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Subject:	Evaluation Guidance
Date:	Monday, April 23, 2012 5:06:17 PM
Attachments:	NEI Flooding Evaluation Guidance Rev D 04-23-12 .docx

Ed,

During the last few meetings we have told you about a flooding evaluation guidance document that we are preparing. The purpose of the document is to provide a general overview of the evaluation process for those that are not familiar with it, to document a “snapshot” of acceptable references for use in flooding evaluations, and to start the process of documenting additional information that will assist utilities in completing their evaluations efficiently and consistently.(information such as clarification to existing guidance or additional details).

The current draft of our evaluation guidance is attached for your review. We would like to discuss this document during our meeting on Thursday and would appreciate any comments you may have on it.

Thank you,

Jim Riley

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Guidance on NPP External Flooding Evaluations

Contents

DRAFT

A. INTRODUCTION

In response to the nuclear fuel damage at the Fukushima-Daiichi power plant due to the March 11, 2011 earthquake and subsequent tsunami, the United States Nuclear Regulatory Commission (NRC) is requesting information pursuant to Title 10 of the Code of Federal Regulations, Section 50.54 (f) (10 CFR 50.54(f) or 50.54(f)). As part of this request, licensees will be required to reevaluate flooding hazards, per present-day guidance and methodologies for early site permits and combined license reviews, to assess margin at safety-related structures, systems, components (SSCs) and effectiveness of current licensing basis (CLB) protection and mitigation measures. The request is associated with the NRC's Post-Fukushima Near-Term Task Force (NTTF) Recommendation 2.1 for flooding, approved by the Commission in SECY 11-0137, *Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned*, dated December 15, 2011.

A.1 Background on External Flooding Evaluations for US NPPs

- **Summary of Flooding Re-Evaluations Associated with IPEEE**

  In June 1991, the NRC issued Supplement 4 to Generic Letter (GL) 88-20, "*Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities"*, to request that each licensee identify and report vulnerabilities to severe accidents caused by external events, including floods. The IPEEE program included the following four (4) objectives:

  1. Develop an appreciation of severe accident behavior;
  2. Understand the most likely severe accident sequences that could occur at the licensee's plant under full-power operating conditions;
  3. Gain a qualitative understanding of the overall likelihood of core damage and fission product releases; and
  4. Reduce, if necessary, the overall likelihood of core damage and radioactive material releases by modifying, where appropriate, hardware and procedures that would help prevent or mitigate severe accidents.

  In most cases, licensees used a qualitative/screening approach, in lieu of a quantative/detailed approach, to assess the flooding hazard. Therefore, new studies may represent the first detailed/comprehensive flooding evaluations since the plants were designed.

- **US Regulatory Post-Fukushima Response**

  As discussed previously, the NRC established a Post-Fukushima NTTF responsible for conducting a review of NRC processes and regulations and determining if the agency should make additional improvements to its regulatory system. A set of recommendations, contained in a report to the Commission dated July 12, 2011 (SECY-11-0093), was developed to assess flood prevention (hardened protection), mitigation, and emergency preparedness (EP) and effectiveness in performing its safety function.

  On September 9, 2011, the NRC staff submitted SECY-11-0124 to the Commission. The document identified those actions from the NTTF report that should be taken without unnecessary delay. As part of the October 18, 2011, staff requirements memorandum (SRM) for SECY-11-0124, the NRC approved the staff's proposed actions, including the development of three information requests, issued March 12, 2012, under 10 CFR 50.54(f). The information collected would be used to support the NRC staff's evaluation of whether further regulatory action was needed in the areas of seismic and flooding design, and emergency preparedness.

On December 23, 2011, the Consolidated Appropriations Act, Public Law 112-074, was signed into law. Section 402 of the law requires a re-evaluation of licensees' design basis for external hazards, including floods, and expands the scope to include other external events. Reevaluation of the design basis with respect to other external events will be requested later as a separate action.

In summary, the NRC is requiring reactor licensees to reevaluate flooding hazards at their sites against current applicable NRC requirements and guidance and respond to the Commission that the design basis for each reactor meets the requirements of its license. Pending results of the evaluations, the NRC may require licensees to update the design basis for each reactor and/or develop a plan for corrective actions, as necessary.

In the 50.54(f) letter, the NRC indicates that flood hazard evaluations should be implemented in two (2) phases as follows:

- *Phase 1: Issue 50.54(f) letters to all licensees to request they reevaluate the seismic and flooding hazards at their sites using updated seismic and flooding hazard information and present-day regulatory guidance and methodologies and, if necessary, to request they perform a risk evaluation. The evaluations associated with the requested information in this letter do not revise the design basis of the plant. This letter implements Phase 1.*
- *Phase 2: Based upon the results of Phase 1, the NRC will determine whether additional regulatory actions are necessary (e.g. update the design basis and SSCs important to safety) to provide additional protection against the updated hazards.*

A.2 Flooding Evaluations Requested by March 2012 50.54(f) Letters

- **Action and Information Requested by the NRC in the 50.54(f) Letter**

Requested Action:

  - Evaluate all relevant flooding mechanisms using present-day regulations, methodologies, engineering practices, and modeling software (Phase 1). Actions associated with Phase 2 (above) are not being requested at this time, pending completion of the Phase 1 evaluations.
  - Where the reevaluated flood exceeds the design basis, submit an interim action plan that documents actions planned or taken to address safety issues (if any) at the new hazard levels.
  - Perform an integrated assessment of the plant for the entire duration of the flood conditions to identify vulnerabilities and corrective actions under full power operations and other plant configurations. The scope also includes those features of the ultimate heat sinks that could be adversely affected by flood conditions and lead to degradation of the flood protection. (The loss of ultimate heat sink from non-flood causes is not included.)

Requested Information:

- Hazard Reevaluation Report – Documents the results of the new evaluations for all relevant flooding mechanisms.
- Integrated Assessment Report – Documents corrective actions (completed and/or planned) for plants where the current design basis floods do not bound the reevaluated hazard for relevant mechanisms and the entire duration of the flood.

Figure 1 and Figure 2 provide an overview of the approach contained in the 50.54(f) letter request for new flooding evaluations. Detailed descriptions for each step in the approach are provided in the 50.54(f) letter. The flood hazard reevaluation should address all relevant flood causing mechanisms at the site. The reason for screening out flood causing mechanisms should be clearly discussed in the final report. A summary of potential flood causing mechanisms and screening process is provided in Section E.

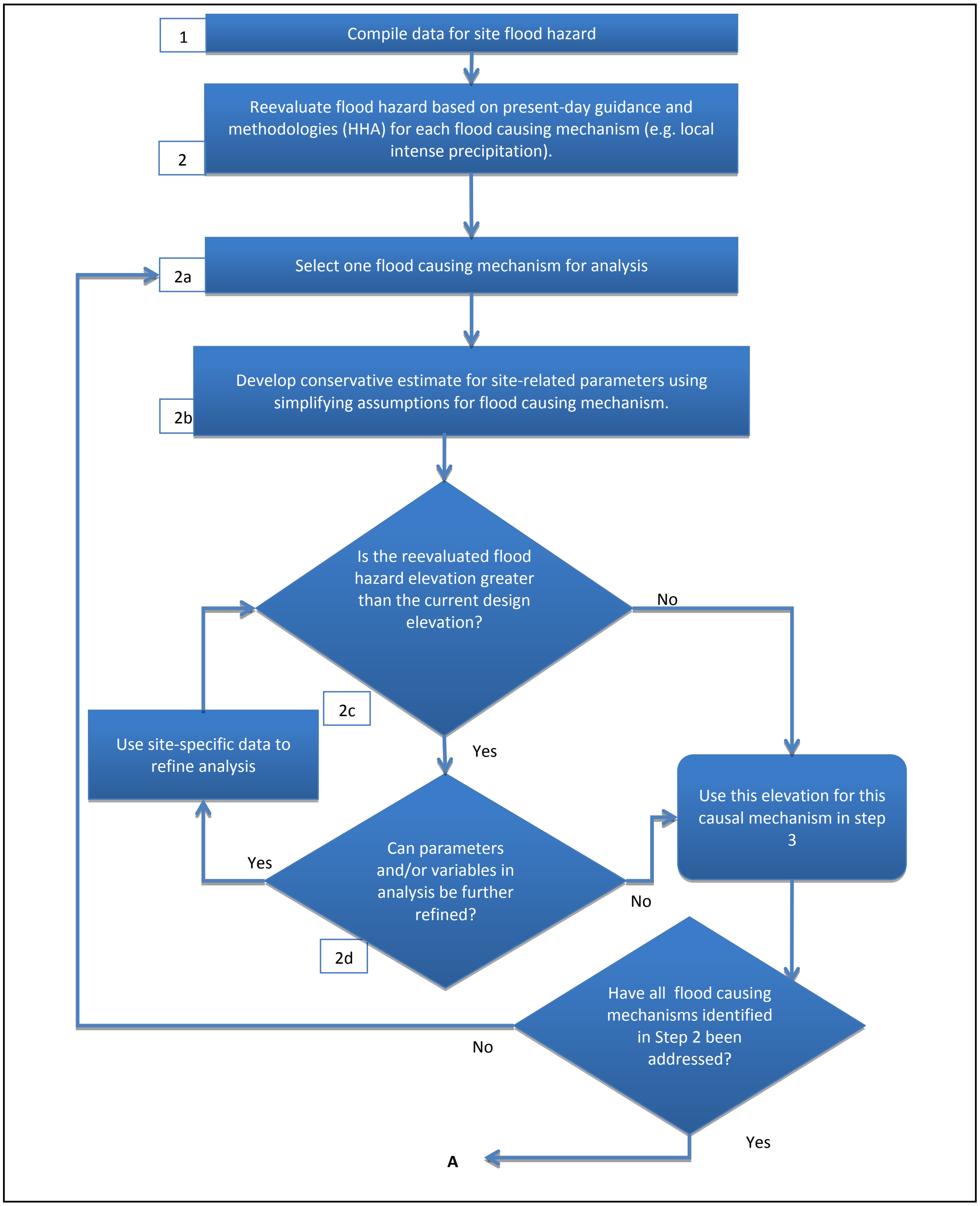

Figure 1 – Process to Develop Requested Flooding Information

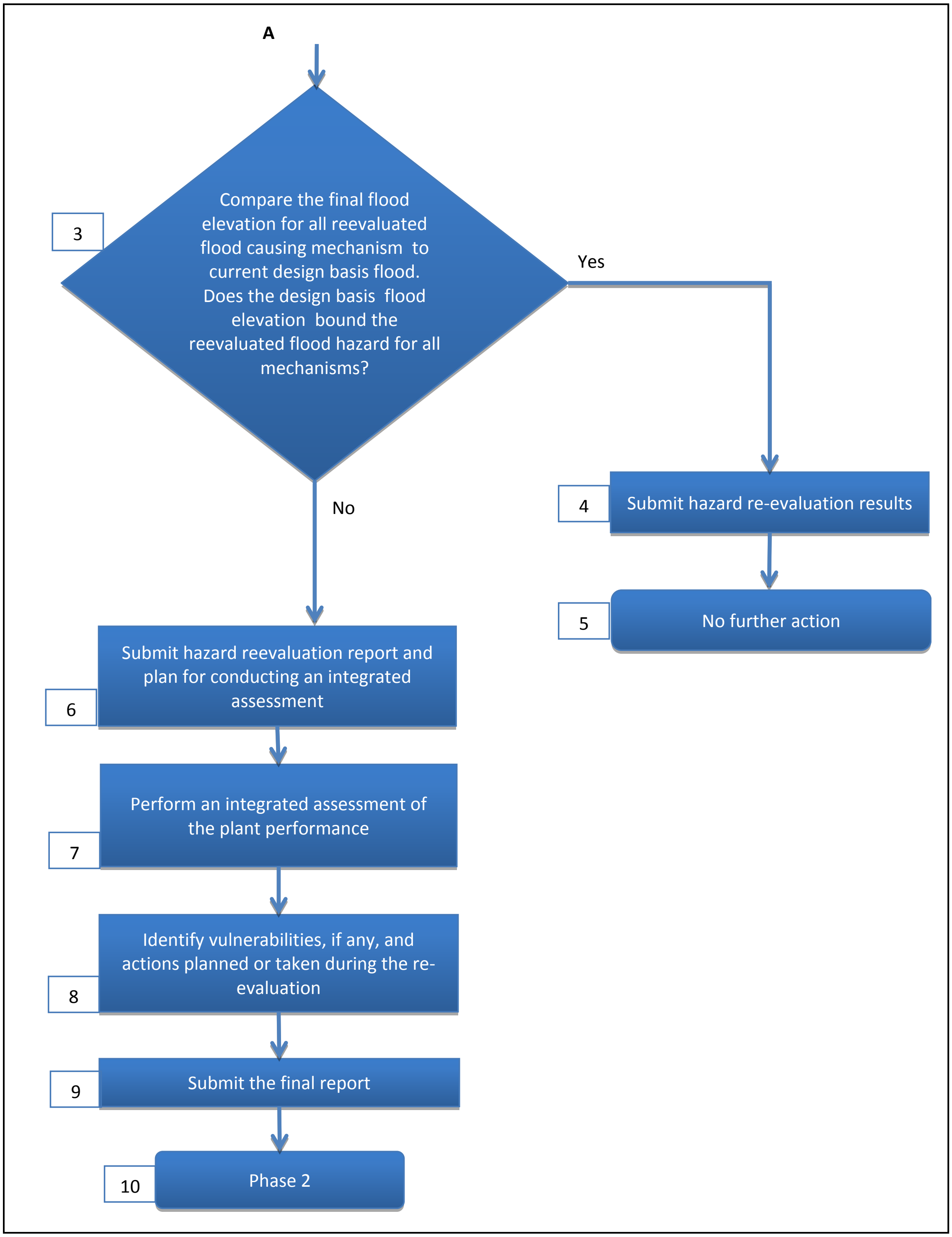

Figure 2 - Process to Develop Requested Flooding Information

- **Overview of RG 1.59 and NUREG/CR-7046**

  Prior to the March 2011 Fukushima-Daiichi earthquake/tsunami events, the NRC standard for flood estimation was the 1977 version of Regulatory Guide (RG) 1.59 and its appendices:

  A. Probable Maximum and Seismically Induced Floods on Streams and Coastal Areas (which references American National Standards Institute (ANSI) Standard N170-1976, superseded by ANSI/ANS (American Nuclear Society) 2.8, "Determining Design Basis Flooding at Power Reactor Sites", July 28, 1992)

  B. Alternative Methods of Estimating Probable Maximum Floods

  C. Simplified Methods of Estimating Probable Maximum Surges

  In the 50.54(f) letter, the NRC is requesting updated flooding hazard information using 'present-day regulatory guidance and methodologies to review early site permits (ESPs) and combined license (COL) applications'. Although the update to RG 1.59 is not complete, the NRC is considering NUREG/CR-7046, "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America", November 2011, as representing present-day methodologies for flooding evaluations; superseding Appendix A of RG 1.59 (ANSI/ANS 2.8).

  NUREG/CR-7046 describes present-day methodologies and technologies that can used to estimate design-basis floods at nuclear power plants for a range of flooding mechanisms, including rivers/streams, dam failures, local intense precipitation (local/site runoff), storm surge, seiche, ice-induced flooding, channel migration/diversion, and combined-effects floods (for dependent or correlated events).

  Note that NUREG/CR-7046 does not address tsunamis; NUREG/CR-6966 ("Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America") is referenced as a guide for the evaluation of tsunamis.

- **Deterministic versus Probabilistic Approaches**

  NUREG/CR-7046 addresses two approaches to conducting flood evaluations – deterministic and probabilistic. Deterministic methods use empirical, mathematical, and/or physical relationships to simulate flooding for a given/specified event or set of events. Typically, the specified event or set of events is established by defining a theoretical maximum event (e.g. Probable Maximum Precipitation (PMP), Probable Maximum Flood (PMF), Probable Maximum Hurricane (PMH), etc.) given physically limiting parameters (e.g. maximum precipitable water in the atmosphere).

  Probabilistic methods are used to establish a relationship between flood magnitude and exceedance probability (typically expressed as percent chance of being equaled or exceeded in any given year (p) or annual recurrence interval (1/p)). Probabilistic methods typically require the use probability distribution models, known to be representative of specified random, extreme flood-causing events (i.e. extreme rainfall, river flow, storm surge, etc.). Probability models are typically 'fitted' to historical flood/precipitation data and, given the limited period of observed flood/precipitation records, subject to significant uncertainty at low exceedance probabilities. Example probability distributions frequently used in flooding evaluations include Log-Pearson Type III and Extreme Value (Types I and II).

NUREG/CR-7046 provides only an introduction to the application of probabilistic methods in flood estimation at nuclear power plants, acknowledging that detailed methodology and guidance are currently not available. Besides high uncertainty at low annual exceedance probabilities, a challenge with using probabilistic methods in flood estimation at nuclear power plants is using a flood-frequency function within the context of Probability Risk Assessment (PRA) models, which estimates annual core damage probability to 10^{-6}. Extrapolating flood-frequency functions to, or beyond, a 10^{-6} annual exceedance probability usually results in exceeding physical limits of flood-causing processes (theoretically captured as the PMP, PMF, PMH, etc.). Further research and development is needed to apply probabilistic methods to flood estimation at nuclear power plants. Such research may include other techniques, such as Monte-Carlo simulations, to estimate frequency of extreme floods. Therefore, the methods in NUREG/CR-7046 focus on the use of deterministic methods.

- **Hierarchical Hazard Assessment (HHA) Approach**

  NUREG/CR-7046 describes the Hierarchical Hazard Assessment (HHA) approach as:

  > "a progressively refined, stepwise estimation of site-specific hazards that evaluates the safety of SSCs with the most conservative plausible assumptions consistent with available data. The HHA process starts with the most conservative simplifying assumptions that maximize the hazards from the probable maximum event for each natural flood-causing phenomenon expected to occur in the vicinity of a proposed site. The focus of this report is on flood hazards. If the site is not inundated by floods from any of the phenomena to an elevation critical for safe operation of the SSCs, a conclusion that the SSCs are not susceptible to flooding would be valid, and no further flood-hazard assessment would be needed."

  The HHA process, illustrated in Figure 3, allows licensees the option to conduct simplified flooding evaluations, based on varying degrees of conservativeness, to assess susceptibility to flooding. The evaluation is refined, using site-specific parameters, when resulting hazard levels exceed acceptance criteria for safety-related SSCs. NUREG/CR-7046 describes the key steps in the process as follows:

  1. Identify flood-causing phenomena or mechanisms by reviewing historical data and assessing the geohydrological, geoseismic, and structural failure phenomena in the vicinity of the site and region.
  2. For each flood-causing phenomenon, develop a conservative estimate of the flood from the corresponding probable maximum event using conservative simplifying assumptions.
  3. If any safety-related SSC is adversely affected by flood hazards, use site-specific data to provide more realistic conditions in the flood analyses while ensuring that these conditions are consistent with those used by Federal agencies in similar design considerations. Repeat Step 2; if all safety-related SSCs are unaffected by the estimated flood, or if all site-specific data have been used, specify design bases for each using the most severe hazards from the set of floods corresponding to the flood-causing phenomena.

  The HHA process is applied to specific flooding mechanisms (e.g. river/stream flooding, dam failure, local intense precipitation, etc.) and can be used to screen these mechanisms, which may be helpful in developing the categorization scheme (Section D). Local intense precipitation is the only flooding mechanism that, in most cases, cannot be screened out.

Applying the HHA approach may not be appropriate for every site, particularly if available data shows the site is susceptible to flooding, has low margin, and/or was licensed as a 'wet' site (where mitigation measures are used to prevent core damage). In such cases, it would be appropriate to conduct site-specific/refined evaluations without making unnecessary conservative assumptions.

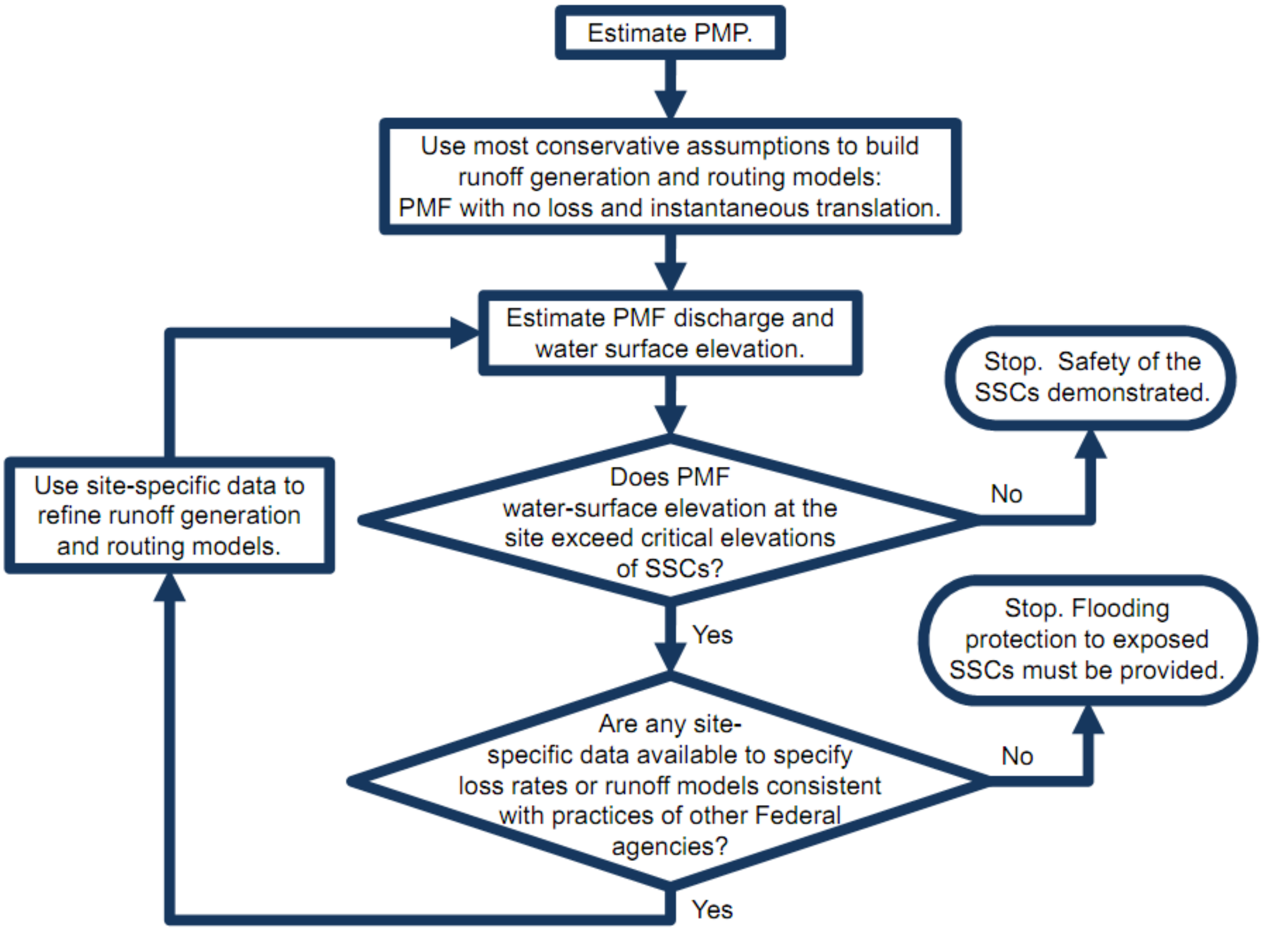

Figure 3 - HHA Process (NUREG/CR-7046)

B. PURPOSE

This document provides guidance for the items listed below in accordance with the NRC recommendation in Item 2.1 of SECY 11-0137:

- Reevaluate the flooding hazards for existing plants using the requirements being imposed on new reactors;
- Compare a plant's existing licensing and design basis and protection features for flooding to the new flooding hazard levels; and
- Identify vulnerabilities and corrective actions (if necessary).

The guidance is intended to give utility staff general information on the various flooding mechanisms, establish industry-wide priorities, develop scoping strategies, and provide technical references/considerations. This document is intended to supplement NUREG/CR-7046 but should not be used as a comprehensive technical reference for completing the evaluations.

The specific request from SECY 11-0137 Item 2.1 is as follows:

- *Interact with stakeholders to inform NRC's process for defining guidelines for the application of present-day regulatory guidance and methodologies being used for early site permit and combined license reviews to the reevaluation of flooding hazards at operating reactors;*
- *Develop and issue a request for information to licensees pursuant to 10CFR50.54(f) to (1) reevaluate site specific flooding hazards using the methodology discussed above; and (2) identify actions that have been taken or are planned to address plant specific issues associated with the updated flooding hazards (including potential changes to the licensing or design basis of a plant)."*

C. DEFINITIONS

Acceptance Criteria – Flood protection features are considered acceptable if protection and/or mitigation measures allow safety-related SSCs to perform its credited function at probable maximum flood conditions, giving due consideration to flood elevations, wind-generated wave activity, dynamic loading conditions, and warning times for the full duration of flooding and various applicable flooding mechanisms. That is, probable maximum flood conditions do not exceed cliff-edge effect conditions. For example, a safety-related SSC may be subject to flooding independently from a precipitation/runoff event and 'sunny day' dam failure (no precipitation). The precipitation/runoff event may produce higher flood levels but has warning times longer than a 'sunny day' dam failure. Therefore, an SSC may have two acceptance criteria; flood levels associated with the precipitation/runoff event and warning times (to implement mitigation measures) associated with a 'sunny day' dam failure.

Channel Migration or Diversion – Flood hazard associated with channel diversion is due to the possible migration either toward the site or away from it. For natural channels adjacent to the site, historical and geomorphic processes should be reviewed for possible tendency to meander. For man-made channels, canals or diversions used for the conveyance of water located at a site, possible failure of these structures should be considered.

Cliff Edge Effect – A small increase in flood level potentially resulting in significant impact to safety-related SSC(s).

Combined Effect Flood – Plausible combination of dependent flooding mechanisms occurring simultaneously.

Dam Breaches/Failures – A breach/failure, which can be caused by several possible mechanisms including overtopping, seismic activity, slope failures, etc., can produce a flood wave with high flow rates, velocities, and depths. The flood wave attenuates as it moves downstream causing the peak flow rates, velocities, and flood depths to dissipate. Flood waves from failures of dams (or other upstream structures) are distinct from wind-generated waves.

Design Basis Flood – A design-basis flood is a flood caused by one or an appropriate combination of several hydrometeorological, geoseimic, or structural-failure phenomena, which results in the most severe hazards to structures, systems, and components (SSCs) important to the safety of a nuclear power plant.

Flood Warning – Alert systems notifying people and/or facilities along low-lying areas that flooding is possible, likely, and/or imminent. Flood warning time is the time between the alert and arrival of floods and is dependent on the flooding characteristics. Flash floods are typically associated with fast-moving, short-duration, highly-intense storms affecting streams and drainage systems with relatively small watersheds, and generally have short warning times. Warning time for dam failure flooding can be very short and unpredictable, depending on the velocity of the flood wave, the dam's distance from the point of interest, type of dam, and the time taken by the dam owner to notify emergency officials.

Hardened Protection – Structural provisions incorporated in the plant design that will protect safety-related SSCs from the static and dynamic effects of floods, are passive, and in-place during normal plant operation.

Hydrodynamic Loads – Hydrodynamic loads are loads that result from water flowing against and around a rigid structural element or system. The hydrodynamic loads can include the effects of broken and non-breaking waves striking structures, initial impact of a rapidly varying flood wave (e.g. dam break or tsunami flood wave), and drag forces on a structure (caused by the pressure differential between the upstream and downstream side of the structure).

Ice Induced Flooding – Ice jams can cause flooding in two ways: 1) by impounding water upstream of a site and subsequently collapsing (analogous to a dam breach/failure) or 2) impounding and backing up water from a downstream location.

Local Intense Precipitation (LIP) – Local intense precipitation represents extreme (high intensity/short duration) precipitation directly over the plant site area.

Mitigation – Per RG 1.59, it is permissible not to provide hardened protection for some SSCs if sufficient warning time is available to safely shut-down the plant and implement adequate emergency procedures; all safety-related SSCs are designed to withstand the Standard Project Flood with wind-generated wave activity, from worst winds of record, and remain functional; and reasonable combinations of the less-severe floods are considered for a consistent level of conservatism.

Probable Maximum Events – Probable maximum events are thought to approach the physical limits of the phenomena, are deterministic in nature, and are thought to exceed all historical occurrences of the phenomena. In the context of flooding, probable maximum events include:

- **Probable Maximum Flood (PMF)** – The PMF is a hypothetical flood (peak discharge, volume, and hydrograph shape) considered to be the most severe reasonably possible, based on comprehensive hydrometeorological application of Probable Maximum Precipitation (PMP) and other hydrologic factors favorable for maximum flood runoff, such as sequential storms and snowmelt. Typically, several PMP scenarios are evaluated to establish the bounding (largest possible) PMF.

- **Probable Maximum Hurricane (PMH)** – The PMH is a hypothetical hurricane having a combination of characteristics that generate the most severe that can reasonably occur in the particular region.

- **Probable Maximum Precipitation (PMP)** – The estimated depth of precipitation for a given duration, drainage area, and time of year for which there is virtually no risk of exceedance. The probable maximum precipitation for a given duration and drainage area approximates the theoretical maximum that is physically possible within the limits of contemporary hydrometeorological knowledge and techniques.

- **Probable Maximum Storm Surge (PMSS)** – The PMSS is generated by the Probable Maximum Hurricane (PMH) or Probable Maximum Windstorm (PMWS).

- **Probable Maximum Tsunami (PMT)** – The PMT is that tsunami for which the impact at the site is derived from the use of best available scientific information to arrive at a set of scenarios reasonably expected to affect the nuclear power plant site, taking into account (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated; (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and (3) the importance of the safety functions to be performed.
- **Probable Maximum Wind Storm (PMWS)** – A hypothetical extratropical cyclone that might result from the most severe combination of meteorological storm parameters that is con- sidered reasonably possible in the region in- volved. The windstorm approaches the point under study along a critical path and at an optimum rate of movement, which will result in the most adverse flooding.

Riverine Flooding – A watershed's response to a rainfall-runoff event that produces overbank flow at a given location. Riverine flooding adjoining the site, associated with the PMF, is determined by applying the PMP to the watershed draining to the site location.

Safety Margin – Difference between probable maximum flood hazard conditions and acceptance criteria (e.g. allowable head on a door seal minus probable maximum flood level; time needed to construct temporary cofferdam and minimum flood warning time; etc.)

Seiche – A seiche is an oscillation of the water surface in an enclosed or semi-enclosed water body initiated by an external cause.

Standard Project Flood (SPF) – The US Army Corps of Engineers' (USACE's) definition of the SPF is floods that produce flow rates generally 40% to 60% of the PMF. Historically, the USACE established the SFP based on the flood of record. More recently, risk-based analysis procedures are used to establish the SPF.

Storm Surge – Storm surge is the rise of offshore water elevation caused principally by the shear force of the hurricane or tropical depression winds acting on the water surface and the associated pressure differential.

Tsunami – A tsunami is a series of water waves generated by a rapid, large scale disturbance of a water body due to seismic, landslide or volcanic tsunamingenic sources.

Vulnerability – Plant-specific vulnerabilities are defined as those features important to safety that when subject to an increased demand due to the newly calculated hazard evaluation have not been shown to be capable of performing their intended safety functions.

D. SCOPING STRATEGY AND DETAILED EVALUATION CONSIDERATIONS

D.1 Scoping Strategy

Before conducting detailed flooding evaluations, a scoping phase should be completed by a person experienced in conducting such evaluations to:

- Compile, review, and understand available information that could be leveraged for the evaluation;
- Identify major physical and operational changes to assess the need for new or supplemental surveys;

- Identify relevant (screen) flooding mechanisms;
- Assess extent of evaluation for each flooding mechanism (HHA approach); and
- Develop site-specific scope for flooding evaluation.

D.1.1 Compile/Review Available Information Related to Flooding Sources

Before proceeding with a screening and detailed engineering analyses, collect available information should be conducted, including but not limited to: FSAR and other design/licensing basis information related to flooding, LiDAR (Light Detection And Ranging), bathymetry, aerials, land use, soils, location/information on upstream dams, tsunami studies, hurricane/surge studies, Operation and Maintained manuals, high watermarks, gage data, Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) and Flood Insurance Study (FIS) reports, etc.

D.1.2 Identify Major Physical and Operational Changes

Frequently, changes to physical features, topography, and/or operations have occurred since available site information was collected. A field reconnaissance should be conducted to review the available information and assess the need for new or supplemental surveys. The supplemental data is intended to define features not adequately represented on available mapping data, such as security fences, concrete barriers, curbs, new/removed buildings, etc. The available, new, and/or supplemental data should be used to construct a digital elevation model (DEM) in GIS format. These updates are particularly important for evaluating the local intense precipitation flooding mechanism.

D.1.3 Identify Relevant (Screen) Flooding Mechanisms

The scoping phase should include a review and assessment of potential flooding mechanisms, listed below, to identify those relevant to a particularly site. This process is intended to be a screening-level review of possible flooding mechanisms and refine the list of mechanisms that warrant further evaluation. Flooding mechanisms should be qualitatively screened based on best-available information and engineering judgment. Conditions should be clear and apparent to warrant a particular flooding mechanism to be eliminated from further consideration, such as ice-induced flooding in Florida. The flooding mechanisms listed below are better defined in Sections C and E.

- Riverine Flooding
  - Probable Maximum Precipitation
  - Snowmelt
- Dam Failure
- Ice-Induced Flooding
  - Downstream – backwater
  - Upstream – ice-jam break (analogous to a dam failure)
- Flooding from Channel Migration/Diversion
- Localized Intense Precipitation
- Hurricanes/Storm Surge
- Seiche
- Tsunamis
- Wind-Generated Waves
- Combined Events
- Flood Warning for Flooding Mechanisms
- Hydrodynamic Loading on SSCs

D.1.4 Assess Extent of Detailed Evaluation for Relevant Flooding Mechanisms

Once relevant flooding mechanisms are screened and identified, the HHA process (discussed in Section A.2) can be employed to further refine the list of flooding mechanisms that could affect the site. The analysis could begin with a review of readily available information (e.g. existing PMF studies). Any new analysis could begin using best available information, simplified methods, and conservative assumptions (e.g. given a PMF peak discharge, use the Manning's equation and assume a mild riverine slope and high Manning 'n' value.)

For example, a site may be located along, but well above, a river with upstream dams. Therefore, the 'Riverine' and 'Dam Failure' flooding mechanisms could not be screened out. However, believing the site is elevated well above the maximum riverine and dam break flood levels, the utility may choose to conduct a simple analysis based on best available riverine flood information, best available stage-discharge data, and conservative assumptions. For this scenario, the initial flooding estimate could include the following steps (see Appendix A for more details on applying each step).

1. Estimate the PMF peak discharge from RG 1.59, Appendix B.
2. Estimate the peak discharge from all upstream dams using simplified methods from the National Weather Service (NWS) or Natural Resources Conservation Service (NRCS).
3. Ignoring affects of storage, attenuation, and timing, simply add the peak discharges from the PMF and upstream dam failures to compute a total peak discharge.
4. Use the stage-discharge curve from a nearby streamflow gage, FEMA FIS flood profiles and discharges, or simplified Manning calculation to estimate the flood elevation at the peak discharge from Step 3.
5. If this flood level exceeds acceptable protection and/or mitigation elevations, refine the assumptions further, such as accounting for attenuation and difference in timing of peak flows from dam failures.
6. If resulting flood levels still exceed design basis hazard levels, a detailed hydrologic and hydraulic analysis, using the latest methodology and technology, is probably warranted.
7. In most or all cases, at a minimum, a detailed flooding evaluation from a local intense precipitation event will be required for each site.
8. Perform a similar sequence of evaluations for each relevant flooding mechanism and combine dependent events that can be reasonably expected to be coincidental.
9. Additional notes to consider for flooding evaluations, preliminary or detailed:
    a. Consider independent flooding mechanisms collectively. For example, a riverine PMF may produce the highest overall flood level at a site but a specific/remote SSC may be higher in elevation and more susceptible to a local intense precipitation event. Defining flooding hazards may involve overlaying the affects of independent events.
    b. Consider the full duration of flooding when defining the hazard; higher velocities and/or hydrodynamic loading conditions may not necessarily occur at the peak. For example, if an SSC is protected by a barrier (dike, levee, floodwall, etc.) that is overtopped by the PMF, higher velocities and loading conditions may occur when the structure begins to overtop, possibly breaching the structure, and before reaching steady-state conditions at or near the peak.

c. Timing issues should be considered with various relevant flooding mechanisms and mitigation measures. For example, a mitigation measure, such as a temporary cofferdam, may require three (3) days to install. The cofferdam may be designed to withstand the highest hydrostatic loading conditions at the peak PMF level. Flood warning for a PMF, resulting from PMP runoff, may far exceed the three (3) days needed to install the cofferdam. However, an upstream 'sunny-day' dam failure may produce lower flood levels but still require the use of the cofferdam to protect safety-related SSCs. Flood warning times for upstream dam failure are typically within hours, far less than the time required to install a temporary cofferdam.

D.1.5 Develop Scope for Detailed Flooding Evaluation

After completing the screening process and preliminary/HHA evaluations for relevant flooding mechanisms, develop the scope for refining and completing detailed evaluations. In theory, the detailed evaluations would only be required for flooding mechanisms, or combinations of flooding mechanisms, that the preliminary/HHA evaluation shows exceed design basis hazard levels. The detailed evaluations should provide all information requested by the NRC in the 2.3 (flooding) 50.54(f) letter for the Hazard Evaluation Report, as follows:

a. Site information related to the flood hazard. Relevant SSCs important to safety and the UHS are included in the scope of this reevaluation, and pertinent data concerning these SSCs should be included. Other relevant site data includes the following:

    i. detailed site information (both designed and as-built), including present-day site layout, elevation of pertinent SSCs important to safety, site topography, as well as pertinent spatial and temporal data sets;

    ii. current design basis flood elevations for all flood causing mechanisms;

    iii. flood-related changes to the licensing basis and any flood protection changes (including mitigation) since license issuance

    iv. changes to the watershed and local area since license issuance;

    v. current licensing basis flood protection and pertinent flood mitigation features at the site; and

    vi. additional site details, as necessary, to assess the flood hazard (i.e., bathymetry, walkdown results, etc.).

b. Evaluation of the flood hazard for each flood causing mechanism, based on present-day methodologies and regulatory guidance. Provide an analysis of each flood causing mechanism that may impact the site including local intense precipitation and site drainage, flooding in streams and rivers, dam breaches and failures, storm surge and seiche, tsunami, channel migration or diversion, and combined effects. Mechanisms that are not applicable at the site may be screened-out; however, a justification should be provided. Provide a basis for inputs and assumptions, methodologies and models used including input and output files, and other pertinent data.

c. Comparison of current and reevaluated flood causing mechanisms at the site. Provide an assessment of the current design basis flood elevation to the reevaluated flood elevation for each flood causing mechanism. Include how the findings from Enclosure 4 of this letter (Le., Recommendation 2.3 flooding walkdowns) support this determination. If the current design basis flood bounds the reevaluated hazard for all flood causing mechanisms, include how this finding was determined.

d. Interim evaluation and actions taken or planned to address any higher flooding hazards relative to the design basis, prior to completion of the integrated assessment described below, if necessary.

e. Additional actions beyond Requested Information item 1.d taken or planned to address flooding hazards, if any.

D.2 Detailed Flooding Evaluation Technical Considerations

D.2.1 Overview of Evaluations for Different Flooding Mechanisms

Local Intense Precipitation (LIP) – Generally, local intense (probable maximum) precipitation values are derived based on methods developed by the National Weather Service (NWS) and published in Hydrometeorological Reports (HMR), including HMR-52 (east of the 105th meridian) and regionalized reports within the HMR publication series. Per NUREG/CR-7046, the local intense precipitation is considered equivalent to the 1-hour/1-mi^2 PMP at the location of the site. Through the use of hydrodynamic computer models, the runoff carrying capacity of the site grading design and the performance of any active or passive drainage systems would determine the depth and velocity of surface runoff at the site. Typically, active drainage systems should be considered non-functional at the time of local intense precipitation event. Similarly, passive drainage systems (i.e. underground pipes, inlets, and small culverts) are typically assumed to be clogged and not providing conveyance. The NRC will likely request justification for evaluations that credit active or passive systems as providing conveyance. Generally, runoff losses should be ignored during the local intense precipitation event to maximize the runoff. Hydraulic parameters that affect the depth and velocity of flow should be chosen carefully and consistent with values used in standard engineering practice.

Riverine (Rivers and Streams) Flooding – The PMF in rivers and streams adjoining the site is determined by applying the PMP to the drainage basin in a rainfall-runoff-routing (hydrologic) computer model to produce a flood flow hydrograph (time history of the discharge). The estimation of PMP for regional areas within the US is typically based on NWS HMRs, in cooperation with other government agencies. However, some watersheds warrant the development of site-specific PMP scenarios to establish the bounding PMF; such as watersheds over 20,000 miles^2 (the upper limit established in HMR-51/52). Site-specific PMP studies should be completed in coordination with the Advisory Committee on Water Information (part of the Water Information Coordination Program), made up of representatives from the NRC, USBR, USACE, and NWS (http://acwi.gov/hydrology/extreme-storm/index.html) and the local district office of the USACE. Several combinations PMP scenarios, considering seasonal variations in precipitation patterns and coincidental snowmelt conditions, should be considered as discussed in NUREG/CR-7046.

Dam Breaches and Failures – Mechanisms that cause dams to fail include overtopping (from a significant runoff event), piping (from uncontrolled seepage), and structural (from seismic activity, slope/stability issues, seepage, and structural deficiencies). The resulting flood waves, including those from domino-type or cascading dam failures, should be evaluated for each site as applicable. Water storage and water control structures that may be located at or above SSCs important to safety should also be evaluated. Models and methods used to evaluate the dam failure and the resulting effects should be applicable to the type of failure mechanism. References provided herein include guidance documents to developing dam break hydrographs. Unsteady-flow or 2D hydraulic models are frequently used to route dam breach hydrographs to the site. Recent analyses completed by State and Federal Agencies with appropriate jurisdiction for dams may be used. Dam breach/failure scenarios should include coincidental failure with the peak PMF and domino-type or cascading dam failures. The NRC will likely request justification for assuming a dam has not failed, by any mode, in a PMF evaluation, including modeling results showing the dam is not overtopping or has overtopping protection, inspection reports, geotechnical/structural engineering analyses, seismic analyses, and/or operation/maintenance plans. See Sections 3.4 and 3.9 and Appendix H.2 of NUREG/CR-7046 for dam failure scenarios to be considered. Part of the HHA approach may include an assumption that all dams fail, regardless of the cause; timed to produce the worse possible flooding conditions at the site (including compounding flows from cascading failures of dams in series).

Storm Surge – Technical reports, from the National Oceanic and Atmospheric Administration (NOAA), provide guidance on developing wind fields for PMH. The wind field parameter is input to coastal hydrodynamic simulation models that predict water surface rise based on the shear forces created by the wind.

Seiche – If a seiche is determined to be possible at the site, then appropriate numerical modeling may be needed. For bays and lakes with irregular geometries and variable bathymetries, numerical long-wave hydrodynamics modeling may be the only viable technique to determine hazard.

Tsunami – A tsunami assessment can include an incremental approach addressing: the susceptibility of the site's region to a tsunami, the susceptibility of the plant site to a tsunami, and specific hazards of the site posed to safety of the plant by a tsunami. NUREG/CR-7046 does not address tsunamis; it references NUREG/CR-6966, "Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America," published in March 2009, for evaluation of tsunamis.

Ice-Induced Flooding – There is no method to assess a probable maximum ice jam or ice dam; therefore, historical records are generally accessed to determine the most severe historical event in the vicinity of the site. This method is based on an observed historical observation and reasonable margin should be considered. The impacts of ice jams at the site, whether downstream or upstream, can be effectively simulated in current hydraulic computer modeling programs. Downstream ice-jams could produce backwater that affects flood levels at the site. Upstream ice-jams could produce flood waves, similar to that of a dam failure, which could affect flood levels at the site.

Wind-Generated Waves – Waves generated by wind passing over the surface of an open body of water caused by wind shear forces along the water surface and air pressure differences across the wave crest.

Channel Migration or Diversion – For natural channels adjacent to the site, historical and geomorphic processes should be reviewed for possible meandering tendencies. For man-made channels, canals or diversions, used for the conveyance of water located at a site, possible failure of these structures should be considered. Localized scour at adjacent bridges and other structures should also be evaluated for impact to the site and safety-related SSCs.

Combined Effect Flood – For sites subject to flooding from combined events, ANS 2.8-1992 provides guidance for combining flooding mechanisms. In addition to those listed in the ANS guidance, additional plausible combined events should be considered on a site-specific basis and should be based on the impacts of other flood causing mechanisms and the location of the site. Dependent events can occur concurrently (e.g., precipitation, snowpack, and wind waves; high tides and storm surges; etc.). Because of their extreme nature, probable maximum events from two separate phenomena should not be combined unless they are clearly dependent or result from a common cause. For example, seismic events causing dam failure or tsunami should not be combined with precipitation events. An exception occurs for PMF and PMH for relatively small drainage basins in regions where the PMP may result from a hypothetical and maximized hurricane event. Wind waves are almost always combined with other flood-causing mechanisms. The combination that results in the most severe flood hazard to the safety-related SSCs is used to specify the design basis, noting that different flood hazards may occur from different combinations (e.g. maximum water levels and hydrostatic loads result from a PMF but maximum hydrodynamic loads may result from fast-moving waters of a PMT).

D.2.2 Error/Uncertainty

Estimating error/uncertainty in the results of deterministic evaluations may be useful in assessing minimum margin. To the extent possible, computer models should be calibrated and verified to multiple historic events. Estimating error/uncertainty can be accomplished using one of the following methods:

1. Apply mean and standard deviation of error between known and simulated values (e.g. flood levels, preferably at several locations) to an assumed probability distribution function (e.g. normal distribution) to estimate non-exceedance confidence levels (e.g. 90% assurance that flood levels will not exceed 'X').
2. Apply error estimated from previous uncertainty studies of similar modeling techniques (e.g. USACE Engineering Manual 1110-2-1619 (1996)).
3. Conduct a sensitivity analysis of flood levels based on previously-established minimums and maximums values of selected variables (e.g. Manning 'n' value, runoff curve numbers, infiltration rates, etc.).
4. Perform a Monte Carlo simulation.

D.2.3 Technical Clarifications

Hydrologic Analysis of the Probable Maximum Flood

- A new hydrologic analysis is being conducted based on older USACE studies to establish a new PMF hydrograph at the site. The USACE study used uniform loss rates, based on land use conditions at the time, to estimate runoff and calibrated the parameters to match observed conditions. This analysis provides the foundation for the new model and will be updated and recalibrated to represent current watershed (land use and flow regulation) conditions, including recalculated uniform loss rates. It will be assumed that the initial loss rate is zero (0) to represent saturated antecedent condition; in lieu of running a preceding storm.

  The calibration storm is the flood of record, over 40 years old, and was used to calibrate the old USACE analysis. The verification storm is significant, but smaller than the calibration storm, and relatively recent. The verification storm also immediately followed a record wet month. Precipitation data will be reviewed to determine if saturated conditions likely existed leading up to the calibration event.

- PMP scenarios are being developed using the watershed-specific HMR, published by the NWS over 40 years ago (e.g. HMR-40), and generalized configurations contained in HMR-51 and 52. Since a watershed-specific HMR exists, despite the vintage, it was assumed that a new meteorological evaluation was unnecessary to develop PMP scenarios, including for watersheds exceeding 20,000 square miles.

- In region of interest, academic studies have been conducted to develop parameters for the Snyder Unit Hydrograph. Therefore, the Snyder Unit Hydrograph will be applied to the calibration, verification, and PMF models. For the PMF model, the following adjustments recommended in NUREG 7046-I.2 will be made to the unit hydrograph: increase the peak discharge of the unit hydrograph by one-fifth and decrease the time to-peak by one-third. The rising limb of the unit hydrograph will be adjusted using the approach described by Saghafian (2006) and falling limb of the unit hydrograph will be adjusted to maintain the runoff volume to a unit depth over the drainage area.

Dam Failure

The following is a summary of how dam failures are being considered at a site with upstream dams per NUREG/CR-7046, Sections 3.4 and 3.9 and Appendix H.2.

- **Hydrologic Failure:** PMF hydrographs, generated from PMP scenarios discussed previously, will be routed through upstream dams using the USACE HEC-HMS model. If the model indicates that one or more dams are unable to safely pass the PMF (i.e. the PMF hydrograph overtops an unprotected portion of the dam(s)), the dams will be breached in HEC-HMS to coincide with the PMF. Dams in series will be breached as cascading failures. Dams where overtopping of unprotected portions is not occurring will be assumed stable (not failued) during the PMF.
- **Seismic Failure:** Per Appendix H.2 of NUREG/CR-7046, the following seismic/precipitation combinations will be considered: 1) shut-down earthquake and 25-year precipitation; and 2) operational earthquake and ½ PMP. Cascading failures of dams in series will also be considered. As part of the HHA approach, the analysis could assume that all dams fail, even under the lesser (operational) seismic event, and apply the ½ PMP. Otherwise, seismic information may need to be provided to justify non-failures.
- **Sunny Day Failure:** A ‘sunny day’ dam failure is typically not associated with a precipitation event and will normally not exceed flood magnitudes resulting from the hydrologic and seismic failure scenarios discussed above. However, it is recommended that the affects of a ‘sunny day’ failure be considered particularly when mitigation measures protect safety-related SSCs from such a failure, given the more limited warning time generally associated with a ‘sunny day’ failure.
- Justification for assuming a dam has not failed, by any mode, in a PMF evaluation may need to be provided, including modeling results showing the dam is not overtopping (or the dam has overtopping protection), inspection reports, geotechnical/structural engineering analyses, and/or operation/maintenance plans.
- Part of the HHA approach may include an assumption that all dams fail, regardless of the cause; timed to produce the worse possible flooding conditions at the site (including compounding flows from cascading failures of dams in series).

Local Intense Precipitation

NUREG/CR-7046 does not include discussion on how external flooding (coincident external high water) should be considered in evaluating site runoff from a local intense precipitation (1-hour, 1-sq mile) event. NUREG/CR-7046 addresses three (3) cases for site drainage: 1) assume collection and conveyance systems (including inlets and piping systems) are fully open and operational, 2) assume some partial blockage occurs in collection and conveyance system, and 3) assume all collection and underground piping conveyance systems are completely blocked and all conveyance and storage is occurring on the surface.

As a starting point, it could be assumed that external water levels are high enough to block flap gates, sluice gates, and other backflow prevention devices, and all collection (i.e. inlets) and underground piping systems are blocked. Crediting these systems with conveyance will likely require justification.

Ice Jams

Ice jam evaluations will begin with a qualitative review of historical records to assess the potential for upstream and downstream ice jam formations. If the qualitative review reveals that ice jams are a known condition, hydraulic models will be updated to incorporate these conditions. Upstream ice jams will be modeled as dam failures.

Debris

Debris (including trees, cars, barges, boats, etc.) loading conditions is difficult to model and will be assessed, at least initially, qualitatively by reviewing the presence of viable upstream sources. Velocity vectors (magnitude and direction) from two dimensional (2D) hydrodynamic models provide good information to support this assessment.

Tsunamis

Screening level evaluations can be conducted to assess the overall risk of the tsunami to a particular region and identify potential tsunamigenic sources. More detailed analyses of tsunamis should include 2D hydrodynamic modeling of the flood wave to account for the topographic affects on wave dissipation. Debris loading should also be considered. Refer to NUREG/CR-6966 for guidance in conducting tsunami analyses.

Combined Events

Floods caused by precipitation events (from ANSI/ANS 2.8):

- Alternative 1
  - Mean monthly base flow
  - Median soil moisture and antecedent or subsequent storm (40% of the PMP and a 500-year rainfall) or assume zero initial losses and saturated uniform loss rates
  - PMP
  - 2-year wind-generated runup in the critical direction
- Alternative 2
  - Mean monthly base flow
  - Probable maximum snow pack
  - 100-year snow season rainfall
  - 2-year wind generated runup in the critical direction
- Alternative 3
  - Mean monthly base flow
  - 100-year snow pack
  - Snow season PMP

- 2-year wind generated runup in the critical direction

Floods caused by seismic failures (see above)

Floods along shores of enclosed bodies of water:

- Streamside location
  - Alternative 1 – Combination of:
    - The lesser of ½ PMF or the 500-year flood
    - Surge and seiche from the worst regional hurricane or windstorm with wind-wave activity
    - The lesser of the 100-year or the maximum controlled water level in the enclosed body of water
  - Alternative 2 – Combination of:
    - PMF in the river/stream
    - A 25-year surge and seiche with wind-wave activity
    - The lesser of the 100-year or the maximum controlled water level in the enclosed body of water
  - Alternative 3 – Combination of:
    - A 25-year flood in the stream
    - Probable maximum surge and seiche with wind-wave activity
    - The lesser of the 100-year or the maximum controlled water level in the enclosed body of water.

D.2.4 Pertinent Primary References

Regulatory

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D.2.5 Pertinent Support References

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10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities"

10 CFR Part 50. Code of Federal Regulations, Title 10, *Energy*, Part 50, "Domestic Licensing of Production and Utilization Facilities."

10 CFR Part 52. Code of Federal Regulations, Title 10, *Energy*, Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

Sections 161.c, 103.b, and 182.a of the Atomic Energy Act of 1954, as amended

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Appendix A to 10 CFR Part 100, Seismic and Geologic Siting Criteria for Nuclear Power Plants

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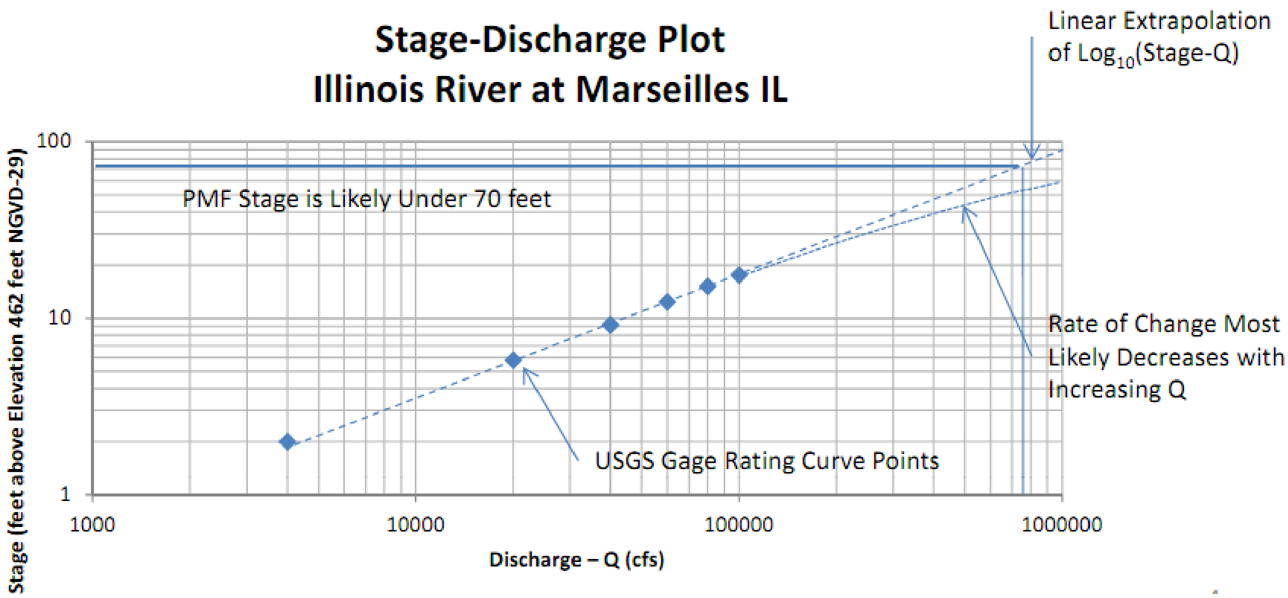
APPENDIX A

Examples – Balkpark Estimates of Probable Maximum Water Levels

Riverine Flooding, Probable Maximum Flood (PMF) – Preliminary Estimate

- Peak Discharge Estimate
  - Use best available site specific studies
  - Or, use approach in RG 1.59 Appendix B (see RG 1.59 for limitiations)
  - Possibly apply a ‘factor of safety’ to account for uncertainties or inaccuracies
  - Example, hypothetical site:
    - Along the Illinois River at Marseilles IL
    - Drainage Area = 8,260 square miles
    - From RG 1.59 Appendix B charts for the PMF Peak Discharge (next page),
      $Q_{5000\ sqmi}$ = 650,000 cfs
      $Q_{10000\ sqmi}$ = 800,000 cfs
    - Through linear interpolation,
      $Q_{8260\ sqmi}$ = 750,000 cfs

- See plot below, **PMF Stage ≈ 70 feet above datum ≈ 532 feet NGVD-29**



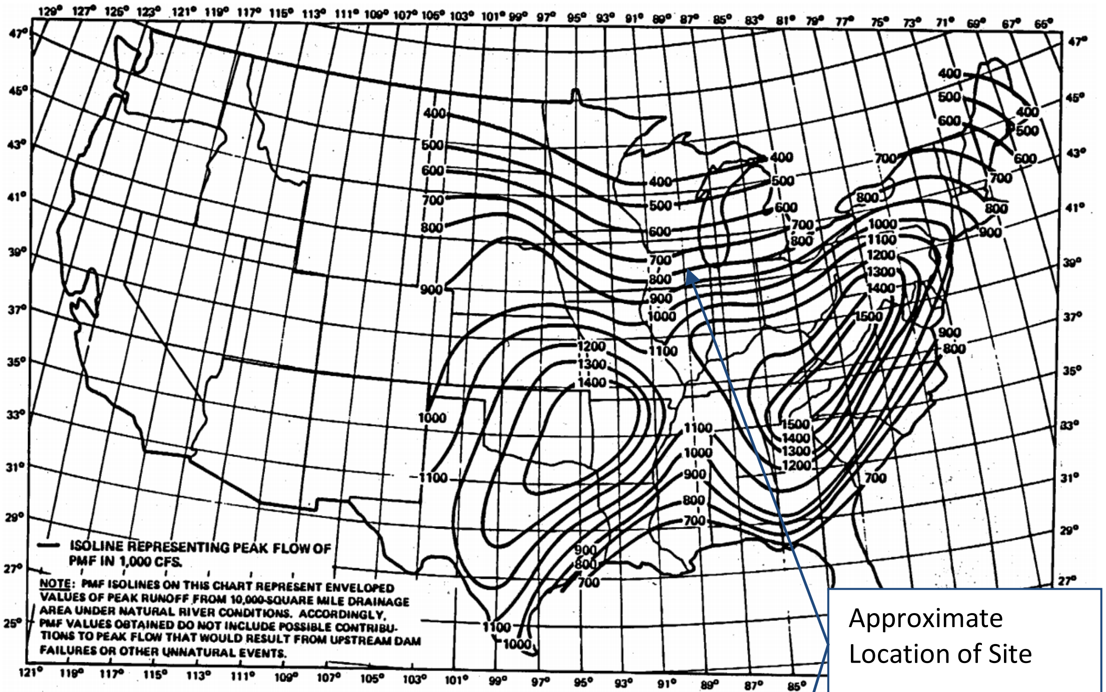


FIGURE B.6 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 10,000 SQUARE MILES

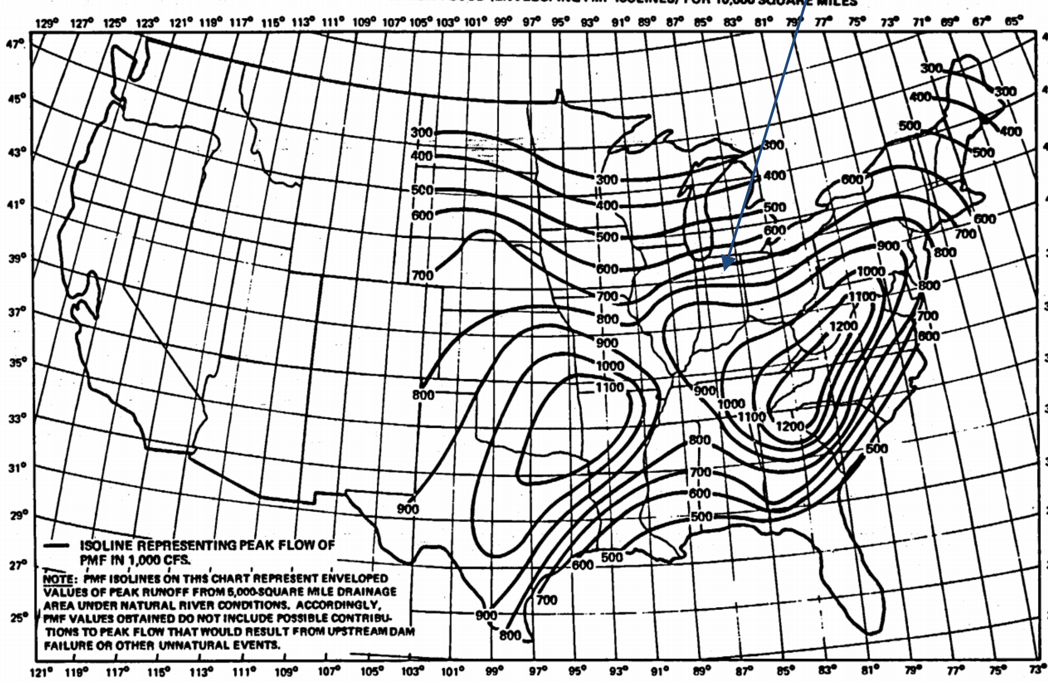


FIGURE B.5 PROBABLE MAXIMUM FLOOD (ENVELOPING PMF ISOLINES) FOR 5,000 SQUARE MILES

Dam Break Peak Discharge – Preliminary Estimate

- National Weather Service (NWS) Simplified Dam Break Model (for dam heights between 12 and 285 feet)

  $$Q_b = Q_o + 3.1B_r\left(\frac{C}{T_f + C/\sqrt{H}}\right)^3$$

  Where:

  - Q_b = Breach flow + non-breach flow (cfs)
  - Q_o = Non-breach flow (cfs)
  - B_r = Final average breach width (feet), approximately 1H to 5H or $B_r = 9.5K_o(V_sH)^{0.25}$
  - C = 23.4 x A_s/B_r
  - A_s = Reservoir surface area at maximum pool level (acres)
  - H = Selected failure depth above final breach elevation (feet)
  - T_f = Time to failure (hours), use H/120 or minimum of 10 minutes or $T_f = 0.59(V_s^{0.47})(H^{0.91})$
  - K_o = 0.7 for piping and 1.0 for overtopping failure
  - V_s = Storage volume (acre-feet)

- Natural Resources Conservation Service (NRCS) – Dam Break Peak Discharge Estimate

  - For $H_w \geq 103$ feet $Q_{max} = (65)H_w^{1.85}$
  - For $H_w < 103$ feet $Q_{max} = (1100)B_r^{1.35}$ $B_r = \frac{V_sH_w}{A}$
    - But not less than $Q_{max} = (3.2)H_w^{2.5}$
    - Nor greater than $Q_{max} = (65)H_w^{1.85}$
  - When width of valley (L) at water level (H_w) is less than

    $$T = \frac{(65)H_w^{0.35}}{0.416}$$

  - Replace Equation $Q_{max} = (65)H_w^{1.85}$ with

    $$Q_{max} = (0.416)LH_w^{1.5}$$

  Where:

  - Q_{max} = Peak breach discharge (cfs)
  - B_r = Breach factor (acre)
  - V_s = Reservoir storage at the time of failure (acre-feet)
  - H_w = Depth of water at the dam at the time of failure; if dam is overtopped, depth is set equal to the height of the dam (feet)
  - A = Cross-sectional area of embankment at the assumed location of breach (square feet)
  - T = Theoretical breach width at the water surface elevation corresponding to the depth, H_w, for the equation $Q_{max} = (65)H_w^{1.85}$ (feet)
  - L = Width of the valley at the water surface elevation corresponding to the depth, H_w (feet)

Probable Maximum Storm Surge – Preliminary Estimate

- RG 1.59 Appendix C – Probable Maximum Storm Surge Estimate (See RG 1.59 for limitiations)

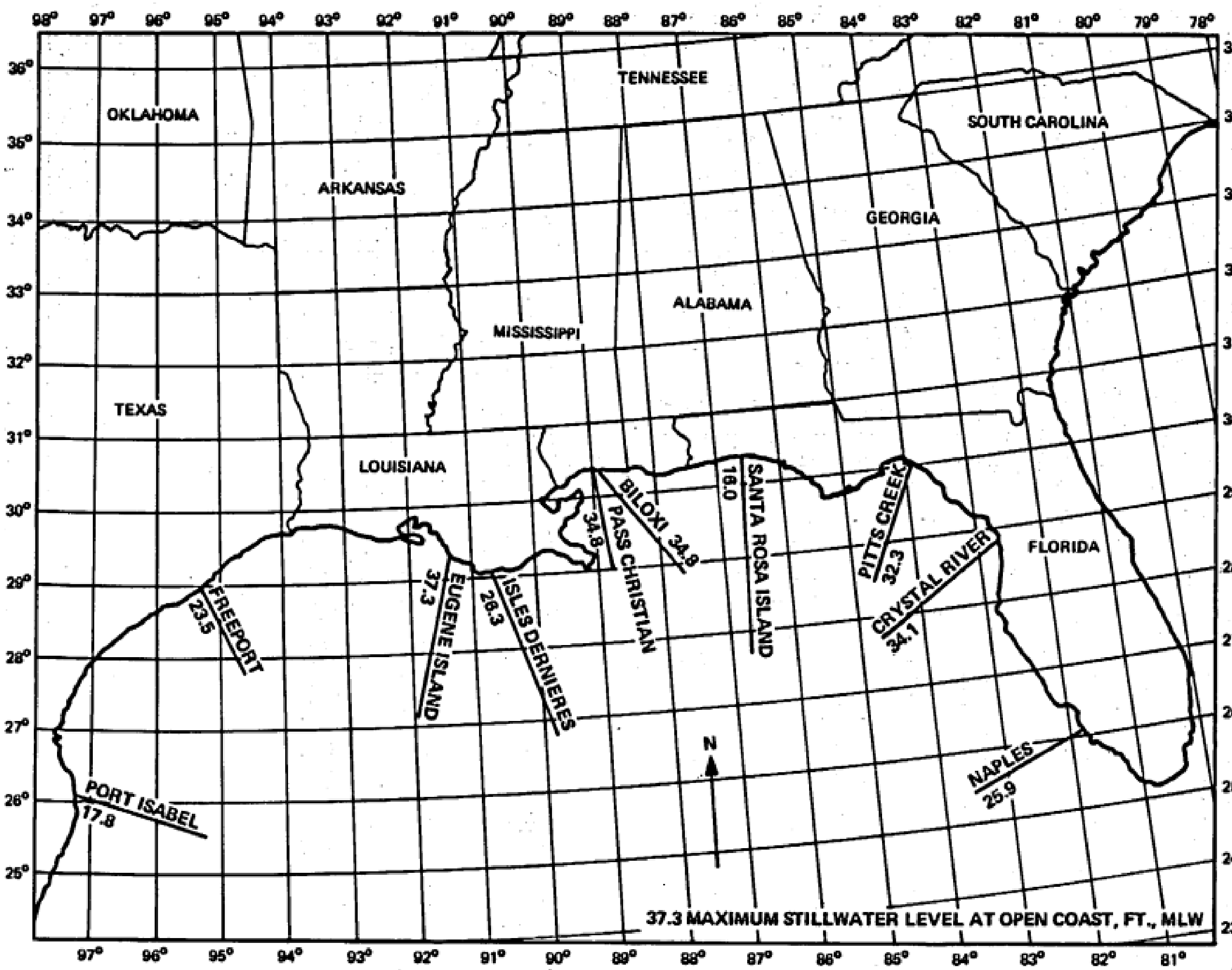


FIGURE C.1 PROBABLE MAXIMUM SURGE ESTIMATES – GULF COAST

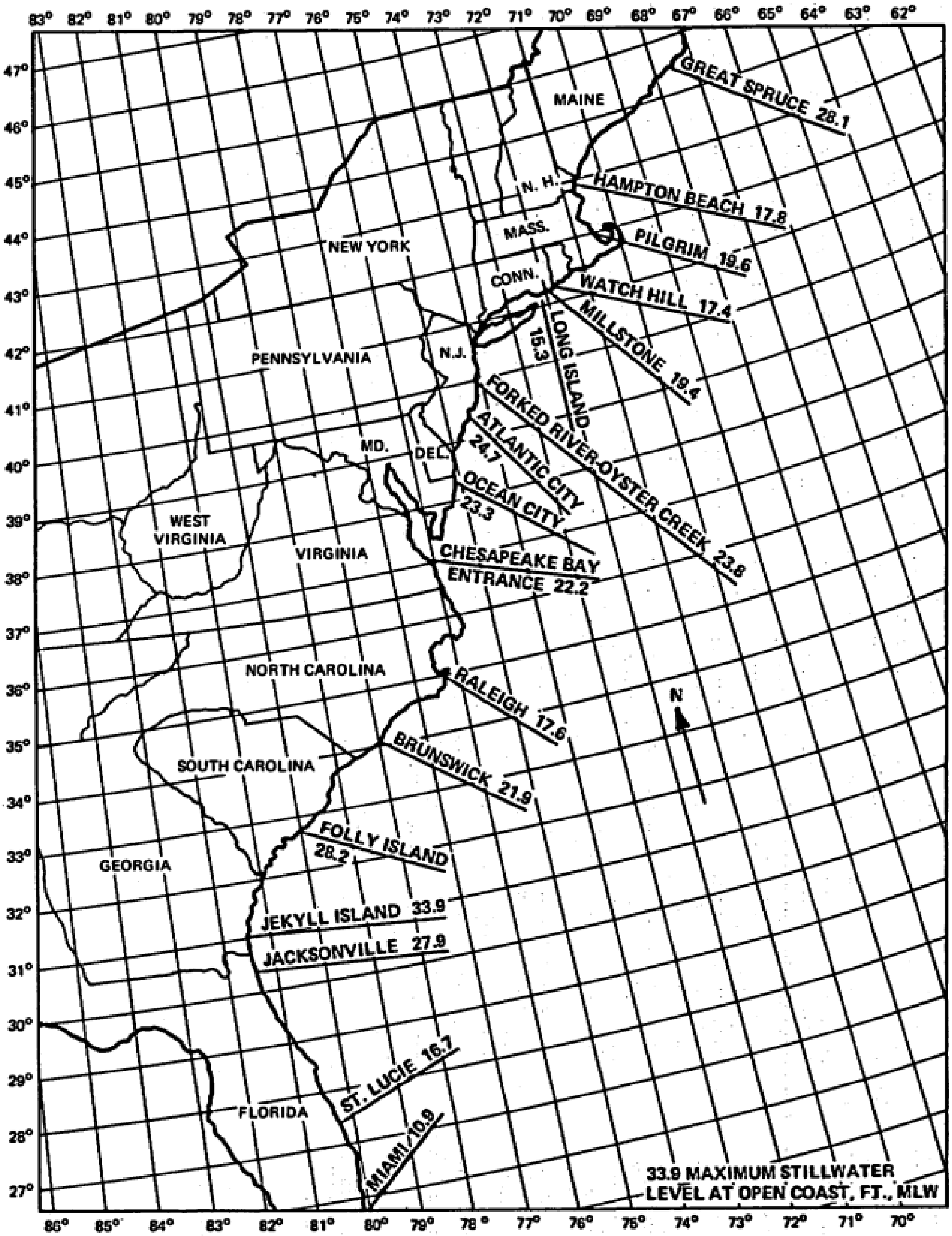


FIGURE C.2 PROBABLE MAXIMUM SURGE ESTIMATES – ATLANTIC COAST