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Sources of Uncertainty in Probabilistic Flood Hazard Assessment (PFHA)

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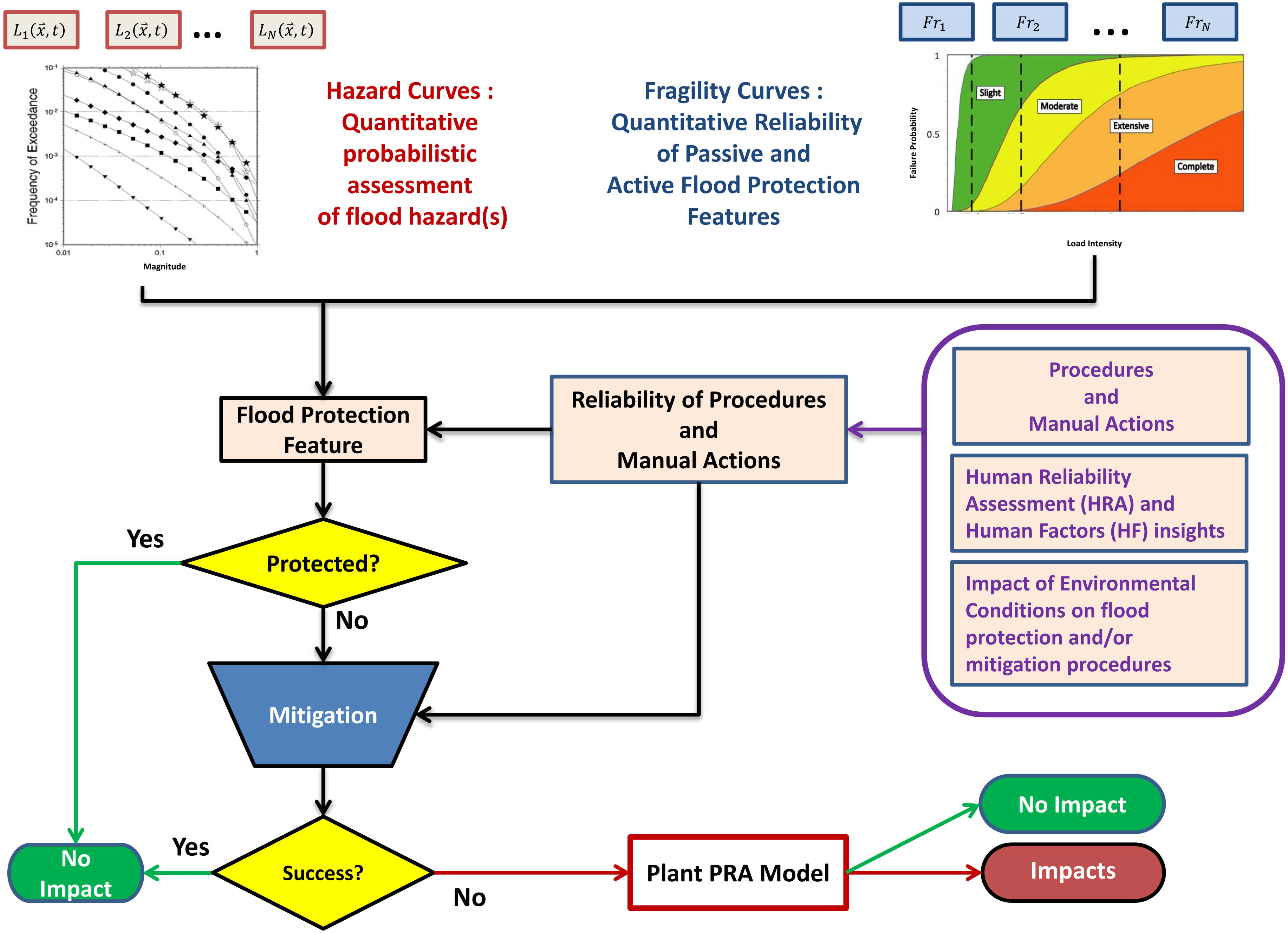
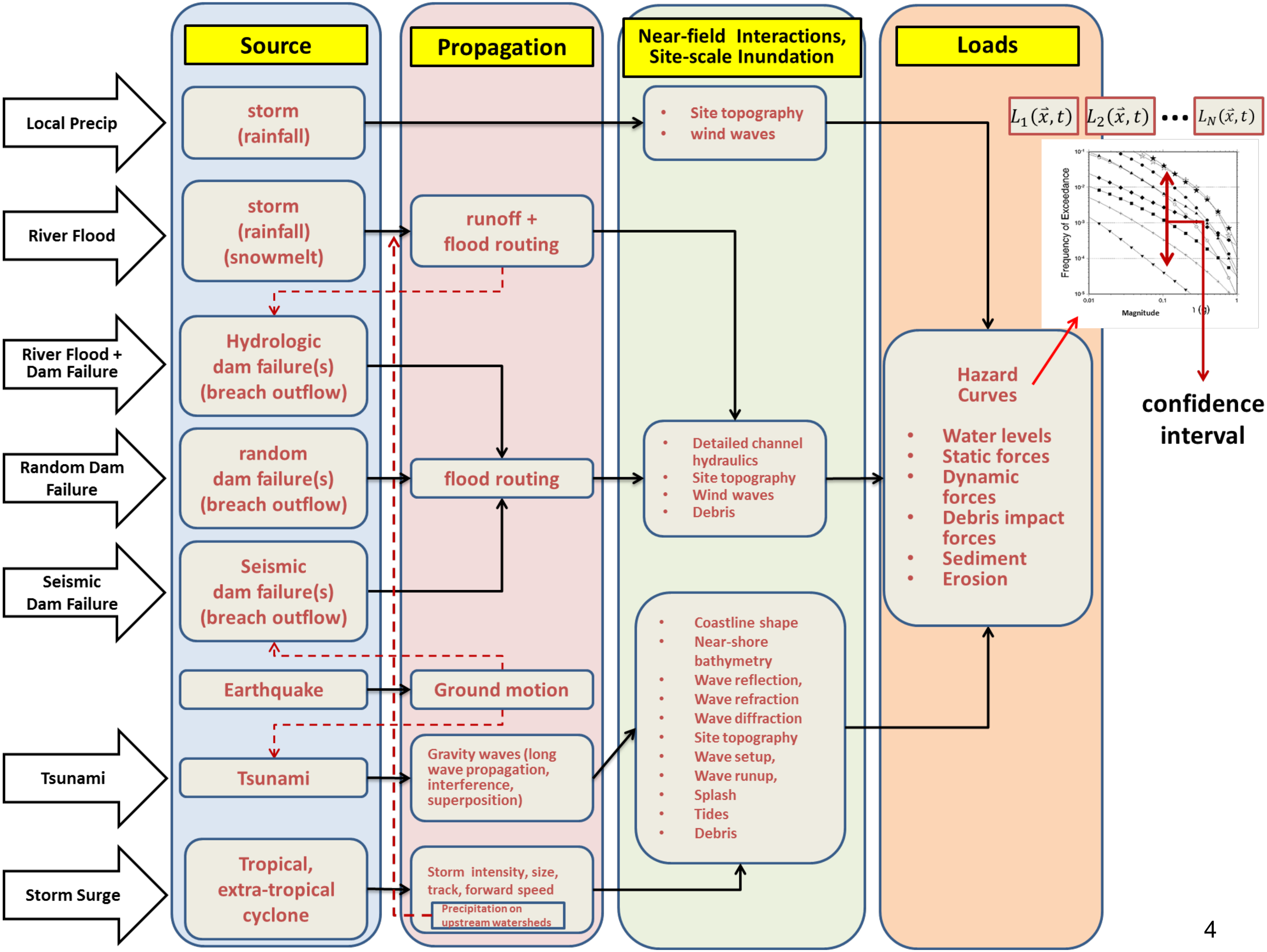
Outline

- Probabilistic Flood Hazard and Risk Assessment Overview
- Dimensions of Uncertainty
- Flooding Scenarios
  - Site-scale Flooding
  - Riverine Flooding
  - Coastal Flooding
  - Combined Flooding
- Summary



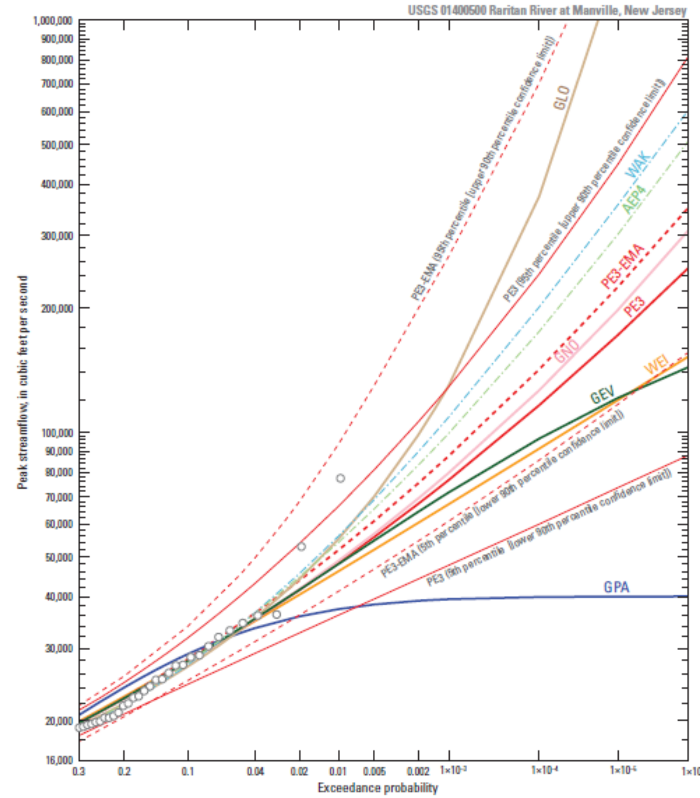
$L_1(\vec{x},t)$
$L_2(\vec{x},t)$
…
$L_N(\vec{x},t)$
Frequency of Exceedance
Magnitude
Hazard Curves : Quantitative probabilistic assessment of flood hazard(s)
Fragility Curves : Quantitative Reliability of Passive and Active Flood Protection Features
Fr_1
Fr_2
…
Fr_N
Failure Probability
Load Intensity
Slight
Moderate
Extensive
Complete
Flood Protection Feature
Reliability of Procedures and Manual Actions
Procedures and Manual Actions
Human Reliability Assessment (HRA) and Human Factors (HF) insights
Impact of Environmental Conditions on flood protection and/or mitigation procedures
Protected?
Yes
No
Mitigation
Success?
Yes
No
No Impact
Plant PRA Model
No Impact
Impacts



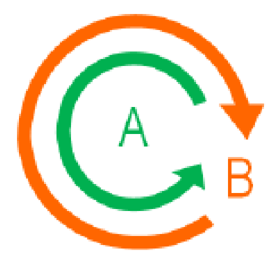
Source
Propagation
Near-field Interactions, Site-scale Inundation
Loads
Local Precip
River Flood
River Flood + Dam Failure
Random Dam Failure
Seismic Dam Failure
Tsunami
Storm Surge
storm (rainfall)
storm (rainfall) (snowmelt)
Hydrologic dam failure(s) (breach outflow)
random dam failure(s) (breach outflow)
Seismic dam failure(s) (breach outflow)
Earthquake
Tsunami
Tropical, extra-tropical cyclone
runoff + flood routing
flood routing
Ground motion
Gravity waves (long wave propagation, interference, superposition)
Storm intensity, size, track, forward speed
Precipitation on upstream watersheds
• Site topography
• wind waves
• Detailed channel hydraulics
• Site topography
• Wind waves
• Debris
• Coastline shape
• Near-shore bathymetry
• Wave reflection,
• Wave refraction
• Wave diffraction
• Site topography
• Wave setup,
• Wave runup,
• Splash
• Tides
• Debris
Hazard Curves
• Water levels
• Static forces
• Dynamic forces
• Debris impact forces
• Sediment
• Erosion
$L_1(\vec{x},t)$
$L_2(\vec{x},t)$
•••
$L_N(\vec{x},t)$
Frequency of Exceedance
Magnitude
confidence interval

PFHA Approaches

- Statistical Approach
  - Fit probability distribution(s) to flood severity metric of interest
    - Flood frequency analysis
    - Precipitation frequency analysis
- (Monte Carlo) Simulation Approach
  - (Mechanistic) simulation models to compute flood severity metric(s)
  - Probability distributions for model parameters, BCs, etc.



1 outer loop B = a realization

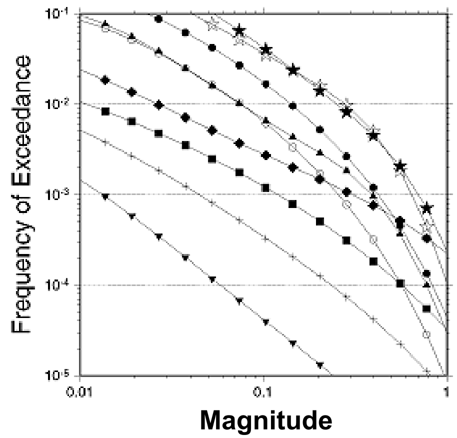


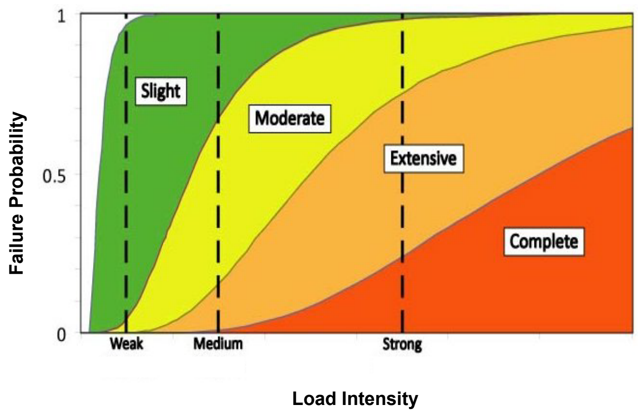
inner loop A varies natural variability, computes Stage $Frequency_i$

outer loop B varies knowledge uncertainty, computes distribution of Stage Frequency

Key Challenges

- Hazard Estimation
  - Range of annual exceedance probabilities (AEPs)
    - Moderately rare to extreme floods
  - Multiple flooding mechanisms
    - Coincident and correlated mechanisms
  - Uncertainty characterization and estimation
    - Aleatory (e.g., storm recurrence rates)
    - Epistemic (e.g., model structure, parameters)
- Impacts
  - Cliff-edge effects, nonlinearity
  - Flood duration may be important
  - Sparse structure/component reliability information
  - Sparse human reliability information





Dimensions of Uncertainty

- Aleatory variability*
  - “Natural” randomness in a process
  - “Irreducible” uncertainty
- Epistemic Uncertainty*
  - Scientific uncertainty in the model of the process
  - Model structure
  - Model parameters
  - “Reducible” uncertainty
- *Characterization is a function of analytical approach
  - An addressed uncertainty may be aleatory in one model while in another model it may be epistemic
  - These concepts only make unambiguous sense if they are defined within the confines of a model of analysis.

Riverine Discharge Example

- (Statistical) Flood Frequency Model
  - Aleatory variability reflected by the use of a probability distribution
    - For a given set of data, sampling uncertainty is not reducible
  - Epistemic uncertainty in choice of distribution

- (Simulation) Hydrologic Model
  - Future is stochastic (aleatory)
    - Timing and spatiotemporal distribution of precipitation
    - Changes in regulation, land use/land cover
  - Epistemic uncertainty in watershed model structure and parameters
    - Unit hydrograph, infiltration, routing

Site-scale Flooding (LIP)

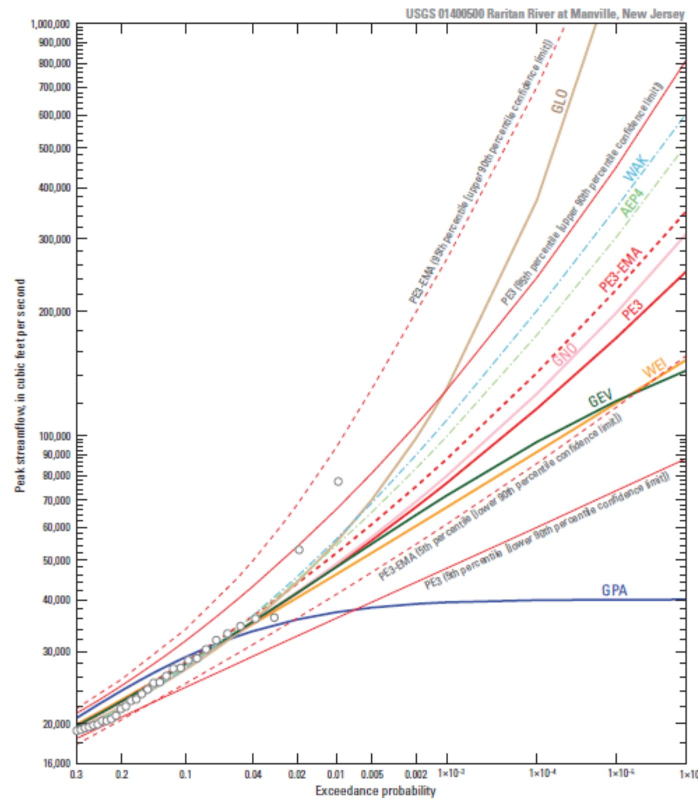
- Aleatory variability
  - Precipitation: magnitude, duration, temporal distribution
    - Precipitation frequency analysis (e.g., NOAA Atlas 14)
    - Stochastic weather generators
    - Numerical weather prediction models (e.g., WRF, HRRR)
  - Initial/antecedent conditions: soil moisture content, surface storage/ponding, initial stormwater drainage system state
  - Long-term temporal trends (e.g., climate change): can affect precipitation, temperature, initial conditions, and boundary conditions

Site-scale Flooding (Cont.)

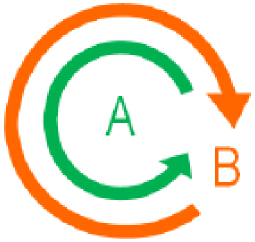
- Epistemic Uncertainty:
  - Boundary conditions: upstream discharge, downstream water levels
  - Process representation: runoff generation-related processes including infiltration and roof runoff; stormwater drainage; hydraulic routing (using one-, two-, and three-dimensional [1-D, 2-D, and 3-D] models); flow transitions (supercritical to subcritical and vice versa); surface roughness effects in shallow, turbulent flows
  - Site configuration: aboveground features including buildings and vehicle barrier systems; status of temporary flood protection; blockage of roof drains; blockage of stormwater drains
  - Model resolution: spatial and temporal

Riverine Flooding

- Flood Frequency Analysis Approach
  - Aleatory: Sampling uncertainty (e.g., limited data)
    - Short records (often only a few decades or less)
    - Data gaps
  - Epistemic: Uncertainty in choice of distribution
    - Extreme flooding not represented in the data
    - Possible mixed population
    - Nonstationarity (climate, regulation, land use/land cover)



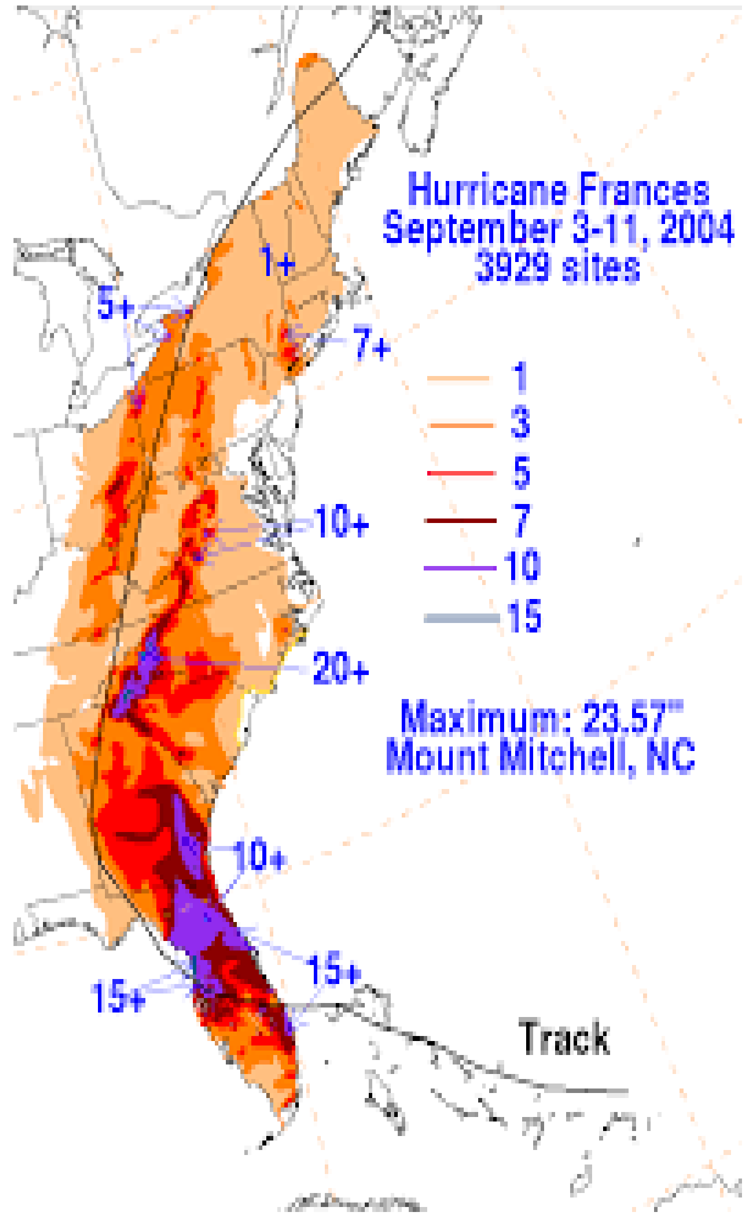
Riverine Flooding (Cont.)



- Simulation Approach
  - Aleatory: Precipitation magnitude, duration, temporal and spatial distribution
  - Discharge:
    - Aleatory: Initial/Antecedent conditions (e.g., soil moisture, flows)
    - Epistemic: Hydrologic model structure and parameters
      - e.g., infiltration, unit hydrographs, and hydrologic routing
    - Epistemic: Model resolution
  - Stage and velocity:
    - Epistemic: Hydraulic model structure and parameters
      - 1D/2D, steady/unsteady
    - Epistemic: Model resolution (e.g., channel/floodplain)

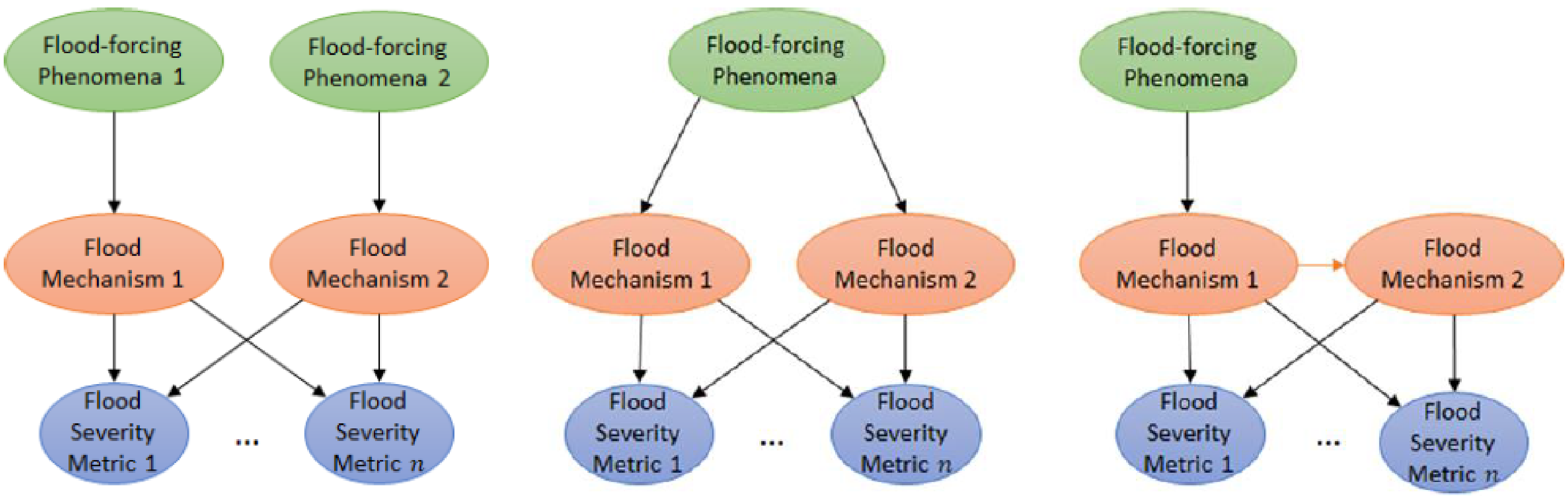
Coastal Flooding (TCs)

- Storm recurrence rate is key aleatory variability for tropical cyclones
- Key epistemic uncertainties:
  - Distributions for storm parameters
    - Track location
    - Heading direction
    - Central pressure deficit
    - Radius of maximum winds
    - Translational speed
  - Hydrodynamic model structure and parameters
    - Bottom friction, wind stress
  - Resolution of bathymetry, topography



Combined Flooding

- Extreme flooding due to combined processes
  - Associated effects (e.g., wave action)
  - Multi-mechanism flooding (e.g., rainfall w/ snowmelt, rainfall w/ dam failure)



(a) Coincident Mechanisms

(b) Concurrent Correlated Mechanisms

(c) Induced Correlated Mechanisms

Combined Flooding (Cont.)

- Statistical Approach (Joint Probability)
  - Direct Estimation of Joint Distributions
    - Assumed functional form for the joint distribution
  - Copula-Based Approaches
    - Individual variables can have different distributions
    - Observations used to separately estimate
      - (1) the parameters of the marginal distributions and
      - (2) the parameters of the copulas, which are typically related to the correlation between the quantities, as estimated from data
- Simulation Approach
  - Fully- or semi-coupled simulation models
    - Coupled hydrologic, reservoir, and hydraulic models to simulate riverine flooding w/ dam failure
    - Coupled atmospheric boundary layer, hydrodynamic, and wave models to simulate coastal flooding
  - Sparse data for calibrating models

Summary

- Separating uncertainty into aleatory variability and epistemic uncertainty is a useful exercise, but these concepts are unambiguous only within a given analytical/modeling framework
- Important sources of uncertainty vary with:
  - Scale and setting (e.g., site-scale, watershed-scale)
  - Analysis approach (e.g., statistical vs simulation)
  - Flooding metric of interest
- Interaction of multiple flooding mechanisms introduces complexity and additional uncertainty

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Questions?

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