and other work. The approach utilizes technologies that were applied by the IPET to investigate performance of the Southeast Louisiana Hurricane Protection System in response to Hurricane Katrina (see Volume IV, *The Storm*). Flood hazard characterization is being based, in large part, on work done in the LaCPR and MsCIP projects to carefully examine the hurricanes that have occurred in the Gulf of Mexico since the 1940's, their characteristics, as well as tendencies of the most intense hurricanes. Documentation and a number of calculation tools are being developed in the LaCPR study to aid in computing wave overtopping and wave forces; water level, wave, and overtopping frequencies; and uncertainties. Appendix D briefly describes the approach being taken by the New Orleans District to evaluate the issue of levee system certification. It represents a good first step toward flood probability and uncertainty assessment in a complex setting where the flood hazard is dictated by storm surge and waves and is indicative of the future state of guidance on this topic. When these project investigations are completed, the methods will be adapted more fully into this ETL, and into subsequent guidance and other technology-transfer efforts. The approaches being developed are also applicable to those river and lake settings where wind-driven water level changes and/or wind-generated waves are important considerations in levee system design and certification.

9.f. <u>Hydrology, Hydraulics in Riverine and Coastal Environments</u>. Probability of exceedance and uncertainty analysis of levee containment is required for USACE certification of all new and existing riverine, coastal/estuarine, and lake levees. The method includes a probabilistic assessment of water levels and waves (to the greatest extent possible), as well as their uncertainty, for the present conditions. The analysis must include a proper treatment of the types of events (for example, elevated river discharge due to far-field precipitation or snowmelt, local precipitation, strong wind events, elevated ambient lake levels) that alone, or in concert with another type of event, produce a level of flooding that must be considered in assessing the 1% chance exceedance performance for a levee system. The analysis must also include proper consideration of whether or not different types of events can be treated as statistically independent event populations, or if there is a statistical dependence of one type of event on another.

9.f.(1) The probability of exceedance and uncertainty analysis procedure for riverine levees is described in Chapters 4 and 5 of EM 1110-2-1619, *Risk-Based Analysis for Flood Damage Reduction Studies*. For riverine levees the analysis will usually include the uncertainty in the discharge-probability function and in the stage-discharge function. To obtain the chance of non-exceedance of the levee elevation the uncertainties in these two functions are combined to get the uncertainty in the stage-probability function. The Monte Carlo analysis in the HEC-FDA ,*Flood Damage Analysis* program can be used to compute this combined uncertainty as well as the assurance (conditional non-exceedance probability (CNP)) of the levee protecting against the one-percent chance exceedance flood. A levee height can be certified only if its CNP meets the requirements in the June 2006 update of the 10 April 1997 guidance. To be certified a levee must have at least a 90% assurance of providing protection from overtopping by the 1% chance exceedance flood. This minimum assurance is required for all reaches of the levee system. If top of levee elevation is less than three feet above the expected (50%) base flood stage, then the levee can only be certified if the assurance (CNP) is 95% or greater. Top of levee elevation shall not be less than two feet above the expected base flood elevation, even if assurance is 95% or greater, unless approved via the waiver process. As risk methodologies improve and more data is gathered, the two feet minimum requirement will be revisited. It is important to note that this assurance is only for containment; it does not include the probability of failure by any other mode or the combined probability of all failure modes.

9.f.(2). Certification analysis for existing levees will sometimes not have current hydrologic and hydraulic data with defined uncertainty. The engineer doing the certification effort needs to determine if the existing data are adequate for assessing the performance of the levee for current conditions. If not, it must be updated for the certification analysis. For example, data that characterize the water levels reached during recent flooding events in the region should be examined (river discharges, hurricanes, extra tropical storms, etc.). If major events have occurred since the hazard was last evaluated and characterized, the analysis should be updated.

9.f.(3). A field inspection can indicate if there have been major changes in the watershed, surrounding topography/bathymetry, or in the channels that would make the existing hydrologic, hydraulic, and coastal data or hazard assessment out-of-date. A large amount of urbanization of the watershed, or new upstream dams, or diversions, or new or altered channels, could mean the current/most recent flood hazard assessment is dated and should be modified to reflect current conditions. For example, in a riverine situation, major channel erosion, sandbars, or vegetation could make the hydraulic data suspect. If there is a long-term gage in the project area the discharge-probability curve can often be checked by a short reanalysis of the discharge-frequency curve at the gage. Compute the discharge-frequency curve based on the gage annual peaks for the period of record used for the past study and then with the annual peaks extended through the latest available. If the change in the 1% flow is small, the old discharge-frequency curve can be used for the certification. The definition of a small change depends on the particular river but might be less than 5-10%, a change that results in a change in the 1% flood level of less than 0.5 feet, or if the old 1% discharge fits within the 95 and 5 percent confidence limits (90% confidence interval) of the new curve (this is the FEMA criteria for when new hydrology should not be used for flood insurance studies as noted in *Map Modernization,* Guidelines and Specifications for Flood Hazard Mapping Partners, FEMA, May 2003.). This method of comparing results using only gage data can be used to determine if the old hydrology is adequate even if the old hydrology was based on a regional analysis. In this case the analysis of the gage data for the period of record previously used won't match the actual curve used in the past study but the comparison of the gage only data will indicate if a change in the frequency curve is needed. The adequacy of the hydraulic data can also be assessed at the gage by comparing recent discharge measurements to older ones. This will show if the stage-discharge relationship has been changing for the range of flows measured. If the relationship has changed it might be possible to recalibrate the existing hydraulic model to match current measurements. However, in some cases new channel surveys will be needed.

9.f.(4). Sensitivity analysis can be used to test the need for updating the existing data. For example, the performance of the levee can be checked using existing hydrologic and hydraulic data and also using conservative assumptions for how they might have changed. If the levee meets the required certification criteria with the conservative assumptions it can be certified. Conservative assumptions for the hydrology could be increasing the curve statistics (mean of logs, standard deviation, and skew) by more than the analysis of the gage indicated, or using the old discharge-frequency if there have not been any major floods since it was completed. For hydraulics conservative assumptions could be assuming the flood profiles have increased from encroachments to the maximum allowable in the FIS with floodway profiles, or using the old profiles if the river has been enlarging and river stages have been decreasing.

9.f.(5). For lake and coastal/estuarine levee systems, or for riverine levee situations where fetches are sufficiently long, a proper analysis of wave conditions that can accompany extreme water levels must be done. The potential exists for wave overtopping to occur while the still water level is below the levee crest. Wave overtopping is defined here as the condition in which individual waves break on the levee slope, broken wave bores advance up the slope, onto the levee crest, and across the crest and down the levee's protected side if the overtopping volume and momentum is great enough. Current guidance for considering waves and wave overtopping in levee certification is being revised. Adequacy of the analysis procedures that were used in the original levee system design should be examined in light of guidance provided below; and, if it was not addressed properly in the original design, this should be done as part of the certification assessment. The following paragraphs reflect current and emerging guidance for addressing the role of wave overtopping in levee certification. Due consideration should be given to each method presented. A number of revisions stem from lessons learned by the Interagency Performance Evaluation Task Force (IPET) in its forensic examination of hurricane protection system performance during Hurricane Katrina, in subsequent work on levee design and certification for the region, and experience in the international community. Note that because this topic is not addressed in a concise and up-to-date manner in existing USACE documents, the flowing sections 9.f.(5).(a). through 9.f.(5).(p). contain extensive and lengthy discussion intended to educate, caution, and provide guidance regarding evaluation of waves and wave overtopping of levees.

9.f.(5).(a) The general requirement for levee certification is a 90% assurance of providing protection from overtopping by the 1% chance exceedance flood. When wind waves are not present, the flooding event is simply an elevated still water level, or stage. When waves are present the flooding event is the possibility of intermittent wave overtopping as defined above. This is a more complicated situation. In any wind-generated sea-state there is great variability among the heights and periods of individual waves (it is a stochastic process). For example, over a time interval of 30 to 60 minutes, it is not unusual to experience an occasional wave having a height (crest to trough distance) that has nearly twice the value of the significant wave height (defined here to be the average of the highest one-third of the waves). Of course most waves will have heights that are much less than the significant wave height. A single broken wave bore or even a few bores that occasionally reach the top of the levee or even overtop it during any 30 to 60 minute period of time will generally not be problematic from the perspectives of either flooding or levee integrity, so the complete absence of wave overtopping is not nearly as critical for certification as it would be for an overtopping situation when the still water level exceeds the levee crest (steady overtopping is not tolerable). The volume of water, in an average sense over a time span of tens of minutes, which would overtop the levee for the two situations described above (very infrequent/intermittent versus steady) differs by about four orders of magnitude or more. In light of the stochastic nature of waves, the intent for levee certification is to have little to no wave overtopping of the levee, and very infrequently, such that the magnitude of overtopping creates no significant interior flooding and the integrity of the levee is not threatened, all with a high level of assurance.

Any small overtopping volume allowed must be easily handled by the existing drainage system.

9.f.(5).(b) For the present time, the recommended approach for examining the issue of wave overtopping in the context of levee certification is to use a conservative deterministic approach for treating the wave contribution and a probabilistic approach for treating the still water level contribution. Complete probabilistic methods are currently being developed and applied, and examples of those emerging methods are presented in Appendix D; but those methods have not yet been codified into guidance and calculation tools are not yet generally available to fully implement them. The recommended deterministic approach for treating wave overtopping in river and small lake situations involves the following general steps for each levee reach: 1) develop the stage-frequency curve for still water level that considers all the important processes that alone or in concert with one another can generate extreme still water levels, 2) for the events that produce still water levels (stages) which range from the expected 1% chance exceedance value up to the value associated with the 95% confidence interval, define the maximum fetch conditions that can occur for water levels of these magnitudes, and identify the maximum wind conditions that can occur along different fetches for these types of events, 3) use the maximum wind along each different fetch to compute the wave conditions, significant wave height, peak wave period, and mean wave direction, that can be created at the toe of the levee under these conditions (note that the methods for computing winds and waves for large lake, estuarine, and coastal situations is different, more complicated, and additional discussion is provided in later paragraphs), 4) using this set of wave conditions, apply the wave overtopping discharge method, along with an appropriate overtopping threshold value which is discussed later, to calculate the maximum freeboard that is required to reduce the level of overtopping to the requisite small value (note that wave overtopping is reduced for oblique wave incidence compared to normal incidence so different fetches must be considered), 5) add the required freeboard to the expected value of the 1% chance exceedance still water elevation, 6) adopt the larger of this value and the 1% chance exceedance still water level (with 90% assurance), alone, to establish the required levee height. If the existing levee crest elevation equals or exceeds the required height, the levee can be certified. Because a rigorous probabilistic treatment of waves and wave overtopping is not being done, in order to provide the higher level of assurance that is sought, a very conservative approach to defining the wind, fetch, and wave conditions is adopted (i.e., selection of the maximum wave overtopping condition possible at the 1% chance still water level and assuming it occurs concurrently with the 1% still water level). It is also believed that the recommended wave overtopping rate thresholds cited below are conservative. These several sources of conservatism provide the higher level of assurance in this deterministic approach. Additional information about two methods for computing wave overtopping potential (the recommended wave overtopping discharge approach and a second approach, the 2% wave run-up method) and more information regarding methods for conducting wave overtopping assessments in river and small lake settings (paragraph 9.f.(5).(l)) and large lake/estuarine/coastal settings (paragraph 9.f.(5).(m)) are provided in subsequent paragraphs. Due consideration should be given to each method.

9.f.(5).(c) The discussion below examines the two methods for defining freeboard required to reduce the wave overtopping volume to a very low, acceptable, level. Both are covered in EM-1110-2-1100 (Part IV, Chapter 5) and both should be considered when selecting the certification criteria. One, the recommended approach, involves computation of wave overtopping discharge rate (of water) and comparison of that rate with a maximum allowable overtopping rate value, or threshold value. Methods for computing wave overtopping rates for two possible levee situations (with and without an embedded wall) are covered in Part IV-5-2 of EM-1110-2-1100. A second method uses the 2% wave run-up elevation, which is the elevation above the still water level that is exceeded by only 2% of the waves. The 2% run-up elevation is a traditional coastal engineering elevation parameter. At low wave energy levels and for short wave periods, and for simple sloping levees, the 2% run-up elevation is a reasonable surrogate for a very low level of wave overtopping rate. However, for high wave energy and longer period wave conditions which are typical for most large lake, estuarine and coastal settings, the 2% run-up parameter becomes an increasingly inconsistent surrogate for a certain level of wave overtopping rate. Also, some levees have a wall located on and embedded in the crest. The 2% run-up method should not be used for this more complicated levee situation; the concept of run-up is appropriate for a sloping levee surface but does not apply to a vertical wall face. The wave overtopping rate method is applicable to both levee situations. Wave overtopping rate is the best parameter to use in levee certification assessment because interior flooding and levee erodability are both intuitively and directly relatable (from an engineering perspective) to the amount of water coming over the levee; an elevation parameter is not.

9.f.(5).(d) It is informative to examine and compare the two methods for a simple sloped levee case with no embedded wall. The table below shows values of required freeboard elevation above the still water level, computed using both methods for several wave conditions. In the table, the parameter H_s is significant wave height (a statistical measure that represents the average of the highest one-third of the waves) at the toe of the levee; the parameter T_p indicates the peak spectral wave period, also defined at the toe. If a numerical model is being used to generate the wave parameters to be used with these methods, it is likely that the model is generating an energy-based significant wave height parameter (computed from the full wave energy spectrum) not the statistical measure. In some situations the two measures of significant wave height can be assumed to be equal; in some situations they can not, and a conversion from one to the other must be done. Part II-1-3 of EM 1110-2-1100 addresses this topic. The first two wave-condition columns, perhaps the third as well, are representative of conditions that might be experienced in a river or small lake under high winds. Wave conditions reflected in columns three and four are representative of waves in larger lakes and in estuaries under high winds. Wave conditions in column five are representative of conditions in large lakes, in estuaries, and along the coast under hurricane-force wind conditions (storm waves generated in the far field within the ocean would have higher wave periods). Wave conditions in columns four

Calculation Method	Incident Wave Conditions					
	$H_s = 1.5$ ft $T_p = 2.5$ s	$H_s = 2$ ft $T_p = 3.5$ s	$H_s = 3$ ft $T_p = 5$ s	$H_s = 5$ ft $T_p = 7$ s	$H_s = 8$ ft $T_p = 7$ s	$H_s = 8$ ft $T_p = 15$ s
$R_{2\%}$ CEM	2.8 ft	4.5 ft	7.8 ft	14.2 ft	17.9 ft	31.2 ft
Q=0.001 cfs/ft CEM	2.4 ft	4.3 ft	8.2 ft	16.2 ft	21.5 ft	31.2 ft
Q=0.01 cfs/ft CEM	1.7ft	3.0 ft	6.0 ft	12.2 ft	16.5 ft	24.2 ft
Q=0.1 cfs/ft CEM	0.9 ft	1.8 ft	3.8 ft	8.4 ft	11.6 ft	17.1 ft
$R_{2\%}$ TAW	2.8 ft	4.5 ft	7.7 ft	14.2 ft	17.9 ft	26.6 ft
Q=0.001 cfs/ft TAW	2.7 ft	4.7 ft	8.9 ft	18.0 ft	23.8 ft	35.3 ft
Q=0.01 cfs/ft TAW	1.9 ft	3.3 ft	6.5 ft	13.6 ft	18.3 ft	27.3 ft
Q=0.1 cfs/ft TAW	1.0 ft	2.0 ft	4.2 ft	9.3 ft	12.9 ft	19.3 ft

and five are quite similar to the conditions that were experienced along the south shore of Lake Pontchartrain during Hurricane Katrina, albeit well seaward of the levee toe. The east-facing levees of St. Bernard and Plaquemines Parishes were exposed to significant wave heights of 5 to 10 ft and peak periods of up to 15 sec during Katrina well seaward of the toe (conditions in column 6). A typical ocean wave peak period is 12 to 15 sec for storm conditions, up to 20 sec on the west coast.

9.f.(5).(e) In all calculations shown in the table, a typical levee slope of 1:4 is assumed. Wave run-up and overtopping are dependent upon levee slope, in addition to incident wave height and period. Other assumptions made in the calculations are: normal wave incidence, no berm present in front of the levee, a smooth grass levee slope (i.e. no frictional reduction), and Rayleigh-distributed waves. Part IV, Chapter 5 of EM-1110-2-1100 provides guidance for considering these other factors. Oblique wave incidence, the presence of a berm in front of the levee, a rougher levee slope, and the presence of shallow water in front of the levee all act to reduce these values of required freeboard. Values in row 1 of the table reflect the 2% run-up elevation computed using the method outlined in EM-1110-2-1100, denoted as “CEM” for Coastal Engineering Manual, (Eq IV-5-3 with coefficients from Table IV-5-2). The next three rows show the freeboard elevations required reduce the average wave overtopping discharge rate to each of three threshold values that are cited and discussed later: 0.1, 0.01 and 0.001 cu ft/sec/ft, using the method of van der Meer and Janssen that is cited in EM-1110-2-1100 (Eq IV-5-24). Recall that the average wave overtopping rate reflects an average rate over a time span of tens of minutes, not the rate that is associated with any individual wave. The last four rows of the table show values of freeboard that are calculated using methods recommended in recent guidance produced by the Technical Advisory Committee on Flood Defense in the

Netherlands, TAW (2002); specifically, equations 3a and 3b in TAW (2002) for the 2% run-up values, and equations 22 and 23 in TAW (2002) for average wave overtopping discharge rate values. The TAW methods are noted by the authors to be slightly conservative, which they recommend for deterministic design. The TAW guidance recommends using less conservative methods in probabilistic assessments of run-up and overtopping. Note that the TAW guidance uses a different wave period parameter than the peak spectral wave period. Therefore, in the computations made using the TAW methods, the peak period was divided by 1.1 which is the factor the authors cite to relate the two wave period measures. The TAW guidelines use the energy-based significant wave height, which was assumed to be equal to the statistically-based significant wave height for these computations. The results for 2% run-up elevation values computed using Corps' guidance and those computed using TAW (2002) guidance are nearly the same. Freeboard values computed using TAW (2002) guidance for calculating wave overtopping rates are quite similar to, but slightly more conservative than, those values computed using Corps' guidance.

9.f.(5).(f) Table IV-5-6 of EM-1110-2-1100 suggests that the start of damage to an earthen grass-covered sea dike subjected to wave action begins when the average wave discharge overtopping rate is between 0.01 and 0.1 cu ft/sec/ft. For a wave overtopping discharge of 0.001 cu ft/sec/ft the table suggests there is no damage. This overtopping rate reflects an extremely small volume of water; expressed another way, 0.001 cu ft/sec/ft is equivalent to 0.6 cups of water over a levee, every 5 sec (a typical short wave period), per foot of levee length. For wave conditions in the first three columns, which are typical for rivers and small lakes, the table shows quite a bit of consistency between freeboard values computed using the 2% run-up method and values computed using the wave overtopping discharge value of 0.001 cu ft/sec/ft. Both are considered very conservative criterion for levee certification, but might be appropriate if absolutely no water on or over the levee crest can be tolerated. However, for more energetic, longer-period waves, freeboards computed using the 2% run-up elevation method are similar to those computed using the 0.01 cu ft/sec/ft threshold. This inconsistency is one reason why the wave overtopping discharge method is recommended over the 2% run-up method; others were cited previously. Historically, for certification in riverine situations, a freeboard of 3 ft was used. For the lowest wave condition in the table, 3 ft of freeboard suggests protection is provided against any, for all practical purposes, water over the levee crest. The freeboard values for the second column (conditions that might be expected in some riverine situations) suggest that a freeboard value of 3 ft is consistent with use of the 0.01 wave overtopping discharge value, which would also be consistent with Table IV-5-6. However, for higher wave energy conditions, significant wave height of 3 ft or higher, a freeboard of 3 ft might not be adequate. Also note the strongly non-linear variation of required freeboard with increasing wave energy. Use of a constant freeboard across the range of wave conditions is not appropriate.

9.f.(5).(g) As a first pass through the levee certification assessment, the use of a very conservative measure of acceptable overtopping, the 0.001 cu ft/sec/ft wave overtopping discharge threshold, is recommended for examining each reach of levee. If the levee meets this freeboard requirement, then it can be certified. If the levee can not be certified using this conservative criterion, then the specifics of the situation should be examined more closely, and a second pass should be made through the analysis. For example, if a levee fronts an area with a great density of population, the area drains poorly, and the wave overtopping might occur for days or weeks, this level of conservatism may be warranted, and the levee should not be certified based on the pass-1 analysis. If the soil properties of the levee are unknown, or if they are known and it is comprised of primarily non-cohesive silty and sandy soil, the levee should probably not be certified. Levees comprised of silty and/or sandy soil are particularly susceptible to erosion by overtopping. However, if the landscape behind the levee can absorb a small volume of water, greater than the amount inherent to the highly conservative criterion used in pass 1, if the duration of wave overtopping is expected for only a few hours, if the land behind the levee is used for farming, not densely populated, if the levee's soil and vegetation properties are known well and the levee is of high quality, and if the levee is well constructed and maintained, then a higher level of wave overtopping is probably acceptable, as long as the overtopping rate does not compromise the integrity of the levee, and the drainage system behind the levee can accommodate the volume of wave overtopping. Keep in mind that this is not a steady flow overtopping situation, and that interior drainage and pump systems might be able to easily accommodate wave overtopping rates in the 0.01 to 0.1 cu ft/sec/ft range, particularly for short durations. Overtopping duration should be considered in the analysis.

9.f.(5).(h) Whether or not wave overtopping degrades a levee depends upon the overtopping magnitude and subsequent velocities at the crest and on the protected side, soil properties, vegetation cover, duration of overtopping, presence and nature of perturbations on the protected slope, and the levee's quality of construction and maintenance. Levee erosion due to wave overtopping is most likely to occur on the protected side of the levee crest for higher overtopping rates where water velocities can approach critical speeds, on the protected slope where speeds can be supercritical, and at the toe where flow transitions from supercritical to subcritical. Erosion on the protected site of the levee begins as head-cutting, which then often advances toward the flood side. Guidelines for establishing the overtopping rate threshold (i.e., the threshold associated with the onset of levee erosion and damage) for earthen sea dikes found in EM 1110-2-1100 (Part VI), Table VI-5-6, are consistent with threshold values adopted by the Technical Advisory Committee on Flood Defence in the Netherlands (TAW 1989 and TAW 2002) for three different levee conditions (each described qualitatively). The TAW guidance cites metric equivalents that are approximately equal to the following values: 0.0011, 0.011, and 0.11 cu ft/sec/ft; so the threshold values recommended here are slightly more conservative than values adopted in the TAW guidance.

9.f.(5).(i) For an unarmored earthen levee, the maximum acceptable value of average wave overtopping is 0.1 cu ft/sec/ft, unless a higher value can well-supported by site-specific results from large-scale testing involving wave overtopping. Use of this wave overtopping threshold value must be reserved for levee systems that were highly engineered and constructed with good field control, constructed of highly compacted clay or similar erosion-resistant material, with a protective layer thickness of 3 ft or more, and with steps taken during construction to control gullying which can compromise the thickness of the protective layer and introduce undesirable perturbations. An important feature that promotes resistance to erosion during overtopping is a high-quality protective vegetation cover. These levees should have high quality vegetation as slope protection, with high-quality protection vegetation that extends well beyond the levee toe on the protected side. The highest-quality levees are constructed with a thin layer of top soil that is placed to promote smooth levee surfaces, vegetated to promote a dense root system and penetration of the root system into the clay layer. The levee should be actively maintained to retain a high-quality vegetative cover which is free of significant gullying or other perturbations on the slopes that might induce local head-cutting in the event of overtopping. The levee should be free of pockets of more erodable soil that would also tend to promote head cutting in the event of overtopping.

9.f.(5).(j) It is believed the maximum threshold value of 0.1 cu ft/sec/ft for high quality clay levees with high quality vegetation cover is conservative (i.e. a higher value of wave overtopping can be withstood before any damage begins). Emerging data suggest that this is the case for high quality levees; that acceptable values might be as high as 0.3 to 0.5 cu ft/sec/ft, perhaps higher. Also, based on Hurricane Katrina experience, east- and south-facing levees in southernmost St. Bernard Parish were undamaged. These levees apparently experienced conditions in which the still water levels were only 1 to 4 ft below the levee crest elevations and significant wave heights were present, on the order of a few feet, and peak wave periods were quite long (on the order of 15 sec). Levees along the south shore of Lake Pontchartrain experienced some overtopping in places but no significant damage to speak of, and peak significant wave heights of about 8 ft or more, and peak periods of 7 seconds, were measured just offshore. The highest high water marks found on the levees along the south shore (based on debris deposited on levee slopes) were about 6 feet above peak still water levels. This suggests that freeboard estimates of 8 to 12 ft (from the table above), even for a threshold value of 0.1 cu ft/sec/ft, might be overly conservative. However, until more data are acquired, the maximum threshold value of the overtopping discharge rate should be retained as 0.1 cu ft/sec/ft in a second pass through the certification analysis, and this value should be reserved for the highest quality, most erosion-resistant levee conditions.

9.f.(5).(k) The wave overtopping rate threshold for lesser quality levees and lesser quality vegetation cover are lower. The overtopping rate threshold for a clayey soil with relatively good grass cover is 0.01 cu ft/sec/ft. This value is expected to be a more typical value for the wave overtopping threshold. As was mentioned previously, levee sections constructed of silts, silty or fine sands, and all hydraulically-placed materials will have even lower overtopping thresholds; and they must be considered highly susceptible to erosion and breaching in the event of any significant wave overtopping. The wave overtopping rate threshold for levees constructed with these types of materials, or via hydraulic placement, or levees with poor turf, is much lower (0.001 cu ft/sec/ft). If the soil composition of a levee is unknown or highly uncertain, this low threshold value of overtopping, 0.001 cu ft/sec/ft, should be used. Selection of a threshold overtopping rate should be well-supported and documented as part of the levee certification assessment. Until more is learned about how the thresholds relate to all the factors that dictate levee erosion and degradation, these are the recommended values. Past experience by both the

Dutch and Japanese have been considered in developing these values, and their experiences have shown these to be reasonable values. Simple methods for calculating average wave overtopping rate are adequate if the actual levee cross-section is similar to those used to develop the method (e.g., simple uniform slopes or similar berm dimensions). For more complex cross-sections that are unlike those used in the development of the simple methods, such as cross-sections having elevated roadways, benches or steps, offshore submerged breakwater features, application of a more rigorous and accurate tool is warranted; either a Boussinesq-type numerical model such as BOUSS2D (see EM-1110-2-1100, Part II, and http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;23) or physical scale model tests involving actual cross sections and wave conditions. For complex open coast wave situations (e.g., narrow-banded sea states that occur on the west coast, or double-peaked wave energy spectra, where the wave field is comprised of both long-period energy generated in the far-field and wind seas generated in the near field) the simple calculation methods are less accurate. Again, in for these conditions, use of a more rigorous numerical model might be warranted.

9.f.(5).(l) Wave Overtopping in Rivers and Small Lakes. At present, waves can be treated deterministically in riverine and small-lake situations because there is no standard accepted methodology for quantifying the uncertainty distribution for riverine waves, and for combining wave uncertainty with the discharge-probability and stage-discharge uncertainties discussed above. The method for defining the 1% chance of exceedance still water levels was described above in paragraph 9.f.(1). For lakes, increased still water levels due to wind forcing and/or changes to ambient lake levels, and waves, are the most likely and dominant contributors to the 1% chance of exceedance. In light of the dependence of wind forcing on water depth, lake levels and wind-driven events might not be statistically independent events, for example in shallow lakes. Wave conditions are a function of the following: wind speed and direction in relation to the available fetch, duration, spatial and temporal wind variability, water depth throughout the fetch, depth gradients that control wave refraction and shoaling, and local depth which controls wave breaking. Paragraph 9.f.(5).(p) discusses several important considerations in estimating surface, over-water winds, for use in computations of wind-generated waves and water levels. Part II (Chapters 2 and 3) of EM 1110-2-1100 provides guidance for estimating wave conditions. The restricted-fetch (or narrow-fetch) assumption, and simplified one-dimensional wind wave prediction methods are generally adequate for use in most flooded river and small lake situations, unless the fetches become quite large and two-dimensional (variable in both horizontal dimensions). Note that the wave overtopping discharge rate method should be used as the threshold for levee certification in all riverine, lake, estuarine and coastal situations where waves are important. However, if a runup elevation method has previously been used in the levee design, and if use of that runup elevation provides a more conservative (higher) value for the required levee elevation than that determined using the analysis method outlined above (based on wave overtopping rate threshold), then the levee is certifiable from a wave overtopping perspective.

9.f.(5).(m) Wave Overtopping in Estuarine/Coastal and Large Lake Situations. For the coastal and estuarine situations, extreme water levels due to a combination of astronomical tide and storm surge (which is primarily, but not exclusively, wind-driven) associated with extratropical and/or hurricanes, combined with waves generated during these events, are primary contributors to the flooding hazard for the 1% chance of exceedance. In most cases it is a reasonable assumption to consider astronomical tide and storm surge to be statistically independent phenomena. Astronomical tide-frequency and storm surge-frequency distributions can be convolved, using the assumption of statistical independence, to yield still water level-frequency curves; or astronomical tide (which is periodic and quite predictable) can be considered as an aspect of uncertainty in generation of still water level-frequency curves. Part 2, Chapter 5, of EM 1110-2-1100 provides information on computing water levels associated with tides and wind-driven events. Multi-dimensional analysis of winds and waves is needed for estuaries and coastal regions, and very large lakes, where the surface wind fields themselves exhibit two-dimensional (in space) variability, and the water bodies (available fetches) are large relative to the size of the wind system, and where moving wind systems produce complex and highly energetic wave fields. Wave conditions can vary considerably along the shoreline in these situations. An approach for conducting a probabilistic analysis of water levels, waves, and wave overtopping in coastal/estuarine settings is being developed and applied to examine certification of levees which comprise the hurricane protection system in southeast Louisiana. The approach utilizes technologies that were applied by the IPET (see Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System: Draft Final Report of the Interagency Performance Evaluation Task Force, Volume IV, *The Storm,* 2006). Definition of the storm threat is being based on work done in the LaCPR and Mississippi Coastal Improvement Projects to carefully examine the hurricanes that have occurred in the Gulf of Mexico since the 1940's, their characteristics, as well as tendencies of the most intense hurricanes. Documentation and a number of calculation tools are being developed in the ongoing studies to aid in computing wave overtopping and wave forces; water level, wave, and overtopping frequencies; and uncertainties. Appendix D briefly describes the approach being taken by the New Orleans District to evaluate the issue of levee system certification; it represents a first step toward a probabilistic treatment of wave overtopping in a complex coastal/estuarine setting where the flood hazard is dictated by storm surge and waves. The approach is the recommended one at this time for coastal/estuarine and large lake situations; and it is indicative of the future state of guidance on this topic. When these project investigations are completed, the methods will be adapted more fully into this ETL, and into subsequent guidance and other technology-transfer efforts.

9.f.(5).(n) Defining the Hurricane Hazard. Hurricanes are the primary flooding event of concern for determining the 1% chance exceedance, along the Gulf of Mexico coast and most of the Atlantic coast. Thus, they are extremely important in certification of levee systems along the coast and in estuaries. Storm surge can propagate tens of miles up rivers and deep navigation channels. Hurricane surge can inundate wetlands and barrier islands, and expose estuaries to high storm surge and long-period, high-energy ocean wave conditions. Hurricanes might also be the primary events for some interior river and lake systems because of the diminished, but still high, wind-generation potential. Current guidance in Part 2 of EM 1110-2-1100 for assessing the hurricane hazard is deficient. Special care must be taken to characterize the hurricane-induced flood hazard. Where hurricanes are the primary cause for severe flooding, land-falling hurricanes are the events that are most relevant to assessments of the 1% chance exceedance event. The occurrence of major land-falling hurricanes at any one location is rare. Central pressure, radius-to-maximum winds (a measure of the storm's size), and the coastline shape and continental shelf width and configuration are the most important factors in determining hurricane storm surge. Also, the hurricane surge experienced at a location is greatly dependent upon the hurricane track. Sole reliance on the local historical hurricane experience (the limited range of central pressure, radius-to-maximum-winds, and track characteristics that are reflected in the small number of hurricanes that have had a major impact, locally), even as part of an Empirical Simulation Technique (EST) application, will not yield a sufficiently accurate assessment of the hurricane flood hazard. An accurate assessment must properly consider other hurricane characteristics that are possible in a local area. Only data acquired since 1940 should be used to characterize hurricane probabilities and their characteristics. Only since the 1940's have aerial reconnaissance, radar, and other sensing technologies enabled hurricanes to be characterized accurately. An exception would be a major hurricane that impacted the region prior to the 1940's, whose characteristics are can be reliably incorporated into the analysis. To assess the 1% chance of exceedance, a Joint Probability Method (JPM) approach should be used to properly define the hurricane hazard (in terms of still water level-frequency relationships). A recommended approach for applying the JPM to define the hurricane hazard, in an optimal manner, has been developed and applied in the LaCPR and MsCIP projects (see the as yet unpublished whitepaper by Resio et al, 2007). The JPM approach is the best approach for properly considering other hurricane characteristics and tracks that are possible for a region but have not occurred historically, as opposed to consideration of historical occurrences only, or use of the EST applied to only historical hurricanes. In the implementation of a JPM approach, in order to accurately characterize what is possible in the way of intense hurricanes, close examination should be made of the characteristics and tracks associated on the most intense hurricanes, and the decay in intensity as hurricanes approach landfall. The JPM tends to be a computationally intensive method to employ, and that has been why the EST method has been adopted in the past. However, the LaCPR project has developed an optimal sampling approach that minimizes the number of storms that need to be considered in applying the JPM. If a JPM approach has not been used to define the hurricane hazard for a levee system where it is a primary design event for 1% chance of exceedance, then levee certification will require that it be done. If a JPM analysis was done previously, but it includes consideration of storms prior to the 1940's and/or does not account for the major hurricanes that have occurred since 1995, then the analysis should be updated. A pattern of increased hurricane activity and intensity began around 1995.

9.f.(5).(o) Defining the Non-Hurricane Hazard. Reliance on historical water level data and fitting of an extreme probability distribution to those data in small-lake situations, or model simulation of extreme water levels associated with historical storms in a large lake or coastal/estuarine situation, along with application of the EST approach, is a sound approach for characterizing the still water level-frequency relationship associated with extratropical storm or non-hurricane, wind-driven events, if sufficient historical data are available. A data record length of 40 to 50 years is considered sufficient for accurate assessment of the 1% chance of exceedance. Data must accurately reflect conditions in the area of interest. Gages where measured data are available are often located in protected areas that may or may not reflect conditions at the locations of interest. Often, sufficient data are not available for this length of time, and other prediction methods or models must be used to characterize the water level (and wave) conditions associated with extratropical storms or other extreme wind events that have occurred over the past 40 to 50 years. In large water bodies, model simulation is usually required because of the two-dimensional nature of storm wind fields. If the still water level-frequency analysis for non-hurricane events has been based on the historical record, but the data record is older and/or of insufficient length, the flood hazard characterization should be reassessed as part of the certification process.

9.f.(5).(p) Defining Wind Conditions. The accuracy inherent in estimates of water levels and wave conditions associated with wind events is only as good as the accuracy of the wind input. And, because wind stress is non-linearly related to wind speed, errors in wind are amplified in water level and wave estimates. Therefore, when defining winds, it is important to maximize the accuracy of wind estimates; it is important to use a wind drag law that changes with wind speed (the Garratt (1977) wind drag is recommended for all wind-driven water level computations); and it is extremely important that consistent measures of wind speed are used for water level and wave prediction, and they can be different for each type of calculation. Wind estimates should reflect estimates of over-water winds, not over-land winds, and they should consider air/water temperature differences. Chapter 3 of EM 1110-2-1100 describes procedures for properly estimating over-water winds and how to account for air-water temperature differences. It is extremely important that the measure of wind speed that is used as input to water level and wave calculations is exactly the same as the wind speed measure that is inherent in the method(s) being used to do the calculations. For example, the Garratt drag law assumes the wind speed to be used with it in computing wind stress reflects a 10-min average wind speed at 10-m elevation above the water surface. So water level computations using the Garratt drag law should use over-water wind input that reflects a 10-min average value at a 10-m elevation above the water surface. Often in wave calculations, a 30-min average over-water wind speed at 10-m elevation is used. Consistency is the key. Chapter 3 of EM 1110-2-1100 also describes procedures for making corrections to reference winds to different wind averaging intervals and to different elevations. Use of an inappropriate measure of wind speed, such as use of a 1-min gust speed with the Garratt drag law, can lead to significant over-predictions (errors) in computations of water level and wave conditions. Another example of inappropriate use is using flight level wind measures, which NOAA often publishes, with the Garratt drag law which requires a surface (10-m) elevation wind measure. This error can also lead to significant over-predictions of water levels and wave conditions. It is advisable to have a trained coastal meteorologist review the method that is being used to create wind input to water level and wave computations because of the crucial nature of wind input

9.f.(6) Levee Erosion on the Flood Side. Erosion of the flood-side of a levee by wave action can also be an issue of concern at elevated water levels. Breaking waves on the flood-side slope, if present for a sufficiently long duration, can erode the levee, diminish its cross-section and potentially lower the crest elevation. Erosion potential is a function of incident wave characteristics, duration of wave action, levee soil properties, and presence of protective vegetation cover. Levees comprised of non-cohesive soils (silts and sands) are especially prone to erosion by this process, even if exposed to wave action for only several hours. Certification assessment should consider the possibility of erosive wave action, the possible duration of this wave action, and the likelihood that erosion that would degrade the levee at the 1% chance exceedance water level, considering the wave conditions that can occur at this water level. At present there are no reliable methods for predicting wave-induced erosion on flood-side levee slopes, for levees comprised of cohesive and mixed sediments. Methods are available for predicting erosion of sand embankments by increased water levels and wave action (see EM-1110-2-1100, Part V, Chapter 4).

9.f.(7) Dynamic Wave Loadings. At locations with potential for dynamic wave loading, an important part of certification procedures for structures is determination of loads and related stresses, deformations, and stability conditions of structural members. If waves are present, dynamic wave loadings can be an important consideration in design and certification of a levee system that contains flood walls or other structures, especially those with vertical faces. Dynamic wave loadings on vertical faces can greatly exceed hydrostatic forces, cause damage through repetitive high-impact loadings, and lead to failures of the flood protection system. Chapter VI-5, Fundamentals of Design, of EM 1110-2-1100 contains information that relevant to structures that are part of levee systems that are exposed to wave action.

9.f.(7).(a) In the case of rubble-mound structures exposed to waves, specific procedures cannot be followed as theory does not cover wave loading on single stones or blocks. Instead, the structure must be considered as a whole and thus an integrated approach is used to establish relationships between certain wave characteristics and structural response, sometimes in terms of armor movements. These types of loading situations are covered in Part VI-5-3 of EM 1110-2-1100.

9.f.(7).(b) For vertical-front monolithic structures such as seawalls and floodwalls, wave loadings can be estimated from theory or experiments. This type of analysis is covered in Part VI-5-4 of EM 1110-2-1100. Different types of wave forces on vertical walls are identified. Non-breaking wave loads can be treated as a pulsating load. It can be treated as a static load in stability calculations. Breaking waves that break in a plunging mode, with an almost vertical front just before contact with the wall can generate very high pressures with short duration resulting in a large single-peaked force with each wave impact. A breaking wave with a large air pocket produces a double-peaked force, in which the first and largest load occurs when a wave crest hits, producing a hammer shock. The second peak is induced by compression of the air pocket, or compression shock. Frequent wave breaking at a vertical structure will not occur for oblique waves with angle of incidence greater than +/-70 deg relative to normal incidence to the structure, so hydrostatic analysis can be performed for these conditions. Otherwise, for waves that approach from angles less than +/- 70 degrees relative to normal incidence to the wall, wave impact pressures must be considered.

9.f.(7).(c) The ability to predict the impact pressures of breaking waves is difficult due to their extremely stochastic nature. The loads can be very large, and chance of failure increases with the number of loads. Design of vertical structures should avoid wave breaking directly on the vertical face to the greatest extent possible. This can be aided by placing armor units in front of the vertical wall to help dissipate wave energy, maintaining a mild slope of 1:50 or less over a distance of several wavelengths in front of the structure, or using a sloping-front face from still-water level to the crest (however a sloping-front structure allows more overtopping than a vertical wall of equivalent crest height). For walls without gentle slopes, or armored slopes, or for walls imbedded into steep-sloped earthen levees, dynamic wave pressures on the walls need to be assessed as part of the certification process, for situations where waves are present at elevated water levels.

9.f.(8) Assess System Weaknesses and Vulnerabilities.. Analyses done to support certification should carefully examine the potential for locations of critical weakness links in the flood protection system. Critically weak locations can compromise an otherwise robust levee system. Water naturally seeks out the low spots in a levee or weaknesses in the soil. Low spots in levee crest elevation can occur at scales much less than the reach scale used in design or certification of the levee. The same is true for local conditions of poor soil or vegetation properties, a poorly maintained section, areas exhibiting tendencies for settlement of a levee or wall, areas where waves and water levels might be locally higher than in adjacent areas, such as a particularly long stretch of river aligned with the predominant wind direction during severe storm conditions, or features that would tend to concentrate wave energy or flow. It is extremely important that the entire levee system be thoroughly reviewed to identify critically weak locations at the highest spatial resolution possible, particularly in systems that are not well compartmentalized on the protected side. Use of high-resolution LIDAR and other survey data, imagery and other visual data sources, and in situ acquisition and analysis of data, should be maximized to search for and identify critically weak locations in the system. An assessment of critically weal locations, or potential critically weak locations, should be included as part of the certification report.

9.f.(9). Interior Drainage. Drainage of storm water from floodplains protected by levee systems is impeded by the presence of the levee at the line-of-protection. Flooding that may occur from the drainage-impeded water must be analyzed and the resulting impacted floodplain reflected on flood insurance maps. Insuring that interior runoff is delivered to the-line-of protection is a local responsibility. The levee certification analysis does not include computation or display of interior flooding that is not impacted by the levee. The analysis of interior flooding is based on a coincident analysis of exterior and interior stages that includes the capacity of gravity and blocked gravity drainage features. Coincident analysis for interior areas is explained in Chapter 4 of EM 1110-2-1413, *Hydrologic Analysis of Interior Areas*. For riverine levee systems, the interior analysis considers interior rainfall events during both low river stages (gravity conditions) and high river stages when the gravity outlets are closed (blocked conditions) and the performance of pumping stations as might exist. As described in the referenced EM, there are several ways to compute the combined probability of interior stages from these events. For certification of existing levees a reanalysis of interior stages may not be required. If the existing levee is considered adequate the current flood insurance study the coincident interior flooded area should already be mapped. In this case the certification of the levee will not require a reanalysis of interior flooding and thus will not require modifications to the flood insurance maps. However, if there are obvious errors in interior mapping the interior flooding analysis should be reanalyzed and the flood insurance maps redone. For lake and coastal levee systems, besides impeded flow from interior runoff, the volume of water that may enter the floodplain from wave overtopping of levees from wind-driven waves as discussed in paragraph 9.f.(5) and its sub-paragraphs must be considered; this can be particularly important if the floodplain under study is small and confined to near the coastal protection levee. Preparation of the final maps and coordination of these with residents is the responsibility of the community, the state and FEMA.

9.g. Structural Technical Evaluation Guidance and Site Visit. There currently is no explicit Corps of Engineers guidance for the structural evaluation of existing levee structures. Most structural evaluations have a number of basic steps in common. The first and most important step is to define the existing condition of all of the flood damage reduction system's structural components. This should be done by reviewing available information, which should include a review of Periodic or Annual Inspection Reports, and a review of any instrumentation data that has been collected. This part of the evaluation should include a review of the most recent corrugated metal pipe (CMP) condition assessments, if any exist. A site visit to visually assess the structural elements is required. The next step is to procure a copy of the design analysis, including calculations, prepared by the original designers to determine how the structural elements were designed, including what loading was assumed. The results of the original analyses must be compared to current USACE guidance to verify that the structures meet current design requirements. If the original design analysis is not available, then a detailed analysis will have to be performed in accordance with current Corps guidance. This step is outlined in some detail within this guidance document. The actual condition of the structures, gleaned from either a site visit or a review of the most recent inspection reports, may cause the section properties in the analyses to be revised from the original analyses. Finally the lessons learned from Hurricane Katrina as outlined in the IPET report must be reviewed to see if any of the project's structural elements, particularly I-Walls, need to be further evaluated in light of the catastrophic failures that occurred in New Orleans.

At the present time, deterministic criteria should be used to perform the analyses associated with certification. The deterministic criteria will be based on the current stability and strength criteria developed from and based on current design standards. Analysis must show the existing structure (floodwall monolith – T-wall, I-wall or L-wall; closure monoliths; closure gates; pump stations; gatewells) meets the criteria below. At least one typical monolith of each size range on the project should be evaluated. For example, if there are 30 different 10-foot high T-wall monoliths on the project, 60 different 15-foot high T-wall monoliths on the project, and 120 different 20-foot high T-wall monoliths on the project, an analysis of one such monolith of each height shall be completed. However if the soil conditions are noted to be different for some of the monoliths, an analysis of one such monolith of each height for each discrete foundation condition shall be completed. An engineer specializing in geotechnical engineering with specific experience and knowledge of flood damage reduction systems should be the person charged with determining how many different foundation conditions must be evaluated for the project.

9.g.(1) Stability Requirements for Concrete Structures - Structural stability criterion shall be based upon EC 1110-2-6058, *Stability Analysis of Concrete Structures*, dated 30 Nov 2005. A determination must be made whether the structure(s) in question are defined as "critical" or "normal" as defined in EC 1110-2-6058; Appendix H of that document provides guidelines for making this determination. However in general a flood damage reduction system for which FEMA certification is sought would have people within the protected area and would be considered a critical structure. Once this determination has been completed the Load Condition Category must be determined. For purposes of levee certification, the 1% event elevation shall be used, and by definition, this is considered an "Unusual" event. The next step is to determine whether the site information available is "Well Defined" or "Ordinary". EC 1110-2-6058 does not allow a structural evaluation to be completed for a Critical structure for which only "Limited" site information is available; for such a case, Certification cannot be completed unless additional site information is obtained. The definition of "Well Defined", "Ordinary" and "Limited" are presented within EC 1110-2-6058. Required factors of safety for sliding, flotation and resultant location (overturning) are provided in Tables 3-2, 3-4 and 3-5, respectively, in EC 1110-2-6058. Using the above criteria the engineer should establish the stability factors of safety for all structures on the project. All analyses shall be prepared and submitted as part of the Certification Report.

9.g.(2) Concrete Structures Strength Requirements

9.g.(2).(a) ACI 318, "*Building Code Requirements for Structural Concrete*", Chapter 20, and ACI 437, "*Strength Evaluation of Existing Concrete Buildings*" both provide a basis for evaluating the strength of existing flood damage reduction structures. In paragraph 4.2.1 of ACI 437 it states that evaluation solely by analysis can be performed if sufficient information is available about the physical characteristics of the structure; and if load testing is impractical or unsafe. It further states that analytical evaluation is appropriate if an accepted methodology exists for analyzing the type of structural system under consideration; and characteristics of the structural elements can be determined and modeled within acceptable limits of error. Accepted methodologies exist for analyzing flood damage reduction structures. These methodologies are discussed in paragraph 9.g.(2)(b) below.

ACI 437 paragraph 4.2.1 also implies that if the conditions outlined above do not hold true for the structure or system under consideration, evaluation by analysis together with in-place load testing is appropriate. This is the basis for the high value placed on performance of floodwalls and levees during floods, which is discussed in detail in paragraph 9.h.3 in this document. It may be very difficult and expensive to perform full scale load testing of flood damage reduction system components because of the effort required to provide the flood loading. In general a cofferdam must be built on the flood side of the structure being tested; inside this cofferdam the test flood load must be impounded. Additionally instrumentation should be installed to measure deflections, stresses, and piezometric head. Full scale flood load tests were performed for I-Walls in Paducah, Kentucky in 1939; at Tell City, Indiana in 1941 and on a series of specially built T-Walls in Cincinnati, Ohio in the early 1950's. At the time of the publication of this document existing I-Walls were being tested along one of the New Orleans Canals near Lake Pontchartrain. None of the test programs listed here included tests to failure.

9.g.(2).(b) Analysis of existing flood damage reduction structures should be performed using the design methods outlined in EM 1110-2-2104, *Strength Design for Reinforced-*

Concrete Hydraulic Structures. This Engineering Manual is consistent with the design methodology of ACI 350, *Code Requirements for Environmental Concrete Structures*. These documents both utilize the Strength Method for design, which uses partial load and resistance factors that are calibrated to achieve a structural design with uniform reliability for all members across a range of loading sources such as wind, gravity, and applied live load for all limit states. For example live loads (such as flood events) are more random and have higher uncertainty than dead loads; hence code calibration results in a higher load factor for live loads than dead loads. On the strength side of the equation, the strength reduction factor is calibrated to account for the accuracy of strength prediction models, repeatability/inspectability of construction methods, and the type of failure mode (brittle or ductile). The strength prediction model for flexure is more accurate than shear; hence the strength reduction factor is higher for flexure than shear. Multipliers less than 1.0 are generally applied to load combinations of wind, live load, dead load, and earthquake to reflect the lower joint probability of all events occurring at their maximum magnitude at the same time; the joint probability is low. EM 2104 requires that the Single Load Factor Method be used, which requires that both the dead and live loads be multiplied by the same load factor (LF) of 1.7. Because flood damage reduction structures are all considered hydraulic structures, all analyses shall include multiplying the basic load factor by the additional hydraulic load factor, H_f. EM 2104 does not require that earthquake loads be combined with flood loads in analysis. Therefore for the certification analysis, earthquake loads do not have to be included in any load combinations evaluated.

9.g.(2).(c) Appropriate concrete strengths and reinforcing steel strength should be used in the analysis. Table 3.1 in ACI 437 provides yield strength properties for reinforcement going back to 1911. The evaluating engineer should review as built drawings and specifications, if available, to determine the steel type and grade that was used. If as built information is not available, the best estimate should still be made using the table referenced above together with the closest known age of the component being analyzed. For concrete the best way to determine compressive strength is to test core samples in accordance with paragraphs 3.1.1.1 and 3.1.3.1 of ACI 437, as there are no in-place tests that provide direct measurement of the compressive strength of concrete.

9.g.(2).(d) Using the above criteria the Structural engineer should establish that the required strength is at least equal to the effects of factored loads for all structures on the project. It is not intended that each individual floodwall monolith be analyzed, but that representative structures for the project be analyzed. For example if any structures on the project are in deteriorated condition, those structures should be analyzed utilizing reduced section thicknesses and reduced reinforcement cross sectional areas, as would be appropriate for the structure. Such damaged or compromised structures are likely weak points in the line of flood protection and therefore represent elements with a higher likelihood of failure. Additionally all representative floodwall types (I-walls, T-Walls and L-Walls) should be analyzed, and a range of heights, including the maximum wall height for each representative structure, should be represented. All analyses shall be prepared and submitted as part of the Certification Report.

9.g.(3) Closure Evaluations. Closure structures, which are temporary structures placed in openings in the protection system such as rail and other transportation crossings, shall be evaluated based on three primary factors:

9.g.(3).(a) Ensure that the structure has been designed consistent with the specific characteristics of the flood threat. Considerations include: Rate of water level rise; duration of need for closure; and velocity and other relevant hydrologic and hydraulic parameters. Care must be taken to ensure that time is available to accomplish the closure by also designing and implementing an associated flood threat recognition and warning system. This implies that for a flood damage reduction system designed for flash-flooding, where the time from flood threat recognition and warning until floodwaters arrive may be only minutes, it is unlikely; that an assembled truss/stoplog type closure nor a sandbag closure are appropriate because construction/assembly of these types of closures may not be possible within the time allowed. A swing gate or rolling gate closure would be more appropriate for a situation of short closure times. On a large river systems where there maybe several days to over a week of forecast time to rise, closures that require a team of laborers several days to construct may be appropriate. Many projects fall between these extremes that will require careful consideration of the reliability of flood forecasts and warning times, hydrograph shape and duration, and analysis of how long a particular closure assembly takes to complete to determine whether or not a certain type of closure is appropriate.

9.g.(3).(b) Structural evaluation of steel closure structures (assembled truss closures; slide gates; roller gates; or swing gates) is required. This shall be based upon a determination that the structures satisfy both current design criteria and are in an acceptable service condition. Structural design review shall be based upon EM 1110-2-2105: *Engineering and Design - Design of Hydraulic Steel Structures*, dated 31 May 1994. The condition of the structure(s) shall be determined in accordance with EM 1110-2-6054: *Inspection, Evaluation, and Repair of Hydraulic Steel Structures*, dated 1 December 2001. Based on the above criteria, verify that all steel closure structures meet all required design criteria, and that the conditions of these structures are Acceptable for service. All analyses shall be prepared and submitted as part of the Certification Report.

9.g.(3).(c) An operational analysis of the closure structure must demonstrate confidence that the closures can all be placed into service, with all materials being available, and the proper manpower and equipment available for the performance of the required tasks. All closures must be operated in accordance with an officially adopted operation manual. Annual or inspection results should be reviewed to verify that all of the project's closures have been assembled within the recent past, that all parts are available and that local sponsors have work crews available with a working knowledge of how to install the closures.

9.g.(3).(d) Special case of sandbag closures. Many of the larger and older flood damage reduction projects such as those located along the Ohio and Mississippi Rivers have sandbag closures that are generally a maximum of about 3 feet in height. These sandbag closures are generally used only at locations well above the 1% annual chance exceedance elevation with 90% assurance, and thus do not come into play in certification determinations. For levee systems wherein sandbag closures are required for protecting against the 1% annual chance exceedance flood, the closes must be designed and implemented as an integral component of the levee system, and demonstrated that the closures will reliably perform their task as well as other alternative more permanent closure devices. Such sandbag closures are not considered an emergency flood-fight measure. For these closures to be found as adequately providing for base flood protection, the following must exist: 1) The sandbag closure design must be commensurate with the flood hazard as noted in a) above, e.g. generally not subject to flash flooding nor used for extended durations, and no more than three feet in height; and 2) The annual inspection report of record verifies that the local sponsor has the required number of sandbags available, has a source of sand readily available, and has a means for filling, transporting and placing the sandbags in the event of a flood event.

9.g.(3).e The sub-paragraphs of paragraph 9.g.(3) speak specifically to planned/designed closures that are part of the authorized project and are incorporated in and described in the project O&M manual. Note that several closure devices, including sandbags, as described therein fall into this category. Flood fighting activities are actions taken under emergency conditions that are required to attempt to keep the system from failing. Flood fighting will not be recognized as a measure that can be employed to ensure that a levee can be certified. If the system requires flood fighting to achieve base flood protection, the system cannot be certified.

9.g.(4) Review of Inspection Reports. The latest Annual or Periodic Inspection reports for the project shall be reviewed to see if there are any conditions or performance issues noted which would reduce confidence in the Factors of Safety already determined by analysis. For example an Unacceptable rating for a floodwall monolith because a monolith has tilted between two recent inspections is likely sufficient reason to suspect that the floodwall may not have the capacity to safely withstand the 1% event. In such a case additional analysis needs to be performed. It may be that the movement of the monolith occurred as a result of a truck collision with the wall, and that the wall still will provide the required protection. Any such analysis performed in response to such issues shall be prepared and submitted as part of the Certification Report. The calculations shall be checked by a Registered Professional Engineer.

9.g.(5) Review of Corrugated Metal Pipe CMP Inspection Records/Reports. The Structural Engineer shall also review the latest CMP Condition Assessment reports for the project to see if there are any conditions or performance issues noted which would reduce the Engineer's confidence in the flood damage reduction system. All CMP's are to be evaluated every five years, using video technology. If the CMP in the levee system under study has not been evaluated in the past five years with video technology, then such an evaluation is required as a component of the study. If any of the CMP's are rated as Unacceptable (as outlined in the latest version of the Corps Levee Inspection Manual), then certification should not be recommended.

9.h. Geotechnical Technical Evaluation Guidance

9.h.(1) Available Information. In evaluating existing levees for certification, the geotechnical engineer must collect and review all available, pertinent information. The list of available resources includes, but is not limited to:

- Regional geology reports, site specific geology reports, aerial imagery, boring logs, soil testing data, foundation material characteristics, and inferred stratigraphy.
- Design documents or design memoranda and all design computations.
- As-built drawings showing levee geometry, material zoning, construction methods. All other construction records (such as daily reports, QA/AC reports, excavations, dewatering requirements, settlements, utility relocations, and construction failures). All post-construction investigations.
- Annual and periodic inspection reports along with the most recent surveys of the levee system and any other available geospatial information.
- Groundwater studies, relief well and piezometer installation reports, relief well and piezometer maintenance reports, and testing performed on the relief wells and piezometers.
- Instrumentation installation reports, instrumentation data and data interpretation.
- Performance history especially reports and records of performance during floods. (See section 3 below),
- Data on any repairs or upgrades made to the levee system plus records of permits for any alterations made to the levee since its construction. Alterations include any changes (additions or subtractions) to the as-designed and constructed levee cross section or adjacent foundation soils. Alterations also include construction or abandonment of utilities (conduits, force mains, water lines, oil or natural gas pipelines, electrical or telecommunication cables), roadways, railroads, crossings either over or under the levee.
- The levee system's operation and maintenance manual. If the project's operation and maintenance manual cannot be located, the Corps of Engineers Levee Owner's Manual for Non-Federal Flood Control Works (published March 2006 or later version) should be used to determine minimum acceptable maintenance practices for a levee system.

9.h.(2) Site Visit. After reviewing all available information, the engineer shall complete a site-visit/field-inspection of the levee system. Immediately prior to and in preparation for the site visit, the engineer should once again review the periodic inspection reports and the system's operation and maintenance manual. All levee systems must be properly maintained to ensure they function properly during a flood event and the proper maintenance should be spelled out in the project's operation and maintenance manual. Improper maintenance may be the basis for not certifying the system if resultant maintenance deficiencies hinder flood fighting efforts or adversely impact the system's ability to adequately contain the 1% chance exceedance flood. During the site visit/inspection, the engineer shall take care to observe, assess and document the condition of the levee system, including the adequacy of the maintenance afforded the levee system. During the site visit the engineer should:

- Verify that seepage control measures (relief wells, seepage berms, cutoffs, riverside blankets) and related collection and discharge systems are functioning properly. The engineer should note any evidence of seepage and piping from previous flood events.
- Verify that the levee's turf provides adequate cover, is regularly mowed, and that all undesired vegetation, especially woody growth, is controlled. Note where large trees have been felled but the roots have not been grubbed out. The engineer should note any locations where turf does not provide adequate cover.
- Note any locations of erosion or scour due to runoff, current velocity, or wave run-up, and where riprap or other slope protection systems are failing.
- Note any locations of burrowing rodent activity, including tunnels, dens, or nests.
- Note conditions at all active utility crossings especially conduits through or under the levee system. Special attention shall be paid to known locations of abandoned utility crossings. Identification of deteriorated conduits through the levee must be considered dangerous and may be cause for withholding certification.
- Note locations where the existent embankment cross-section or template is substandard or irregular with respect to as-built drawings. Note locations of settlement, cracks, or signs of slope instability.
- The engineer should note any encroachments or alterations in the levee system not identified by the post-construction permitting process. The engineer should also note any activities adjacent to the levee, even those that do not appear to affect the structural integrity of levee.

9.h.(3) Previous Flood Fighting Information. A very important piece of information available to the geotechnical engineer for levee certification is knowledge of how the levee system performed during past floods. If the system in question has successfully withstood a 1% annual exceedance flood event, records of its performance during that event will provide essential information to the certification process. Levee performance can be determined by reviewing flood fight records and other written accounts of flood performance and from interviews with witnesses having first-hand experience during the flood event. These witnesses can be levee commissioners, flood fight personnel, and property owners. This review will identify weak spots and other problem areas in the levee system. Any observed and documented deficiencies should be considered in the levee certification process. Performance records of seepage related issues from previous flood events are generally good indicators of future performance. Observed seepage problems at low flood stages may indicate potentially larger problems at higher flood stages. Measured piezometric levels should be plotted against the flood elevation and trends extrapolated to the one-percent annual probability flood stage. Measured piezometric levels and measured relief well flows should generally match values predicted in original designs. The engineer should determine the locations of seepage induced soft spots, pin boils, or sand boils, and at what river stage these features appeared. Levee structures that have withstood a one-percent annual probability flood stage are likely to do well again at the same flood stage. One notable exception to this is that sand boils noted during one flood event have become active at lower flood stages in subsequent flood events, especially if a substantial amount of soil has piped out of the foundation in the prior event. This clearly implies that previous piping problems may worsen with each subsequent flood event of equal or even lesser severity.

9.h.(4) Additional Information. If a definitive determination cannot be made concerning capability of the levee system to withstand the 1% chance exceedance flood based on the information review, site visit, and subsequent analyses, the geotechnical engineer may determine that additional data must be obtained and additional analyses completed. The request for additional data may require new field exploration, soil testing, or surveying to help characterize existing conditions. Also additional analyses may need to be performed to resolve problem areas and to quantify missing information. The geotechnical engineer should understand and identify all potential failure modes when determining the need for additional investigations and analyses. These are identified in paragraph (6) below.

9.h.(5) Identification of the Potential Modes of Failure. Identifying and understanding probable failure modes are the basis for scoping and prioritizing additional investigations and analyses. For example, with respect to piping, uncontrolled seepage through the levee, through the foundation, or through the levee into the foundation can all cause failure of the levee. With respect to levee stability, sliding or deformation may be the result of insufficient strength of levee fill and/or foundation materials to resist gravity and seepage forces, may be induced by seepage induced excessive pore pressures, or could be induced by an external loading. All potential modes of failure should be identified. For existing levee structures, review of the latest annual or periodic inspection reports should be performed to see if there are conditions or performance issues relevant to the failure modes described above.

9.h.(6) Seismic Stability. Levee systems located in regions which experience strong ground motions from earthquake activity should be analyzed for seismic stability. The peak ground acceleration (PGA) should be determined for the 10% in 50-yr earthquake from the United States Geological Survey (USGS) ground-motion database. If the PGA is less than 0.15g no evaluation is required. For PGA's greater than 0.15g , the levee and its' foundation should be checked for liquefaction using a simplified approach as discussed in EC 1110-2-6001 *Seismic Analysis of Dams and Levees* (2008). Where liquefaction is indicated, the geotechnical engineer should perform a post-earthquake limit equilibrium stability analysis using an estimate of un-drained residual strength for the liquefied soils. These should be based on published empirical correlations. Appropriate drained or un-drained soil strength parameters should be used elsewhere. If post earthquake factors of safety are greater than 1.2 then no further evaluation is necessary. For factors of safety less than 1.2 a more detailed seismic deformation analysis will be required to determine how the levee will perform in the seismic event. Projects with an indication of wide-spread liquefaction and an inadequate post earthquake factor of safety cannot be certified unless a more rigorous seismic deformation study demonstrates the levee system will have minor deformation and will continue to provide the required level of protection. All seismic evaluations should assess the impacts on relief wells, toe drains, or other seepage control measures linked to the stability of the levee. If damage to these systems is not identified and repaired, the loss of or reduced effectiveness of these features can result in levee failure during subsequent flood events. Seepage control measures are typically located along the protected side levee toe, and are especially susceptible to damage from even relatively minor shear deformations and differential settlements. If parts of the levee system are found to be unstable during an earthquake, the probability of the occurrence of the earthquake and the flood at the same time should be determined. And, where widespread liquefaction and/or sliding are indicated, the capability to repair all earthquake damaged reach(es) prior to the next flood event shall be taken into account in the levee system certification process.

9.h.(7) Analytical Methods. The analyses and criteria described in EM 1110-2-1913, "Design and Construction of Levees," and ETL 1110-2-569, "Design Guidance for Levee Underseepage," should be used as a guide to evaluate levee structures for certification. Failure modes which must be considered include, but are not limited to: erosion, erosion protection, and erosion rates; foundation and levee stability; through-seepage, underseepage, performance of relief wells, and seepage induced piping; structural performance and stability of floodwalls (including L, T, and I-walls); effectiveness of gravity drain closure structures; corrosion of drain pipes; bearing capacity; settlement; and overtopping performance. All of these failure modes shall be evaluated to ensure the levee system meets criteria established in the Engineering Manuals referenced in Paragraph 10e(11).

9.h.(8) Method of Analysis. For the near future and until appropriate risk-based protocols are developed and fielded by future guidance, determinations of levee certification in the area of geotechnical engineering shall be based on widely accepted deterministic analyses using appropriate factors of safety against unacceptable performance, experience and engineering judgment. Risk analyses may be performed to enhance the geotechnical engineer's understanding of the fragility of various system components. Such analyses will also help the engineer understand the impact of potentially random variables (such as widely varying material properties and in-situ conditions) on levee integrity and the probability of failure. The results of risk analyses shall be used as an aid to experience and engineering judgment about whether levees are stable with respect to specific failure modes. However, at this time, the existing risk assessment tools available to the Corps of Engineers Geotechnical community of practice only determine probabilities within relative orders of magnitude. Mature risk assessment procedures are not presently available which allow estimates of the probability of failure with the accuracy needed to incorporate these probabilities into the overall certification process.

9.i. <u>Electrical and Mechanical</u>.

9.i.(1) General. Pump stations operate as a component of the interior drainage system. The interior drainage system is the system of culverts, canals, ditches, storm sewers, drainage structures with associated gates and valves, which convey interior water from rainfall or seepage by gravity to outside the protected area~~,~~ to interior ponding areas, or to a pump station to be pumped outside the protected area if gravity drainage is not possible. Failure of any of these components could prevent water from collecting in ponding areas or from being pumped from the protected area. This collection of water could cause flooding or damages to structures or infrastructure. This section will address how the mechanical and electrical components of the interior drainage system, namely pump stations and gates and valves, will be incorporated into the certification process.

9.i.(2) Probability-based Analysis. Characterizing the performance of pumping stations probabilistically is possible but with varying degrees of uncertainty depending on the level of analysis performed and the accuracy of information on component failure rates. The general approach would be to determine these failure rates and apply them in properly constructed event or fault trees. For such analysis, two more components are required to calculate the chance of pump station failure besides the probability of failure: the probability of loading and the consequences of partial or complete pump station failure. The probability of loading would be the coincidental probability of both the base flood on the river and on the interior producing a given inflow to the pump station. Consequences would typically be economic damages resulting from partial or complete failure of a pump station. The hydraulic loading information will likely be available from the interior drainage analysis (paragraph 9.f.(9)), but the pump station performance data will most likely be problematic. As a consequence, herein is presented an alternate assessment method based on the concept of 'Condition Assessment.' In the future, as performance data for aging pumping stations of reasonable fidelity becomes more readily available, and risk and probabilistic analysis methods and tools mature, the preferred analysis method is expected to evolve consistent with a comprehensive risk-based event and fault tree approach.

9.i.(3) Condition Assessment. Condition assessment is the analysis method that will be used in the certification process to determine failure modes of pump stations and drainage structures. The initial or continuing eligibility inspection documentation contained in Appendix B of EP 500-1-1 provides the process to evaluate the condition of those components contributing to the failure modes. An "Unacceptable" rating for any of the components which directly contribute to one or more of the failure modes could be cause for the levee not receiving certification. An "Unacceptable" rating is defined as the deficiency being so serious that the item will not adequately function in the next flood event, compromising the project's ability to provide reliable flood protection. Judgment should be exercised in determining the significance of component(s) with unacceptable ratings. For example, a single inoperable 12" flap valve, may not be cause to withhold certification, because it can be easily sandbagged or the volume of water which could enter the protected area would not cause damages in the amount of time the water level would cover the opening. A similar judgment should be made in the case of pump stations. If over time, the purpose of a pump station has changed to the point where it is no longer considered a critical component of the interior drainage system, then only those components of that pump station contributing to active failure modes should be considered. For example, those components could include flap valves or sluice gates preventing exterior water from entering the interior.

9.i.(3).(a) The failure modes for pump stations that will be assessed include failure of the pumps, drivers, controls, or the backflow of water through the pump station to the protected area. The following list of items contributes to these pump station failure modes and should be considered in a certification determination:

- Plant Building
- Pumps
- Motors, Engines, Fans, Gear Reducers and Back Stop Devices, etc
- Power Supply

- Megger Testing on Pump Motors and Critical Power Cables
- Motor Control Center
- Enclosures, Panel, Conduit and Ducts
- Circuit Breakers
- Instruments
- Sumps/Wet well
- Intake and Discharge Pipes
- Flap Gates/Flap Valves/Pinch Valves (when component of pump station)
- Mechanical Operating Trash Rakes
- Non-Mechanical Trash Racks
- Sluice/Slide Gates (when component of pump station)
- Fuel System for Pump Engines

In addition to the criteria defined for the item “Power Supply”, the reliability of the commercial power system and presence or lack of backup power should be considered. If commercial power is judged to be unreliable then backup power must be provided in the form of an alternate commercial power source, a properly sized generator set, or provisions for connection of a properly sized generator set which is readily available in an emergency. Commercial power reliability under the worst conditions should be investigated with cooperation of the local utility. Frequency and duration of outages and the size and importance of the pump station should be considered when determining the need for alternate power provisions. These considerations are described in Chapter 13 of EM 1110-2-3105.

9.i.(3).(b) Pump stations which are part of hurricane protection systems merit additional scrutiny of certain features that may contribute to station failure only as a result of exposure to a hurricane. These features include the ability of the pump station structure and equipment to withstand high winds, the provision of safe housing for operators, and the ability of the pump station to be operated while not exposing the operators to dangerous conditions. For example, trash raking equipment should not require an operator outside during raking operations. During Hurricane Katrina, a significant proportion of pump stations were abandoned. This not only resulted in the loss of pumping capacity but also combined with the loss of commercial power which is more likely in a hurricane resulted in significant backflow in several cases. The Mechanical Engineer shall review all of the assembled data, reports, project photographs, Plans and Specifications with emphasis given to the IPET recommendations and lessons learned in their report: *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System* Draft Final Report. The text of this report is available at https://ipet.wes.army.mil/ . In particular, Volume VI, The Performance – Interior Drainage and Pumping, and the appendices under Volume VI shall be reviewed and the project under consideration for Certification shall be considered in this context.

9.i.(3).(c) The mechanical failure mode of concern for drainage structures, pipes and other conduits that convey water out of the protected area is the drainage structure becoming unable to exclude water from the interior during flooding. This can happen due to failure of a flap or pinch valve or sluice gate in the open position. An "Unacceptable" rating of any one of these components could be cause to withhold certification.

9.i.(3).(d) Mechanical or electrical components necessary for the operation of closure structures should be considered in certification. These components would include winches, rollers, etc. An unsatisfactory rating of any of these components could be cause to withhold certification. If the structure can be closed in a reasonable time without the use of a component that has an unacceptable rating then that consideration may be used in certifying. For example, a gate that relies on a winch for closure may also be closed with help of mobile machinery if the need arises.

9.j. <u>System Evaluation.</u> The objective of the certification analysis is to verify that the levee system functions as an integrated set of features and components to provide reasonable assurance that it will protect its associated floodplain from flooding with greater than 1% chance. The focus is thus upon the levee system that is associated with a given separable floodplain. The term 'system' as used herein thus is inclusive of all components that are necessary to insure protection of the associated floodplain – levee and floodwall sections, closure structures, pumping stations, culverts, interior drainage works, and system operation and maintenance. In some instances, the system may include components that were not designed and built as part of the flood protection system, such as high ground areas, road and railroad embankments, bridge abutments, etc., and these must be included in the system analysis as well. Note that reaches of levee systems can be certified if the associated floodplains are sufficiently separable as to be unaffected by performance of other reaches of the levee system.

9.j.(1) A basic tenant of the system evaluation consists of determining whether the individual components and perspectives {as described in previous paragraphs of hydrology, hydraulics and coastal floods containment, structural and geotechnical performance, mechanical and electrical requirements, operations and maintenance plans, and recent inspection results} adequately pass their individual certification requirements. Also key to system evaluation is ensuring that possible interaction among the components will not result in failure. A useful framework for the system evaluation is that of 'Failure Mode Analysis' (FMA) wherein possible failure modes are postulated and analyzed. A discussion of FMA as applied to dam safety investigations is contained in *Dam Safety Risk Analysis Methodology,* US Department of Interior, Bureau of Reclamation, May 2003. For levee systems, FMA might emphasize potential failures that might result from interfaces and interactions among system components. Examples of such interaction might include: Permissible overtopping or overwash (from waves) criteria for levee overtopping that might result in erosion that would degrade the embankment or floodwall stability; deteriorating drainage pipe through levee detected in inspection that might provide critical through-seepage path; intersection of structural features such as levees abutting floodwalls; or ponding at interior drainage works that might saturate and weaken the land-side of levee system.

9.j.(2) Identifying Critical Sections, and Considering Complex Systems. Levee systems must be parsed into reaches and then systematically evaluated based on their specific location and features.

9.j.(2).(a) The levee system associated with a specific floodplain could be comprised several lengths and combinations of features. This might include a relatively short section of levee/floodwall or long section of levee/floodwall. The levee system could also be on a single stream or section of lake shore or coastline. The levee system could also be comprised of several sections of levees on a mainstream or coastline and one or more tributaries or even completely separate streams, coastline, or lake shore. Levee system sections will likely have other appurtenant features, such as interior drainage culverts, closure structures, outlet gates, pumping stations and perhaps other works. The complexity of the system will determine the degree to which a 'systems components' perspective is needed for the certification analysis. Note that as probability and uncertainty analysis technology evolves, it is expected that eventually it will be possible to describe the performance characteristics of each component of simple or complex systems and perform a system risk analysis to make the overall levee system certification determination. In the interim, the following basic concepts are presented for application.

9.j.(2).(b) For a levee system comprised of a short section with the usual imbedded features of culverts and closure structures, it is appropriate to locate through preliminary investigation, the location or feature that is critical from a protection standpoint (levee height with respect to flood profile, embankment/structural strength, etc.) and then perform the analysis for that feature/location. If the critical section or sections passes the criteria of preventing 1% chance flooding of the floodplain, then the levee system would be certified provided that the system evaluation that considers interaction among components would validate the critical section analysis findings.

9.j.(2).(c) For a levee system comprised of a long section with the usual imbedded features, there may be several 'critical features' at several locations along the protected area that will need to be analyzed for performance. Typically, the most critical of the several critical locations analyzed will govern the certification determination. This would be the circumstance if the levee sections protecting the floodplain are subjected to essentially the same event/loading, thus loading at the several sections would be considered to be perfectly correlated.

9.j. (2).(d) For levee systems comprised of two or more sections protecting from flooding from a mainstream or coastal or lake flooding, tributary, or independent streams, the appropriate systems approach will be dependent on each site-specific circumstance. It is key to note that when flooding may occur from more than one source, the likelihood of the floodplain experiencing flooding is higher than the likelihood from either source independently. The following flooding circumstances and approach for system performance determination is presented as general guidance. Note that the required analysis is focused on the floodplain and is based on the protection performance of each levee section expressed as Annual Exceedance Probability (AEP), e.g. level of protection of each section expressed as probability.

9.j.(2).(d).(1) Main stem or coastal or lake flooding, and tributary or two separate streams: For <u>perfectly correlated flood loading</u> (e.g. 1% chance exceedance loading would occur on both simultaneously), then the condition of 9.j.(2).(c) above applies.

9.j.(2).(d).(2) Main stem or coastal or lake flooding and tributary or two separate flooding sources: For completely independent flood loading (e.g. loading may occur for one or the other or both but are uncorrelated) then the system protection performance is determined from the Total Probability Methods – see *Probability, Random Variables, and Stochastic Processes, 2nd ed. New York: McGraw-Hill* - as noted in the following formula;

$$P(S) = P(A) + P(B) – P(A)*P(B)$$

Where: P(S) is the AEP of flooding the floodplain from the levee system; P(A) is the AEP of flooding from capacity exceedance or failure from stream/coast/lake A; and P(B) is the AEP of flooding from capacity exceedance or failure from stream/coast/lake B. For example, if the two independent flooding sources are both providing 1% level-of-protection, then the chance of the floodplain experiencing flooding would be: .01+.01-(.01)*(.01) or about 2%. In this circumstance, the system comprised of these two protection sections could not be certified as protecting the floodplain from 1% chance flooding.

9.j.(4).(d).(3) Main stem/coastal/lake source and tributary or two separate streams: For partially correlated flood loading (e.g. loading is correlated but not always occur simultaneously on both streams) then the system protection is determined from the two conditions as follows:

$$P(S) = P(A) + P(B) – P(A)\cap P(B)$$

Where P(A) and P(B) are as before, and P(A)∩P(B) is the is the probability of both A and B occurring simultaneously.

9.j.(4).(d).(4) For floodplain protected from three (or more) streams/coasts/lakes: For systems comprised of several perfectly correlated flood loading (1% chance exceedance loading will occur on all simultaneously), the condition of 9.j.(2).(c) above continues to apply.

9.j.(4).(d).(5) For systems comprised of three completely independent/uncorrelated sources, then the system performance is determined from the following formula:

$$P(S) = P(A) + P(B) + P(C) – P(A)*(P(B) – P(A)*P(C) – P(B)*P(C) + P(A)*P(B)*P(C) .$$

Where: P(S) is the AEP of flooding the floodplain from the levee system; P(A) is the AEP of flooding from capacity exceedance or failure from stream/coast/lake A; and P(B) is the EP of flooding from capacity exceedance or failure from stream/coast/lake B and P(C) is the AEP of flooding from capacity exceedance or failure from stream/coast/lake C

9.j.(4).(d)(6). For complex systems with more than three flooding sources, particularly for systems with partially correlated flooding sources, (e.g. loading from several sources is correlated but will not always the same exceedance probability), the analysis can be quite complex and likely will require customized case-specific analysis. In this instance, it is recommended that experts be engaged that specialize in complex system risk analysis, such as staff from USACE Engineer Research and Development Center (ERDC) and USACE Institute for Water Resources, Hydrologic Engineering Center (HEC).

9.k. Residual risk and public safety. Paragraph 5.b. noted that *"Levee certification is only concerned with the levee system performance associated with the 1% chance exceedance flood event. Levee certification findings do not address nor are the findings concerned with public safety, performance of the levee system for floods other than the 1% event, nor risk to floodplain residents from floods that will exceed system capacity".* That said, while only one of the elements of residual risk and public safety (Emergency Response Plan, paragraph (9.k.(4)) is a required technical factor in the certification determination, USACE will examine and report in the LCR, all elements of residual risk and public safety as noted in paragraphs 9.k(1) through 9.k.(4). The issues addressed here are focused on residual risk and public safety that are significant during the occurrence of flood events exceeding the capacity of the levee system or from flood events that may result in system failure prior to capacity exceedance. The elements to be addressed here are: Probability of capacity exceedance; consequence of capacity exceedance; project features that address capacity exceedance; and emergency plans to ensure public safety in the event of a flood that exceeds the levee system capacity or results in failure prior to capacity exceedance.

9.k.(1) Probability of capacity exceedance. The threat to floodplain residents and businesses is best described by the probability of flooding of the floodplain. The probability is to be estimated based on the information compiled on flood flow and stage and associated uncertainties, levee embankment and associated structures integrity and potential failure probabilities and modes of failure, and closure devices, interior drainage facilities and other component operations analysis. The probability of capacity exceedance is to be expressed as Annual Exceedance Probability (AEP) as defined herein and in USACE ER 1105-2-101.

9.k.(2) Consequence of capacity exceedance. The general scope and nature of impact on floodplain residents, businesses, transportation systems and other critical infrastructure systems, and the environment will be assessed in general terms and reported. The intent is not a detailed impact analysis, but an assessment that reflects the threat to floodplain occupants that indicates the approximate numbers and demographics of residents, businesses, and disruption that would likely occur from a capacity exceedance or system failure. This information would clearly distinguish between floodplains that may experience slow, shallow flooding and those that may experience rapid, deep flooding, floodplains that have adequate routes and capacity for occupant evacuations and those that do not, and floodplains that if flooded from a levee system failure, could result in the crippling of a regional economy or have significant national economic impact and those that would not. A further consideration is the issue of time that would be needed to repair/reconstruct failed system components and consequent vulnerability of to the floodplain during that time period. As concepts and methodologies mature, potential lives lost from capacity exceedance or failure as a measure of life risk is expected to become a key public safety metric.

9.k.(3) Project features for capacity exceedance. Levee system projects will be expected to have features and other means of accommodating the inevitable capacity exceedance. The concept is that where feasible and practical, the system will be designed and constructed such that capacity exceedance is accounted for so that should capacity exceedance likely result in breaching and failure of the levee system, the failure will occur gradually in a predictable manner, allowing orderly floodplain evacuation and minimizing the reconstruction requirements (time and cost) after an exceedance or failure. Levee superiority is one physical means for such accommodation and another is to harden sections to withstand overtopping. See USACE ER 1110-2-229 "Overtopping of Flood Control Levees and Floodwalls" for further discussion of this topic.

9.k.(4) Emergency response plan. The system under evaluation shall have an emergency response plan supported by a flood warning system. Such plans are often a component of floodplain management plans developed by USACE and project local sponsors as a component of agreements signed when the project is transferred to the local sponsor at completion. Projects developed by others may have such plans developed in support of communities' obligations under the FEMA Flood Insurance Program and associated mitigation grant programs. The emergency response plan shall be under the jurisdiction of Federal, state, or community officials. The flood warning system must provide that sufficient warning time is available to ensure that the system will be operated as planned during the occurrence of a flood event. The emergency response plans must also seek to maximize public safety from the occurrence of flood events that exceed levee system capacity, demonstrating that the possibility of exceedance and failure has been planned for and that the plan has a high likelihood of being successful should such a flood event occur. Emergency response plans will address the key issues of flood threat recognition, warning dissemination, evacuation, and search and rescue. It shall also be demonstrated that such plans are current and tested (updated and tested at an interval of five years or less).

10. Documentation and Independent Technical Review.

10.a. Levee Certification Report. A Levee Certification Report (LCR) shall be prepared to document and describe the basis for the certification determination of the levee system under evaluation. The LCR shall contain full documentation of data, information, assumptions, and explanation sufficiently clear so that an individual not familiar with the project could review the LCR and understand how the levee certification determination (certified or not certified) was made. It shall be sufficient to support execution of the Independent Technical Review (ITR) process as described in Paragraph 10.c. The following is a basic outline of the information required for the LCR.

I. Table of Contents.
II. System Description (location, project authorization (type), main features, and local owner, etc).
III. References (including design documents, reports, as-builts, models, etc. used for the analysis).
IV. Certification Team Members.
V. Previous Certification Information/FIRM or DFIRM.

VI. Letter of Intent, Memorandum of Agreement, Scope of Work (whichever applicable) between district and requester.
VII. Levee Certification Determination Letter.
VIII. Overall Performance History/O&M (inspection reports, past flood events and associated flood fight activities, rehabilitation measures, etc).
IX. Engineering Studies, Investigations, and Analyses.
   a. Site Visit Summary (participants, scope, itinerary, and summary of findings).
   b. Hydrology and Hydraulics Evaluation.
      1. Summary of Available Information.
      2. Characterization of the Flood Hazard.
      3. Capacity Exceedance/Criteria and System Performance.
   c. Structural Evaluation.
      1. Summary of Available Information.
      2. Closure Devices.
      3. Stability and Strength Requirements.
      4. Corrugated Metal Pipe (CMP) Condition Assessment.
   d. Geotechnical Evaluation.
      1. Summary of Available Information.
      2. Embankment Protection.
      3. Embankment and Foundation Stability.
      4. Settlement.
      5. Seismic Issues.
   e. Electrical and Mechanical.
   f. Interior Drainage.
   g. Other Analysis/Pertinent Data.
X. System Evaluation.
   a. Emergency Response Plan and Status.
   b. Probability of Failure and Consequences.
   c. System Capacity Exceedance Provisions.
XI. Residual Risk and Public Safety.
XII. Appendices
   a. Site Visit Report.
   b. Applicable Meeting Minutes and Decision Milestones.
   c. Independent Technical Review (ITR) Documentation.
   d. Additional Appendices (as needed).

10.b. <u>Levee Certification Determination Letter</u>. The Levee Certification Determination Letter is a signed letter stating the final determination of the certification evaluation and summarizing key factors leading to the conclusion. This letter shall be addressed to the local sponsor requesting the determination. Example template letters are found in Appendix C.

10.c. <u>Independent Technical Review (ITR)</u>. An Independent Technical Review (ITR) shall be performed on each LCR in accordance with ER 1110-2-1150, *Engineering and Design for Civil Works Project,* Appendix F. An ITR is a review by a qualified team not involved in the day-to-day production of the report for the purpose of confirming the proper application of established criteria, policies and, professional practices, in addition to, ensuring that appropriate methods of analyses were performed and documentation is sufficient. This ITR will not replace other quality control processes. All ITR documentation shall be included in the final LCR.

10.d. Requirements for Final Signature. The Levee Certification Report (LCR) and Levee Certification Determination Letter shall be reviewed, concurred with, and signed by a registered professional engineer designated by the district. The signatory must also be a member of the senior staff competent in the areas of design, construction, operation, inspection, and evaluation of levee systems.

10.e. Notification. A copy of the final LCR and Levee Certification Determination Letter shall be provided to the local sponsor requesting the determination, the corresponding FEMA regional office, state NFIP coordinator, and the county NFIP. If possible, district offices should upload final LCRs into the National Levee Database.

APPENDIX A

References

Applicable list of ERs, EMs and ETLs (Intent is to provide a comprehensive listing of appropriate guidance, with annotations as might be necessary to identify outdated or contradicting components thereof and point to contemporary technical material not yet in USACE Manuals.)

1. ER 500-1-1, “Emergency Employment of Army and Other Resources - Civil Emergency Management Program.” Defines policy related to the USACE Rehabilitation and Inspection Program (RIP).

2. ER 1110-1-12, “Engineering and Design – Quality Management”

3. ER 1110-2-1150, “Engineering and Design for Civil Works Program”

4. ER 1140-1-211, “Support for Others: Reimbursable Work”

5. ER 1165-2-119, “Modifications to Completed Projects”

6. ER 11-2-220, “Civil Works Activities, General investigation”

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

8. HEC-FDA: Flood Damage Reduction Analysis, User's Manual, CPD-72, Hydrologic Engineering Center, Davis, CA

9. Federal Emergency Management Agency, National Flood Insurance Program “Guidelines and Specifications for Mapping Partners,” http://www.fema.gov/plan/prevent/fhm/gs_main.shtm.

10. 44 Code of Federal Regulations 65.10, Mapping of Areas Protected by Levee Systems.

11. EM 1110-2-1100, “Coastal Engineering Manual” (http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Publications;8)

12. EM 1110-2-1913, Design and Construction of Levees, 30 April, 2000

13. ER 1105-2-100, Planning - Planning Guidance Notebook, 31 January, 2006

14. ER 1105-2-101, Planning - Risk Analysis for Flood Damage Reduction Studies, 3 January, 2006

15. FEMA Memorandum No. 34 – “Interim Guidance for Studies Including Levees”, 22 August, 2005

16. CECW-EG Memorandum "Guidance on Levee Certification for the National Flood Insurance Program," April 10, 1997

17. CECW-P/CECW-E Memorandum, "Guidance on Levee Certification for the National Flood Insurance Program – FEMA Map Modernization Program Issues," June 23, 2006

18. CECW-P/CECW-E Memorandum, "Authority and Funding Guidance for USACE Levee Certification Activities", 15 August, 2006

19. EM 1110-2-1100, "Coastal Engineering Manual", 31 July 2003

20 CECW-EG Memorandum, "Geotechnical Activities in Support of Levee Certification for Federal Emergency Management Agency (FEMA) Flood Insurance Purposes," June 30, 1997

21. Title 44 of the Code of Federal Regulations Section 65.10 (44 CFR Section 65.10), *Mapping Areas Protected by Levee Systems*, 10-1-02 Edition

22. Title 44 of the Code of Federal Regulations Section 61.12 (44 CFR Section 61.12, 10-1-02 Edition

23. Title 44 of the Code of Federal Regulations Section 65.2(b) (44 CFR Section 65.2, 10-1-02 Edition

24. ER 500-1-1, "Emergency Employment of Army and Other Resources - Civil Emergency Management Program." Defines policy related to the USACE Rehabilitation and Inspection Program (RIP).

25. ER 1110-2-1150, "Engineering and Design for Civil Works Program"

26. ER 1140-1-211, "Support for Others: Reimbursable Work"

27. ER 1165-2-119, "Modifications to Completed Projects"

28. ER 11-2-220, "Civil Works Activities, General investigation"

29. Guidelines and Specifications for Mapping Partners

30. 44 Code of Federal Regulations 65.10, Mapping of Areas Protected by Levee Systems.

31. EM 1110-2-1100, "Coastal Engineering Manual"

32. EM 1110-1-1904 "Settlement Analysis"

33. EM 1110-1-1905 "Bearing Capacity of Soils"

34. EM 1110-2-301 “Guidelines for Landscape Planting at Floodwalls, Levees & Embankment Dams”

35. EM 1110-2-1901 “Seepage Analysis and Control for Dams”

36. EM 1110-2-1902 “Slope Stability”

37. EM 1110-2-1908 “Instrumentation of Embankment Dams and Levees”

38. EM 1110-2-1913 “Design and Construction of Levees”

39. EM 1110-2-1914 “Design, Construction and Maintenance of Relief Wells”

40. EM 1110-2-2502 “Retaining Walls and Floodwalls”

41. EM 1110-2-2504 “Sheet Pile Walls”

42. EM 1110-2-2906 “Design of Pile Foundations”

43. ER 1110-2-1942 “Inspection, Monitoring, and Maintenance of Relief Wells”

44. Levee Owner’s Manual for Non-Federal Flood Control Works March 2006

45. ER 1110-2-1806, Earthquake Design and Evaluation of Civil Works Projects, 31 July 1995

46. ETL 110-2-569, Design Guidance on Levee Underseepage, 01 May 2005

47. Guidelines for Design of River Dikes, Part 2 – Lower River Area, Technical Advisory Committee on Flood Defence, the Netherlands, Sep 1989.

48. Technical Report: Wave Run-up and Wave Overtopping at Dikes, Technical Advisory Committee on Flood Defence, The Netherlands, May 2002.

49. Probability, Random Variables, and Stochastic Processes, Papoulis, A., 2nd ed. New York: McGraw-Hill

50. Dam Safety Risk Analysis Methodology, US Department of Interior, Bureau of Reclamation, May 2003

51. Economy Act: Title 31, Subtitle II, Chapter 15, Subchapter III, § 1535

APPENDIX B

Templates Certification Letters

The following letters should be used as templates for submitting findings from a levee certification effort:

1) Letter for certification of levee system.
2) Letter stating system should not be certified.
3) Letter for providing technical information in support of certification effort done by others.

Template 1: Letter of Certification

District Letterhead

(*Date here*)

(*Name and address of requester of determination here*)
[Mr./Ms.] (Full Name of Requester)
(Title of Requester)
(Requester Address)
(City, State Abbreviation, and Zip Code)

Dear [Mr./Ms.] (Last Name of Requester),

The _(*district name here*)_ District of the US Army Corps of Engineers (USACE) has certified __(*levee identification and location here*). This means that _(*levee identification here*) has met all of the requirements established by USACE for determining that the levee system can be reasonably expected to protect against a flood event with at least a 1% chance of being exceeded in any given year, also referred to as the base flood. Enclosed with this letter, you will find a Levee Certification Report documenting the criteria used, assumptions made and analyses conducted to make this levee certification determination.

Under the National Flood Insurance Program, levee certification is a prerequisite for receiving levee accreditation from the Department of Homeland Security, Federal Emergency Management Agency (FEMA). If the levee is accredited, FEMA will remove the area located behind the levee from the Special Flood Hazard Area, which is an area subject to flooding by the base flood. The area will be designated as a shaded Zone X or moderate risk zone. The purchase of flood insurance and elevation of structures is not federally mandated in a moderate risk zone; however, it is encouraged.

This certification determination expires on_(*date equal to 10 years from the date of letter*) __. After this time, _(*levee identification here*) is no longer certified by USACE and you and FEMA will be notified. At any time prior to this date, it is at the *(district name here)* District's discretion to revoke this certification should the District decide that *(levee identification here)* no longer meets certification criteria, which may include reasons such as inadequate operations and maintenance or change in hydraulic conditions. USACE will notify you and FEMA Region *(number of appropriate FEMA region here)* should this situation occur. If this certification is deemed invalid, it will be the responsibility of the local community or other entity that desires to retain accreditation of this levee system to pursue recertification. At that time, we recommend that we are contacted to discuss potential next steps.

This certification does not assure that _(*levee identification here*) will protect against all future flood events. Even with a certified levee in place, a possibility of flooding that overtops or fails the levee exists. Floodplain management measures to reduce the consequences of this possibility are strongly advised, such as elevating structures, maintaining a current flood warning system and evacuation plan, and wisely managing floodplain development.

This letter of certification and a copy of the enclosed Levee Certification Report has been transmitted to FEMA Region _(*number of appropriate FEMA region here*). It has also been sent to the National Flood Insurance Program Coordinator for the County of (*appropriate county here*) , and State of (*appropriate state here*).

For any questions regarding this letter, please contact *(name and title of district point of contact here)* at *(contact information here)*. For questions about accreditation or the National Flood Insurance program please contact *(name and title of FEMA region contact)* at *(contact information here)*.

Sincerely,
(Name of P.E. here)

___(*district name here*)___
US Army Corps of Engineers

Enclosure

Copies Furnished:
Point of contact for FEMA Region
County National Flood Insurance Program Coordinator
State National Flood Insurance Program Coordinator

Template 2: Letter for Not Certified

District Letterhead

(*Date here*)

(*Name and address of requester of determination here*)
[Mr./Ms.] (Full Name of Requester)
(Title of Requester)
(Requester Address)
(City, State Abbreviation, and Zip Code)

Dear [Mr./Ms.] (Last Name of Requester),

The _(*district name here*)_ District of the US Army Corps of Engineers (USACE) is unable to certify __(*levee identification and location here*). This means that _(*levee identification here*) has not met all of the requirements established by USACE for determining that the levee system can be reasonably expected to protect against a flood event with at least a 1% chance of exceedance in any given year. Specifically, the levee system failed to meet the following necessary criteria for certification:

> ___(*provide a brief description of the specific criteria that were not met and levee conditions that prevented certification*)___.

Enclosed with this letter, you will find a Levee Certification Report documenting the criteria used, assumptions made and analyses conducted to make this determination.

Under the National Flood Insurance Program, levee certification is a prerequisite for receiving levee accreditation from the Department of Homeland Security, Federal Emergency Management Agency (FEMA). If levee accreditation is denied by FEMA, the purchase of flood insurance and structure elevation requirements may go into effect. Floodplain management measures to minimize the consequences associated with the possibility of the levee overtopping or failing, such as elevating structures, maintaining a current flood warning system and evacuation plan, and wisely managing floodplain development are strongly advised.

We understand that you may be interested in discussing your options for improving the levee system or implementing other flood risk reduction measures and we will work collaboratively with you and other stakeholders to determine the next steps.

This letter of determination and a copy of the enclosed Levee Certification Report have been transmitted to FEMA Region _(*number of appropriate FEMA region here*). It has also been sent to the National Flood Insurance Program Coordinator for the County of _(*appropriate county here*) , and State of _(*appropriate state here*). For any questions regarding this letter, please contact *(name and title of district point of contact here)* at *(contact information here)*. For questions about accreditation or the National Flood Insurance Program, please contact *(name and title of FEMA region contact)* at *(contact information here)*.

Sincerely,
(Name of P.E. here)

___*(district name here)*___
US Army Corps of Engineers

Enclosure

Copies Furnished:
Point of contact for FEMA Region
County National Flood Insurance Program Coordinator
State National Flood Insurance Program Coordinator

Template 3: Letter for Technical Support

District Letterhead

(*Date here*)

(*Name and address of requester of determination here*)
[Mr./Ms.] (Full Name of Requester)
(Title of Requester)
(Requester Address)
(City, State Abbreviation, and Zip Code)

Dear [Mr./Ms.] (Last Name of Requester),

The _*(district name here*)_ District of the US Army Corps of Engineers (USACE) submits the following *(information, technical data, or analysis result described here)* for __*(levee identification and location here*). This submittal is information to be used in support of a certification determination to be performed by another entity and does not constitute a certification or partial certification by USACE.

Under the National Flood Insurance Program, levee certification is a prerequisite for receiving levee accreditation from the Department of Homeland Security, Federal Emergency Management Agency (FEMA). If the levee is accredited, FEMA will remove the area located behind the levee from the Special Flood Hazard Area, which is an area subject to flooding by the base flood. The area will be designated as a shaded Zone X or moderate risk zone. The purchase of flood insurance and elevation of structures is not federally mandated in a moderate risk zone; however, it is encouraged.

For any questions regarding this letter, please contact *(name and title of district point of contact here)* at *(contact information here)*. For questions about accreditation or the National Flood Insurance program please contact *(name and title of FEMA region contact)* at *(contact information here)*.

Sincerely,
(Name of P.E. here)

___*(district name here)*___
US Army Corps of Engineers

Enclosure

APPENDIX C

Example Procedures for Selected Analyses

Example 1 – H&H Procedure

METHOD 1 - LEVEE CERTIFCATION – H&H Component

DATA NEEDED
Minimum:

1. Latest flow frequency curve and statistics for the gage
2. USGS discharge measurements for the gage
3. Levee elevation at the gage
4. Design Memorandum or similar for the project.

Other data that might be needed:

1. Peak flows since the frequency curve was done
2. Official FIS 100-yr flow at the gage
3. Official FIS 100-yr stage at the gage

FREQUENCY CURVE

1. Determine if the existing frequency curve is still adequate. Adequacy is based on judgment but the usual assumption is it's adequate for a risk analysis unless there have been some very large, flood of record, type floods.
2. How old is it? How many large floods have there been since it was developed?

RATING CURVE

1. Read the hydraulics portion of the Design Memorandum (DM) to see if the gage has been stable.
2. Put the measured flows vs. stages in Excel. (The USGS on line text data can be fed directly into Excel. "Surface Water Field Measurements". Tab-separated data, save as a .txt file and open with Excel.) If the DM and the measurements show that the rating at the gage has been changing, only use the recent measurements. Usually the non-flood measurements don't have to be included.
3. Extension for the rating curve. The curve should extend higher than the top of levee. Provided below are some ways to extend the curve.
    a. Method 1 - Plot the log of the measured flows vs. the log of the stages and fit a curve thru them. This could be a straight line or a polynomial. You need to try different types until you have a good eye-ball and R squared fit. Make sure you use Excel to extend the fit curve to above the top of levee. Sometimes a good fit to the measured data looks terrible extended – it could bend over and go down.
    b. Method 2 - Use computed design conditions flood profiles from the DM to extend the curve. This method is especially good if the extension in step 3.a. looks bad and if the design profiles were computed with a backwater model. You need to check to see if these points fit the rating curve based on measurements.

4. Extending the rating curve. Add some points from the rating extension in step 3 to the measurements in step 1. Fit a curve thru the measured and extended points. For the curve fitting it's usually best to use flow divided by 1,000 or 10,000.
5. Get uncertainty in the rating curve. Use the equation for the fit curve to get the rating curve stage for every measurement used. Get the differences between the actual and rating curve predicted stages. The standard deviation of these differences is the standard deviation of the rating curve for the portion where there are measurements. Assumed the standard deviation is twice that for the upper portion of the curve where there are no measurements.

RUN FDA

1. Hydrology. For LP3 curves: mean, standard deviation, skew and record length are used. For graphical curves there is a procedure to use in FDA that includes the record length.
2. Hydraulics. Input the extended rating curve points and uncertainty.
3. Enter the top of levee at the gage.
4. Economics. For the current version of FDA you will need to enter fake economic values to get it to run.

OTHER CONSIDERATIONS

Superiority. Newer projects include superiority with varying freeboard (old design) or assurance (new design with risk and uncertainty). For these the gage may not be the critical location for assessing performance. In these cases you should also do an analysis at the location with minimum freeboard – usually the downstream end of the project. For the St. Paul study the rating curve for the measurement portion was assumed to be the same as at the gage but with each point adjusted by the difference in the design flood profile in the DM. The profiles in the DM were used to get the extension at the d/s curve. Often the upper end of the rating curve is flatter at the d/s end of a project since the channel d/s of the project is not constrained by levees.

Example 2 – H&H Procedure and Text – This is an **example** of how to certify a project without a gage using the approximate method.

APPROXIMATE STUDY FOR MINNESOTA CERTIFICATION

The Minnesota, MN, levee is on the South Branch of the Yellow Medicine River. The project design is shown in the February, 1961, Detailed Project Report (DPR). The project was designed for the then estimated 110-yr flood, 6900 cfs, with 3 feet of freeboard. The Corps certified the project in 1994. Recertification requires the use of probability of exceedance and uncertainty for the hydrologic and hydraulic analysis.

Hydraulics:

The HEC-2 hydraulic model is fairly recent. It was used in 1994 to certify the levee. There are actually two models. One is for downstream of the city and the other goes through the city and upstream. These models were used as is. The comment cards include good documentation. Converting the models to HEC-RAS was attempted but the special bridge routine for the bridge at the downstream end of the project, SAR No. 3, did not transfer well. Therefore, HEC-2 was used for the analysis.

LOCATION	TOP OF LEVEE ELEVATION	HEC-2 CROSS SECTION	100-YR STAGE (Q=5870 CFS)	DIFF-TOP OF LEVEE – 100-YR STAGE
D/S END OF D/S LEVEE	1166.1	32.3	1160.75	5.35 ft
U/S END OF D/S LEVEE	1167.0	34.2 (.342)	1162.93	4.07 ft
D/S END OF U/S LEVEE	1168.8	34.4 (.344)	1163.53	5.27 ft
U/S END OF U/S LEVEE	1169.4	1.4	1167.57	1.83 ft

All elevations 1929 datum. Levee elevations from the 1961 DPR.

From the table above the upstream end of the upstream levee is the critical location. To estimate the uncertainty in the rating curve the n values were increased 10 and 20%. The results are shown below. In the project reach the original channel and overbank n values were 0.045 and 0.120. The 20% increased n values for the channel and overbank were 0.054 and 0.144. The n values resulting from the 20% increase are quite high for this type of stream. They probably represent a probability less than that for two standard deviations, but to be conservative it is assumed the increased stages from an n value increase of 20% represent about one standard deviation in the stage uncertainty. As seen below there was about a 0.6 foot increase in stage for the 20% increase in n value and 0.6 foot was set as the standard deviation for the discharge-elevation rating curve in the Monte Carlo analysis for levee reliability.

Cross Section	Discharge	Original n Stage	n plus 10% Stage	n plus 20% Stage	DIFF 10% Stage	DIFF 20% Stage
1.4	0	1155.00	1155.00	1155.00	0.00	0.00
	2240	1164.90	1,165.18	1,165.43	0.28	0.53
	4600	1166.89	1,167.25	1,167.54	0.36	0.65
	5550	1167.57	1,167.91	1,168.20	0.34	0.63
	5870	1167.78	1,168.12	1,168.39	0.34	0.61
	6900	1168.41	1,168.71	1,168.96	0.30	0.55
	7180	1168.56	1,168.85	1,169.11	0.29	0.55
	9470	1169.90	1,169.91	1,170.20	0.01	0.30

Hydrology:

The hydrology for Minneota from the 1994 certification analysis was used. The details of the analysis were not found. The only results available were the 10, 50, 100 and 500-yr flood discharges. The frequency curve on the 1961 DPR was developed by a transfer from the gage on the Yellow Medicine River near Granite Falls, MN. In the 1961 analysis the period of record for the gage was 1931-1958. The Granite Falls discharges were reduced by the ratio of drainage areas to the 0.6 power, resulting in a factor of 0.353. The 1961 analysis was graphical but using the LP III statistics for the gage record and a weighted skew of -0.37 gave a good match to the 1961 curve. The Granite Fall station skew for that period was -0.62 and the regional skew is -0.20, thus a skew of -0.37 is reasonable. It was assumed that the 1994 curve was also developed from the Granite Falls gage data. Using the Granite Falls 1931-1993 records and a weighted skew of -0.32 gave a very good match to the 1994 Minnesota curve (using the same 0.353 reduction factor). The results are shown below.

Flood	1961 DPR	LP III curve developed to match 1961	1994 Certification	LP III curve developed to match 1994	LP III curve for 1931-2005
10-yr	1900	2082	2240	2051	1973
50-yr	4700	5177	4600	4510	4176
100-yr	6600	7008	5870	5880	5375
200-yr	9200	9126	N/A	7418	6706
500-yr	N/A	12393	9470	9735	8686

The last column in the above table uses the Granite Fall period of record up to 2005 and the skew of -0.32 used to match the 1994 analysis. It shows that the frequency curve would probably be a little lower if updated. Thus the 1994 curve is conservative.

Appendix 5 of Bulletin 17B gives a way to determine the LP III statistics if you know the various frequency flood discharges. This method was not used since it would not allow a comparison to use of a different periods of record. Using the Bulletin 17B method would not allow you to know how the 1994 curve would compare to an updated curve.

The following table shows the hydrologic parameters used in the Monte Carlo analysis for levee reliability.

MATCH 1994 ANALYSIS	
AVE=	2.64150
STD DEV=	0.53992
SKEW=	-0.37
YEARS=	62

Monte Carlo Results:

The Monte Carlo results of this approximate analysis showed that the levee at the upstream end has a 92.15% probability of not being overtopped by a 100-yr flood. The minimum required for certification is 90% when a detailed analysis is performed. When performing an approximate analysis like this one, to certify you either need to have an assurance well in excess of 90% if you use your best estimate for average hydrology and hydraulics, or have at least 90% if you use conservative assumptions for the H&H. In this case the hydrology is conservative since an updated frequency curve would likely be lower, and assuming a 20% increase in n value only represents two standard deviation is also conservative. Therefore, the 92% assurance of the levee meets the risk and uncertainty assurance. However, criteria the Corps and FEMA agreed to is that if the assurance is less than 95% then the levee has to have at least 3.0 feet of freeboard. If that criteria is not met and **the levee cannot be recertified based on this approximate analysis**, to be certified a detailed analysis would either have to result in at least 3 feet of freeboard or give more than a 95% assurance for the 100-yr flood.

In a detailed analysis the upper end of the hydraulic model should checked. The new model gives stages much higher than the original DPR at the upstream end of the levee. There is good topography for the area and the model should be compared to the topography to ensure it correctly reflects the area. Updating the hydrologic model would also probably increase the performance. A more thorough analysis of the hydraulic uncertainty might decrease it. The DPR has a highwater profile from 1957, 4,700 cfs. The model results were not compared to that profile. Since 1957 at least one bridge has been replaced. The new model also does not have the railroad bridge that was in the 1961 analysis. It should be confirmed that the bridge has been removed.

APPENDIX D

Toward a Probability and Uncertainty-Based Approach for Characterizing the Flood Hazard Associated with Storm Surge, Wave, and Overtopping of Levees

D-1. High winds during storms (hurricanes and extratropical events) are the primary forcing for the abnormally high water levels and wave conditions that are experienced in lakes, estuaries and along the coast. The abnormally high water levels and energetic wave conditions can create a flooding hazard. In efforts to characterize this hazard, the quality of storm-induced water level and wave prediction is only as good as the accuracy and resolution of the wind conditions used to make the assessment. Lakes are generally much smaller in spatial extent than the weather systems that generate extreme winds, so wind conditions over the lake may be assumed to be uniform for smaller lakes. For large lakes, the Great Lakes for example, and for coastal and estuarine situations, the full two-dimensional variation of wind fields must be considered for estimating water level and wave conditions. Time variation of the winds is important in storm situations.

D-2. Historically, most attention has been paid to estimation of water level changes associated with high winds (often referred to as wind setup) or storm surge which arises form forces in addition to the wind, because water level is the first-order parameter of importance in flooding. However, in some cases, insufficient attention was given to waves generated by the same winds, to the dependencies and interaction of waves and surge, and to the role of waves and wave overtopping in levee system design and performance. Generation of significant wave heights of 2 to 4 feet or more is possible even in restricted-fetch situations subjected to high winds, where fetches are only a few miles in length (much higher wave heights are possible for hurricane-force winds). Very large lakes and estuaries can experience wave heights of up to 10 ft or more; and major storm-generated significant wave heights can reach 30 feet or more in open coastal areas. For restricted fetches of several miles and very strong wind events, wave periods are generally 3 to 5 sec; for larger lakes, wave periods are generally 5 to 8 sec; and, for ocean conditions storm wave periods can range from 12 to 20 sec.

D-3. As waves which are generated across an open-water fetch propagate into shallow water, they begin to break and their energy is dissipated. In very shallow water (shallow in terms of water depth-to-wave length ratio) wave height tends to be limited by breaking and it becomes proportional to the local water depth. To aid in a quick first assessment of the importance of waves to levee system overtopping, the depth-limited significant wave height at the toe of a levee fronted by extensive shallow water areas with very small slopes (such as natural marsh areas) is roughly 40% of the local still water depth at the toe. The depth-limited significant wave height is about 60% of the local still water depth at the toe for situations where the water is deeper seaward of the levee toe. Depending on the other factors that govern wave generation and propagation (fetch and wind speed along the fetch are important), significant wave heights may not reach this depth-limited value, but they probably won't exceed this value. More rigorous analysis of waves is required to support levee design and certification, and these depth-limited conditions may not always be realized depending upon the actual incident wave conditions, but these rough rule-of-thumb estimates provide a starting point to assess whether or not waves are an issue to be considered further.

D-4. The IPET investigation of Hurricane Katrina and response of the Hurricane Protection System in Southeast Louisiana to that extreme event showed that levee and floodwall failure was dominated by overtopping, either overtopping of levees and subsequent erosion of the levee from the protected side toward the flooded side, or overtopping of walls, scour on the protected side of the wall, and subsequent failure of the wall, and to a lesser degree by scour at transitions between levees and hard structures. Levee response and wave and water level conditions throughout the system were far from uniform. It was not possible within the time frame of the IPET investigation to fully and definitely tease out the relative roles of the following factors in the overtopping and levee erosion process: spatially varying waves and still water levels, overtopping duration, levee soil variability, vegetation cover, construction method, and protected side inundation.

D-5. Current coastal engineering design practice is to use an overtopping discharge rate threshold to define the onset of levee damage (see Table VI-5-6 of EM 1110-2-1100, TAW 1989 and TAW 2002). These overtopping rate thresholds are rather crude and uncertain. They somewhat account for certain factors that can influence levee resistance to erosion, such as quality of levee soils (clayey versus sandy sediments, for example), condition of vegetation cover, and presence of armoring. However, the thresholds do not incorporate, nor are they so sensitive to, several other key site-specific conditions that influence levee erosion in response to overtopping: thickness of protective soil cover, degree of root system development or lack thereof, degree of cracks and gullies in the levee soil, spatial variations in soil properties or presence of perturbations or structural features on the levee that would promote local scour if overtopped, duration of overtopping, or degree of inundation on the back side that might serve as a buffer to degradation of the levee toe. The overtopping rate threshold criteria identified in the references cited above do not account for differences between the periodic unsteady nature of wave overtopping and steady flow over the levee. The thresholds have been developed primarily based on situations where the still water level is above the levee crest and overtopping is rather steady. During wave overtopping alone, or wave overtopping in addition to still-water overtopping, the velocities associated with each wave crest passage can be significantly higher than velocities associated with steady flow alone. Computations made by IPET investigators showed that velocities on the back side of levees due to wave overtopping were three or more times greater than velocities associated with steady flow overtopping (which translates into an erosion potential of about 30 times or more greater, albeit not a steady forcing). The overtopping rate thresholds do not distinguish between steady velocities at lower speeds, and intermittent and shorter duration velocities at much higher speeds. This factor needs to be examined further.

D-6. Despite the crudeness and limitations which are inherent in these threshold values, those listed below and described in more detail in the main text are believed to be conservative. They appear to have worked reasonably well in engineering practice. Site-specific, full-scale tests, are the preferred method for defining the threshold values for a particular levee condition/configuration, but data from these tests is sparse and not nearly inclusive of all the important factors that can effect levee erosion. The threshold values cited here are intended to define the onset of erosion, or levee damage. However, a small amount of erosion on a large earthen levee might not erode much of the levee cross-section at all, and might not lower the levee crest elevation and therefore not compromise levee performance at all. Levee erosion and damage is a function of duration, which is not considered in these thresholds. This is another reason why the thresholds might be conservative. At present, for unarmored earthen levee system certification, a high value of the average wave overtopping rate threshold, 0.1 cu ft/sec/ft, should be reserved for the highest quality levees, unless a higher value is well-supported by large-scale testing. The overtopping rate threshold for a clayey soil with relatively good grass is 0.01 cu ft/sec/ft. This is a more typical value. The wave overtopping rate threshold for sandy soils and poor turf is lower, 0.001 cu ft/sec/ft, which is effectively zero overtopping. Simple methods for calculating average wave overtopping discharge, as a function of still water level relative to levee system crest, levee cross-sectional shape, and incident wave conditions, are provided in Part VI (Chapter 5) of EM 1110-2-1100. Large-scale field tests, or smaller-scale laboratory tests, or application of numerical models which solve the Boussinesq equations, are more rigorous and accurate alternatives for levee configurations that differ significantly from the laboratory test conditions that were used to produce the data upon which the simple calculation methods in EM 1110-2-1100 are based. Work is underway in the Louisiana Coastal Restoration and Protection Study (LaCPR) to further examine the issue of wave overtopping threshold for the onset of damage to earthen levees; additional work is needed on this topic to refine the thresholds for various types of levee conditions. Also, work is being pursued in the LaCPR project to establish a linkage between wave overtopping flows and what is currently known about steady flow overtopping.

D-7. The average overtopping discharge rate due to wave action should be used as a threshold parameter for the evaluation of potential levee failure/damage, instead of the 2% wave runup elevation, or some other runup elevation, or some other parameter based directly on wave crest height or wave height as is done in the current HEC-FDA treatment of wave overtopping. The discharge parameter is a more appropriate surrogate for the processes by which levees degrade (velocity, shear stress and turbulence) than is a runup elevation or wave crest elevation; and currently, thresholds for levee resistance to erosion (damage) in wave regimes are couched in terms of the average overtopping rate parameter. Also, run-up elevation becomes a nebulous parameter when the computed wave run-up value exceeds the levee crest elevation. Therefore, the average discharge parameter should be used as the threshold for levee certification in all riverine, lake, estuarine and coastal situations, until thresholds that more accurately treat both the levee erosion process and levee sediment/vegetation/condition properties can be developed.

D-8. In addition to changes to the mean water surface due to wind or other forces, wave setup is another process that needs to be considered. Wave setup arises as a result of momentum transfer from the short wave field into the water column as wave height changes, due primarily to breaking. The changing wave height, and changing momentum, exerts a thrust on the water column that can create a local change in the mean, or still, water level. For mild slopes, wave setup can be 15% of the incident significant wave height; 30% of the incident significant height for steep slopes The simple methods for calculating discharge in Part VI (Chapter 5) of EM 1110-2-1100, the Boussinesq-type numerical models and physical-scale modeling, implicitly include the effects of wave setup which occurs right at the levee. They do not however, account for wave-setup generated away from the levee. This process is best considered through interactive wave and storm surge modeling, as was done in the IPET investigation, and in the

LaCPR and Mississippi Coastal Improvement Project (MsCIP) studies. In some coastal situations, interactions among different frequency components in the incident wave field are very important, such as the incidence of energetic narrow-banded wave spectra and the infragravity wave motions that can result (for example that which is often experienced on the west coast) or double-peaked wave spectra that are comprised of both short- and long-period components (as was the case for the portions of the southeast Louisiana levee system that were exposed to both long-period Gulf waves and locally-generated short-period wave energy). Infragravity wave motions can be thought of as longer-period (up to several minutes) time-varying wave set-up. In these situations, wave-wave interactions can be extremely important in determining the magnitude of the wave run-up and overtopping, and the simple calculation methods of EM 1110-2-1100 (and the laboratory test cases that produced the data that lead to these calculation methods) might not adequately capture these non-linear effects. Boussinesq-type numerical modeling will produce information that more accurately captures wave overtopping discharge rates for these types of situations.

D-9. Current engineering calculation tools and methods should be used to assess the storm surge and wave flooding hazard. Two-dimensional models are needed to accurately represent hurricane surface wind and atmospheric pressure fields. Planetary Boundary Layer (PBL) models are recommended for simulating hurricane wind fields. The ADCIRC model, see http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;39, is the recommended tool for computing storm surge. It has been well tested and validated in the IPET, LaCPR, and MsCIP work. The WAM and STWAVE models (see http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;9) are the recommended tools for computing hurricane wave fields. Both have been well tested and validated in these projects. The WAVEWATCH III and SWAN wave models are other suitable models for making offshore and nearshore wave computations, respectively; both models were evaluated during the IPET examination. Comparisons between results from the ADCIRC, WAM, STWAVE, WAVEWATCH III and SWAN models and measurements made during Hurricane Katrina, and inter-wave-model comparisons, are presented in the IPET report (https://ipet.wes.army.mil/). The interactions between storm surge and waves (surge changes water depth which influences wave transformation and breaking, and generation of wave setup is a contributor to surge levels in a regional sense) must both be considered; the interactions are important for levee system design and certification in coastal and estuarine settings.

D-10. In general terms, the most technically sound and rigorous approach to assess the risk of levee overtopping/damage associated with hurricanes is to perform the following steps:

a. Define the hurricane hazard by computing the probabilities associated with each hypothetical hurricane considered in a Joint Probability Method Optimal Sampling (JPM-OS) application. Careful consideration needs to be given to decay in intensity of hurricanes as they approach land in the area of interest and the characteristics and tendencies of hurricanes in the region, particularly those of the most intense and largest hurricanes.

b. Simulate the wind/atmospheric pressure fields for each hurricane. Ensure that the specific time-averaging interval (for example a 10-min average) and the reference elevation (typically a 10-m elevation) for the computed winds matches those inherent in the wind shear stress formulations of the storm surge and wave models to be used. If they are not, some scaling of wind speed will need to be done. This is an extremely important issue that is often not properly treated.

c. Simulate the water level and wave fields for each hurricane in an interactive manner to capture regional short wave effects on storm surge and vice versa. Compute storm water levels and wave conditions just seaward of the levee toe, and identify and use the maximum conditions that occur within a segment of a levee system, for the entire segment of levee being considered.

d. Use the water level and wave information to compute wave overtopping discharges for each storm event at all segments where levee overtopping assessments are needed by applying a simple average wave discharge computation method, a Boussinesq-type model (BOUSS2D for example, see http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;23), or physical scale model. The Boussinesq model or physical scale model can be applied to compute overtopping for a matrix of wave conditions, water levels, and levee configurations, and a look-up table approach can be adopted to select the appropriate overtopping rate results for any particular levee segment, water level, and set of incident wave conditions.

e. Develop probability-response surfaces for locations of interest that relate the flood response parameter of interest (such as storm surge still water level, combined still water level (astronomical tide and surge), wave conditions, or average wave overtopping discharge rate) to the storm probabilities; finely and consistently discretize those probability-response surfaces, accounting for uncertainty in the surfaces; and then integrate the surface(s) to develop the statistical flooding exceedance probabilities (1% exceeedance values with 90% assurance, for example) that are desired, factoring in uncertainty, for each levee segment.

f. Compare values of the 1% chance exceedance wave overtopping rate (having 90% assurance) to the overtopping threshold for each segment or important component of the levee system. If the 1% chance exceedance wave overtopping value (at 90% assurance) is less than the overtopping threshold, then that segment of levee can be certified. Levee systems are only as robust as the weakest link, so each segment of the levee system should pass this overtopping assessment before certifying the entire system.

D-11. This is the general direction in which risk assessment is heading for the coastal/estuarine/lake environment. This same approach has applicability to non-hurricane events. Other methods for computing still water levels and waves associated with extratropical storm events could be used in place of steps (a) and (b) above in the JPM-OS approach.

D-12. The following step-by-step approach is being used by the New Orleans District for design/certification of the levees in the New Orleans vicinity. It represents a reasonable first step toward the more general approach outlined above. It is a somewhat conservative approach in that 1% significant wave heights and 1% wave periods are computed independently and used with 1% exceedance still water levels, to compute wave overtopping rates; as opposed to computing wave overtopping rates using the actual wave conditions that were associated with the still water level conditions for each of the individual storms. The approach outlined below is most valid if the wave conditions are highly correlated with the water levels, which might not be the case.

Step 1: Define Water level

1.1 Examine the 1% surge elevation from the surge-frequency plots at all output points along the levee segments under consideration. The 1% surge elevations are the results based on the 152 storm combinations and using the probabilistic tool (JPM-OS method).

1.2 Determine the maximum 1% surge elevation for each levee segment and use this number for the entire segment. The maximum is chosen to meet the certification/design criterion at the most critical point within the segment.

Step 2: Define Wave Characteristics

2.1 Examine the 1% significant wave height and 1% peak period from the separate wave- and period-frequency plots at all output points along each levee segment. The 1% wave heights and 1% peak periods are the results based on the 152 storm combinations and using the probabilistic tool based on the JPM-OS method.

2.2 Determine the maximum 1% significant wave height and 1% peak period for the segment and use these numbers for the entire segment. The maximum significant wave height and wave period are chosen to meet the certification/design criterion at the most critical point in the segment.

2.3 Determine if the foreshore in front of the levee is shallow. The foreshore is shallow if the ratio between the significant wave height (Hs) and the water depth (h) is small ($Hs/h > 1/3$) and if the foreshore length (L) is longer than one deep water wave length L_0 (thus: $L > L_o$ with $L_o = gT_p^2/(2\pi)$). If so, the wave height at the toe of the structure should be reduced according to $H_{smax} = 0.4$ h (the broken wave height limit). This reduction should only be applied if an empirical method is applied for determining the overtopping rate. The breaking wave effect is automatically included in the Boussinesq model results.

Step 3: Define Overtopping Rate

3.1 Determine if Boussinesq results are available for the specific levee segment. If so, use the Boussinesq results from the lookup table. If not, use the Van der Meer formulations (see EM 1110-2-1100 or TAW 2002).

3.2 Determine the overtopping rate based on the 1% expected values for the surge level, the significant wave height and the peak period. Use the reduced wave height in case of a shallow foreshore in the empirical approach only.

3.3 Check if the wave overtopping rate is less than the adopted threshold rate, 0.1 cu ft/s per ft. If this criterion is exceeded, the levee geometry should be adapted in such a way that the overtopping rate is lower than 0.1 cu ft/s per ft. Note, the mean overtopping rate should be (much) less than 0.1 cu ft/s per ft in order to meet the criterion of 90% non-exceedance in Step 4 because average values are applied for the 1% surge level and 1% wave characteristics.

Step 4: Dealing with Uncertainties

4.1 Apply a Monte Carlo simulation to compute the chance of exceedance of the overtopping rate given the levee crest elevation and levee slope from Step 3. This method takes into account the uncertainties in the 1% water level, the 1% wave height and the 1% wave period.

4.2 Check if the overtopping rate will not exceed the overtopping criterion of 0.1 cu ft/s per ft with a 90% assurance. If yes, the design or certification process is finished from a hydraulic point of view and the levee is certifiable. If not, levee is not certifiable (adapt the levee or floodwall height or slope in such a way that this threshold criterion is not exceeded).

4.3 The hydraulic and geometrical parameters in the design/certification approach are uncertain. Hence, the uncertainty in these parameters should be taken into account in a probabilistic treatment. The following sections propose a method that accounts for uncertainties in water levels and waves, and computes the overtopping rate with state-of-the-art formulations. The objectives of this method are to include the uncertainties and check if the overtopping criterion of 0.1 cu ft/s per ft is still met with a certain percentage of assurance, 90%. The parameters that are included in the uncertainty analysis are the 1% water level, 1% wave height and 1% wave period. Uncertainties in the levee geometrical parameters are neglected. Uncertainties in the method used to predict wave overtopping are included.

4.4 The criterion used in this design approach is the overtopping rate, as mentioned above. For this purpose, the probabilistic overtopping formulation was applied but also the Boussinesq results could be incorporated in the method. Besides the geometrical parameters (levee height and slope), hydraulic input parameters for determination of the overtopping rate are the water level, the significant wave height and the peak period. In the design/certification process, the expected 1% chance exceedance values for these parameters are from the JPM-OS method. Obviously, these numbers are uncertain. An additional analysis provided the standard deviation in the 1% still water level (which accounted for a number of sources of uncertainty). Standard deviation values of 10% of the average significant wave height and 20% of the peak period were used; these were based on expert judgment. All uncertainties are assumed to be normally distributed.

4.5 The Monte Carlo analysis that was applied is executed as follows:

a. Draw a random number between 0 and 1 to set the exceedance probability p.

b. Compute the water level from a normal distribution using the expected value 1% surge level and standard deviation as parameters and with an exceedance probability p.

c. Draw a random number between 0 and 1 to set the exceedance probability p.

d. Compute the wave height and wave period from a normal distribution using the expected value 1% wave height and 1% wave period and the associated standard deviations and with an exceedance probability p.

e. Repeat step 3 and 4 for the three overtopping coefficients in the overtopping formula, independently, using estimates of variability (standard deviation) in each coefficient.

f. Compute the overtopping rate for these hydraulic parameters and overtopping coefficients

g. Repeat the steps 1 through 5 a large number of times (N)

f. Compute the 50%, 90% and 95% value of the overtopping rate (i.e. q_{50}, q_{90} and q_{95})

D-13. The procedure was implemented in MATLAB. Several test runs showed that N should be approximately 10,000 to reach statistically stationary results for q_{50}, q_{90} and q_{95}. The computation time to perform this analysis was on the order of tens of seconds on a current state of the art personal computer.

APPENDIX E

Glossary

1-Percent-Annual-Chance-Exceedance Flood - The flood that has a 1-percent chance of being exceeded in any given year. (1% chance exceedance is also used in this document**)**

Accredited Levee - A levee that the Federal Emergency Management Agency (FEMA) has shown on the Flood Insurance Rate Map as providing protection from the 1-percent-annual-chance or greater flood. This determination is based on the submittal of data and documentation as required by Section 65.10 of the National Flood Insurance Program regulations. FEMA will accredit a levee that has been certified by the USACE or by a registered professional engineer.

Annual Exceedance Probability (AEP) - The probability that flooding will occur in any given year considering the full range of annual possible flood discharges.

Assurance – Alternative term for 'conditional non-exceedance probability'; see below.

Base Flood - The flood that has a 1-percent-annual–chance of being exceeded in any given year.

Base Flood Elevation (BFE) - The water surface elevation of the 1-percent-annual–chance-exceedance flood.

Community—Any state or area or political subdivision thereof, or any Indian tribe or authorized tribal organization, or Alaska Native village or authorized native organization, which has the authority to adopt and enforce floodplain management regulations for the areas within its jurisdiction.

Conditional non-exceedance probability (CNP, alternatively 'Assurance') – The probability that a target stage will not be exceeded during the occurrence of a specified flood. For example, USACE requires that for a levee system to be certified, it must have at least a 90 percent chance of not being overtopped when subjected to a 1% chance exceedance flood event.

Deterministic Analysis – A technical analysis approach that is accomplished using single values for key variables as opposed to using a probability distribution of values for the key variables.

Digital Flood Insurance Rate Map (DFIRM)—A Flood Insurance Rate Map (FIRM) that has been prepared as a digital product. Linkages are built into an associated database to allow users options to access the engineering backup material used to develop the DFIRM, such as hydrologic and hydraulic models, flood profiles, data tables, DEMs, and structure-specific data, such as digital elevation certificates and digital photographs of bridges and culverts.

Discharge-exceedance probability – The relationship of peak discharge to the probability of that discharge being exceeded in any given year.

Equivalent record length – Length in years of a systematic and complete record of peak discharges or stages at a gage. For flood-frequency curves derived for ungaged locations using model or other data, the equivalent record length is estimated based on assigning the overall "worth" of the flood frequency curves expressed as a number of years of record. This value is key in probability of exceedance and uncertainty-based analysis because it directly determines the uncertainty of the flood-discharge probability function.

Federal Emergency Management Agency (FEMA)—The agency within the Emergency Preparedness and Response Directorate of the U.S. Department of Homeland Security. FEMA oversees the administration of the National Flood Insurance Program.

Flood damage reduction Measures – Measures structural and non-structural taken to reduce flood damage. These may include implementation of reservoirs, detention storage, channels, diversions, levees and floodwalls, interior systems, flood-proofing, raising, relocation, and flood warning and preparedness actions.

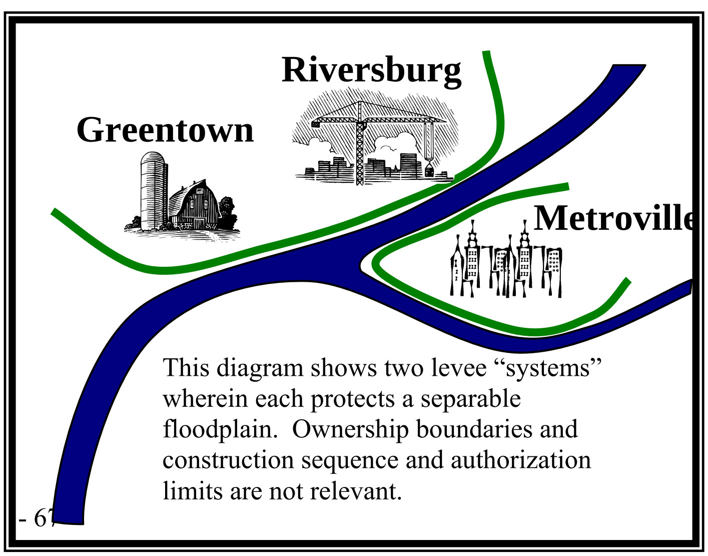
Flood-frequency curve – A graph showing the relationship of the flood variable of interest (peak flow, peak stage, 3-hour volume, etc.) to the probability of the variable being exceeded in any given year.

Flood Insurance Rate Map (FIRM)—The insurance and floodplain management map produced by FEMA that identifies, based on detailed or approximate analyses, the areas subject to flooding during a 1-percent-annual-chance (100-year) flood event in a community. Flood insurance risk zones, which are used to compute actuarial flood insurance rates, also are shown. In areas studied by detailed analyses, the FIRM shows Base Flood Elevations (BFEs) to reflect the elevations of the 1-percent-annual-chance flood. For many communities, when detailed analyses are performed, the FIRM also may show areas inundated by 0.2-percent-annual-chance (500-year) flood and regulatory floodway areas.

Flood Map Modernization (Map Mod) Program—The multiyear program undertaken by FEMA to perform flood hazard assessments and produce new or updated DFIRMs and Flood Insurance Study (FIS) reports for flood-prone communities throughout the United States.

Freeboard – The increment of levee height added to the design flood height to increase the likelihood of the design event being contained without the levee overtopping.

Levee System - A levee system is made up of one or more components which collectively provide flood damage reduction to a defined area. Failure of one component within a system constitutes failure of the entire system. The levee system is inclusive of all components that are interconnected and necessary to insure protection of the associated separable floodplain – levee/floodwall sections, closure structures, pumping stations, culverts, and interior drainage works.



This diagram shows two levee "systems" wherein each protects a separable floodplain. Ownership boundaries and construction sequence and authorization limits are not relevant.

This diagram is an example of how levee systems are to be interpreted for the purposes of this ETL.

Level-of-protection - The recurrence interval of the flood event that results in the protection system capacity exceedance or failure.

Life risk - The threat to loss of life from failure of a flood protection system or feature. Life risk is often expressed as an annual probability vs. lives lost function or expected value of that function (annual lives lost), sometimes referred to as 'annual statistical lives lost.'

Monte Carlo analysis – A method that produces a statistical estimate of a variable of interest by drawing many random samples from a set of variables with associated uncertainty, or relationships of interest with their associated uncertainty. The method is typically used when values for variables are uncertain and best described by appropriate probability distributions.

National Flood Insurance Program (NFIP) — Federal program under which flood-prone areas are identified and flood insurance is made available to the owners of the property in participating communities.

Non-Structural Measures – Nonstructural measures reduce flood damages without significantly altering the nature or extent of flooding. Damage reduction from nonstructural measures is accomplished by changing the use made of the floodplains, or by accommodating existing uses to the flood hazard. Examples are flood proofing, relocation of structures, flood warning and preparedness systems (including associated emergency measures), and regulation of floodplain uses.

One-hundred-year-flood (for FEMA certification) – A median peak flood discharge having a 1 percent-annual chance of being exceeded in any given year.

Probability: A measure of the likelihood, chance, or degree of belief that a particular outcome or consequence will occur. A probability provides a quantitative description of the likelihood of occurrence of a particular event. This is expressed as a value between 0 and 1.

Probabilistic Analysis – the application of probability theory and statistical methods to make inferences about information, facility performance, and the associated uncertainty in inferences.

Probability Function – A discharge-exceedance or stage-exceedance probability relationship for a reach developed by traditional, site-specific, hydrologic engineering analysis procedures.

Public Safety - The concept that agencies and persons have a responsibility to consider and take measures that recognize that actions may directly or indirectly affect the well being of persons impacted by those actions.

Reach - A levee reach is a portion of a levee system (usually a length of levee) that may be considered as a unit taken for analysis purposes to have uniform representative properties. A levee reach will be the unique entity having different properties than other reaches of the levee system and is used to determine the risk assessment of the levee system. There is not a maximum length associated with a reach.

Residual risk – The flood risk (probability of capacity exceedance or failure and the associated consequences) that remains after the flood damage reduction project is implemented.

Return period – The average time interval between occurrences of a hydrological event of a given or greater magnitude, usually expressed in years. It can be expressed by the reciprocal of the annual-chance-exceedance, usually expressed in years.

Risk - Measure of the probability and severity of an adverse effect to life, health, property, or the environment.

Risk Analysis – An approach to evaluation and decision making that is based on the probability of undesirable consequences.

Risk and Uncertainty Analysis – Risk analysis that explicitly, and analytically, incorporates consideration of uncertainty of parameters and functions used in the analysis to determine the undesirable consequences.

Separable floodplain: The portion of a floodplain that may be protected by its associated levee system that is unaffected by the performance or failure of adjacent levee systems.

Special Flood Hazard Area (SFHA)—The area delineated on a National Flood Insurance Program map as being subject to inundation by the base flood.

Stage – Water height measured as the vertical distance in feet (meters) above or below a local or national elevation datum.

Stage-discharge function (alternatively 'Rating Curve')– A tabular or graphical relationship that yields the stage for a given discharge at a specific location on a stream or river.

Stage-discharge functions with uncertainty – Relationship of the water surface stage and discharge. Uncertainty is the distribution of the errors of stage estimates about a specific discharge.

Standard deviation – A statistical measure of the spread of the values of a probability distribution about the mean.

Structural measures – Those water resources project measures designed to modify the flow of flood waters.

Uncertainty – A measure of the imprecision of knowledge of variables and functions used in the risk analysis. Uncertainty may be represented by a specific probability distribution with associated parameters, or sometimes expressed simply as standard deviation.

APPENDIX F

Lessons Learned from the Interagency Performance Evaluation Team's (IPET) report: *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System*

OVERVIEW

The performance of the I-Walls in New Orleans in the 2005 Hurricane Katrina disaster provides numerous lessons learned, all of which should be understood and considered when performing a certification. This appendix provides a very brief summary of the structural aspects of the disaster, including specific discussions of some of the well analyzed failures. The entire IPET report is a very large document and it is well beyond the scope of this appendix to capture all of the information pertinent to the safety of a levee system. The text of this report is available at https://ipet.wes.army.mil/ . In particular, Volume V. The Performance - Levees and Floodwalls, and the structural appendices shall be reviewed and the project under consideration for certification shall be considered in this context.

Over 220 miles of the New Orleans area's protective structures were damaged by storm surges and waves generated by Hurricane Katrina, as well as 34 of 71 pumping stations. Approximately 41 miles of structures were judged to be severely damaged. Initially there were a total of 50 major breaches identified, areas where the structures failed, causing a dramatic reduction in protective elevation and loss of the ability to prevent the inflow of external water. Of the 50 major breaches, four were caused by foundation-induced failures and the remainder from a combination of overtopping and scour. Three of the four foundation breaches occurred in the outfall canals and one in the Inner Harbor Navigation Canal (IHNC). I-wall structures were particularly vulnerable as were levee sections created from hydraulic fill, and transitions where either elevation or strength differences occurred from changes in structure type or capability. Transitions between types of flood protection structures were also vulnerable, especially where the transition included a significant change in elevation between the structures.

The overtopping waves created very high water velocities down the back sides of the levees, reaching 10 to 15 ft/sec. These velocities were two to three times those experienced on the water side of the levees (4 to 6 ft/sec). The potential for erosion is related to the cube of velocity; thus the back sides of the levees, especially where they were comprised of erodible materials, were scoured away leading to, in many cases, complete breaching.

DESCRIPTION OF FAILURES

Early in the morning, around 0500 hr, CDT, a section of I-wall along the Lower Ninth Ward breached. Underlain by the same marsh deposits and clay as the 17th Street Canal, the rising water and waves caused the wall to deflect enough to open a crack that created a direct avenue for high water pressures to reach the foundation. The weak clays underneath, now only reacting with the mass of soil on the protected side of the levee, could not withstand the force and displaced backward, a process that would repeat itself on the 17th Street Canal. The water levels in the IHNC were approximately 9.5 to10.5 ft when the foundation failure occurred. At the 17th

Street Canal, failure began with apparent displacement of a wall panel at about 0630 hr and ended with a full breach by 0900 hr. At about 0630 hr, the water level was estimated to have been 7 to 8 ft, and possibly 1 to 2 ft higher at the time of the catastrophic breach created by displacement of a levee section. No overtopping had occurred and the design water elevations had not been reached at either location, at the time of levee displacement.

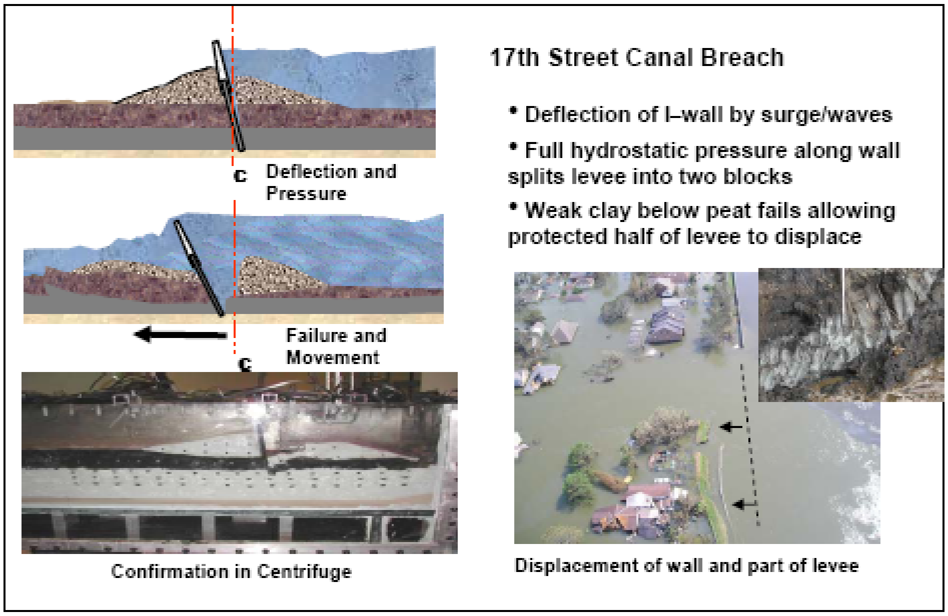


Figure 20. Depiction of failure mechanism for 17th Street and IHNC foundation failures. A crack forming along the front of the I-wall introduced high forces down the face of the sheet pile, resulting in lateral movement of the floodwall along a shear plane in the weak clay foundation.

At around 0700-0800 hours, not long after the 17th Street Canal breach started, the south breach on the London Avenue Canal was initiating. As in the case of the 17th Street Canal and IHNC failures, water elevations below the design levels caused a crack to form on the water side of the floodwall and allowed high pressures to be introduced directly into the foundation materials of the levee, this time relic beach sand. The porous sand quickly conveyed the pressure under the levee and caused significant uplift on the protected side. It also is likely that significant subsurface erosion occurred under the levee and caused a blowout on the protected side through which much sand and water flowed, decreasing the support for the levee and floodwall and causing a narrow failure. The north breach on the London Avenue Canal suffered a similar fate around the same time, 0700-0730 hr. This breach was much wider and involved less erosion, failure being caused by a loss of stability from the uplift. Water levels in the London Avenue Canal reached about 9 ft, below the design levels and well below the height of the I-walls. Figure 21 depicts the breaching mechanisms for the London Avenue breach sites. This finding was arrived at through detailed field investigations, independent seepage and stability analyses by Virginia Tech and Engineering Research and Development Center (ERDC) teams and separate centrifuge modeling by Rensselaer Polytechnic Institute (RPI) and ERDC. Ironically, the Orleans Canal, geographically located between the 17th Street and London Avenue Canals, and having similar geological conditions, did not suffer failure, even though water levels there reached over 10 ft. The geology at the north end of the Orleans Canal is similar to 17th Street conditions (peat underlain by clay) and the south end is similar to London Avenue subsurface conditions Peat underlain by relic beach sands). The design of the levees and I-walls for the Orleans Canal was more conservative than for the other canals with a broader and stronger levee section and less I-wall height above the levee crest. Soil strength assumptions were also more conservative than for the structures along the 17th Street Canal. This knowledge was an important component of the development of criteria for evaluating the integrity of the sections of the Hurricane Protective System (HPS) that were not severely damaged. Combined with the knowledge of the failure modes for the I-walls and levees, a series of remedial actions were developed that could be used to at least temporarily strengthen sections of the HPS that were deemed least able to withstand a large storm. This led to a large scale examination of the HPS by the New Orleans District to identify areas needing remedial action prior to the 2006 hurricane season.

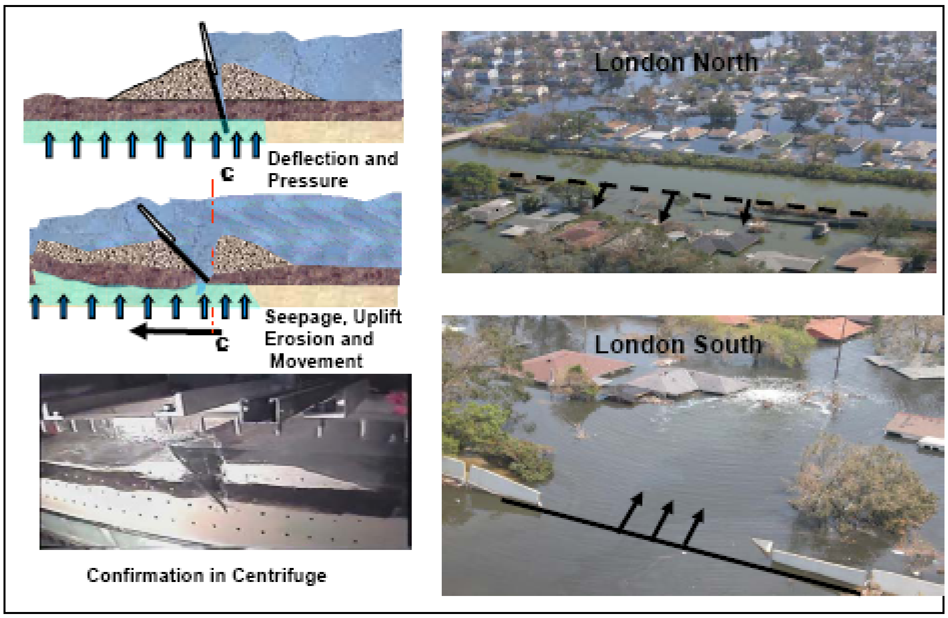


Figure 21. Depiction of London Avenue Canal north and south breaches caused by deflection of the I-wall and high uplift pressures introduced through the underlying porous sands, confirmed in centrifuge testing.

During mid-morning, the I-walls along the IHNC were overtopped and erosion behind the wall reduced their stability, causing three separate sections to fail. The top photograph in Figure 21 shows a section of I-wall along the IHNC collapsed after overtopping created a scour trench behind it and reduced its stability. The bottom photograph shows an adjacent section of I-wall where the scour trench formed but the wall did not fail. Water levels reached over 14 ft in the IHNC. There was also a levee failure along the west side of the IHNC that caused additional flooding into the Upper Ninth Ward. There were no T-wall failures with the exception of a small section in southern Plaquemines Parish.

SUMMARY OF LESSONS LEARNED:

Of the 50 major breaches experienced by the HPS during Katrina, all but four were due to overtopping and erosion. For floodwalls, the overtopping caused erosion behind the walls that eventually caused instability and wall failure. For levees, the scour eroded the back sides and tops of the levees due to high velocities of the overtopping waves in areas of erosion susceptible soils creating breaching. Areas with high quality levee materials performed well in the face of water conditions that exceeded their design criteria. Structures at authorized design elevations would have reduced the amount of overtopping.

There was no evidence of systemic breaching caused by erosion on face or water sides of the levees exposed to surge and wave action. The water velocities on the face side were only one-third of those experienced at the crest and back or protected side of the levees. The levees largely performed as designed, withstanding the surge and waves until overtopping, at which time they became highly vulnerable to erosion and breaching, especially those constructed by hydraulic fill.

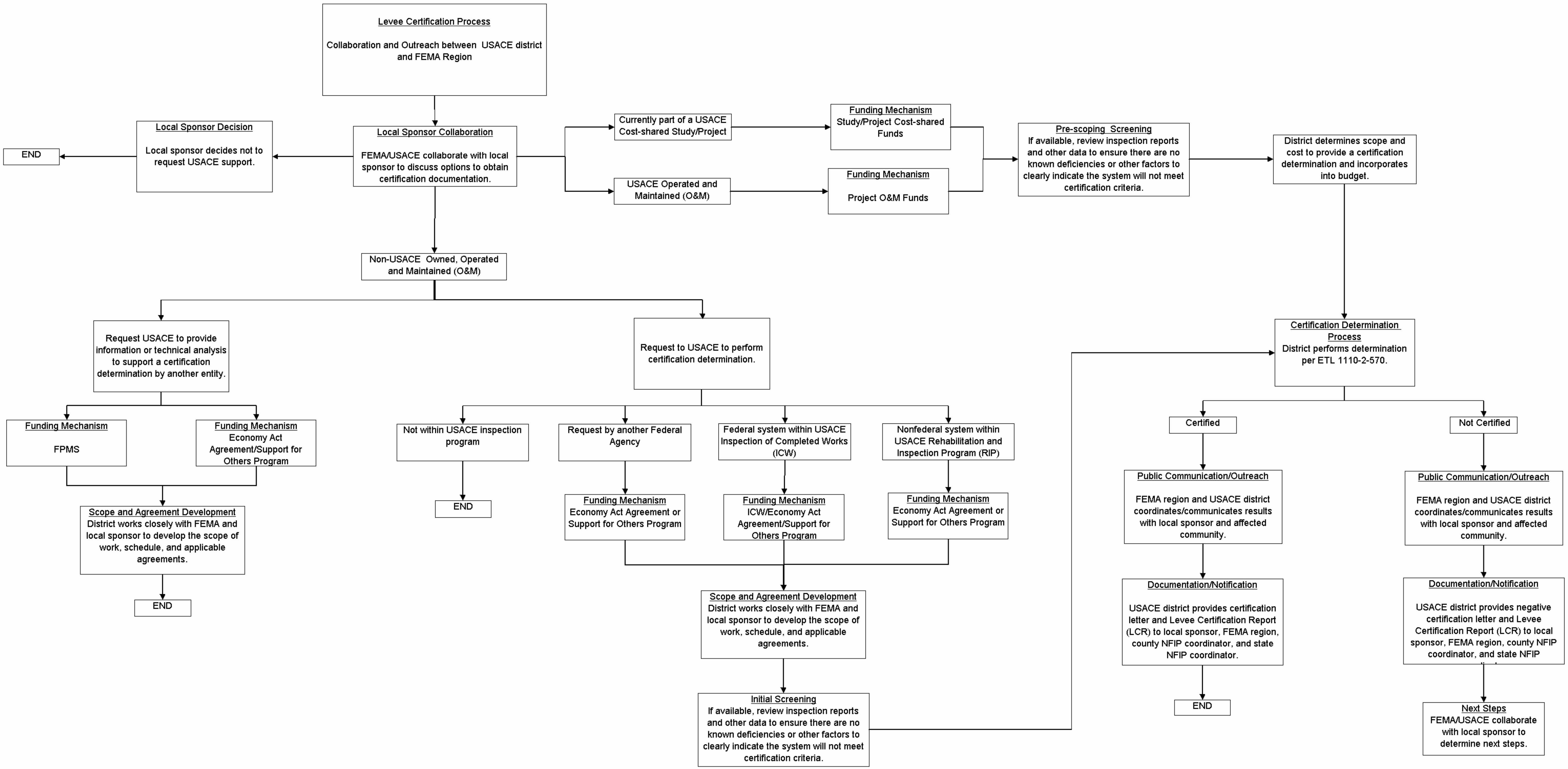
Four breaches, all in the outfall canals and IHNC and all involving I-walls, occurred before water levels reached the top of the floodwalls. All were caused by foundation failures induced by the formation of a gap along the canal side of the floodwall. All of these structures were built over a layer of marsh sediments, in two cases underlain by clays and in the other two underlain by relict beach sand deposits. Along the outfall canals, the subsurface conditions dictated the specific mechanics that, coupled with the high hydrostatic pressures introduced to depth by the gap along the face of the sheet pile, led to instability and failure. The sites underlain by sand experienced significant uplift pressures, seepage and, in one case, a massive piping of subsurface sand from under the levee to the protected side. This action undermined the floodwall.

Transitions between types and levels of protection and between protection structures and other features created vulnerabilities to erosion and breaching and reduced the effectiveness of the protection. Some of the transitions are associated with changes in the organization responsible for the structures, some are due to incompletion of the authorized construction, and others are associated with necessary penetrations through the levee/floodwall system.

APPENDIX G

Procedural Flowchart

Version September 12, 2007



Levee Certification Process Flowchart