Suggested Approaches for Probabilistic Flooding Hazard Assessment

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Presentation Overview

Why Probabilistic Flood Hazard Assessment (PFHA)?

A Problem-Specific Approach to PFHA

Confidence and Uncertainty

Example Project: Storm Surge

Example Project: Intense Precipitation

Challenges and Areas for Improvement for PFHA

Why Probabilistic Flood Hazard Assessment?

- For engineering design: Avoid over/under-engineering
- For policy-makers to evaluate different alternatives and risks and level of conservatism in deterministic analysis
- For businesses to allocate resources efficiently
- Integrated Assessment – Post Fukushima: "Depending on site characteristics, the [Integrated Assessment] approach supports assessments that range from engineering evaluations of individual flood protection features to evaluations based on probabilistic risk assessment (PRA) techniques. (JLD-ISG-2012-05)

Example #1:
A large city's budgeting decision-makers…

> "How much should we invest in flood protection barriers along our waterfront to protect against extreme storm surge levels?"

Example #2:
A power plant operator…

> "How likely am I to loose functionality of my important equipment due to flooding?"

A Problem-Specific Approach to PFHA

Each PFHA problem has some unique aspects. The approach to PFHA should account for the uniqueness of each problem.

- What factors affect the flood level?
  - Storm surge
  - Rain intensity
  - Tsunami
  - River flooding or Dam breach
- What data is available and how does this limit analysis options?
  - Good historic record?
  - No data?
- What approaches have good technical justification?
  - Purely probabilistic approach?
  - Hybrid probabilistic / deterministic approach
  - Clear documentation of uncertainty

Confidence and Uncertainty

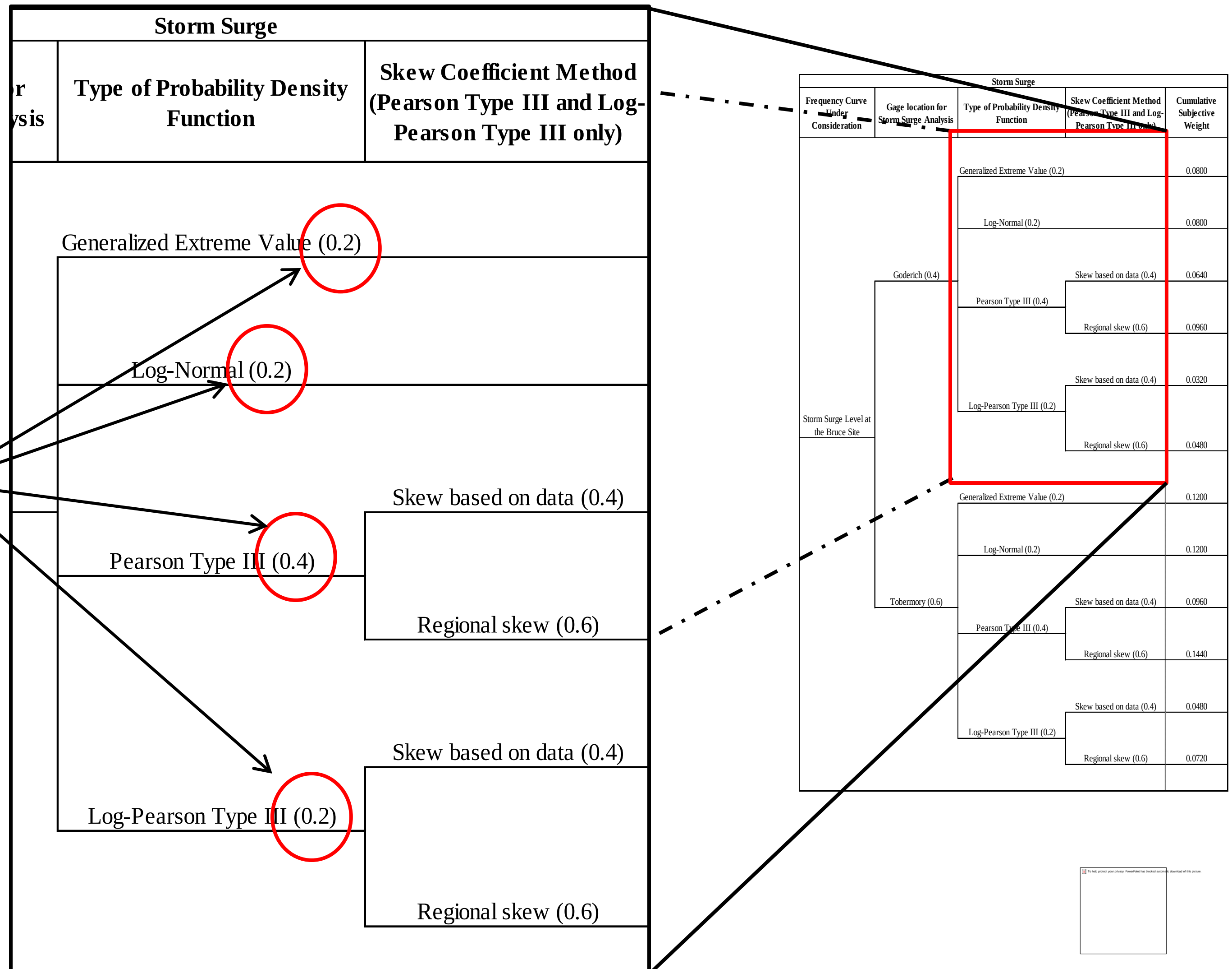
Two critical requirements for a thorough PFHA are:

- Identify, quantify, and (to the extent possible) compensate for the sources of uncertainty affecting the analysis. Some examples include:
  - Uncertainty inherent to the input data, and
  - Uncertainty in which statistical distribution is most applicable.
- Understand an appropriate level of confidence in the results. This can include the following:
  - Computing statistically-based confidence intervals for the results, and
  - Understanding the uncertainty the remains in the analysis, and not claiming accuracy beyond what is allowable given that uncertainty.

Confidence and Uncertainty

Logic Trees

Subjective weights assigned to each probability density function.



Example Project #1: Storm Surge in the Great Lakes

Problem Background

The Question:

To account for potential inundation effects of Storm Surge at a vital structure on the Great Lakes…

> "What surge levels (including wind-wave run-up) are associated with extremely low AEP events (e.g., 10^{-4}, 10^{-5}, and 10^{-6} AEP)?"

Example Project #1: Storm Surge

Deterministic Approach

Conservative parameters estimates (e.g., wind speed)

↓

Sensitivity analysis to find the most conservative combination of flood parameters

↓

Hydrodynamic Modeling

↓

Most conservative flood level (including wave run-up)

Probabilistic Approach

Characterize flood related parameters with probability density functions

↓

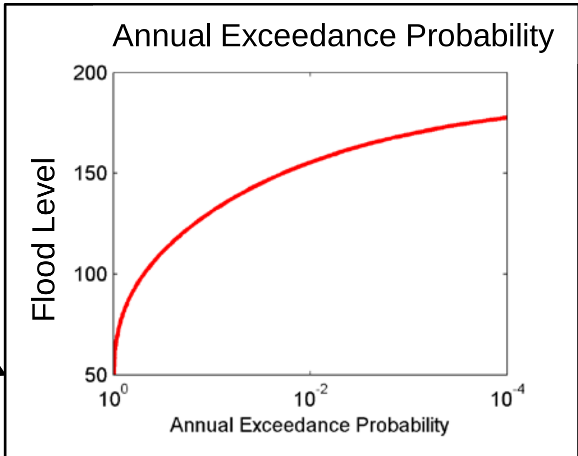
Synthetic data from distribution(s) and account for uncertainty

→ Hydrodynamic Modeling

Hybrid

Hydrodynamic Modeling → **Compute Exceedance Probabilities for Flood Levels**

→ Hazard Curve



Example Project #1: Storm Surge

- **What data and methods are available? Are they applicable for the Great Lakes?**

The Approach:

- **Gather relevant data (i.e., components of total flood level)**
  - Water Level Data – includes lake level and surge
    - Detailed water level data from nearby stations near the location of interest: approximately 50 years of records at hourly or sub-hourly intervals.
    - Monthly mean lake level data from 1860 to present.
    - Paleo Lake level data from published studies: approximately 4000 years of data showing the long-period cycles of the lake level.
  - Wave Data
    - Approximately 30 years of Wave Information Study Data was available from the United States Army Corps of Engineers. Data from the nearest two stations was used.

Example Project #1: Storm Surge

Applying the Approach:

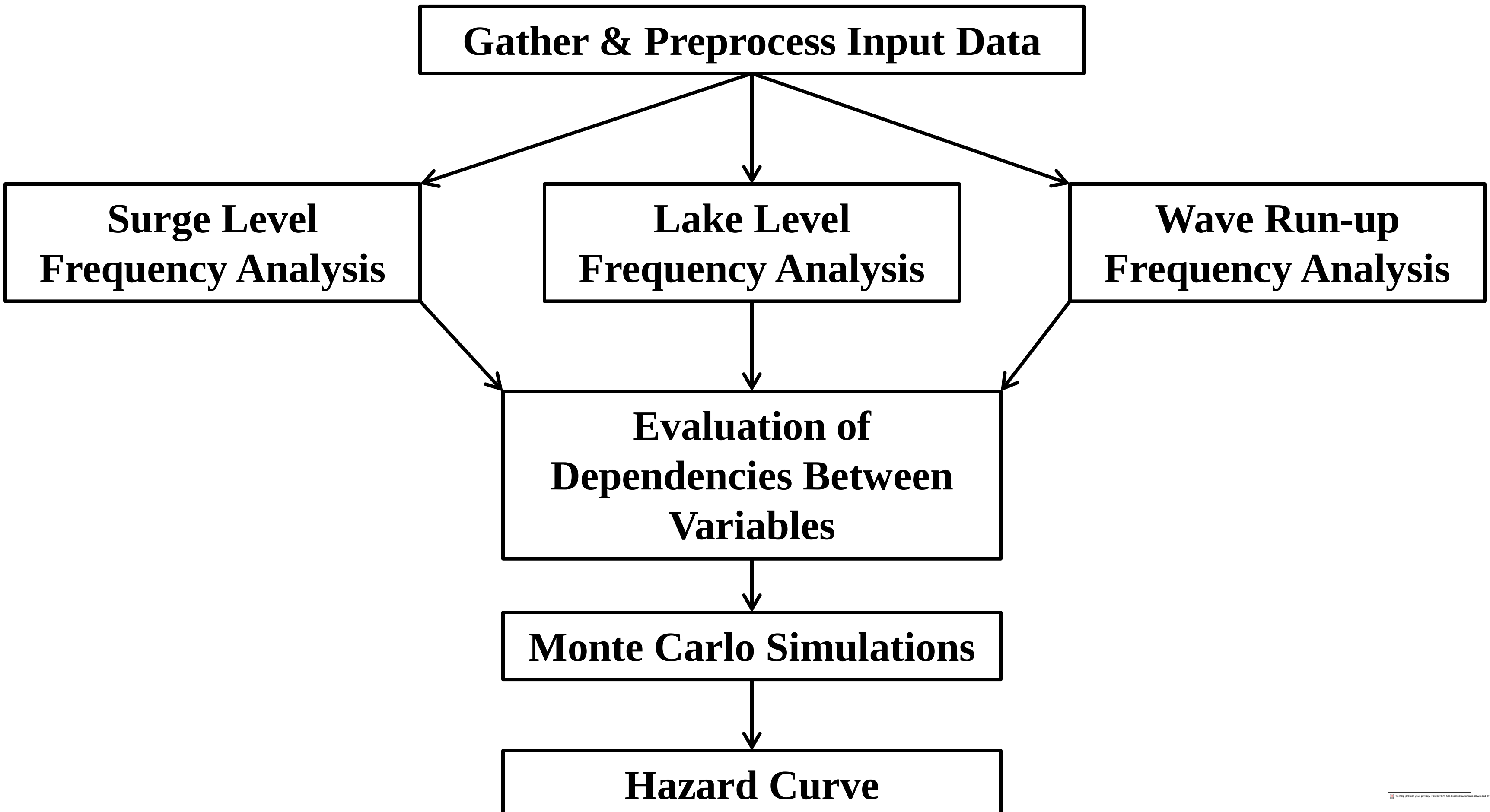
- **Four variables identified for statistical analysis**
  - Lake level (fluctuates due to many factors including seasonal effects)
  - Surge level
  - Wave Height
  - Wave Period
- **Correlation and dependencies evaluated**
  - Storm surge and lake level – not correlated
  - Surge level and wave height – correlated
  - Wave period and wave height – correlated, which is conservative and generally expected.

Example Project #1: Storm Surge

Applying the Approach:

- **Surge level analysis**
  - Separate surge “events”
  - Multiple statistical distributions
  - Goodness-of-fit
  - Weighted mean distribution
  - Weights are also assigned to the different gage stations based on a hydrodynamic model sensitivity analysis that demonstrated which gage better reflected the conditions at the area of interest for the study.

Example Project #1: Storm Surge



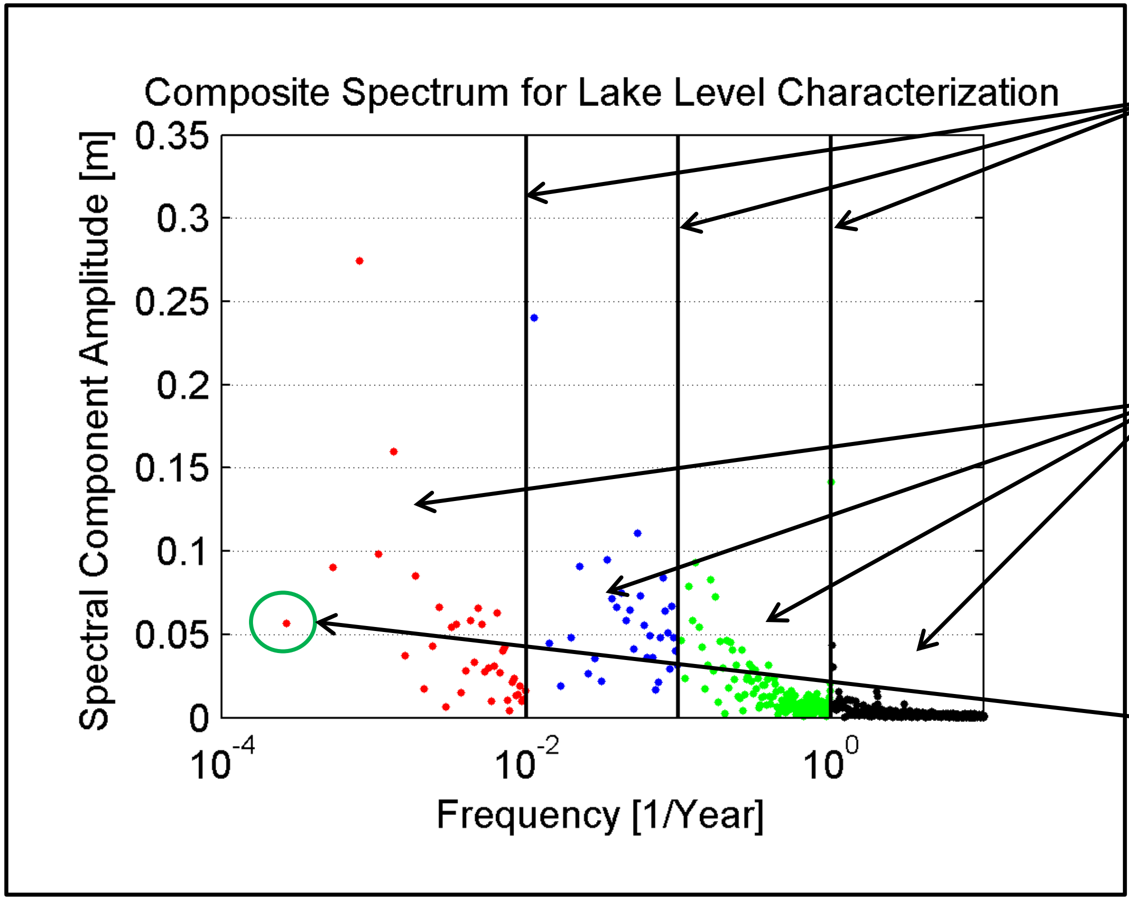
Example Project #1: Storm Surge

Applying the Approach:

- **Two approaches for lake level analysis**
  - Fitting statistical distributions to the data (similar to surge levels)
  - Fourier analysis method
    - Developed for this analysis to include paleo lake level data
    - Perform a Fast-Fourier Transform (FFT) on each dataset (e.g., paleo data, mean monthly data, and hourly data).
    - Combine datasets, taking spectral components from each dataset based on what information is best expressed by that dataset. For example:
      - Information about 100-year cycles is taken from the paleo data, and
      - Yearly oscillations are accounted with the mean monthly lake level data.
    - Synthetic lake level data can be generated from the combined Fourier components to compute annual exceedance probabilities.

Example Project #1: Storm Surge

Applying the Approach: Fourier Analysis of Lake Levels



Thresholds based on engineering judgment and sensitivity analysis.

Multiple datasets, including paleo lake level data, mean monthly data, and hourly data.

Each spectral component represents the amplitude of a cosine function used as part of a Fourier series to characterize the lake levels.

Example Project #1: Storm Surge

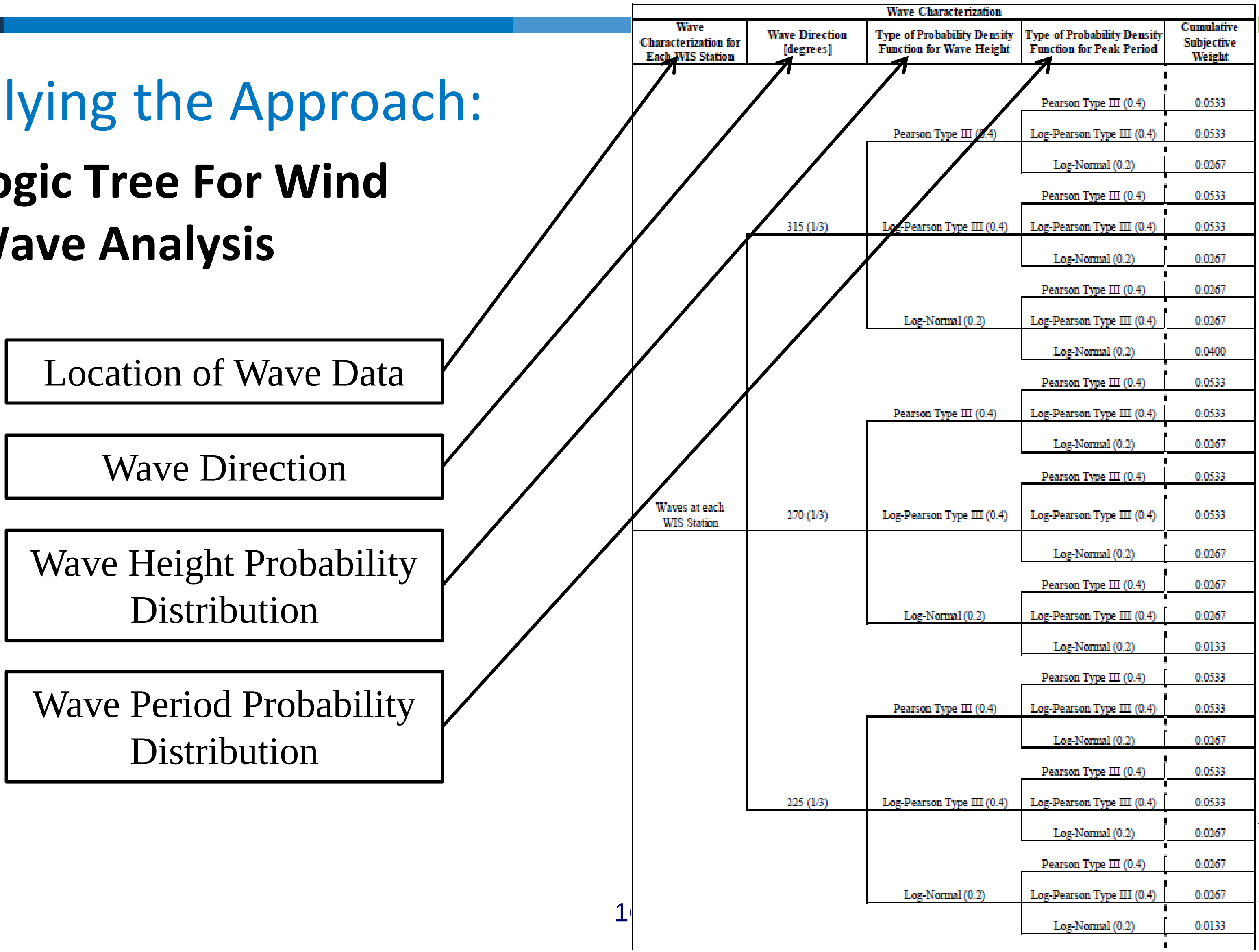
Applying the Approach:

- **Wind-wave analysis**
  - Fit statistical distributions to wave height and wave period (similar to surge levels)
  - Wave model to simulate wave transformation (many simulations)
  - Compute run-up using empirical run-up equations
- **Total water level analysis**
  - Monte Carlo
  - Mean Hazard Curve

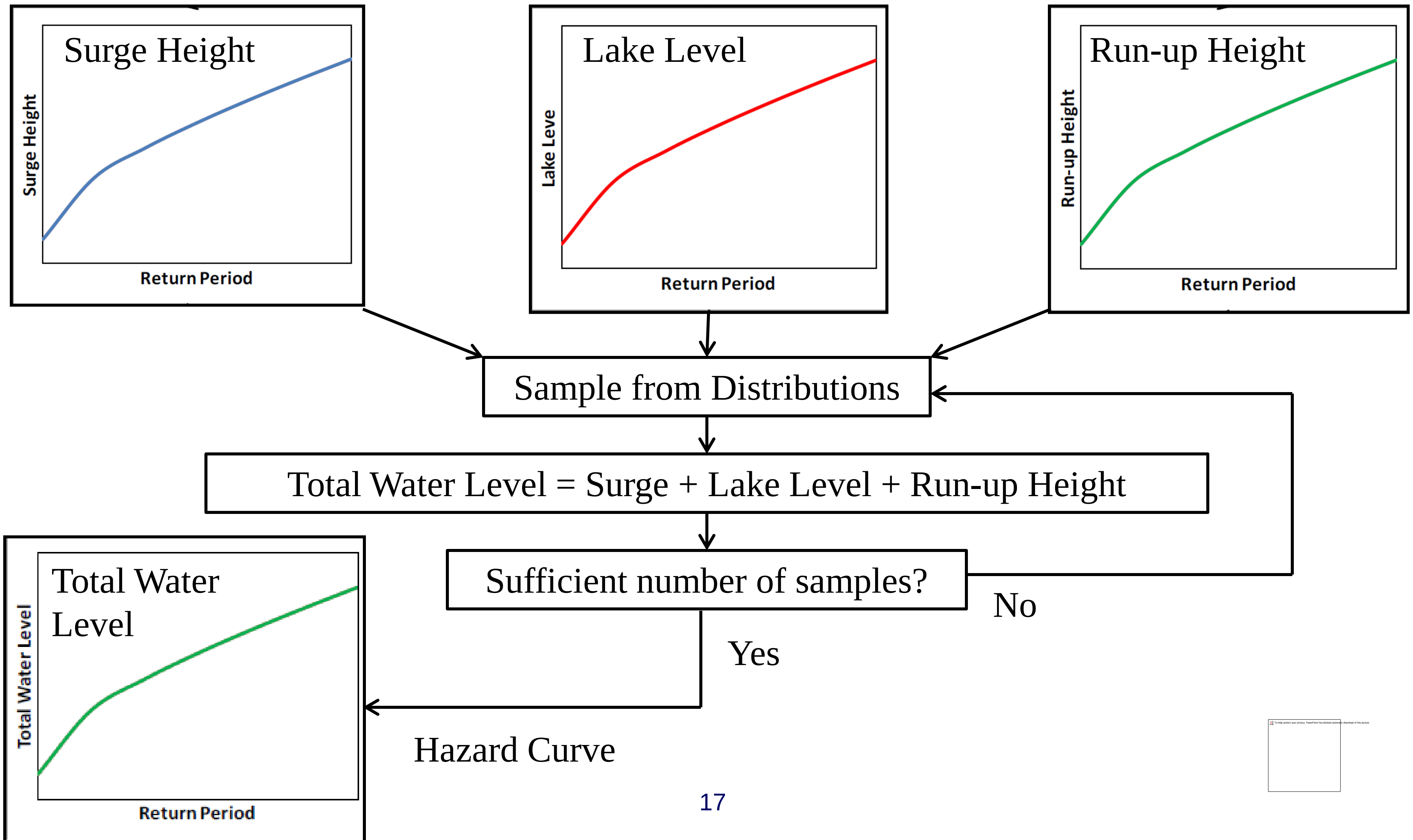
Example Project #1: Storm Surge

Applying the Approach:

- **Logic Tree For Wind Wave Analysis**



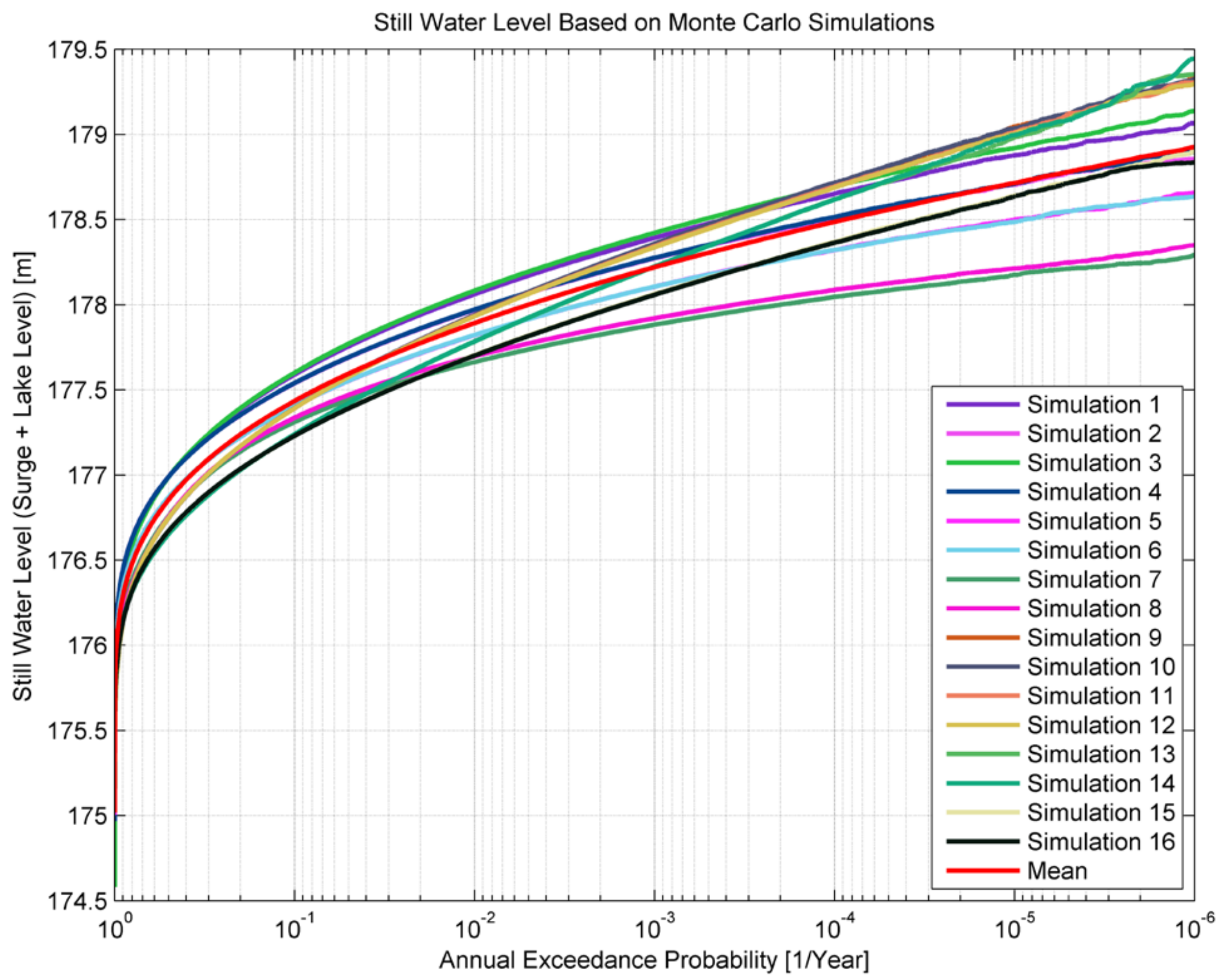
Example Project #1: Storm Surge



Example Project #1: Storm Surge

Results:

Many scenarios are considered to understand the uncertainty



Example Project #1: Storm Surge

The Answer to the Question:

Q: "What water levels (including wind-wave run-up) are associated with extremely low AEP events (e.g., 10^{-4}, 10^{-5}, and 10^{-6} AEP)?"

A: The water levels associated with low AEPs are computed as follows:

Location of interest is at elevation 180 m, between 10^{-3} and 10^{-4} AEP.

Deterministic Probable Maximum Storm Surge indicated 181.15 m.

Annual Exceedance Probability	Mean Estimate of Total Water Level [meters IGLD85]
10^{-1}	178.64
10^{-2}	179.28
10^{-3}	179.80
10^{-4}	180.29
10^{-5}	180.75
10^{-6}	181.16

Sources of Uncertainty: Addressed and Incorporated

- Data measurements of lake level
- Data resolution
- Applicability of utilized stations (representativeness)
- Paleoflood data records
- Choice of statistical distribution
- Choice of parameters for each distribution
- Best method to characterize background lake level
- Frequency thresholds used in Fourier analysis
- Methods to evaluate goodness-of-fit

Example Project #2: Intense Precipitation

Background

The Question:

To account for a Probable Maximum Precipitation in a Probabilistic Risk Assessment at a vital structure…

"What is the annual exceedance probability of the Probable Maximum Precipitation?"

Example Project #2: Intense Precipitation

Compute flood levels based on hydrologic input conditions

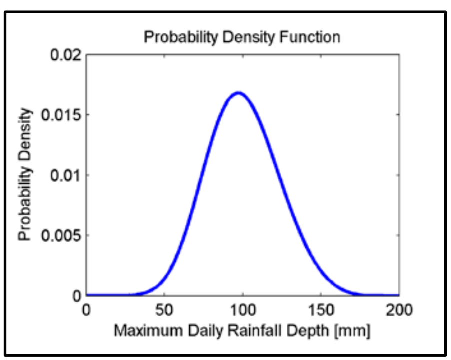
Rainfall Characteristics:
- Depth
- Duration
- Storm Shape

Watershed Characteristics:
- Topography
- Surface Roughness
- Infiltration Properties

?

Hydrologic model:
- 1D Models (e.g., HEC-HMS, HEC-RAS)
- 2D Models (e.g., FLO-2D, Delft3D)

Multiple simulations



~~Flood Levels~~ in Areas of Interest

Hazard Curves

Example Project #2: Intense Precipitation

The Approach:

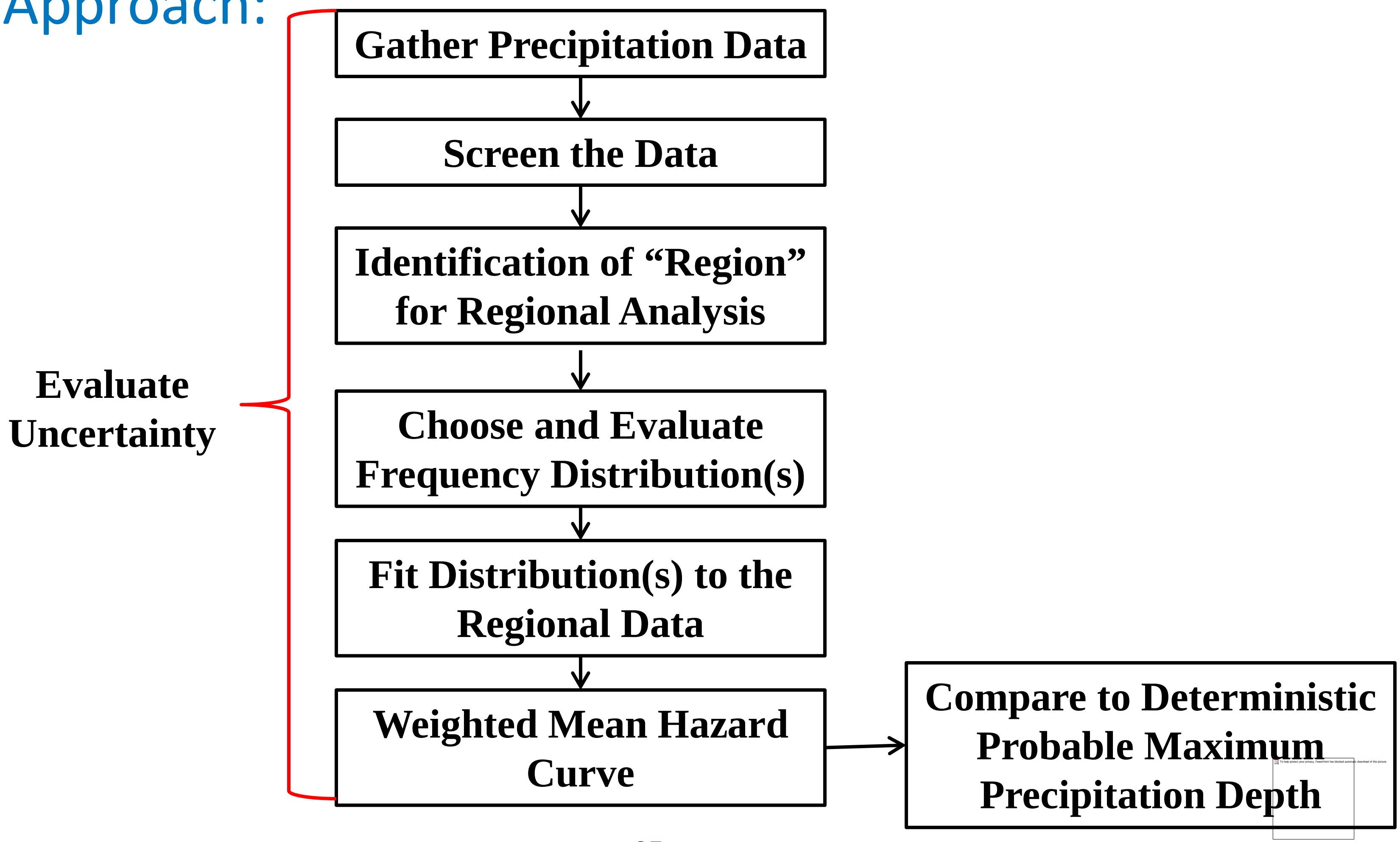
- **Rainfall intensity is the variable of interest**: Perform a frequency analysis for rainfall intensities in the area of interest.
- **Data is available**: The region near the area of interest contains numerous rain gages. Is this enough data? … to be determined.
- **A good method is available**: The method of regionalization using L-moments provides a good technical basis for using regional datasets to reduce uncertainty in site-specific analyses.
- **Uncertainty is Addressed**: The method of L-moments provides for a good analysis (i.e., quantification) of uncertainty.
- **Multiple methods are applied**: The results are compared to a "traditional" statistical analysis for precipitation.

Source of uncertainty

- Rainfall measurements
- Choice of “region” for regionalized rainfall estimates
- Choice of statistical distribution
- Choice of parameters of statistical distributions
- Conversion of rainfall depths between different stations

Example Project #2: Intense Precipitation

The Approach:



Example Project #2: Intense Precipitation

Results

ANNUAL EXCEEDANCE PROBABILITY	DEPTH (mm)
1×10^{-2}	94
1×10^{-3}	132
1×10^{-4}	175
1×10^{-5}	226
1×10^{-6}	285
1×10^{-7}	353
1×10^{-8}	433
1×10^{-9}	526
3.6×10^{-10}	572
1×10^{-10}	635

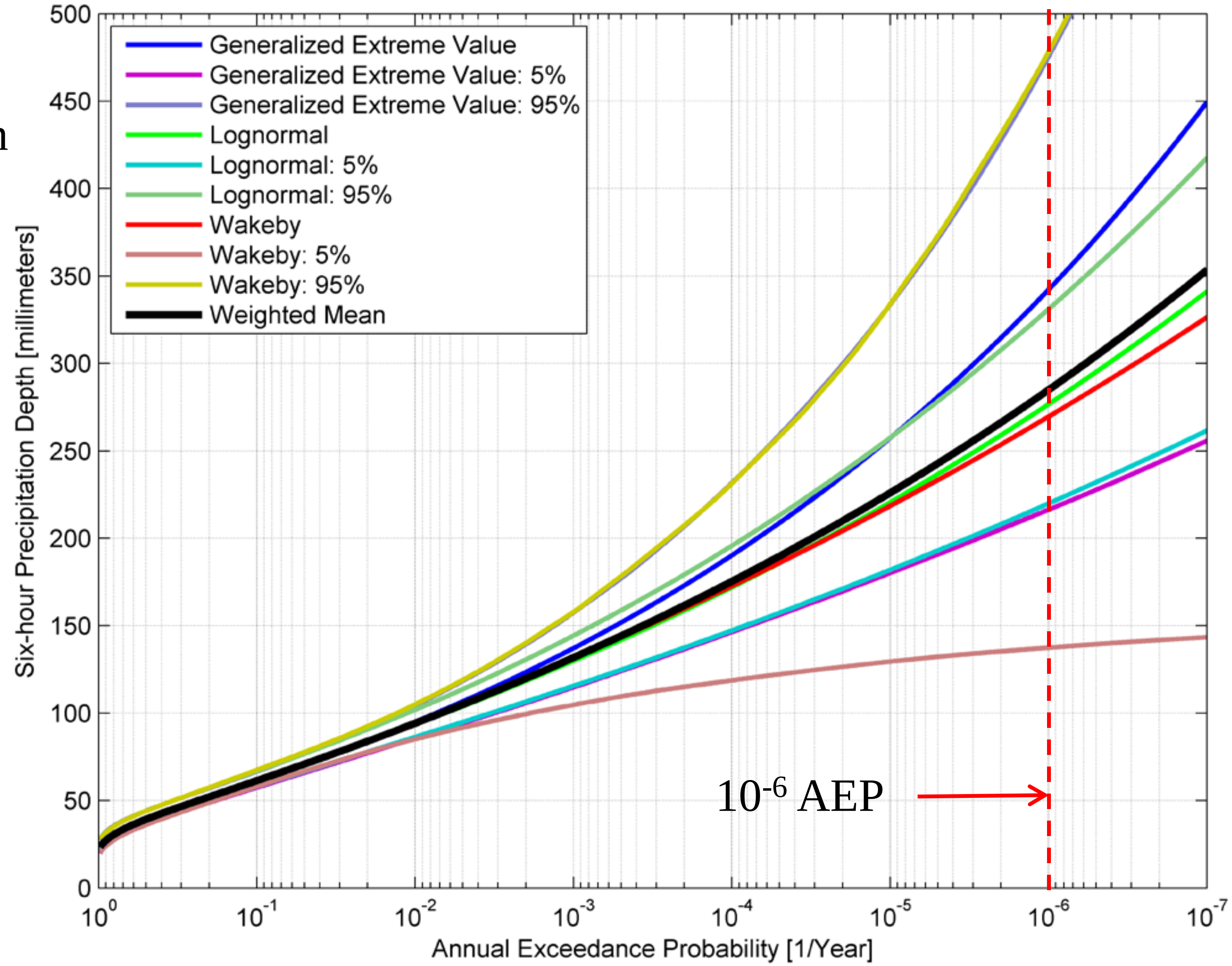
PMP Probability → 3.6×10^{-10}

PMP Depth → 572

Example Project #2: Intense Precipitation

Results

PMP Depth



The PMP depth is approximately 20% greater than the 95% error bound of the most conservative distribution at 10^{-6} AEP.

Example Project #2: Intense Precipitation

The Answer to the Question:

Q: “What is the annual exceedance probability of the Probable Maximum Precipitation?”

A: The following was determined:

- The PMP has an (mean value) AEP of less than 10^{-9}.
- However, use 10^{-6} AEP as the frequency of the PMP for the purposes of the PRA. This accounts for the 95% error bound and other uncertainty in the analysis.

Challenges and Areas for Improvement for PFHA

- Not enough data
  - Common problem.
  - Takes time, but large-scale data initiatives will improve this situation for future generations.
- Lack of unified methodology/guidance
  - Various guidance documents exist internationally, but much still needs to be done in the USA.
  - Many engineers shy away from probabilistic analysis as overly complex. This requires a paradigm shift.
  - SSHAC-like committee for flooding?
- How to account for a finite limit to rainfall?

Probabilistic Flood Hazard Assessment

Questions or comments?