A Comprehensive Look at Hydrologic Modeling and Uncertainties

Presented By:

Christopher N. Dunn, P.E., Director
Hydrologic Engineering Center
Institute for Water Resources

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http://www.hec.usace.army.mil

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Objectives

- Introduction to Corps Risk and Uncertainty Analysis
- Hydrologic Uncertainties
- Regulation Uncertainties
- Hydraulic Uncertainties
- Economics and Performance
- Need for System Approaches and Risk Analysis
- Example of Systems Approach
- Future Activities/Challenges

ER 1105-2-100 Planning Guidance Notebook
ER 1105-2-101 Risk Engineer Regulation
EM 1110-2-1619 Risk Engineer Manual

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Background/History

- One of the primary Civil Works Missions of the USACE is to provide flood protection;
  - During Flood Episodes
  - Studies and Implements Flood Risk Reduction Measures
- Corps manages flood damage by implementing many structural and nonstructural measures
- Procedures and Programs;
  - meet changing needs of the country
  - utilize new science & technology

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Flood Risk Management

- We need to answer the question "Which proposed flood risk management plan is the best from an economic standpoint?"
- Compare plans using Expected Annual Damage (EAD), damage reduction benefits and project performance.
- Assess the integrity and viability of dams and levees and recommend actions to assure they do not present unacceptable risks to the public, property, and the environment.
- Since 1996, use risk analysis procedures.

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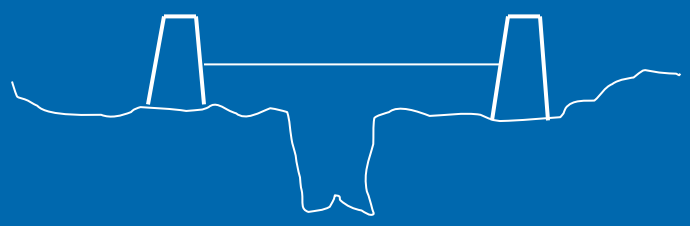
Why Use Risk Analysis?



Situation 1. Flat gradient, flow/stage variability low, long record.
Situation 2. Steep gradient, flow/stage variability high, short record.

Risk analysis explicitly distinguishes between these situations, and better assures consistent treatment of risk associated with project performance.

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Risk Analysis

- The analysis of flood risk management measures and plans using the principles associated with the probability of an adverse impact including the uncertainty inherent in water resources.
- Key quantities frequently exhibit both variability and uncertainty.
- Approach that uses a probability distribution rather than a single value for key variables, producing a result that captures and describes uncertainty.
- e.g. expected flow including a range of possible flows in computation

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Risk Analysis

- Considers the uncertainties associated with imperfect/short record lengths, incomplete knowledge, imperfect analysis methods, nature.
- Risk is a function of the probability of an event occurring, the probability of exceedance/failure, and the consequence of exceedance
- We now consider Loss-of-Life

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Risk Analysis

- Perform traditional analysis of hydrology, hydraulics, economics.
- Define uncertainties of discharge-frequency, regulation, stage-discharge, and stage damage functions, and geotechnical failure relationships.
- Perform Monte Carlo Analysis to obtain expected values for economics and performance.

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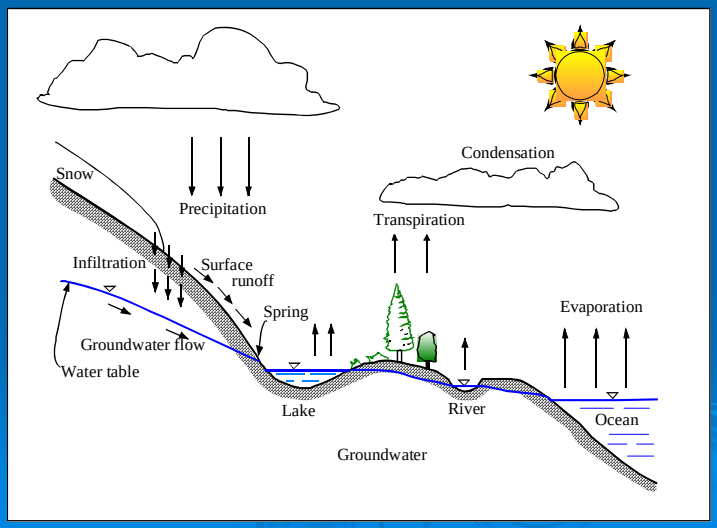
Uncertainty in the Runoff Process
(Hydrologic Cycle)



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How Do We Estimate Flow Frequency?

- Many ways…
  - Estimate from historical data **(frequency analysis)**
  - Build rainfall/runoff models, and estimate from statistical precipitation and model
  - Estimate from known values in the region
- **Bulletin 17B,** Guidelines for Determining Flood Flow Frequency, provides guidelines when there's unregulated streamflow data available

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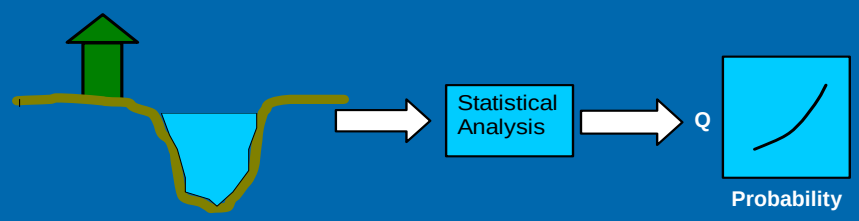
Analytical Flow-Frequency Curve
Statistical Analysis of Gaged Data



- Apply Bulletin 17B Procedures
  - Log-Pearson III Distribution
    - Method of analyzing peak flow data
  - Assumptions
    - Watershed Characteristics Unchanged (Stationarity)
    - Observed frequency = estimated probability
    - Sufficient Record Length

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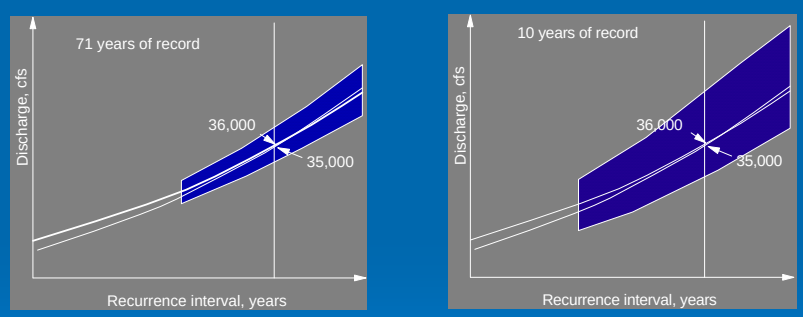
Discharge-Probability Uncertainty

"Length of Record" Determines Confidence



In other words, the smaller the sample or the greater the sample spread, the lower the confidence

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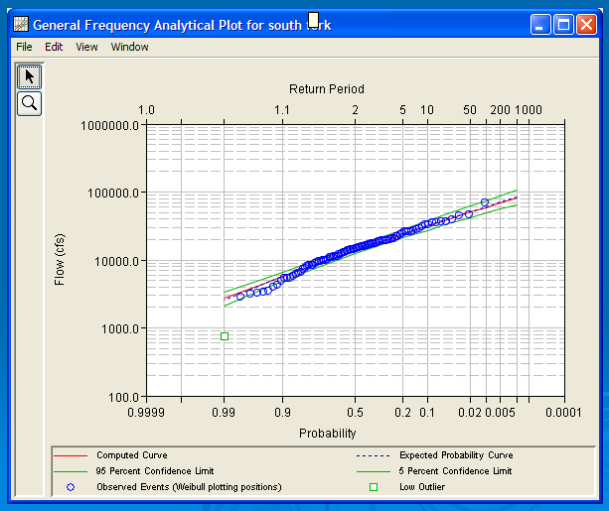
Statistical Software Package
HEC-SSP



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Ungaged Flow-Frequency Analysis

- Flow-Frequency Curve Developed at Ungaged Location
  - Regional Gage Analysis (Sort of like Log Pearson III)
  - Rainfall Runoff Methods
  - Handbook Methods
- Use with Regulated Flow, Stage – Frequency and Hypothetical Frequency Curves
- Need Equivalent Years of Record for Risk Analysis (Found in Risk EM 1110-2-1619)

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Ungaged Flow-Frequency Analysis

- Guidelines for determining Equivalent Years of Record from the EM 1110-2-1619, "Risk-Based Analysis for Flood Damage Reduction Studies"
  - Long-Period Gage Record Available at Site
    - Systematic Record Length
  - Long-Period Gage on Stream, Drainage Area within 20%
    - 90% to 100% of Record Length
  - Watershed Model Calibrated to Regional Frequency Curve
    - Average Number of Gaged Record Years of regional data
  - Short-Period Event Gage in Watershed, Model Calibrated to Several Events
    - 20 to 30 Years
  - Regional Model Parameter Data Available, No Calibration
    - 15 to 30 Years
  - Handbook/Textbook Model Coefficients Only
    - 10 to 15 Years

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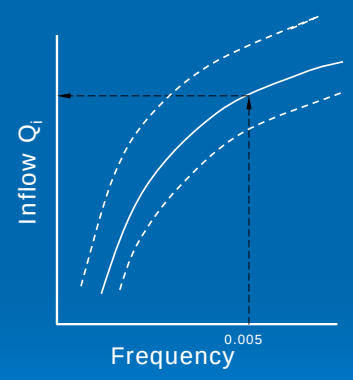
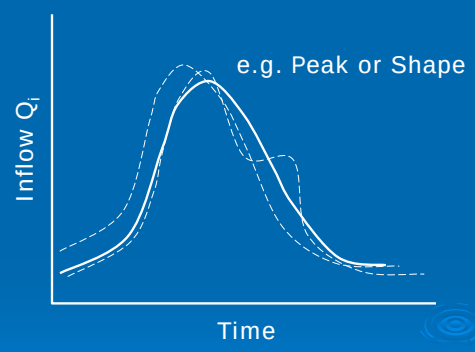
Uncertainty in Inflow





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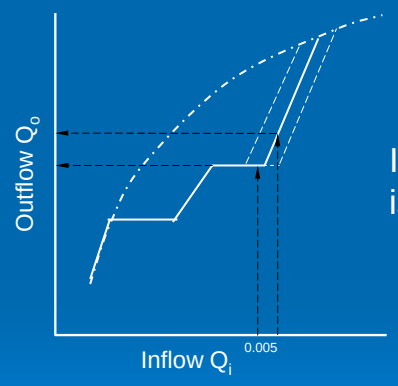
Uncertainty in Reservoir Regulation



If estimate of Inflow is off

Reservoir Operation Rule Curve with Uncertainty

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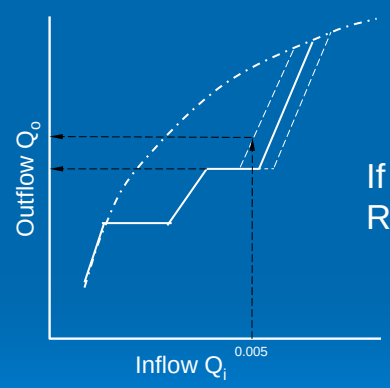
Uncertainty in Reservoir Regulation



If estimate of Regulation is off

Reservoir Operation Rule Curve with Uncertainty

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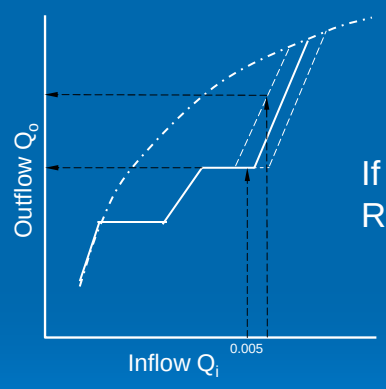
Uncertainty in Reservoir Regulation



If estimate of Inflow and Regulation are off

Reservoir Operation Rule Curve with Uncertainty

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Stage Discharge Curves

- Stage-Discharge Curves can be developed by the following methods:
  - Measured Streamflow Data (gaged locations)
  - Computed Water Surface Profiles
    - Steady flow analysis
    - Unsteady flow analysis
    - Movable-bed Analysis
    - Multi-dimensional modeling

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Uncertainty in Stage Estimates

- Some Factors that Cause Uncertainty:
  - Cross section shape, area, and roughness
  - Debris and other obstructions
  - Sediment transport, scour, and deposition
  - Bedforms (changing with depth and temperature)
  - Backwater effects
  - Bridges, culverts, and other hydraulic structures
  - Survey error
  - Measurement error
  - Surge, wind wave and wave period

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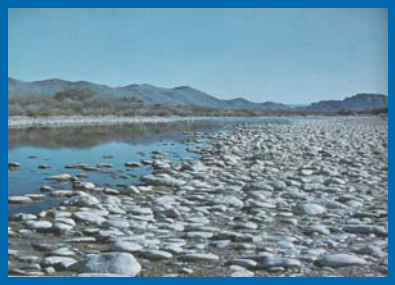
Manning's *n* values

n = 0.032



n = 0.055

n = 0.075

n = 0.097

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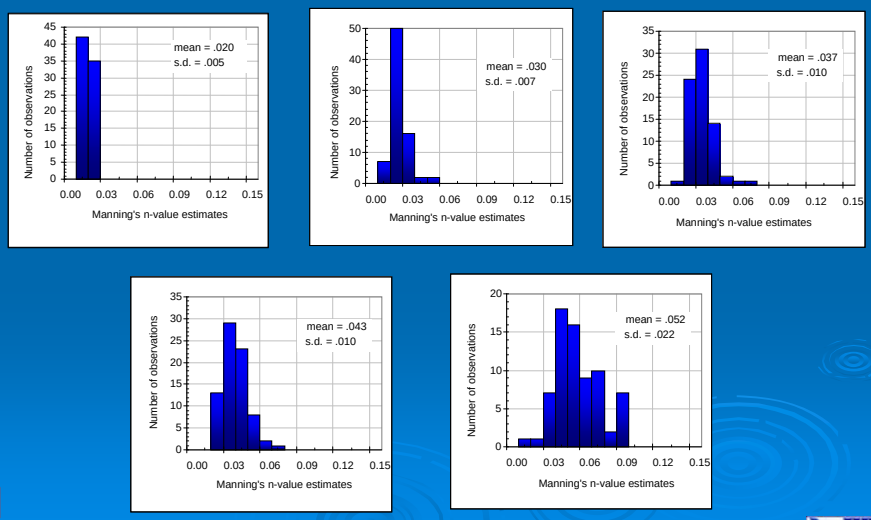
Uncertainty in Manning's *n* values



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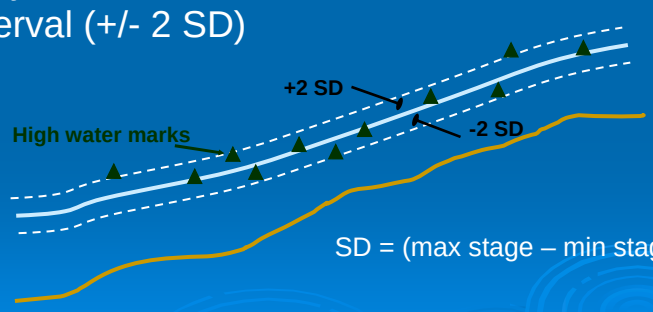
Sensitivity Analysis and Professional Judgment

- Calibrate
- Sensitivity analysis of key parameters
- Vary *n* to estimate the 95% confidence interval (+/- 2 SD)



SD = (max stage – min stage)/4

Perform for a range of frequency events

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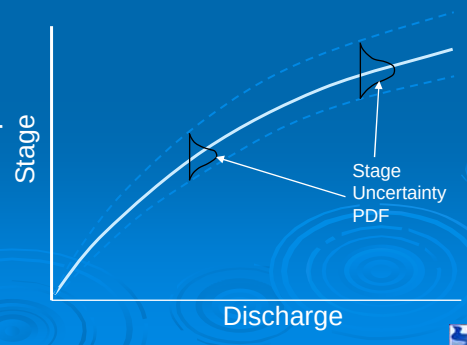
Stage Uncertainty Probability Density Function

- Uncertainty is zero at zero discharge.
- Uncertainty increases as discharge increase to Bankfull Stage.
- Above Bankfull, uncertainty may increase, decrease, or remain constant.



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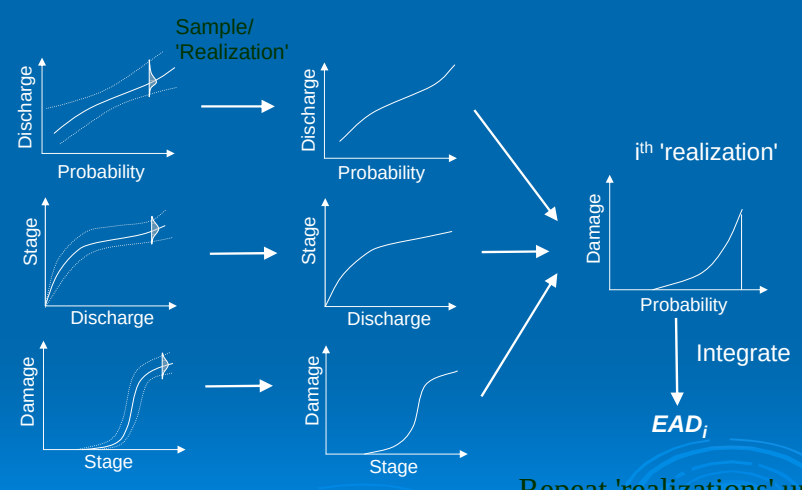
Calculating EAD using Monte Carlo



Repeat 'realizations' until stable statistics.

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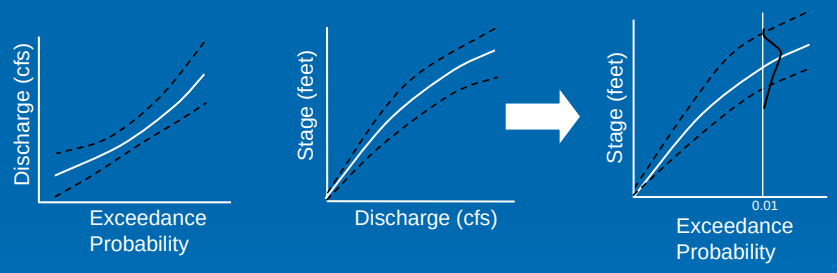
Stage - Probability and Project Performance

Criteria – CNP > 90% for 0.01 event



Conditional Non-exceedance Probability or Assurance is the probability that a specified event will be contained by the project.

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Hurricane Katrina and the Performance of New Orleans' Levee System

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Corps' Actions for Change

- Derived from the failure and unacceptable systems performance of the hurricane protection systems during Katrina and Rita
- Goal: Improve public safety and the Nation's water resources infrastructure
- Shift decision-making focus from individual, isolated projects to an interdependent system...
- Communicate risk in simple, clear terms...

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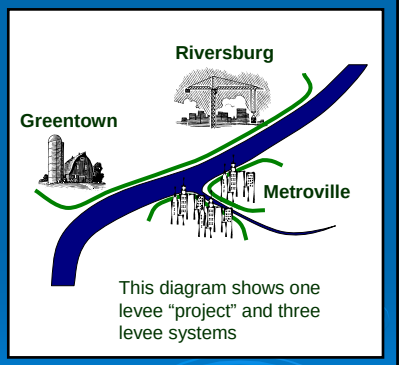
Certification of Levee Systems for the NFIP (EC 1110-2-6067)

- Focus is on the levee system that is associated with a given separable floodplain.
- A levee system is inclusive of all components that are interconnected and necessary to insure protection of the associated floodplain – levee/floodwall sections, closure structures, pumping stations, culverts, interior drainage works, and system operation and maintenance
- No PARTIAL system certifications



This diagram shows one levee "project" and three levee systems

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Development of Systems Tool
HEC-FRM
(Flood Risk Management)

- Systems approach for assessing risks and uncertainties in complex, interdependent systems
- Incorporation of social and environmental consequences
- Tools for levee assessment and certification
- Effective risk communication
- New computational methodology?
- Software Design Document, HEC-FRM, "*Model Design for Flood Damage and Risk Analysis of Complex Riverine Systems"*

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Current Example of Systems Approach

- *"Documentation and Demonstration of a Process for Conducting Risk Analysis for Hydraulic Impacts of Proposed Modifications to the Sacramento River Flood Control Project Levees"*
- Joint effort between Corps' Field Offices, HQ, HEC and WEST Consultants
- Purpose: Demonstrate a process for evaluating system-wide hydraulic impacts of proposed modifications to the Central Valley levees using risk analysis.
- Product: Document describing how one would conduct a system-wide H&H study using risk analysis while explicitly defining uncertainties.

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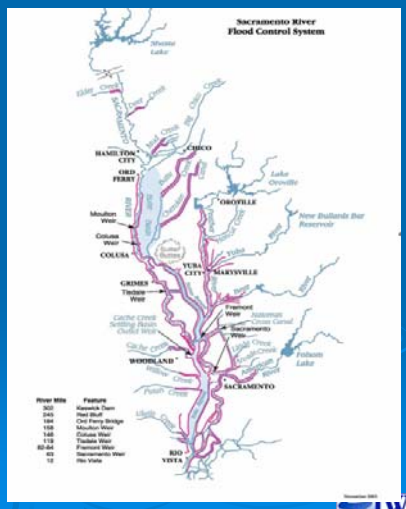
Sacramento River Flood Control Project

- 1300 mi (2092 km) of levees
- Protects 800k Ac (324k ha)
- Significant Upstream Storage Reservoirs
- Downstream channel capacity must be maintained



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Uncertainties

- Hydrologic: Inflow hydrographs at defined Hand Off Locations, reservoir operations.
- Hydraulic: Topographic data, roughness coefficients, weir coefficients, breach characteristics, downstream boundary, discharge at index locations (risk-based).
- Operational: Levee system performance (based on criteria), Flood fighting activities (not considered).

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Challenges with Uncertainty Analysis

- Including all failure modes/features
- Must be effectively communicated to stakeholders and decision makers.
- Stationarity
- Climate Change
- New methods and approaches are needed to quantify the risks and acknowledge uncertainties in terms of economics, human health and safety, environment …
- H&H support of Risk Analysis (e.g. realistic physical limits on frequency analysis and update equivalent record length procedure…)

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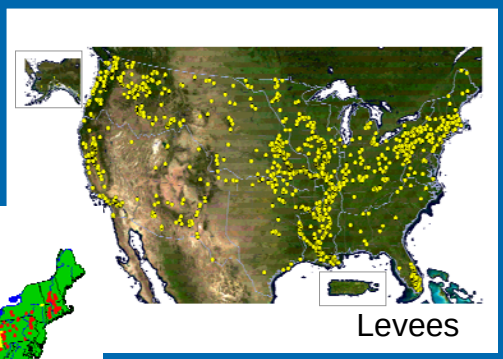
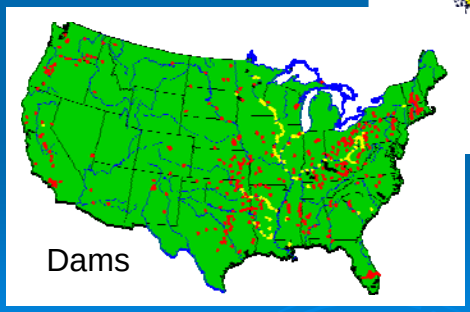
USACE Infrastructure

- Large portfolios
- Relatively old
- Relatively untested





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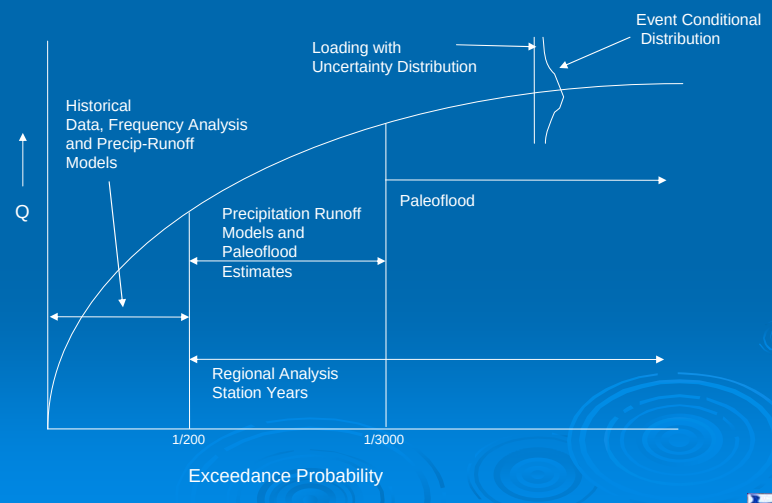
Annual Exceedance Probability of Extreme Events



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Charge to the Corps (Uncertainty)

"Gone are the days when an analysis can be collapsed into or summarized by a single number or scenario."

"The Corps operates in an uncertain reality. Rather than cling to a deterministic approach to decision-making, the Corps needs to establish a 'culture of uncertainty"

From White Paper – "Transforming the Corps Into a Risk Managing Organization" Moser et. Al., 2008

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