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PROBABILISTIC PRECIPITATION HAZARD ASSESSMENT INCLUDING TWO-DIMENSIONAL FLOOD ROUTING ANALYSIS

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ABSTRACT

Extreme precipitation events for nuclear power plants have traditionally been evaluated using the concept of a Probable Maximum Precipitation (PMP). Contrary to "PMP" including the word "probable" in its definition, the PMP concept does not assign a probability to the PMP rainfall depth. Thus, it is difficult to quantify the risk associated with a PMP event. For example, how can a PMP event be included in a Probable Risk Assessment (PRA) for a nuclear power plant? A probabilistic analysis of precipitation must be conducted to evaluate probabilities associated with extreme rainfall events.

A methodology is presented for a regional extreme rainfall analysis using the method of L-Moments. The method involves applying one or more probability density function types. Each probability density function type is evaluated individually for its goodness-of-fit for the regional precipitation data. Multiple distributions can be retained in the analysis with probability weights being assigned to each distribution type based on appropriate criteria (e.g., goodness-of-fit or expert opinion). Consideration is given to the various sources of uncertainty, and methods for quantifying and reducing uncertainty are discussed.

The probabilistic precipitation analysis produces a family of hazard curves that relate precipitation depths to annual exceedance probabilities. The hazard curves are used as input to a run-off model that produces hazard curves at individual structures (e.g., hydrodynamic forcing versus annual exceedance probability). These structure-specific hazard curves could be used as input for a PRA analysis, including fragility analysis for individual structures. This paper includes an example study for illustration purposes.

INTRODUCTION

Traditional methods for evaluating the effects of extreme precipitation for nuclear sites involve conservative deterministic analysis, e.g., IAEA (1983); IAEA (2011); USNRC (1977); USNRC (2011). Often reference is made to the so-called "Probable Maximum Precipitation" (PMP), which is said to be "a deterministic estimate of the theoretical maximum depth of precipitation that can occur at a time of year over a specific area." The result of a deterministic local intense precipitation analysis is generally a single flood level (or multiple levels corresponding to different plant areas) that is used for design/decision-making purposes.

One benefit of a deterministic, PMP-type analysis is that it provides a method of screening out flooding hazards that (with significant margin) do not affect a site. There are drawbacks to a deterministic approach as well. First, there is often very little discussion or quantification of the uncertainty. Therefore, it is difficult to determine how much margin should be required above a PMP flood level to account for uncertainty. Another drawback is that because the concept of a PMP is not associated with an Annual Exceedance Probability (AEP), it is not possible to incorporate the results of a PMP analysis into a Probabilistic Risk Assessment (PRA). While it is possible to perform vulnerability assessments for a PMP flood level, there would be no quantitative insight into the actual plant risk (in terms of AEP) for cases where the design basis flood affects one or more plant Structures, Systems, or Components (SSCs).

A Probabilistic Flood Hazard Assessment (PFHA) establishes a better basis for decision-making than a deterministic approach because it provides quantitative information about risk to various plant structures. SSCs that contribute the most to the overall plant risk (based on the localized flood hazard and the SSC safety category) can be identified as so-called “weak links”, allowing for targeted plant modifications. The goal is to create a balanced plant risk profile.

This particular study addresses the flooding hazard of Local Intense Precipitation (LIP) within a probabilistic framework. LIP is a particularly interesting flood hazard for probabilistic approaches for a couple of reasons. First, the LIP hazard is applicable to all power plants, i.e., unlike tsunami flooding or dam failure flooding, it is not possible to build a plant that is not subject to local rainfall (though some plants are graded such that local rainfall will not lead to ingress of water into buildings). Second, the controlling variable in a LIP analysis is typically the rainfall intensity, which leads to essentially a single variable probabilistic analysis, making it difficult to draw inferences about extremely low probability events (e.g., 10^{-6} AEP) without large error bounds.

Some relatively recent advances in statistics and probabilistic methods have made it possible to draw better conclusions about low probability precipitation events. These methods include fitting probability density functions to regional precipitation data, as well as methods for explicitly accounting for epistemic uncertainty, e.g., using multiple probability distributions and giving each distribution a weighting factor as a contribution to a weighted mean hazard curve. In addition to the mean hazard curve, curves can be produced corresponding to other fractiles (based on the acceptable level of risk) to account for the uncertainty.

A rainfall frequency hazard curve can serve as an input to a two-dimensional surface water run-off model. By running a suite of simulations in a run-off model, hazard curves (e.g., depth vs. AEP or hydrodynamic force vs. AEP) can be produced for specific plant structures, doorways, hatches, etc.).

The overall methodology outlined in this paper consists of four parts:

I. Overall site rainfall hazard curve (or family of curves) – Relating rainfall depths to annual exceedance probabilities.
II. Structure-specific hazard curves – Relating flood depths, forces, etc. adjacent to specific structures to annual exceedance probabilities.
III. Evaluation of uncertainty and peer review – A comprehensive review of the sources of uncertainty and their effect on the resulting hazard curve(s), including an appropriate level of peer review.
IV. Plant response to flooding effects – Evaluation of flooding effects inside of buildings and/or interface with component fragility calculations.

Parts I, II and III are the focus of this paper; part IV is discussed briefly. Example data and results from a pilot project are presented toward the end of the paper for illustration purposes.

PROBABILISTIC PRECIPITATION HAZARD ASSESSMENT METHODOLOGY

In order to establish an appropriate method for a probabilistic precipitation hazard assessment, it is important to outline the critical characteristics that should be accounted for. The following criteria are put forward for the purposes of this paper (the methodology should…):

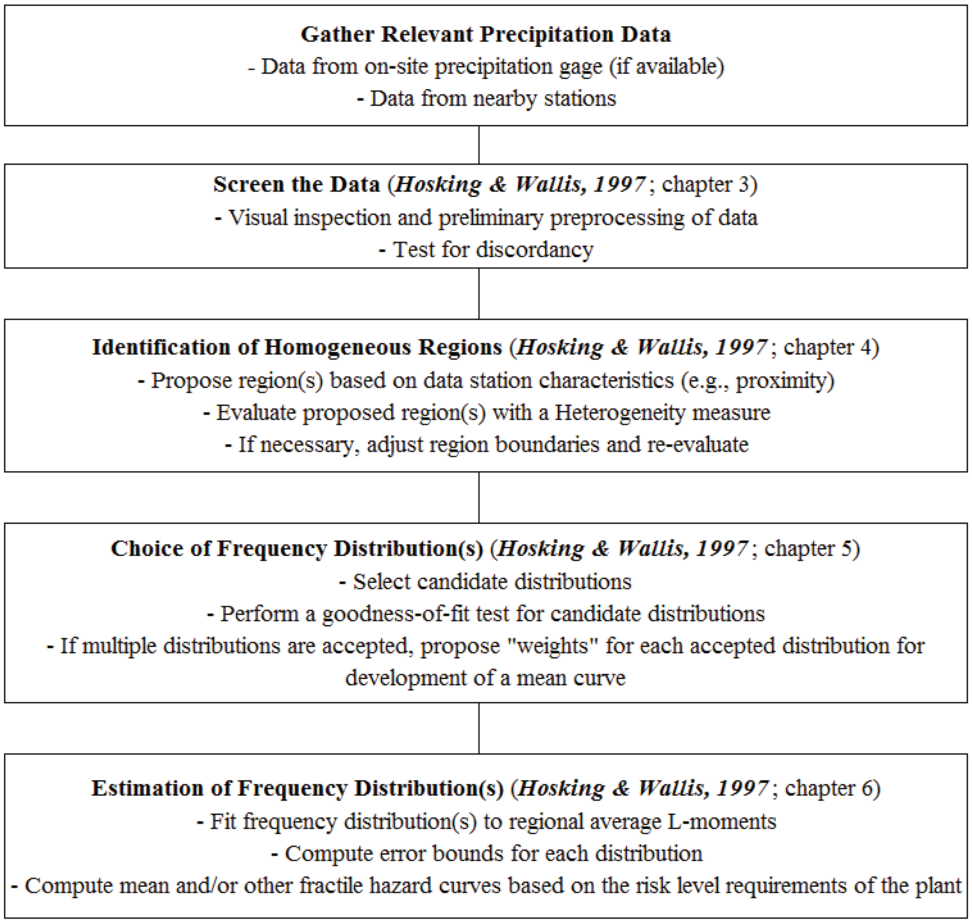
- Account for regional precipitation data (i.e., multiple data stations);
- Provide a quantitative method for screening out erroneous precipitation data;
- Provide a quantitative method of affirming which data should be used in the analysis (i.e., the definition of a “region”);
- Provide a quantitative method for comparing the goodness-of-fit for multiple probability distributions;
- Facilitate an intensity-duration analysis and the development of temporal distributions;
- Include a method for relating precipitation estimates to floodwater depths/forces near site structures;
- Allow for a detailed evaluation of uncertainty; and

- Incorporate the role of subject matter experts for peer reviewing the analysis and treatment of uncertainty.

While there may be many methods of achieving these goals, this study outlines a specific method that is based on L-moment analyses (Hosking and Wallis, 1997). The L-moment precipitation analysis is augmented with additional details (e.g., a site run-off model) to produce hazard curves for flood depths and forces near structures.

Site Rainfall Hazard Curve

The overall methodology applied in this study for conducting a regional precipitation frequency analysis is outlined in Hosking and Wallis (1997). The method is based on L-moment statistics. L-moments are analogous to conventional moments (i.e., mean, standard deviation, skew, kurtosis, etc.), but are developed with a more linear approach. Using linear statistics decreases sensitivity to outliers and improves the quality of site-specific estimates based on regional precipitation data. The method of L-moments is now a standard methodology used by many experts (e.g., the United States National Oceanic and Atmospheric Administration [NOAA, 2004]). The regional precipitation analysis approach used for this analysis is summarized in Figure 1 and elaborated further in the following subsections.



Gather Relevant Precipitation Data
- Data from on-site precipitation gage (if available)
- Data from nearby stations

Screen the Data (***Hosking & Wallis, 1997***; chapter 3)
- Visual inspection and preliminary preprocessing of data
- Test for discordancy

Identification of Homogeneous Regions (***Hosking & Wallis, 1997***; chapter 4)
- Propose region(s) based on data station characteristics (e.g., proximity)
- Evaluate proposed region(s) with a Heterogeneity measure
- If necessary, adjust region boundaries and re-evaluate

Choice of Frequency Distribution(s) (***Hosking & Wallis, 1997***; chapter 5)
- Select candidate distributions
- Perform a goodness-of-fit test for candidate distributions
- If multiple distributions are accepted, propose "weights" for each accepted distribution for development of a mean curve

Estimation of Frequency Distribution(s) (***Hosking & Wallis, 1997***; chapter 6)
- Fit frequency distribution(s) to regional average L-moments
- Compute error bounds for each distribution
- Compute mean and/or other fractile hazard curves based on the risk level requirements of the plant

Figure 1: Process for Regional Precipitation Frequency Analysis

Gather Relevant Precipitation Data – In addition to any on-site precipitation data, precipitation data should be gathered for a wide area around the site (e.g., from online databases). The area should be large enough to include all nearby precipitation gages that could be expected to be classified (further in this analysis) as part of a homogeneous region with the site. This may involve identifying gages at similar elevations to the site or gages that have similar proximity to a coastline.

Screen the Data – Prior to any quantitative analysis with the precipitation data, it is important to visually inspect the data to observe any trends, inconsistencies, or gross anomalies (e.g., negative precipitation values). After the initial, qualitative data screening, a more quantitative data screening is performed. The discordancy test proposed in chapter 3 of Hosking and Wallis (1997) provides a statistical test for identifying stations that are grossly discordant with the group as a whole.

Identification of Homogeneous Region(s) – For a large study area (e.g., a large watershed), multiple hydrologically distinct "regions" may exist within the study area. However, for the purposes of a local precipitation study, only one region is necessary (the region containing the site).

The first step for identifying a homogeneous region around the site is to propose a region based on similar gage station "characteristics" (e.g., elevation, proximity to other stations, etc.). Hosking and Wallis (1997) point out that it is important to not use statistical measures to identify similar stations. The stations must first be grouped into logical regions based on similarities between stations. This is necessary because statistical measures will be used later in the methodology to test the homogeneity. If statistical quantities are used both to develop and test the regions, the statistical tests do not provide an independent verification of homogeneity.

The hypothesized region is then subjected to the heterogeneity test described in chapter 4 of Hosking and Wallis (1997). The heterogeneity test compares the variation in the sample data to the variation observed in randomly generated datasets with similar statistical properties.

Choosing Probability Distributions – The choice of an appropriate probability distribution (or distributions) is critical. Potential distributions should be proposed based on general distribution characteristics, e.g., the existence of an upper bound or lower bound. A precipitation analysis cannot apply a distribution that gives a finite probability of occurrence to a negative precipitation. The proposed distributions should be evaluated with a goodness-of-fit measure to determine whether each distribution should be "accepted" or "rejected" as a potential representation of the data (Hosking and Wallis, 1997). The degree of fit for each distribution can also be evaluated.

Refer to chapter 5 of Hosking and Wallis (1997) for details about performing the goodness-of-fit test using the L-moment method. The goodness-of-fit test provides a quantitative assessment of how well each distribution type is able to represent the data. For scenarios where multiple distribution types are accepted by the goodness-of-fit test, it may be appropriate to retain multiple distribution types and assign weights to each distribution type based on a degree-of-belief that each distribution provides the best estimate. Retaining multiple distributions and assigning weights is a way of reducing uncertainty in the overall analysis because it does not rely in the applicability of a single distribution.

At this point, it is important to note the role of subject matter experts in a probabilistic flooding hazard analysis. A peer review process with subject matter experts is important to review the choice of probability distributions and the weighting factors assigned to each. Weights may be assigned based on results from the goodness-of-fit test, expert opinions, or other rationale.

Estimation of Probability Distributions – After determining the distribution type(s) to be included in the analysis, the distribution(s) are fit to the data. Hosking and Wallis (1997) outline a procedure for computing error bounds for each probability density function, providing an understanding of the uncertainty associated with each distribution.

It should be noted that the frequency distributions will reflect rainfall depths with the durations associated with the input precipitation data. For example, if daily precipitation values were used in the precipitation analysis, the precipitation hazard curve will assigned AEPs to daily rainfall depths. The rainfall intensity-duration relationships (e.g., determination of rainfall depths for durations of 24 hour, 6 hour, 1 hour, etc.) should be established using credible methods and be subject to peer review. Multiple methods are available for establishing rainfall intensity-duration relationships. For example, a Montana

Law type relationship could be used to establish intensity-duration curves. Alternately, intensity-duration curves could be adopted based on prior extreme precipitation studies for the area of interest.

In addition to the intensity-duration relationship, a temporal distribution (or distributions) must be developed to represent each storm. Both the intensity-duration relationship(s) and the temporal distribution(s) applied are additional sources of uncertainty for the analysis.

Structure-specific Hazard Curves

The precipitation depth hazard curve can be used as an input to a surface-water run-off model of the site. Hazard curves for specific locations within a site can be developed by running multiple simulations in the run-off model, each with a different rainfall depth (and associated AEP). Multiple rainfall temporal distributions could be applied at this point to quantify the uncertainty associated with the temporal distribution. The overall approach for developing structure-specific hazard curves is outlined in Figure 2.

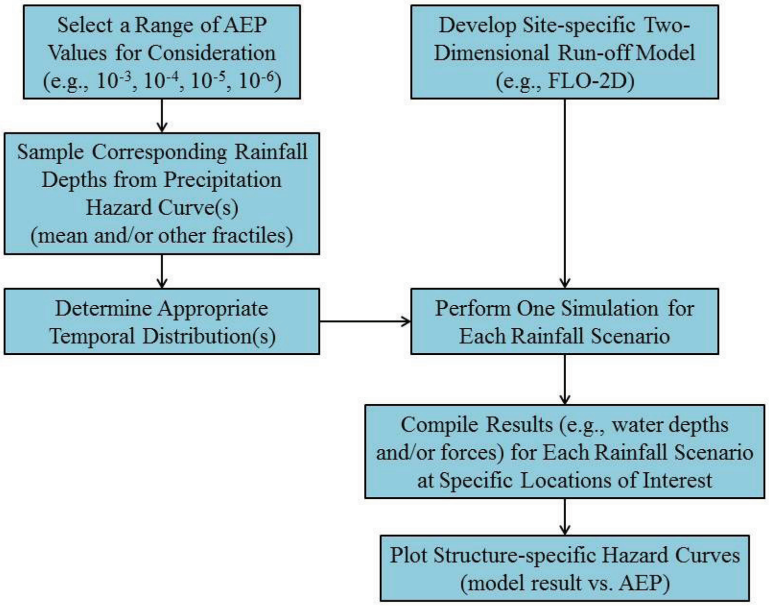


Figure 2: Process for Developing Structure-specific Hazard Curves

The site-specific run-off model could take a variety of forms, though a two-dimensional model is preferred because it provides detail of flow around and between site buildings. The model should characterize the site-specific topography and hydrologically important features (including surface roughness, soil infiltration properties, and vehicle barriers that could affect flow paths.

Once the site-specific run-off model has been developed, a suite of scenarios can be developed, each with a different rainfall depth. Note that for each rainfall depth, one or more temporal distributions should be considered. The development of temporal distributions can be based on a variety of methods. The choice of temporal distribution(s) is another source of uncertainty that should be evaluated based on available literature and technical opinions. Multiple temporal distributions could potentially be applied and weighted to reflect the understanding of subject matter experts. The model results for each simulation indicate flood levels (or forces) associated with a specific AEP. Rates of ingress can also be calculated based on assumptions about door positions (i.e., opened or closed) and specific door geometries.

Uncertainty Analysis and Peer Review

There are many sources of uncertainty that affect the results of a PFHA for LIP, which are accounted for with various methods including peer review. Peer review can be carried out in several different ways throughout a project. In-process peer review solicits the opinions of Subject Matter Experts (SMEs) (e.g., through various processes including formal Expert Elicitation) or PRA experts throughout the course of the project. In contrast, an overall peer review can be conducted at the end of the project. Both internal and external peer review can be performed. One of the primary goals of peer review in a probabilistic flooding analysis (and the reason that "Peer Review" is included in the "Uncertainty Analysis" section of this study) is to ensure that the uncertainty in the analysis is accounted for appropriately.

Uncertainty is often categorized into two separate categories, aleatory and epistemic. Aleatory uncertainty is uncertainty that is understood to be intrinsic variability in the system being studied. Uncertainty that cannot conceivably be reduced by larger datasets, better models, better science, etc. is considered aleatory uncertainty. In contrast, epistemic uncertainty can conceivably (though not necessarily practically) be reduced by increased understanding of the system. It is worth noting that the uncertainty analysis should be ongoing during the PFHA process (e.g., the uncertainty associated with the precipitation distributions should be addressed before proceeding to the run-off analysis).

Since epistemic uncertainty can conceivably be reduced, it is important to take practical steps to quantify and/or reduce it as much as possible. This can involve peer review subject matter experts and considering multiple characterizations, with sensitivity analyses to determine which parameters/factors are the most critical. Logic trees and/or Bayesian approaches can also be applied. A comprehensive analysis of uncertainty is a study in-and-of-itself and cannot be included in this paper. However, the following list highlights some of the relevant sources of uncertainty for a PFHA for LIP:

- **Uncertainty in Rainfall Measurements**: Potential inaccuracies exist in the physical rain gage apparatus and associated data processing activities. This includes measurement tolerances, systematic errors, and errors due to various potential equipment malfunctions. For practical purposes, this source of uncertainty would likely be treated as aleatory uncertainty in a PFHA analysis (i.e., random variation). Also, the discordancy test discussed above is a contributor to reducing this source of uncertainty. The discordancy test can detect grossly discordant data (e.g., due to systematic measurement errors).
- **Uncertainty in the Choice of a "Region" for Regionalized Rainfall Analysis**: The initial choice of region(s) is somewhat subjective (though based on engineering judgement as described above). The proposed regions are tested with quantitative statistical analysis to confirm the validity of the region boundaries. This statistical test reduces this source of epistemic uncertainty. The sensitivity of hazard curve results to the region boundaries could be tested through sensitivity analyses.
- **Uncertainty in the Choice of Probability Density Function Types**: There are many types of probability density functions (e.g., Generalized Extreme Value or Lognormal) that are available for an engineer to apply. Goodness-of-fit tests provide a quantitative way of reducing this epistemic uncertainty; however, more than one distribution may pass all available goodness-of-fit tests. Some goodness-of-fit tests provide more detail than a simple "pass" or "fail" and allow for better comparison between distributions. When multiple distributions are acceptable, the engineer must decide whether to choose the "best" distribution alone as representative or to use some combination of multiple distributions that pass the goodness-of-fit test. Using a weighted average of multiple distributions explicitly acknowledges the epistemic uncertainty involved in choosing a distribution type and provides a more stable mean hazard curve.
- **Uncertainty in the Surface-water Run-off Model**: A run-off model uses many datasets as input (e.g., topographic data, land use data, soils data, and building geometries), each of which has some level of uncertainty associated with it. Often tolerances are reported for topographic data,

which can be used to guide an understanding of the vertical and horizontal accuracy of a model. Land use data is often delineated from recent aerial imagery or a site plan drawing. These can provide a good estimate of land use. However, land use can change over the life of a plant due to various plant modifications.

- **Uncertainty in Temporal Distribution(s) for Rainfall**: There is uncertainty associated with the choice of temporal distribution(s) for the rainfall input to the run-off model. There are multiple methods that could be used to develop temporal distribution. Expert opinion could be used to weigh in on the choice temporal distributions.

Site Response

Once hazard curves have been developed, they can be used in support of a vulnerability assessment (both on an individual component level and a total site level). The vulnerability assessment can take a range of forms from semi-deterministic, to fully probabilistic (PRA). A full PFHA with structure-specific hazard curves allows for a detailed PRA-type evaluation of site vulnerabilities. Some important SSCs may screen out initially as not affected by flood levels of any consequential AEP. However, other SSCs may require detailed fragility calculations.

Fragility calculations can range from simple cliff-edge type failures (i.e., assuming that any SSC that reached by floodwater fails to perform its safety function) to detailed analyses of seals and ingress of water with consideration for sumps, and other mitigating strategies.

EXAMPLE STUDY

The following sections summarize an example probabilistic precipitation study that includes details regarding the precipitation hazard curve, structure-specific hazard curves, and the uncertainty analysis. The site response is not discussed for the example study.

Site Rainfall Hazard Curve

The example study is summarized as follows (Figure 1).

Gather Relevant Precipitation Data: Available precipitation data was surveyed, and the 60 precipitation gage stations that were located within 100 kilometers of the site were used for the regional analysis. Potentially, a larger area could have been incorporated, but 60 gages were determined to be sufficient for the purposes of the specific application.

Screen the Data: The data was visually inspected for obvious flaws. Then, annual maximum series were prepared for each station, and the data was inspected. Years that had missing data points were not included in the annual maximum series (to avoid errors introduced by missing data), and datasets with less than 20 years of data were removed to avoid errors that could potentially be introduced by extremely short datasets. Twenty years is a semi-arbitrary threshold recommended by the World Meteorological Organization (WMO, 2009). Note that shorter datasets could potentially be included in the analysis (if necessary) subject to careful evaluation of the associated uncertainty. This was not considered necessary for the example study. After the initial screening, 18 precipitation gage stations remained as applicable for further analysis. As a quantitative screening method, a discordancy test (Hosking and Wallis, 1997) was applied to the remaining stations. Based on the discordancy test, two more stations were removed from consideration. The remaining 16 stations were used for the regional analysis.

Identification of Homogeneous Region(s): The group of data stations selected for the screening process were relatively close in geographic proximity and elevation. These stations were hypothesized to represent a single "region" for the regional precipitation analysis. This hypothesized region was then subjected to the heterogeneity test described in chapter 4 of Hosking and Wallis (1997). The H statistic computed for the heterogeneity test was a value of less than one, indicating that the variability observed in the region was within the range of variability expected for a homogeneous region. Thus, the proposed region was considered appropriate for further analysis.

Choosing Probability Distribution(s): Based on general distribution characteristics, several potential probability density function types were identified for the example study, including:

- Wakeby Distribution,
- Generalized Extreme Value (GEV) Distribution,
- Generalized Logistic Distribution,
- Lognormal Distribution, and
- Pearson Type III Distribution

Each of the identified potential distributions was subjected to a goodness-of-fit test, which provided a quantitative comparison of how well each distribution was able to fit the regional precipitation data. The goodness-of-fit test rejected the Generalized Logistic Distribution and the Pearson Type III distributions (see Hosking and Wallis [1997] for details regarding the acceptance criteria for the goodness-of-fit test). The other three distributions were retained and included as contributing factors (with weighted contributions) to a mean distribution. Based on project-specific criteria, it was determined that the mean curve was sufficient for use in the analysis (other applications may require the use of other fractile quantities). The distributions were weighted according to how well each distribution fit the data, with the Wakeby Distribution given equal weight as the GEV Distribution (the Wakeby Distribution has five parameters, making it extremely flexible).

Estimation of Probability Distributions: After determining the distribution types to be included in the analysis, each distribution was fit to the data, and error bounds were computed for each distribution. The hazards curves are illustrated in Figure 3.

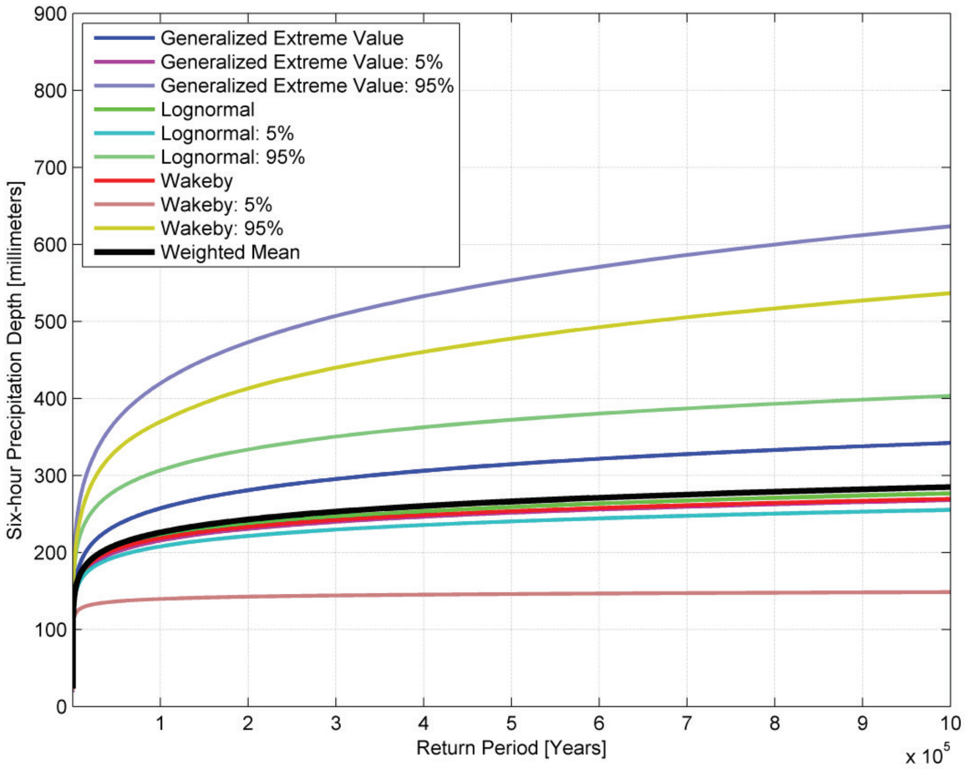


Figure 3: Rainfall Frequency Hazard Curves for Example Project

It should be noted that Figure 3 represents 6 hour rainfall depths; the conversion from 24 hour to 6 hour rainfall depths is not discussed in this paper in detail. As discussed above, there are many approaches for determining intensity-duration curves. For the example study, conversion factors for relating rainfall depths of various durations were obtained from the United States National Oceanic and Atmospheric Administration Hydrometeorological Report (HMR) No. 52 (NOAA, 1982).

Structure-specific Hazard Curves

The precipitation hazard curves computed above were used as input to a surface-water run-off model. Based on project-specific criteria, it was determined that the mean curve was sufficient for use in the analysis (other applications may require the use of other fractile quantities). A single temporal distribution was applied using the intensity-duration ratios from HMR 52 (NOAA, 1982), with the understanding that further analysis could involve sensitivity analyses with multiple temporal distributions. The FLO-2D pro model (FLO-2D, 2012) was applied for simulating surface-water run-off.

The model results for each simulation indicate flood levels (or forces) associated with a specific AEP (Figure 4). Rates of ingress can also be calculated based on assumptions about door positions (i.e., opened or closed) and specific door geometries (e.g., Figure 4, bottom right).

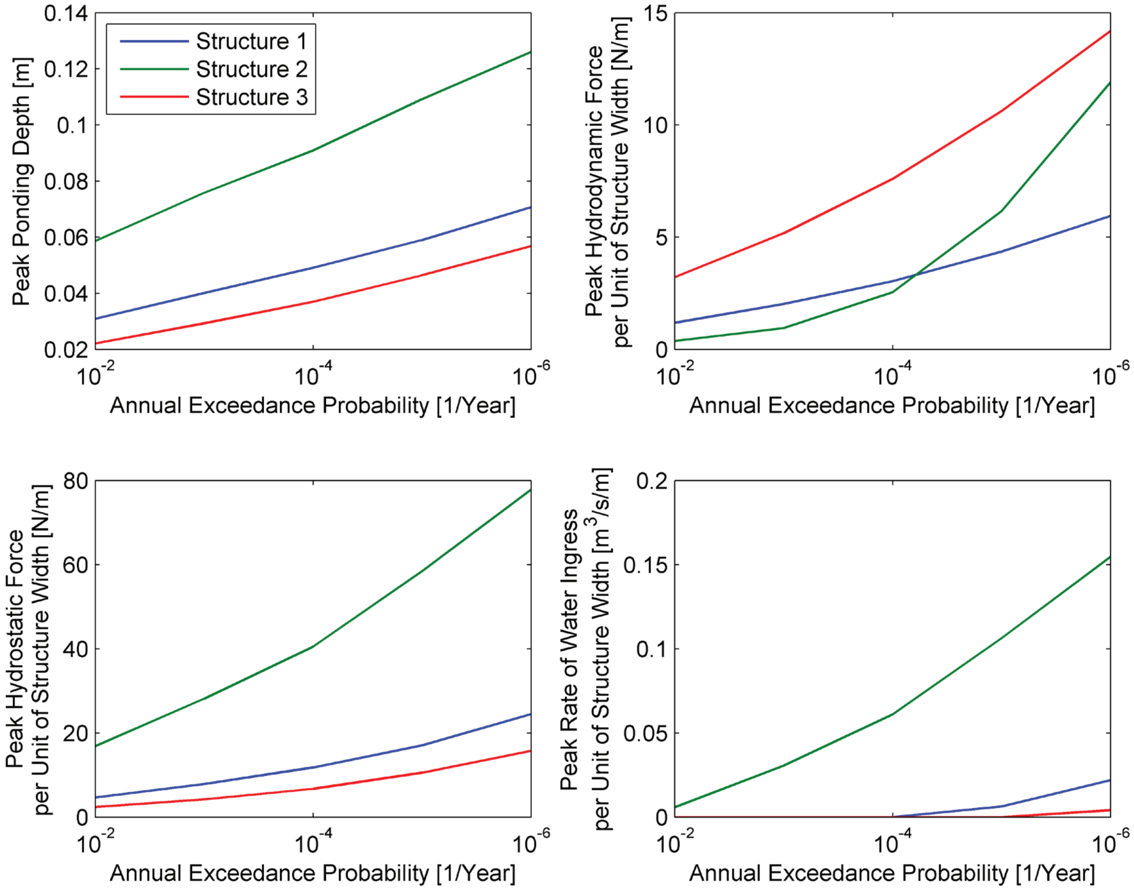


Figure 4: Structure-specific Hazard Curves

Uncertainty Analysis and Peer Review

The uncertainty associated with the example study was evaluated as outlined in the methodology above. Each source of uncertainty was clearly identified, quantified, and reduced (when possible). This involved many diverse efforts, including (but by no means limited to):

- Collating information such as data tolerances for precipitation data;
- Removing discordance gage stations and verifying the homogeneity of the region;
- Performing a goodness-of-fit test to evaluate multiple probability density function types;
- Retaining multiple probability density function types in the analysis;
- Computing error bounds for the distributions that passed the goodness-of-fit test;
- Comparing the 95 percent error bound to a deterministically estimated PMP value (the 95 percent error bound for the 10^{-6} AEP precipitation value was significantly less than the PMP estimate);
- Subjecting the entire probabilistic precipitation and run-off analysis to exhaustive peer review.

CONCLUSIONS

This paper outlines a method for conducting a Probabilistic Flood Hazard Assessment for Local Intense Precipitation. An example project is presented for illustration. The methodology includes application of L-moment methods for conducting a regional frequency analysis for precipitation depths. It is proposed that multiple probability distribution function types should be used (subject to goodness-of-fit tests and other appropriateness criteria), and a weighted average of the different distributions can be used as a "mean" local precipitation hazard curve (other fractile curves can also be computed). Error bounds should be reviewed as part of an uncertainty analysis.

The regional precipitation hazard curve is used as input to a two-dimensional surface-water run-off model. The results of the run-off model provide structure-specific hazard curves (e.g., depth, hydrostatic force, hydrodynamic force, rate of water ingress to a building, etc.) that can be used to interface with plant fragility calculation and a plant Probabilistic Risk Assessment model.

REFERENCES

FLO-2D (2012). "FLO-2D Reference Manual," FLO-2D Software Inc., Nutrioso, Arizona, pp. 75.

Hosking, J. R. M. (1990). "L-moments: Analysis and Estimation of Distributions using Linear Combinations of Order Statistics," *Journal of the Royal Statistical Society*, Wiley, Series B (Methodological) 52(1), 105-124.

Hosking, J. R. M. and Wallis, J. R. (1997). "Regional Frequency Analysis," Cambridge University Press, Cambridge, UK, pp. 224.

IAEA (1983). "Design Basis Flood for Nuclear Power Plants on River Sites: A Safety Guide," Safety Series No. 50-SG-S10A, International Atomic Energy Agency, Vienna, pp. 80.

IAEA (2011). "Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations," Specific Safety Guide, International Atomic Energy Agency, Vienna, pp. 172.

NOAA (1982). "Application of Probable Maximum Precipitation Estimates – United States East of the 105th Meridian," NOAA Hydrometeorological Report No. 52, Washington D.C., pp. 182.

NOAA (2004). "Precipitation-Frequency Atlas of the United States," NOAA Atlas 14, Volume 2, Version 3.0, pp. 301.

USNRC (1977). "Design Basis Floods for Nuclear Power Plants," Regulatory Guide 1.59, Revision 2, U.S. Nuclear Regulatory Commission, pp. 66.

USNRC (2011). "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America," NUREG/CR-7046, pp. 185.

WMO (2009). "Manual on Estimation of Probable Maximum Precipitation (PMP)," WMO-No. 1045, World Meteorological Organization, Geneva, pp. 291.