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Riverine PFHA for NRC Safety Reviews – why and how?

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Overview

- Probabilistic Flood Hazard Assessment (PFHA)
  - What it is, in the NRC context
    - A tool for **site characterization** and selection of **design bases** that uses probabilistic approaches
    - A tool to determine exceedance probabilities of riverine flood **hazards**
    - A tool to evaluate potential **changes** to flood hazards in the future
  - What it is **not**, in the NRC context
    - A probabilistic risk assessment tool
    - A systems design tool
    - A licensing basis tool
- During this presentation
  - The term **PFHA** is used for **Riverine PFHA**
  - The terms **PFHA methods** is used for **methodologies to carry out Riverine PFHA**

Background

- Current NRC approach to hydrology safety reviews – regulatory bases
  - 10 CFR 50
    - Appendix A, General Design Criteria, Criterion 2 (GDC 2)
      Criterion 2—Design bases for protection against natural phenomena. Structures, systems, and components important to safety shall be designed to withstand the effects of **natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches** without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: **(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.
  - 10 CFR 52
  - 10 CFR 100

Background

- Current NRC approach to hydrology safety reviews
  - Deterministic
    - Relies on "**probable maximum**" events
    - Relies on "**bounding**" assumptions
    - Relies on "**reasonable and conservative**" design bases with "**margins**"
    - Philosophy of "**defense-in-depth**"
    - **Hierarchical Hazard Assessment**
  - Guidance for Applicants
    - Regulatory Guides 1.27, 1.29, **1.59**, 1.102, 1.113, 1.125
  - Guidance for NRC Staff
    - Standard Review Plan **NUREG-0800**, Section 2.4
- PNNL's role during the last ~10 years
  - Assisted NRC in performing ESP and COL safety reviews (since 2003-04)
  - Assisted NRC in updating Section 2.4 of NUREG-0800 (2007)
  - Assisted NRC in developing tsunami review guidance, NURG/CR-6966 (2009)
  - Assisted NRC in updating Regulatory Guide 1.59, NUREG/CR-7046 (2011)

PFHA – the Need

- Why PFHA?
  - NRC's 1995 Probabilistic Risk Assessment Policy Statement (60 FR 42622)
  - Current deterministic approach to flood site characterization
    - Expresses the hazard as **a single number**
    - Provides **no exceedance probabilities**
    - Provides **little uncertainty information**
    - Inconsistency in selection of design bases
    - Does not explicitly evaluate the consequences of design bases being exceeded or significant consequences of near-design bases events
  - Regulatory decisions increasingly need exceedance probabilities
    - Can a design basis be exceeded? How likely is it?
      - **Beyond design-basis** issues
    - Can a design basis **not** be exceeded yet result in significant damage and/or compromised operations?
      - **Less than design-basis** issues
  - To support performance-based, risk-informed approaches

PFHA – the Hazards

- What are flood hazards?
  - Characteristics of floods that may adversely affect safety-related systems
  - Examples
    - Flood water surface elevation
    - Hydrodynamic load (velocity, momentum)
    - Areal extent and duration
    - Debris load (availability, velocity, momentum)
    - Scouring potential (velocity, momentum)
  - The hazards are not only site-specific, they are also extremely likely to be very sensitive to location of a safety-related system on/at the site
    - Examples
      - Flow velocity patterns can vary significantly with bathymetry, channel properties, obstructions, and such
      - Hydrodynamic loads, debris loads, and scouring will also vary significantly with flow velocity patterns, availability of debris, and substrate conditions

PFHA – Objectives and Methods

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- What do PFHA methods need to accomplish?
  - Estimate complete probability distributions of the **flood hazards**
  - Estimate the **uncertainty** associated with exceedance probabilities
  - Provide a way to **update** probability distributions of future flood hazards
- How can we perform PFHA?
  - Two general approaches:
    - **Data-centric approaches** (e.g., flood frequency analysis)
    - **Runoff modeling** or simulation approach
  - Outcome:
    - For each flood hazard and for each safety-related system exposed to that flood hazard, an annual exceedance probability distribution (the **Hazard Curves**)
    - In NRC terminology, hazard curves can be thought of as **characteristics** of the site
      - And these site characteristics can change with time

PFHA Methods – the Data-Centric Approach

- Data-centric PFHA
  - Typically, a frequency analysis of observed floods
    - (some of this would have been talked about in Panels 1, 2, and 5)
    - Estimate a probability distribution of floods
    - Use the probability distribution to estimate floods of desired frequencies
  - Examples
    - Bulletin 17-B
      - Fits a log-Pearson Type III probability distribution to annual peak discharge data
    - GEV approaches
      - Used in UK and elsewhere
    - Non-parametric approaches
      - Kernel density estimators
  - For desired exceedance probability, obtain the flood magnitude

PFHA Methods – the Data-Centric Approach

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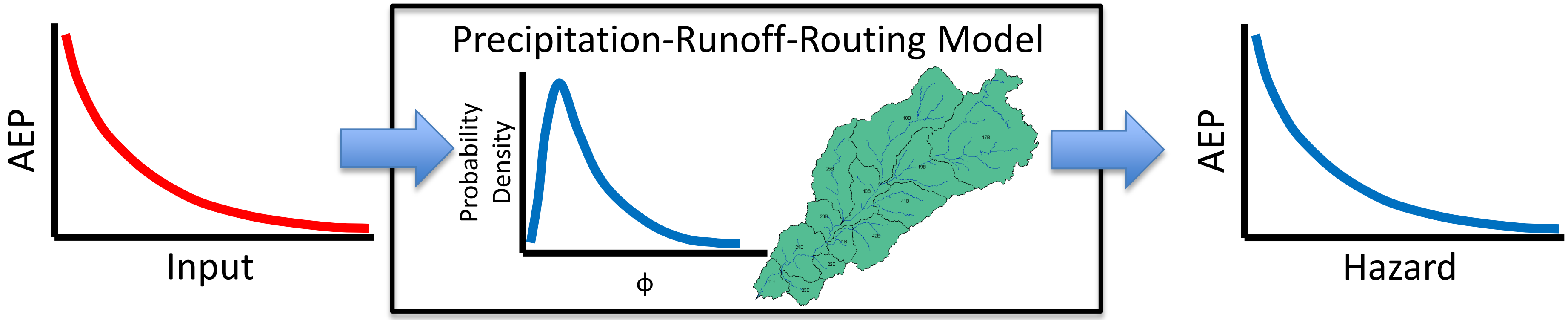
- Data-centric PFHA
  - Caveats
    - Limited length, sometimes even unavailability of historical flood record at/near location of interest
    - Supplemental data (paleo-flood data, tree rings data, …), regional similarity
    - Non-stationarity
    - Choice of parametric or non-parametric probability distributions to "fit" observed (and extended) record
    - Extrapolation to very low exceedance probabilities
    - Quantification of uncertainties
    - Updating fitted probability distributions as more data becomes available
    - Need to estimate hazards other than just the flood discharge

PFHA Methods – the Runoff Modeling Approach

- PFHA using Runoff Modeling
  - Basically, uses a Monte Carlo-like simulation approach using a precipitation-runoff-routing model
    - Needs inputs: hydrometeorology, initial conditions, and watershed characteristics along with properly selected values of model parameters
    - Hydrometeorology, initial conditions, watershed characteristics, and model parameters can all have their own probability distributions
      - There could be some combinations of model parameters and/or initial and watershed conditions that are physically unrealistic
    - Construct the probability distribution of flood hazards predicted by the precipitation-runoff-routing model



PFHA Methods – the Runoff Modeling Approach

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- Runoff Modeling PFHA
  - Caveats
    - The model must be validated
    - Probability distributions of inputs, initial conditions, and model parameters must be specified
    - Multiple inputs, multiple initial conditions, and multiple model parameters quickly result in a need to run a large number of simulations to adequately cover the range of hazards
      - Need to keep number of simulations manageable
    - Uncertainty in hazard estimates
      - Contribution from input uncertainty
      - Contribution from model parameter uncertainty
      - Contribution from model inability to accurately represent river basin processes

PFHA Methods – the Runoff Modeling Approach

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- Runoff Modeling PFHA
  - Model validation
    - Needs to account for the fact that the model would be predicting extreme floods
      - Current practice is to validate against “floods of record”
      - Typically, discharge is used for validation
    - What to validate model predictions to?
      - Peak discharge
      - Complete hydrograph
      - Flow velocities
  - Probability distribution of inputs
    - Hydrometeorology
      - Precipitation, temperature, …
    - Initial conditions
      - Baseflow, soil moisture, reservoir levels, snowpack, …

PFHA Methods – the Runoff Modeling Approach

- Runoff Modeling PFHA
  - Probability distribution of model parameters
    - Equifinality
      - GLUE, adaptive sampling of parameter “hyperspace”
  - Management of simulations
    - GLUE
    - Metropolis-like sampling algorithms

PFHA Methods – addressing Non-stationarity

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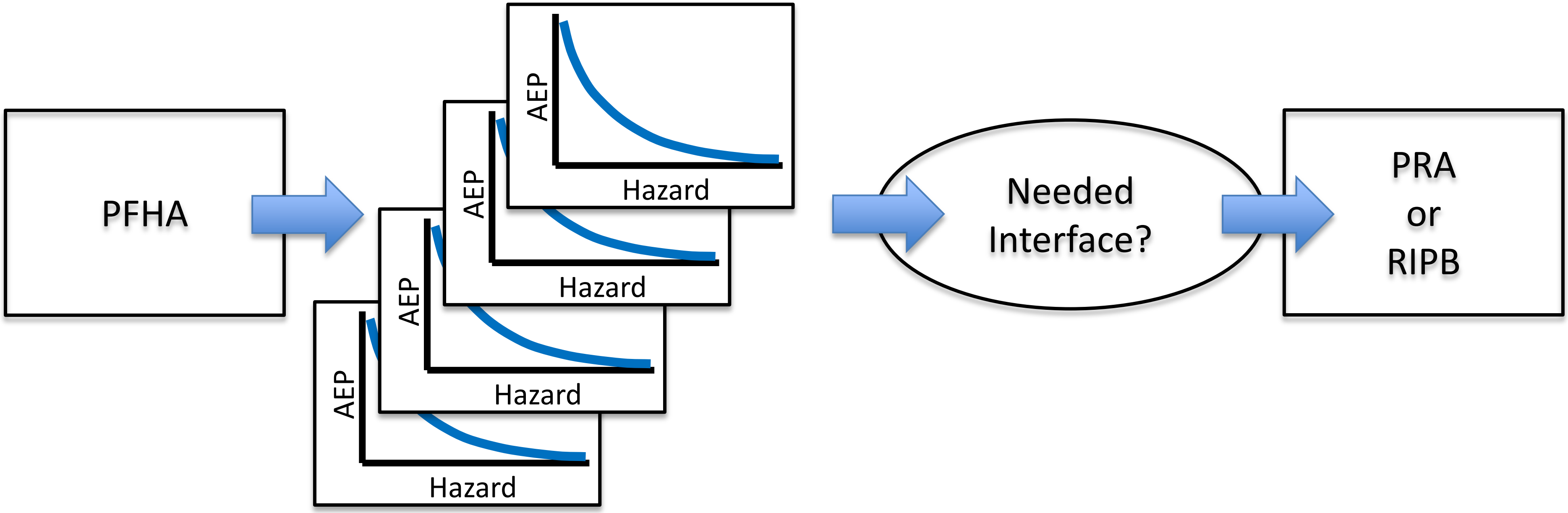
- Global Climate Change
  - *"Climate change is real," he said. "It is denial to say each of these situations is a once-in-a-lifetime. There is a 100-year flood every two years now. It is inarguable that the sea is warmer and there is a changing weather pattern, and the time to act is now."* Andrew Cuomo, Governor of New York State in his State of the State Address, as cited in the New York Times January 9th, 2013.
  - Changes in precipitation
    - Amount, phase, and seasonality
  - Changes in temperature
    - Amount, and seasonality
  - Changes in storm patterns
  - Sea-level rise
    - Backwater issues related to near-coast riverine floods
    - Subsidence issues

PFHA Methods – addressing Non-stationarity

- River Basin Changes
  - Development/urbanization/land use changes/water use and flood control
  - Basin flood management changes
    - Example: installation of new flood control reservoirs or changes in flood management rules of existing reservoirs
  - How do these changes affect PFHA?
    - Data-centric methods
      - Observed floods are already, at least to some extent, affected by past changes and will continue to be affected
    - Runoff-modeling methods
      - Need to account for the effects on probability distributions of model parameters and may also need to update the model structure

PFHA Methods – the Results

- Results from PFHA
  - Presentation of hazard curves
    - As parametric or non-parametric distributions?
    - As look-up tables?
    - Other ways
  - Interfacing with plant PRA or risk-informed, performance-based evaluation
    - Role of Section 2.4 (FSAR/SER) in supporting PRAs



PFHA Methods – Gaps

- Where do we need to focus?
  - Data-centric methods
    - Selection of probability distributions
    - Use of supplemental data (paleo-flood data, tree rings data, …)
    - Regional flood frequency analysis
    - Treatment of non-stationarity
    - Extrapolation to very low exceedance probabilities
    - Validation
    - Uncertainty estimation
    - Ways to estimate hazards other than just flood discharge
  - Runoff-modeling methods
    - Estimation of probability distributions of inputs, initial conditions, and model parameters
    - Validation
    - Management of number of simulations
    - Uncertainty estimation