



ANS

Probabilistic Evaluation of External Flood Hazards for Nuclear Facilities

An American National Standard

ANSI/ANS-2.8-2019

Published by the
American Nuclear Society
555 N. Kensington Ave
La Grange Park, IL 60526



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**American National Standard
Probabilistic Evaluation of
External Flood Hazards for
Nuclear Facilities**

Secretariat
American Nuclear Society

Prepared by the
**American Nuclear Society
Standards Committee
Working Group ANS-2.8**

Published by the
**American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60526 USA**

Approved December 17, 2019
by the
American National Standards Institute, Inc.

American National Standard

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Foreword

(This foreword does not contain any requirements of American National Standard “Probabilistic Evaluation of External Flood Hazards for Nuclear Facilities,” ANSI/ANS-2.8-2019, but is included for informational purposes.)

The purpose of this standard is to establish a process for identifying and evaluating design-basis flood hazards at nuclear facilities using a probabilistic approach. This standard represents a major revision to ANS-2.8-1992 (W2002), “Determining Design Basis Flooding at Power Reactor Sites.” ANS-2.8-1992 specifically focused on design-basis flood methodologies for “evaluating the worst site-related flood at a power reactor site caused by either a probable maximum flood on streams and rivers and any dam failures resulting therefrom; a seismically induced dam failure flood; a probable maximum surge and seiche flood; and any attendant wind-generated wave activity associated with these events or caused by a reasonable combination of less severe events.” Despite the reference to probable maximum flood hazards, the resulting hazard was established based on deterministic rules and did not rely on probabilistic concepts. As part of a periodic review of the standard’s applicability in 2002, the American Nuclear Society (ANS) judged the standard in need of revision, and therefore, it was withdrawn. The working group to revise the standard was formed in 2012. At that time, the working group—composed of members from the U.S. Department of Energy, the National Performance of Dams Program, the U.S. Geological Survey, the U.S. Nuclear Regulatory Commission, and various representatives from the nuclear industry—jointly undertook comprehensive reviews of the applicability of ANS-2.8-1992 (W2002) and recommended a major rewrite be performed. By that time, through insights gained from the events at the Blayais reactor as well as experience with Hurricane Katrina and, more recently, Fukushima, it became clear to the working group that a more formal probabilistic approach should be used for setting design flood parameters. The rewrite was therefore to focus on a probabilistically based approach for assessing the magnitude and occurrence of flood hazards that could be used in applications for the evaluation of nuclear facilities, including risk assessments, establishing the design-basis flood hazard, etc.

This standard differs from its predecessor in the following areas:

- The applicability of the standard extends to all nuclear facilities, not just power reactors.
- Probabilistic assessment: This standard replaces the prescriptive “probable maximum” approach for establishing design flood hazards with a probabilistic approach for analyzing the frequency and magnitude of flood hazards. Thus, this standard focuses on the performance of a probabilistic flood hazard assessment and development of site probabilistic hazard frequency curves. An integral part of this process is the treatment of uncertainty.
- The scope of this standard is expanded to include tsunamis.

The first issue of the standard was approved by the American National Standards Institute (ANSI) on November 1, 1976, and was published by ANS as ANSI N170/ANS-2.8-1976, “Determining Design Basis Flooding at Power Reactor Sites.”

The first revision of the standard was approved on February 17, 1981, and was published as ANS-2.8-1981.

The standard was revised in 1992 to cover material that meets the requirements of Sec. 2.4, “Hydrologic Engineering,” of Regulatory Guide 1.70, Revision 3, November

1978, “Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” issued by the U.S. Nuclear Regulatory Commission for the flood hazards within the scope of that standard.

This standard might reference documents and other standards that have been superseded or withdrawn at the time this standard is applied. A statement has been included in the references section that provides guidance on the use of references.

The working group has incorporated risk-informed and/or performance-based requirements into this standard.

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Probabilistic Evaluation of External Flood Hazards for Nuclear Facilities

1 Introduction

1.1 Background

This standard¹⁾ is developed to fill an important gap in the current set of American Nuclear Society (ANS) standards and supersedes ANS-2.8-1992, “Determining Design Basis Flooding at Power Reactor Sites” [1],²⁾ which was administratively withdrawn in 2002 in compliance with American National Standards Institute (ANSI) requirements.

ANS-2.8-1992 presented a standard for flood hazard evaluations using deterministic methods to develop estimates of “probable maximum” or “worst case” flood events. The incident at Fukushima highlighted limitations of deterministic external flood hazard assessment approaches and the importance of a systematic process for the identification and evaluation of flood hazards. Quantitative assessment of the likelihood that a specific magnitude flood event may occur requires use of a probabilistic approach.

Floods are temporal and spatial stochastic phenomena. As with other natural phenomena (earthquakes, volcanoes, extreme winds, etc.), their future occurrence is described in terms of their frequency of occurrence and magnitude (e.g., size of the hazard). Further, estimating the frequency of occurrence and the magnitude of future flood events is subject to uncertainties such as data limitations, incomplete understanding of the physical phenomena, model uncertainties, and model parameter uncertainties. Technical and regulatory developments in the past few decades have established a framework for performing probabilistic assessments of extreme events. This framework is built on a few key concepts:

- evaluation of the present state of knowledge, which includes data, direct and indirect evidence, scientific understanding, and alternative interpretations of this information, to form an integrated estimate of the probability of future events;
- use of scientific and engineering models to describe the hazard;
- a probabilistic framework for modeling the aleatory variability associated with natural phenomena and epistemic uncertainties in estimating the frequency of occurrence and magnitude of hazards;
- explicit modeling of epistemic uncertainties through an evaluation and integration process that often involves formal expert assessments.

This standard establishes a probabilistic approach to evaluate flood hazards at nuclear facilities. This standard, however, does not prescribe the design basis or acceptable level of risk for a specific flood hazard or set of flood hazards. The criterion for an acceptable level of risk for a nuclear facility is made by the applicable authority or regulatory body.

¹⁾ The current standard, ANSI/ANS-2.8-2019, is hereinafter referred to as “this standard.”

²⁾ Numbers in brackets refer to corresponding numbers in Sec. 11, “References.”

1.2 Purpose

The purpose of this standard is to present requirements for performing a probabilistic flood hazard assessment (PFHA) for a nuclear facility.³⁾ This standard also can be used to update an existing PFHA. This standard also provides guidance for conducting efficient, site-specific screening analyses to screen out noncredible external flood hazard sources and mechanisms.⁴⁾ A PFHA considers sources of flooding and flooding mechanisms that pose a credible hazard to a nuclear facility.

Results from the PFHA can be used in conjunction with applicable authority or regulatory body requirements to evaluate the design-basis flood (DBF) for a nuclear facility or for individual structures, systems, and components (SSCs) important to safety. PFHA results also may be used as input to external flood probabilistic risk assessments (PRAs), for development of emergency response plans, for assessment of safety-related SSCs and site vulnerability, and to design flood protection or mitigation systems.⁵⁾

The DBF may be characterized by one or more hazards or parameters, depending on the flood events that are being modeled and site-specific circumstances. The characterization of the DBF may include, but is not limited to,

- inundation or water surface elevation (WSEL);
- wind-wave effects (wave setup, wave run-up, wave splash);
- flood flow rate (discharge) and velocity;
- tsunami wave speed and wave height;
- hurricane speed, direction, and strength;
- ice effects;
- erosion and/or sedimentation;
- floating objects or debris.

In this standard, reference will be made to the DBF without referring specifically to the fact there may be multiple coincident hazards that are a part of it. When the DBF is referred to, it is understood that all hazards (WSEL, flow velocity, debris, etc.) are included, depending on the flood and site-specific circumstances.

The result of a PFHA will be a set of flood hazard curves that quantify the frequency of exceedance of a measure of the flood hazard (e.g., WSEL) and the uncertainty in the frequency of exceedance. In this context, this standard will refer to the flood hazard curve for a SSC, facility, or site. When reference is made to a flood hazard curve(s), it is used in the context that the flood hazard and its probabilistic representation may involve the quantification for multiple measures of the hazards as noted above.

³⁾ A PFHA may be performed for individual SSCs, for a single facility, for multiple facilities at a single site, or for a site depending on the circumstances. In this standard, reference is made to a nuclear facility, where it is understood that one or another set of circumstances may be considered.

⁴⁾ This standard distinguishes between flood sources and mechanisms. The flood source is viewed as the root cause of the flooding event, while the flooding mechanism refers to the collection of processes involved in propagating flooding to the site. For example, in many cases, a rainfall event is the flood source, while flooding mechanisms include all of the runoff and flood wave propagation processes that influence the characteristics and severity of flooding at the site.

⁵⁾ This standard uses the term “important to safety” to encompass those structures identified by the utility or the regulator the failure of which during a flood could create a potentially risk-significant outcome. The term “safety-related” is restricted to those SSCs in a nuclear power plant that meet the U.S. Nuclear Regulatory Commission requirements for the SSC to be safety-related.

Hydrologic and hydraulic information from the DBF can be used to design new nuclear facilities or to assess the vulnerability of existing nuclear facilities. Since the design, elevation, regulatory requirements, and other details will vary given the type of facility and/or SSC, the relevant DBF event(s) will most likely be specific to the site, facility, and SSC being addressed.

1.3 Scope

Table 1 lists the external flood sources and mechanisms that are addressed in this standard.

Table 1 – External flood hazard sources and mechanisms considered

- | |
|---|
| <ul style="list-style-type: none"> (1) Local intense precipitation (2) Riverine flooding (resulting from watershed precipitation) (3) Water release from dams, levees, or other impoundments (4) Storm surge, tsunamis, and seiche (5) Combined events (e.g., snowmelt/rainfall) |
|---|

1.4 Organization of the standard

The standard is organized as follows:

- Sec. 2 presents the main acronyms and terms used in this standard;
- Sec. 3 describes a framework for conducting external flood hazard assessments;
- Sec. 4 includes guidance for gathering site and regional data necessary for performing screening and/or a detailed PFHA;
- Sec. 5 provides requirements for conducting flood screening analyses;
- Sec. 6 provides requirements for conducting a PFHA;
- Sec. 7 provides flood-type-specific requirements for conducting a PFHA;
- Sec. 8 provides requirements for organizing the peer review of a PFHA;
- Sec. 9 provides requirements for documentation of a PFHA;
- Sec. 10 provides requirements for quality assurance (QA) of the final PFHA produced;
- Sec. 11 provides references.

1.5 Exclusions

This standard considers only the flood sources and mechanisms listed in Table 1. Internal or external flooding from failure of piping, tanks, or cooling towers is not part of the scope of this standard, nor is the probabilistic treatment of snow/ice loading. This standard addresses the flood hazard that may impose loadings on SSCs important to safety but does not address the calculation of the loads. This standard advises the reader to refer to the available technical methods that can be utilized to compute loadings associated with flood hazards—for instance, publications by the U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS), Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology, Natural Resources Conservation Service, and American Society of Civil Engineers.

The results of the PFHA performed in accordance with this guidance can be utilized to evaluate the frequency of exceedance and characteristics of the DBF for a facility or individual SSC. This standard, however, does not specify target frequency or magnitude of the flood hazard required for any particular facility or SSC.

2 Acronyms and definitions

2.1 Acronyms

1-D:	1-dimensional
2-D:	2-dimensional
ANS	American Nuclear Society
ANSI:	American National Standards Institute
DBF:	design-basis flood
EE:	expert elicitation
FEMA:	Federal Emergency Management Agency
FHSA:	flood hazard screening analysis
HLR:	high-level requirement
LIP:	local intense precipitation
NOAA:	National Oceanic and Atmospheric Administration
PFHA:	probabilistic flood hazard assessment
PRA:	probabilistic risk assessment
PTHA:	probabilistic tsunami hazard analysis
QA:	quality assurance
SC:	safety category
SME:	subject matter expert
SR:	supporting requirement
SSC(s):	structure(s), systems(s), and component(s)
USACE:	U.S. Army Corps of Engineers
USGS:	U.S. Geological Survey
WSEL:	water surface elevation

2.2 Shall, should, and may

shall, should, and may: The word “shall” is used to denote a requirement; the word “should” is used to denote a recommendation; and the word “may” is used to denote permission, neither a requirement nor a recommendation.

2.3 Definitions

aleatory uncertainty: The variability inherent in natural phenomena (i.e., stochastic, random). Aleatory variability is accounted for by modeling the stochastic aspect of the phenomenon under study in terms of a probability distribution. In principle, aleatory uncertainty that results from aleatory variability cannot be reduced by the accumulation of more data or additional information, but the detailed characteristics of the probability model can be improved [2].

aleatory variability: The variability inherent in natural randomness in a process. Sometimes aleatory variability is called “randomness.”

bias: When referring to data a bias is a systematic error. It is that portion of the total error that is solely separated from the random portion. Bias is not imprecision. In flood data collection bias is related to data acquisition and processing. In floods, for example, bias can be found in the deviation between rainfall depth measured by a radar system or by a network of gauges. When referring to modeling assumptions, bias is a systematic increase or decrease of the mean value of (a) a model parameter, (b) an input value or correlation, or (c) the results.

epistemic uncertainty: Uncertainty attributable to incomplete knowledge about a phenomenon that affects the ability to model it. Epistemic uncertainty is captured by considering a range of model parameters within a given expert interpretation or multiple expert interpretations, each of which is assigned an associated weight representing statistical confidence in the alternatives. In principle, epistemic uncertainty can be reduced by the accumulation of additional information associated with the phenomenon or by refining models. The uncertainty in the parameters of the probability distribution of a random phenomenon is epistemic. Uncertainty in model structure (i.e., processes included in the model and how they are represented) is considered epistemic.

randomness: See “aleatory variability.”

structure(s), system(s), and component(s) [SSC(s)]: A general term encompassing all the elements (items) of a facility. A structure is an element, or a collection of elements, to provide support or enclosure, such as a building, free-standing tanks, basins, dikes, or stacks. A system is a collection of components assembled to perform a function, such as piping; cable trays; conduits; or heating, ventilation, and air conditioning (HVAC). A component is an item of mechanical or electrical equipment, such as a pump, valve, or relay, or an element of a larger array, such as a length of pipe, elbow, or reducer.

SSC important to safety: The term “important to safety” is meant to encompass those SSCs identified by the utility or the regulator the failure of which during a flood could create a potentially risk-significant outcome.

uncertainty: See “aleatory uncertainty” and “epistemic uncertainty.”

3 External flood hazard assessment framework

An external flood hazard assessment characterizes and quantifies potential flood hazards that may impact SSCs important to safety at a nuclear site or facility. This section describes the general framework for external flood hazard assessment as defined in this standard. It is a graded approach that allows for screening out from further analysis flood sources or mechanisms that do not pose a credible hazard to a site or facility and for scaling of PFHA based on the facility safety category (SC) and complexity of the flood hazard issues. The complexity of flood hazard mechanisms; the data, models, and methods to evaluate them; and the quantitative assessment of uncertainties in model inputs and methods often require interpretation on the part of experts.

3.1 Overview

The characterization of flood hazards refers to the metrics that are used to define the loads (challenges) to a facility. The characterization depends on the type of flood events that can occur, the intended use of the

hazard assessment results (e.g., design, probabilistic risk analysis, emergency planning), and the potential vulnerability of SSCs important to safety that may be impacted.⁶⁾

Peak flood elevation is a necessary and common characterization of the severity of a flood event; however, elevation alone may not completely characterize all of the flood hazards a facility or site may be exposed to. The hazards that shall be considered include, but are not limited to,

- inundation (e.g., still water levels);
- flow velocities;
- erosion and sedimentation;
- wind-wave effects (e.g., wave setup, wave run-up, wave splash);
- waterborne objects or debris;
- duration of flooding above critical elevations;
- warning time that may be associated with the flooding event.

The flood hazard quantification involves the use of scientific and engineering models to compute estimates for the applicable flood hazard metrics described above. In a PFHA, the quantification results in a set of flood hazard curves that quantify the frequency of exceedance per year (or frequency per year) of a measure of the flood hazard at the facility or site. Aleatory variability in the flood hazard is expressed in terms of a frequency of exceedance. A PFHA also evaluates and quantifies (as required in this standard) epistemic uncertainty in the estimates of the frequency of exceedance and magnitude of the flood hazard. Thus, the PFHA produces a set of multiple flood hazard curves quantifying both the aleatory variability and the epistemic uncertainty.

The framework of the external flood hazard assessment consists of the following high-level elements:

- collection of site and regional data (see Sec. 4);
- identification of potential flood sources and mechanisms (see Sec. 4);
- screening analysis (see Sec. 5);
- probabilistic flood hazard assessment (see Secs. 6 and 7);
- peer review (see Sec. 8);
- documentation (see Sec. 9);
- quality assurance (see Sec. 10).

Figure 1 presents a flow diagram of the elements of the external flood hazard assessment. The following subsections describe each element of the external flood hazard assessment.

⁶⁾ The identification of potential SSC vulnerabilities should be coordinated with the facility owner and users of the flood hazard analysis results.

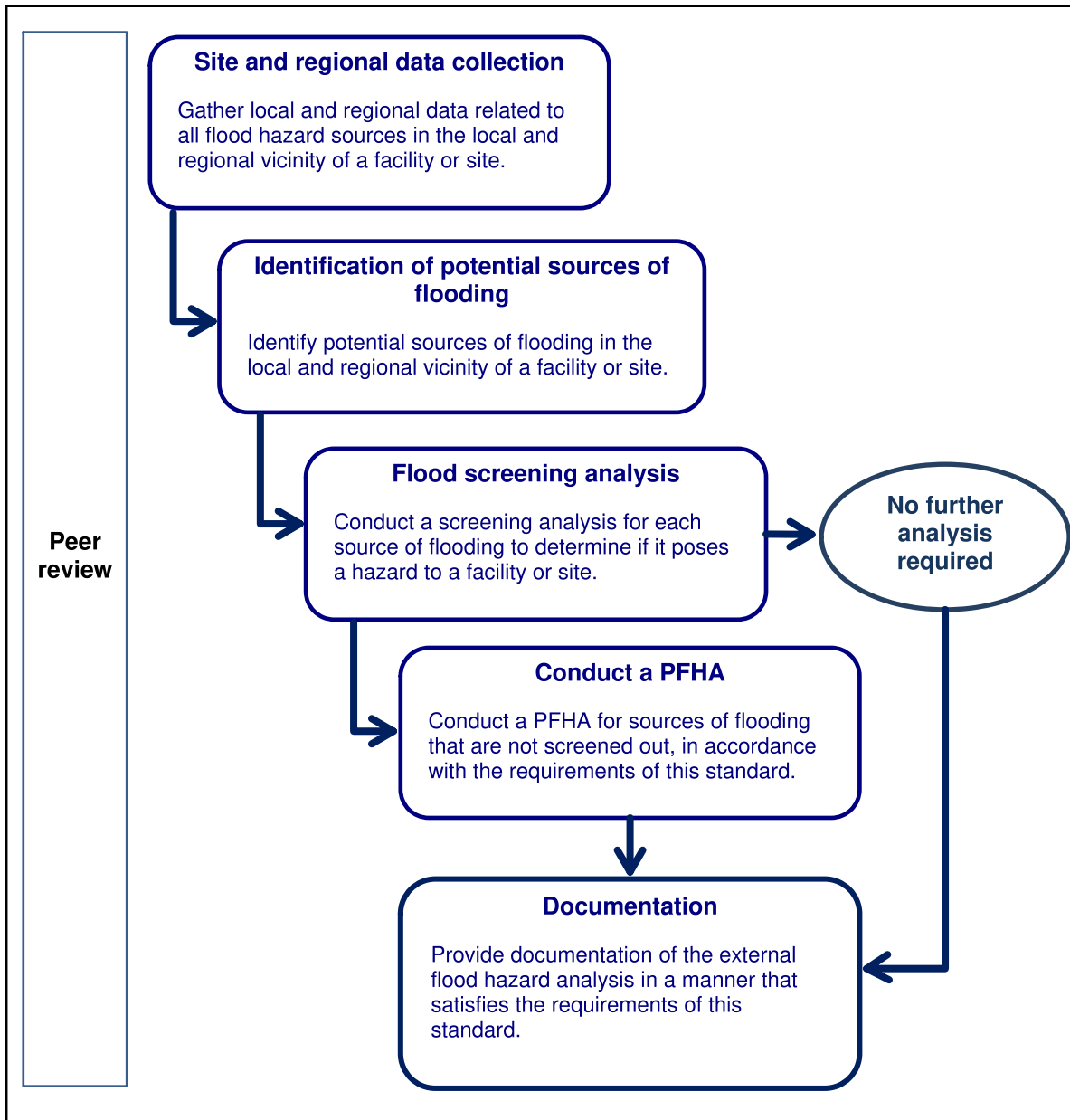


Figure 1 – External flood hazard assessment flowchart

3.2 Uncertainty

Evaluation of uncertainty is an integral part of an external flood hazard assessment—in a screening analysis as well as in a PFHA. There are different sources of uncertainty that impact the assessment of external flood hazards. A useful step to address the types of uncertainty that impact the flood hazard assessment is to establish a framework for identifying and modeling uncertainties. The framework should identify sources of uncertainty and categorize them in terms of aleatory variability and epistemic uncertainty [3].

Aleatory variability or randomness is intrinsic to phenomena such as precipitation and flooding. The temporal occurrence and spatial structure of these events are stochastic in nature, and thus predictions will always contain some random, irreducible uncertainty.

Epistemic or knowledge-based uncertainty arises from alternative engineering methods or from alternative interpretations of available evidence on how to model a particular phenomenon (e.g., model structure). Another part of this lack of knowledge is attributed to limitations in available data (amount or length of record, and data quality) that impact the assessment of model parameters (e.g., parametric epistemic uncertainty). Uncertainties are characterized as epistemic if there are alternative, technically defensible models or parameter estimates that are consistent with available evidence. Epistemic uncertainties can also be characterized in terms of an expectation that they can be reduced by gathering more information on the phenomenological processes, by gathering additional data, or by refining models. Epistemic uncertainty is typically captured by considering a range of alternative models and parameter estimates.

3.3 Goal of an external flood hazard assessment

The goal of an external flood hazard assessment in general, and of a PFHA in particular, is to capture the center, body, and range of technically defensible estimates of the flood hazard. This is achieved by carrying out a process of

- (1) Evaluation: The consideration of the set of available data, models, and methods relevant to the modeling and characterization of flood hazards proposed by the larger technical community that is concerned with such hazard analyses;
- (2) Integration: The integration of the outcomes of the evaluation process into models that represent the center, body, and range of technically defensible interpretations.

The evaluation and integration processes are applicable to all aspects of the external flood hazard assessment. Further, the goal of a PFHA is the same for all levels of analysis as described in Sec. 6.

3.4 Site, local, and regional data collection

An important step in the evaluation process involves gathering site, local, and regional information (e.g., data and flooding-related documentation) to support identification and evaluation of flood sources in the vicinity of a facility or site and the estimate of flood hazards. For sites that are co-located with existing nuclear facilities, the design documents, Safety Analysis Reports, and other relevant documentation for the facility shall be gathered and reviewed. The impact of newer datasets (e.g., more recent topographic/bathymetric surveys) on the design documents shall be considered. As a general matter, the collection of data is an iterative process as data needs evolve as the evaluation progresses from flood source identification to screening analyses and, subsequently, to a PFHA (if performed).

The process of site, local, and regional data collection is described in Sec. 4.

3.5 Identification of potential flood sources and mechanisms

Once data for a facility or site (including regional data) have been gathered, this information is reviewed to identify all potential flood sources and mechanisms. This step determines which of the sources and mechanisms listed in Table 1 should be carried forward for site-specific analysis. For each element in Table 1, the features of the flood source and flooding mechanisms that may occur shall be identified. For example, for a large body of water such as a lake or ocean, the potential flooding mechanisms may include seiche, tsunamis, or storm surge. For each flood source, its location and distance from the site and its relative elevation difference from the facility or site should be documented. The result of this step is a detailed summary of potential flood sources and mechanisms by which floods may propagate to and impact the site or facility. This site-specific flooding inventory is used in the flood screening analysis (Sec. 5).

3.6 Screening analysis

In principle, each source of flooding and flooding mechanism that is identified in the local or regional vicinity of a site, as well as possible combinations of sources of flooding, is considered in a PFHA. However, as a practical matter, not all flood sources or mechanisms pose a hazard at a particular site. For instance, physical circumstances may preclude a specific flooding mechanism at a site, or if flooding can occur, the frequency of occurrence may be shown, using demonstrably conservative techniques, to be sufficiently low such that it does not have to be considered. In these cases, the specific flood source or mechanism and associated flood hazards it may generate do not need to be considered in a PFHA. Note that the criteria for screening of flood sources or mechanisms from a PFHA on the basis of frequency may require agreement with relevant regulatory authorities.

A screening analysis is an efficient evaluation that is carried out to assess whether a source of flooding poses a hazard(s) to a facility or a site and whether it should be included in the PFHA or can be screened out from further analysis. Sec. 5 describes the methods and requirements for conducting a screening analysis.

3.7 Probabilistic flood hazard assessment

Flooding sources and mechanisms that cannot be screened out shall be further evaluated in a PFHA. A PFHA provides a quantitative estimate of the frequency of exceedance for those unscreened external flood hazard mechanisms that have been identified as having the potential to challenge a facility. Specifically, the PFHA develops the site-specific probabilistic flood hazard curves (e.g., peak flood depth, flow velocity, time to peak, duration of inundation, period of recession) and characterizes and quantifies the uncertainty associated with the occurrence of these hazards. In so doing, the PFHA quantifies the aleatory and epistemic uncertainties in a manner that characterizes the flood hazard and supports the intended application of the PFHA results.

For the purposes of this standard, the term “level of analysis” (PFHA level) refers to the breadth and depth of the evaluation that is performed, particularly with respect to the probabilistic evaluations. PFHA level selection for a specific assessment will necessarily be approved by appropriate authorities (e.g., study sponsor, regulator).

Sec. 6 provides the requirements of this standard for PFHAs. Sec. 7 describes specific considerations that are required when conducting a PFHA for specific flood sources or mechanisms.

3.8 Peer review

The purpose of peer review is to provide assurance of the technical adequacy of the evaluations that are performed and that an appropriate process for conducting the assessment has been carried out. In addition, the peer review will assess whether the documentation is complete. Peer review requirements for the PFHA, including those meant to ensure that a structured process for evaluating epistemic uncertainties has been used, are described in Sec. 8.

3.9 Documentation

Documentation for an external flood hazard assessment shall be complete such that the analyses performed are traceable and reproducible and support project sponsor and user needs, peer review, and regulatory requirements. Documentation of a PFHA and associated requirements are discussed in Sec. 9.

4 Site and regional flooding characteristics

The gathering of site and regional information to support the identification and evaluation of potential flood hazard sources are high-level flood assessment framework elements.

4.1 Datum

The vertical datum and adjustments used for topographic/bathymetric data, elevations of SSCs, and flood elevations, as well as their relation to other, locally used datums, shall be identified. Similarly, horizontal reference frames (e.g., horizontal datum, universal transverse Mercator zone, state plane coordinate zone) shall be identified. Units shall be identified for all datums. It is also important to emphasize that the applicable datum should be selected when different sources of data are amalgamated into one dataset (e.g., different sources of topographic data merged into one digital elevation model). Merging the datasets while on different datums will cause errors and increase the level of uncertainty.

4.2 Site and facility description

The physical characteristics of the site (or facility) shall be described in sufficient detail to support the external flooding assessment. The land area of the site shall be stated, and the site boundaries described. A site walkdown shall be conducted to gain familiarization with the facility site and SSCs important to safety that may be vulnerable to flooding. External flood hazard analyses for existing facilities or for new facilities co-located with existing facilities should review any available design or construction drawings, making note of any changes since the original design or construction.

4.2.1 Location

The location of the site or facility with respect to nearby streams, rivers, lakes, reservoirs, bays, or oceans in terms of horizontal distances and directions shall be stated. A location map of the site that shows the main hydrologic features in the region (e.g., streams, lakes, oceans, gauges) and identifies surrounding watersheds that may impact the site external flood assessment shall be prepared. Resolution of the location map shall be sufficient to support the type of analyses to be performed.

4.2.2 SSCs important to safety

The critical elevation and location of SSCs important to safety provides the PFHA analysts and peer reviewers with a perspective on the flood vulnerability of SSCs and facilitates screening analysis. This information shall be considered in establishing the scope of the PFHA.

4.2.3 Site topography and drainage

Topographic/bathymetric data of the site and its environs, in sufficient resolution to support the assessment, shall be collected. Changes to the existing topography or bathymetry planned to accommodate the design and construction of new facilities shall be described. The planned or existing site drainage shall be described, including the direction and outlet of runoff and drainage from roofs and buildings. All characteristics needed to evaluate discharge (e.g., inverts, types, sizes, lengths) of all stormwater pipes shall be reported. Features that protect the facility, such as seawalls/revetments/dikes, shall be described including instances of damage during past high-water events.

Collection of new topographic data may be necessary for the purposes of the flood evaluation (e.g., changes in the landscape of existing sites that may have been made and could potentially affect site drainage). The site drainage plan for existing sites shall be reviewed and compared against any new topographic data collected as well as against visual observations that are made during the site walkdown. The performance of existing site drainage during past storms should be reviewed.

4.3 Site and regional climatological, meteorological, and hydrologic description

4.3.1 Meteorology and climate

The climate and meteorology of the site and region shall be described. This includes weather patterns and storm types that bring precipitation (solid or liquid) to the region, average annual precipitation, seasonal variation in precipitation, and recorded precipitation events, including extreme events. Sources of weather and climate data (e.g., weather station records, atlases, climatological studies) shall be identified. Previous precipitation or storm studies covering the region surrounding the site shall be reviewed. Applicable studies and databases on regional weather and climate may include those provided by federal agencies [e.g., National Oceanic and Atmospheric Administration (NOAA), USACE, USGS], state and local agencies (e.g., state climatologists, water resources agencies, floodplain management agencies), and peer-reviewed scientific/engineering journals. See Refs. [4] and [5] for examples.

4.3.2 Hydrology

Water bodies in the area that might influence the site shall be described, including streams, lakes, reservoirs, and shore regions. If facility construction will change a drainage area, pre- and post-construction drainage areas shall be stated. Drainage areas of pertinent watercourses shall be stated or recomputed (i.e., validated) if new topographic data are collected. Lengths and slopes of pertinent ungaged streams shall be computed using the most up-to-date regional topographic data. For lakes and reservoirs, the area, average elevation, normal range of elevation, and representative depths shall be provided. Normal tidal range shall be provided for ocean or estuary sites. Available data or information concerning land use changes and future land development plans that may impact hydrology, to the extent that it affects hazard assessment, shall be described.

4.3.2.1 Watercourses

The following information shall be collected for all watercourses located within the site's watershed:

- name of watercourse;
- location in relation to nuclear facility sites in river distance;
- length of watercourse within the watershed and above the site;
- drainage area of watershed and of drainage area above the site;
- monitoring stations (location, type, record length);
- channel capacity at the site and at a sufficient number of cross sections to support any needed hydraulic modeling;
- prior flood hazard studies (e.g., FEMA studies [6]);
- other relevant information, such as facility elevation above rivers and streams.

4.3.2.2 Dams, levees, and other water control structures

The following information, if available, shall be collected for all dams that could pose a credible challenge to facility safety. Consideration of dams shall include all water impounding structures, whether or not defined as dams in the traditional sense (e.g., mine waste dumps, highway construction fill across valleys). Information that shall be collected (if available) includes the following:

- name of dam and reservoir;
- owner and designer, if known;

- type of dam;
- location in relation to the nuclear facility sites in river distance;
- drainage area above the dam;
- date construction completed;
- streambed elevation at dam site;
- dam crest elevation and other available dam geometry;
- normal and maximum reservoir elevation;
- range, volumetric capacity, and purpose of operating levels;
- type, capacity, and elevation of hydraulic control systems such as spillways and outlets;
- structural and geotechnical properties of the dam, dam foundation and abutments, and surrounding site;
- seismic and hydrologic design criteria, if available;
- rule curves for reservoir operations and operations manuals for flood or emergency situations;
- dam operating history;
- dam break inundation studies.

Initially, all dams upstream of the facility site shall be considered for potential failure, but some may be eliminated from further consideration because of low differential head, small volume, distance from the facility site, and major intervening natural or reservoir detention facilities.

4.3.2.3 Coastal setting

For sites located on or near shorelines (e.g., oceans, bays, estuaries, large lakes), the following information shall be collected:

- bathymetry and topography datasets sufficient to support site-specific storm surge, seiche, or tsunami inundation modeling;
- tidal datasets of sufficient length to evaluate tidal range (e.g., astronomical tides, local sea level anomalies, tidal currents);
- wave data from fixed gauges or buoy stations sufficient to characterize local wave climate;
- records of historical relative sea level rise (i.e., sea level change plus land subsidence or uplift);
- previous storm surge and tsunami studies.

4.3.3 Flood record

The flood record (e.g., gauged water levels, gauged streamflows, high-water marks, historical records, paleoflood information⁷⁾) in the regional vicinity of the site shall be compiled. This information shall be compiled for both inland and coastal sites. It is also important to investigate the impact of man-made

⁷⁾ Including historical and paleoflood data increases the effective record length and extends the credible limit of extrapolation for the flood frequency analysis. However, historical and paleoflood data are not equivalent to gauged streamflow data when the magnitude of the flood is inferred, and present knowledge may allow for only an estimate of a range for the flood magnitude or identification of a flood threshold that was or was not crossed.