Stochastic Event Flood Model (SEFM)

Stochastic Modeling of Extreme Floods

A Hydrological Tool for Analysis of Extreme Floods

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Stochastic Modeling of Extreme Floods …

PURPOSE

Develop Magnitude-Frequency Relationships (Hydrologic Hazard Curves) for:

- *Flood Inflow Discharge (Peak, Max 6-hr, 24-hr, 72-hr, etc)*
- *Flood Runoff Volume*
- *Maximum Reservoir Level (primary interest)*
- *Maximum Reservoir Outflow*
- *Depth of Overtopping Flows*
- *Duration of Spillway Flows exceeding a discharge threshold*

Stochastic Modeling of Extreme Floods …

APPLICATIONS

- *Hydrologic Hazard Curves for Risk Analysis*
- *Conduct Global Sensitivity Analysis*
- *Assess Conservatism of Proposed PMF*

Provide Information for <u>Decision Making</u> about:

- *Flood Magnitude-Frequency*
- *Seasonality of Floods*
- *Reservoir Operations for Floods*

Advances That Make Stochastic Flood Modeling Possible…

- *Increases in Computational Power of PC*

20,000 simulations in 1-hour

- *GIS Spatial Mapping Products and Methods*

particularly for Precipitation (PRISM)

- *Regional Analysis Methods and L-Moment Statistics*

for developing basin-specific
precipitation-frequency relationship including extreme events

Long record lengths for precipitation data
35+ years records in mountains (SNOTEL)

History of SEFM …

Development started in 1996

Used by USBR for Hydrologic Risk Analyses since 1998

Bumping Lake Dam – Bumping River, WA

A.R. Bowman Dam – Crooked River, OR

Cle Elum Dam – Cle Elum River, WA

Keechelus Dam – Yakima River, WA

Minidoka Dam – Snake River, ID

Whiskeytown Dam – Clear Creek, CA

Trinity Dam – Trinity River, CA

Altus Dam – North Fork Red River, OK

History of SEFM …

BC Hydro

Mica Dam (787-ft), Upper Columbia River, BC

received International Peer Review - 2001

US Corps of Engineers

Folsom Dam, American River, CA

SEFM Accepted by USCOE

for Analysis of Extreme Floods and PMF - 2005

Puget Sound Energy

Baker River Project, Baker River, WA

FERC Licensed Project - 2009

BC Hydro

Campbell River System, Vancouver Island BC

3 Dams in series 1,500-km^2 watershed - 2012

Current Projects 2012 - 2013 - SEFM …

USBR and Southern California Edison

Friant Dam and Mammoth Pool Dam, San Joaquin River, CA

6 SCE Dams in Upper Watershed - 1,600-mi^2 watershed

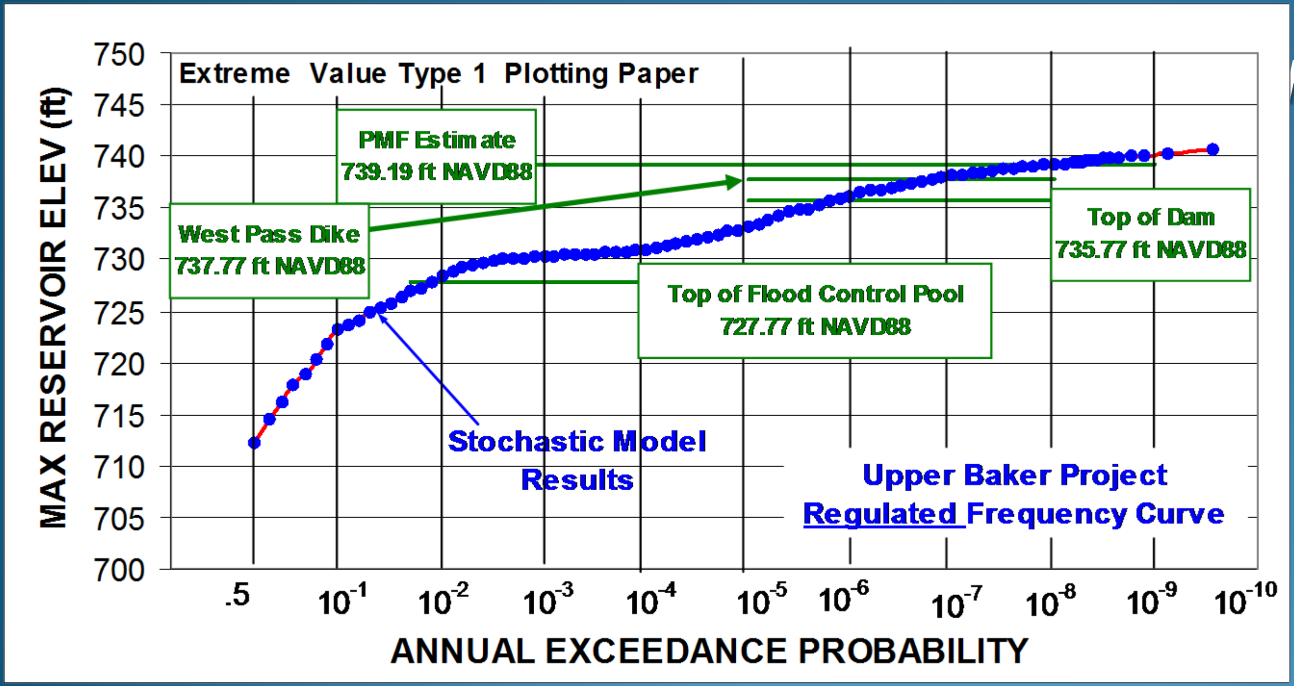
BC Hydro

Bridge River System, Coastal Mountains, BC

3 dam system - 3,500-km^2 watershed

SEFM – Primary Deliverable …

Magnitude-Frequency Curve for Maximum Reservoir Level (Hydrologic Hazard Curve)



Integrates Frequency Information

Flood Peak Discharge

Runoff Volume

Hydrograph Shape

Initial Reservoir Level

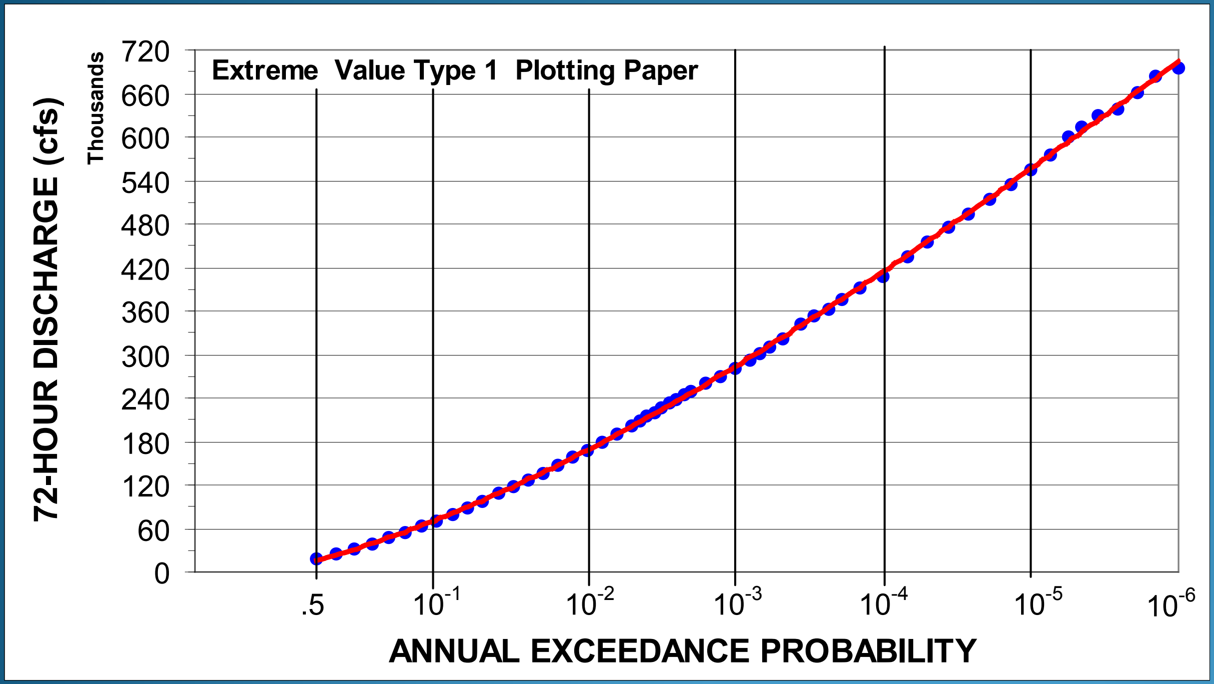
Reservoir Operations

while

Preserving Seasonality of Events

SEFM – Other Outputs …

Magnitude-Frequency Curves for Flood Discharge



Model Outputs

for Reservoir Inflow

Instantaneous Peak

Max 6-hr Discharge

Max 24-hr Discharge

Max 72-hr Discharge

SEFM Structure …

SEFM Engine

conducts stochastic simulations
and many rainfall-runoff and snowmelt computational tasks

Watershed Model

conventional watershed modeling tasks
that were not conducted by SEFM engine;
for HEC-1, primarily used as network model
for routing of streamflow from sub-basins

Post Processor

processes watershed model output
to develop flood-frequency relationships,
stores all simulation inputs and outputs, flood hydrographs, etc

SEFM Operational Modes …

- Completely Deterministic Mode
- Completely Stochastic Mode
- Mixed Mode - Some Inputs are Set (Fixed) Other Inputs Treated as Variables (Stochastic)

Stochastic Approach …

GOAL

Simulate the hydrologic behavior of the watershed in a manner that provides an unbiased measure of the magnitude-frequency characteristics of floods

(looking for reality/truth, not conservative estimates)

SEFM draws heavily on the analysis of historical data using regional analysis methods

Historical data are analyzed to obtain a better understanding of the actual behavior of the hydrometeorological components to assist in the realistic simulation of floods

Stochastic Approach …

1) Use Deterministic Rainfall-Runoff Model
   HEC-1,UBCWM, WATFLOOD, (HEC-HMS in future)

2) Treat Hydrometeorological Inputs as Variables

3) Stochastically Generate Multi-Thousand Years of Storms and Dates of Storm Occurrence

4) Select Hydrometeorological Inputs to Accompany Storms and Maintain Seasonal Characteristics and Dependencies

Stochastic Approach …

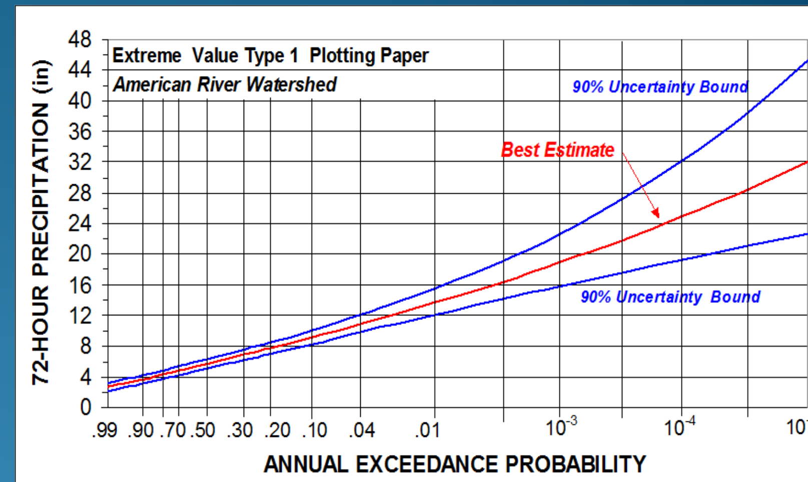
5) Compute Multi-Thousand Flood Annual Maxima using Hydrologic Model and Input Datasets – Conduct Sufficient Simulations to Exceed Flood Magnitudes of Interest

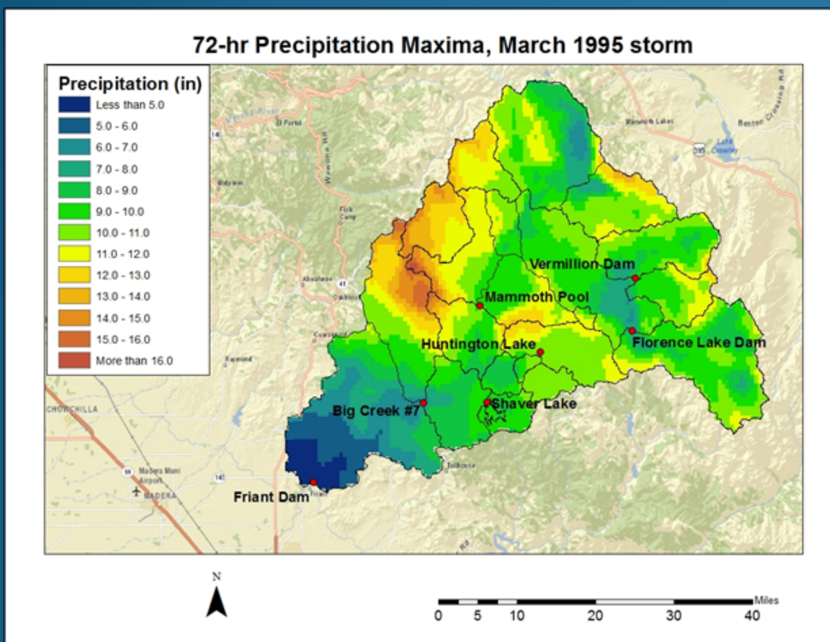
6) Rank Flood Outputs in Descending Order of Magnitude and Assign Exceedance Probabilities using a Plotting Position Formula

7) Construct Probability-Plots for Flood Characteristics of Interest – No Need to Fit a Probability Distribution, Floods Characteristics of Interest Found from Interpolation Not Extrapolation

Stochastic Simulation Storm Related Variables …

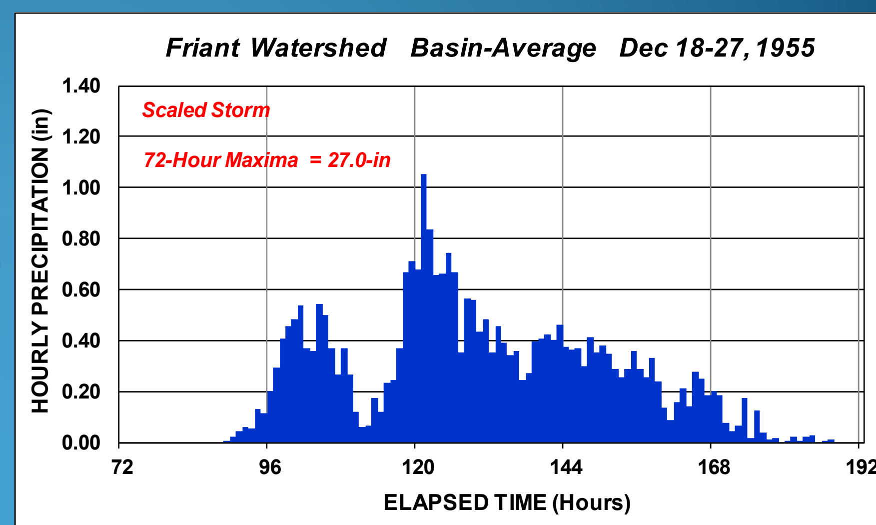
Magnitude of Basin-Average Precipitation (24-hr, 72-hr)





Spatial Distribution of Precipitation over Watershed

Temporal Distribution of Precipitation over Watershed variable storm duration



Stochastic Simulation Hydrometeorological Variables …

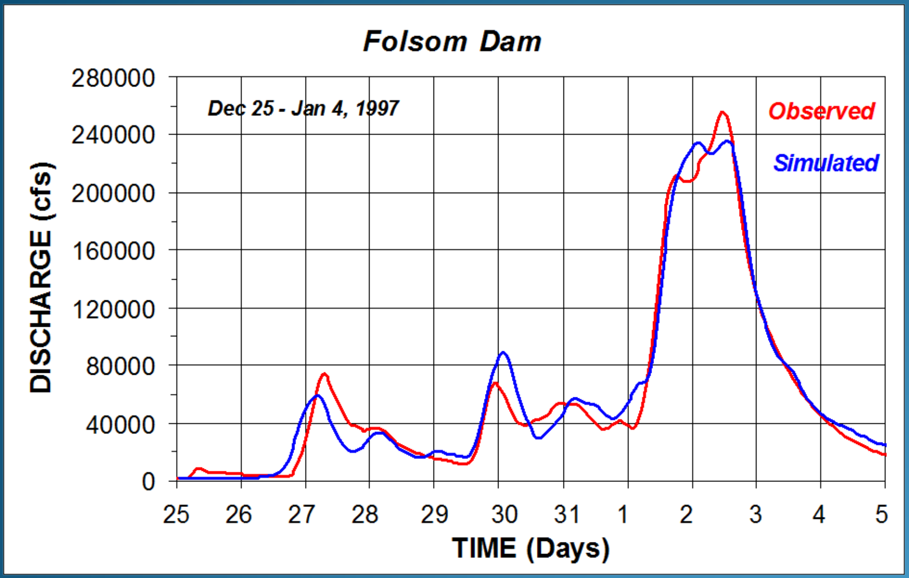
- *Antecedent Precipitation – Spatially Distributed*
    - *Antecedent Snowpack (spatially distributed snow depth and density)*
    - *Antecedent Soil-Moisture (spatially distributed by soil type)*
- *Freezing Level and Air Temperature Temporal Pattern*
- *Initial Streamflow*
- *Initial Reservoir Level*

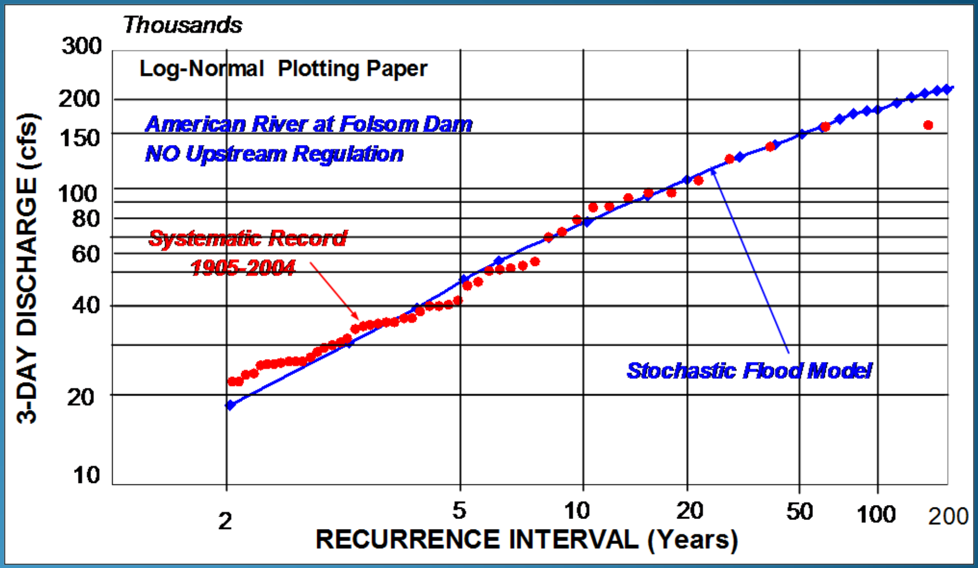
Stochastic Simulation Rainfall-Runoff Modeling …

- *Runoff Modeled on Distributed Basis*
- *Surface Runoff Response*
- *Interflow Runoff Response*
- *Snowmelt Runoff Computation*
  includes Snow Water Accounting within Snowpack and Energy-Budget Approach

Watershed Model Calibration …

- Watershed Model Calibrated to Historical Floods





- Stochastic Model Calibrated to Historical Flood-Frequency Curves at Multiple Durations (24-hr, 72-hr)

Stochastic Simulations

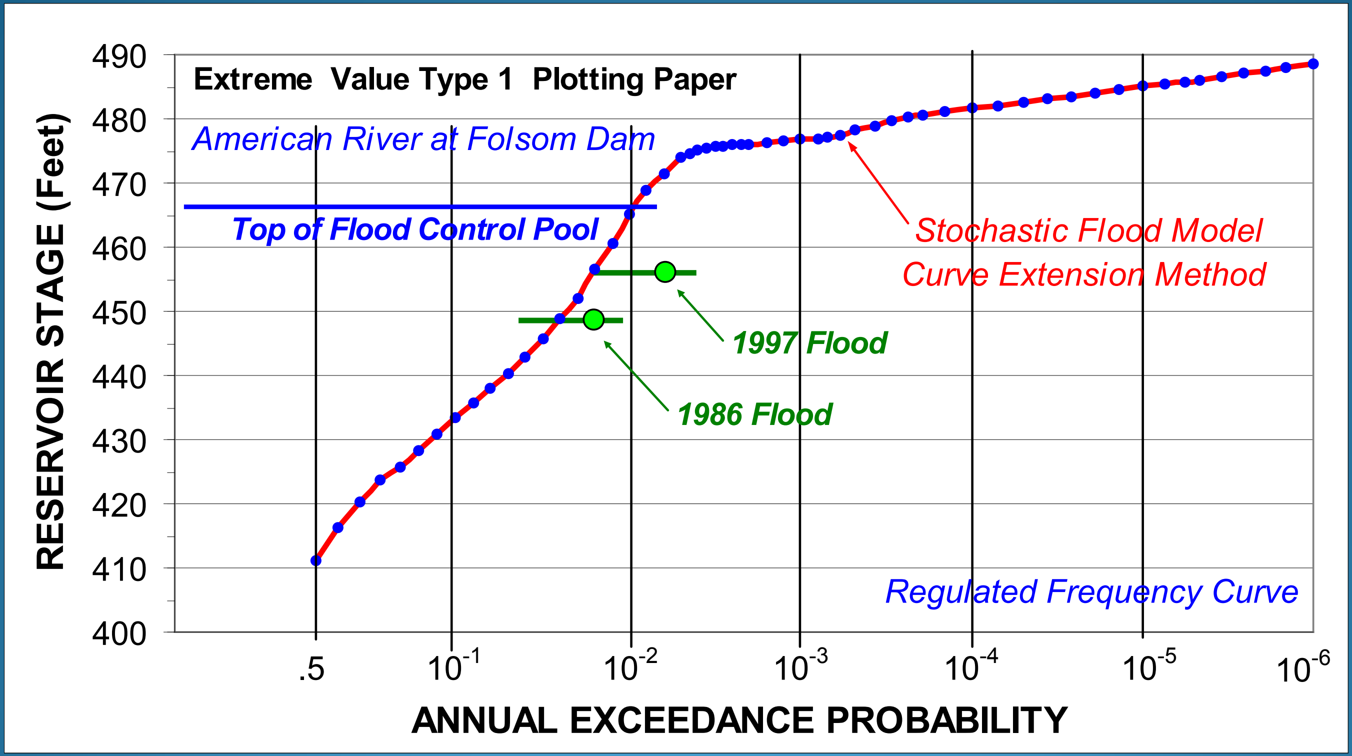
Each flood simulation represents an annual maxima flood
based on historical behavior of the hydrometeorological inputs and the observed flood response of the watershed

Sufficient flood simulations conducted so there is no need to fit a probability distribution to the flood outputs
flood-frequency relationship can be depicted via a probability-plot

Flood simulations reflect flood hazards based on current climatic characteristics
effects of climate change can be assessed through sensitivity analysis or uncertainty analysis

SEFM – Output…

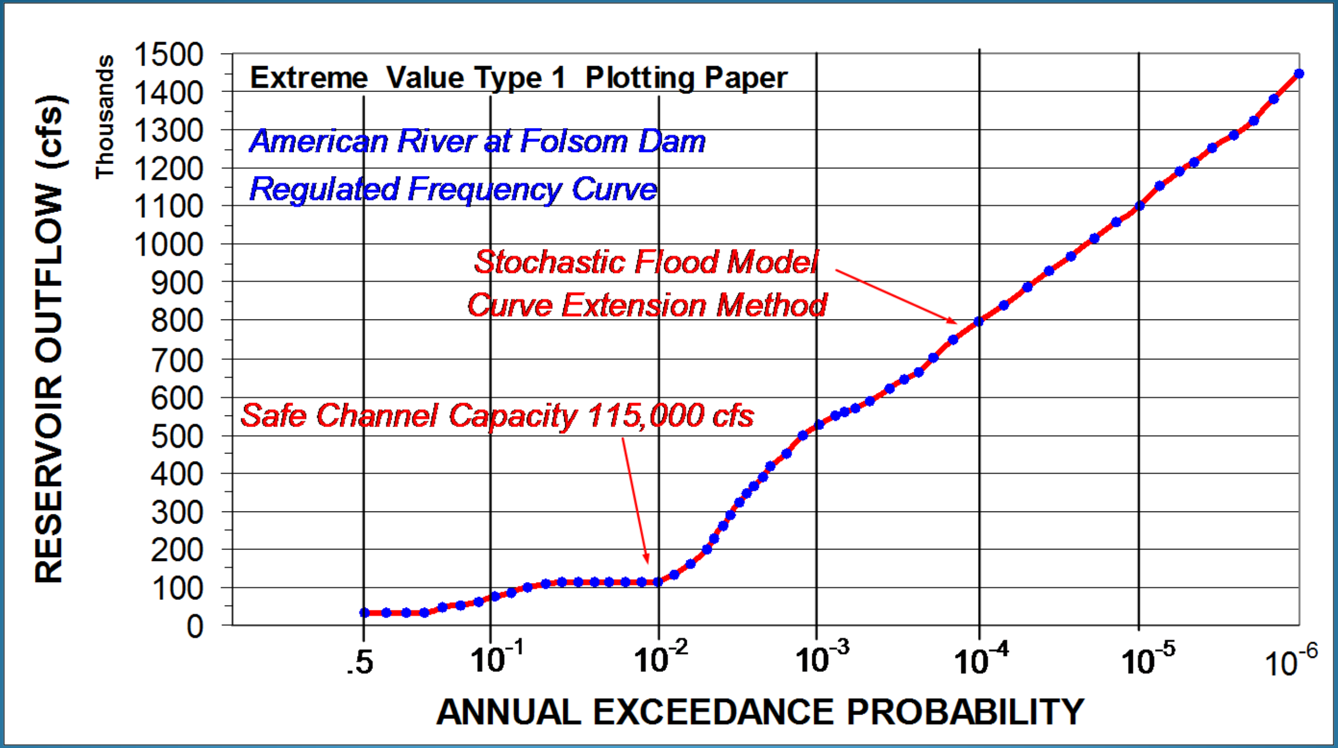
Primary Outputs are Magnitude-Frequency Curves (Hydrologic Hazard Curves)



Hydrologic loading for extreme floods are of primary interest

SEFM – Example Output…

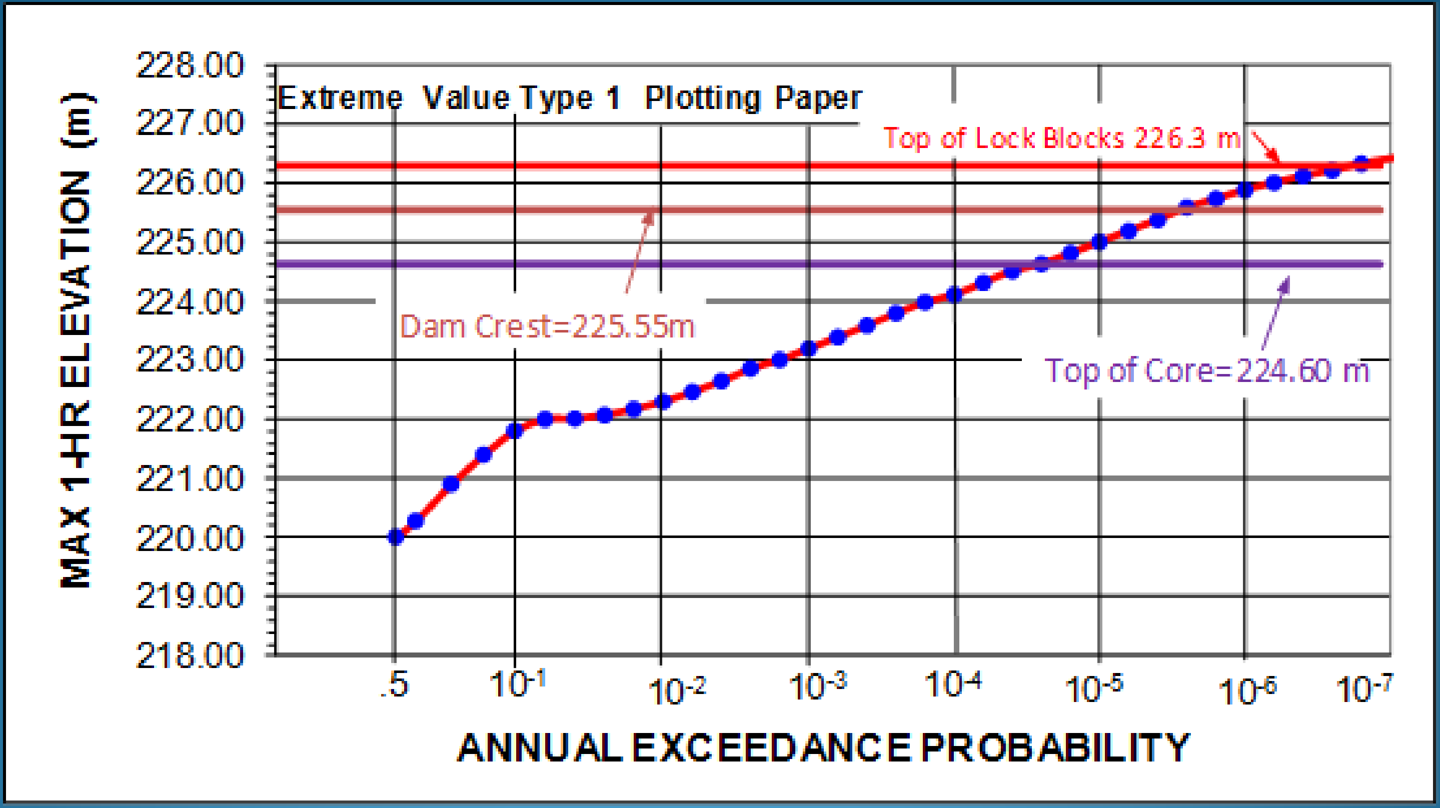
Safe Channel Capacity within the Levee System is a Concern in the Sacramento Valley



Magnitude-Frequency Relationships for Maximum Reservoir Level and Reservoir Discharges are Typically Very Non-Linear - Due to Operations

SEFM – Example Output…

Strathcona Dam - Vancouver Island BC



Various Reservoir Elevations Are Often of Interest for Evaluating Potential Failure Modes

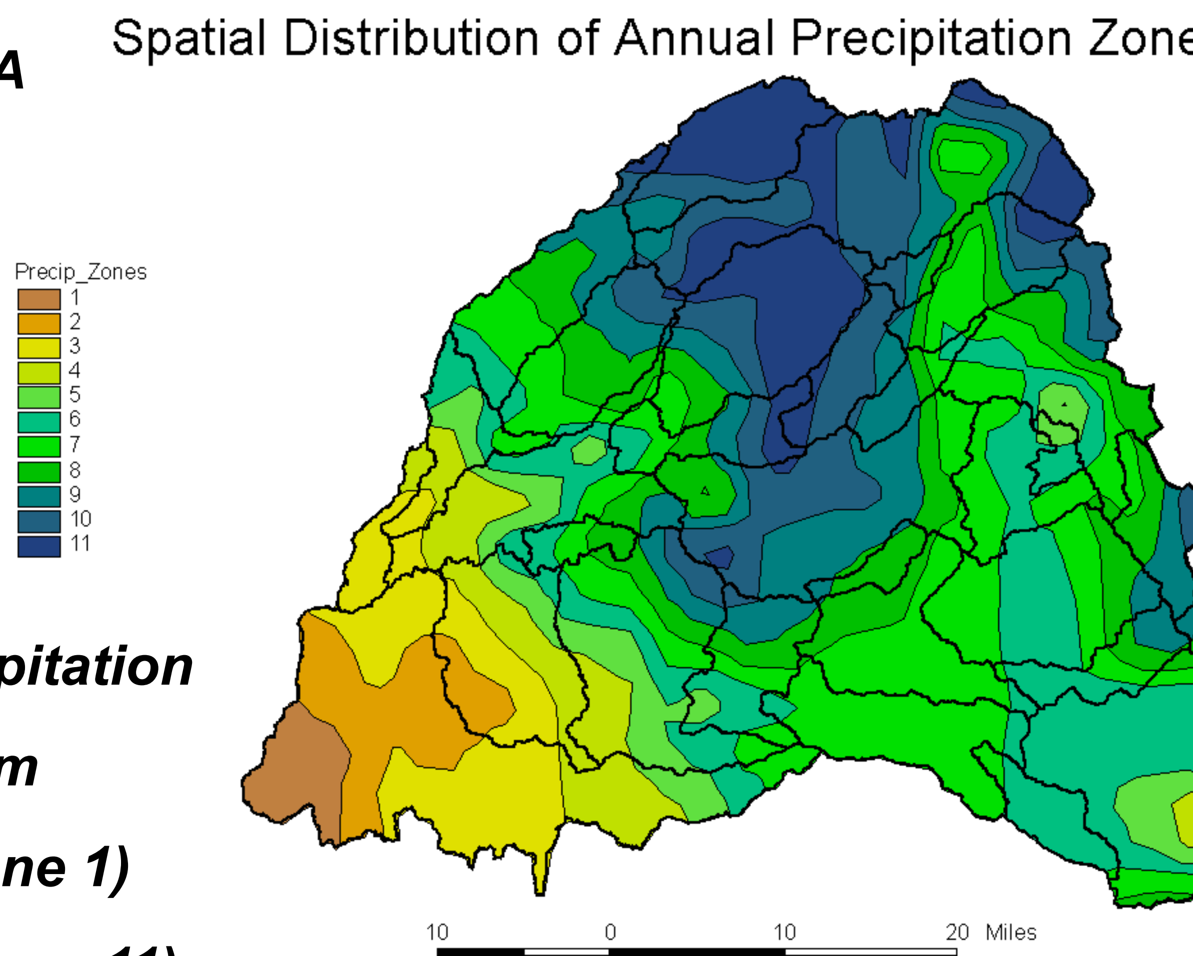
Selected Examples of Interest …

- *Watershed Layout for Distributed Rainfall-Runoff Modeling*
- *Seasonality of Storms*
- *Precipitation-Frequency Relationships for Watershed*
- *Diversity of Temporal Patterns for Storms*

Distributed Rainfall-Runoff, Snowmelt Modeling

11 Zones of Mean Annual Precipitation

American River, CA



Mean Annual Precipitation

varies from

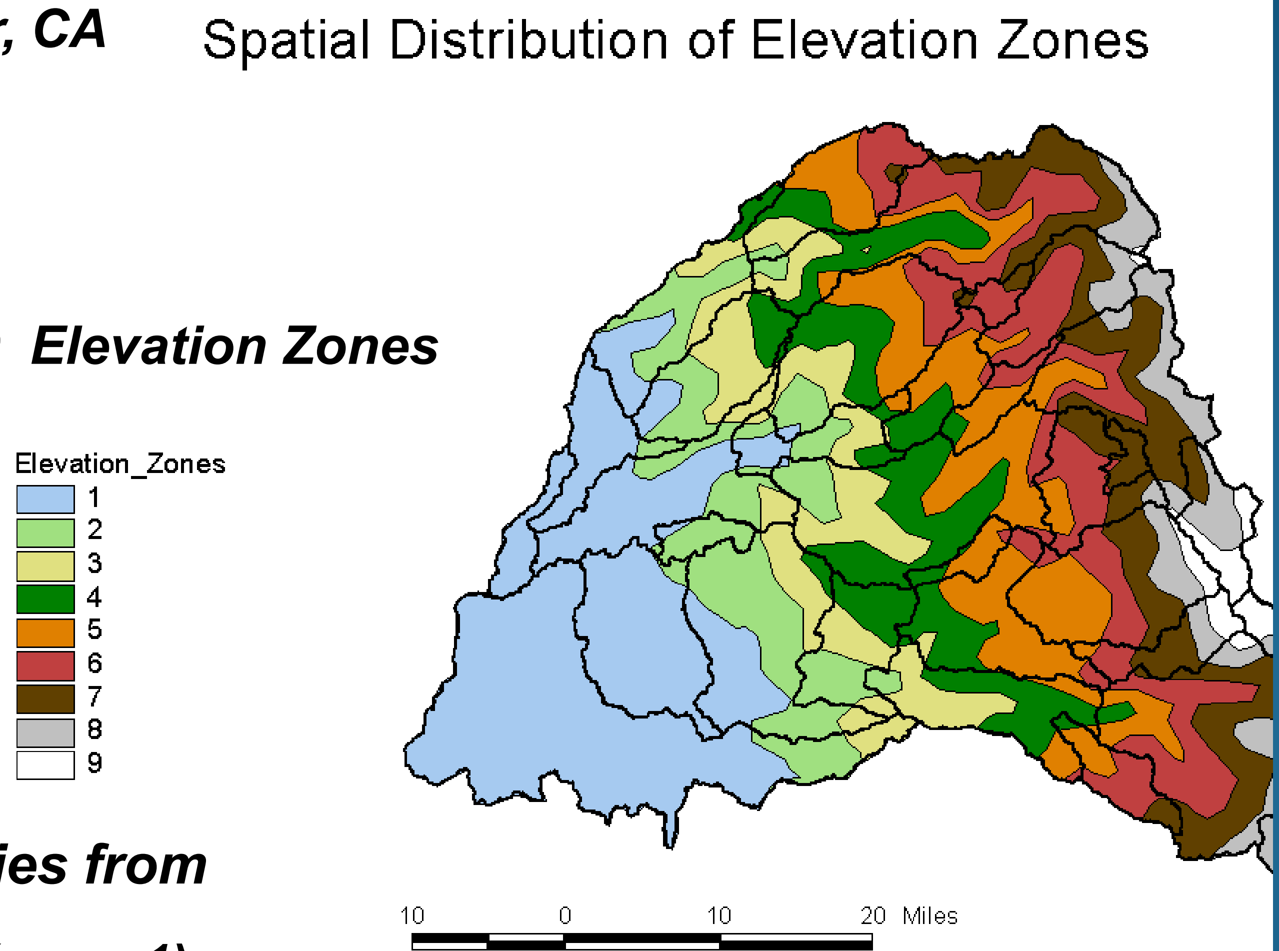
20-inches (zone 1)

to 72-inches (zone 11)

Distributed Rainfall-Runoff, Snowmelt Modeling

American River, CA

9 Elevation Zones



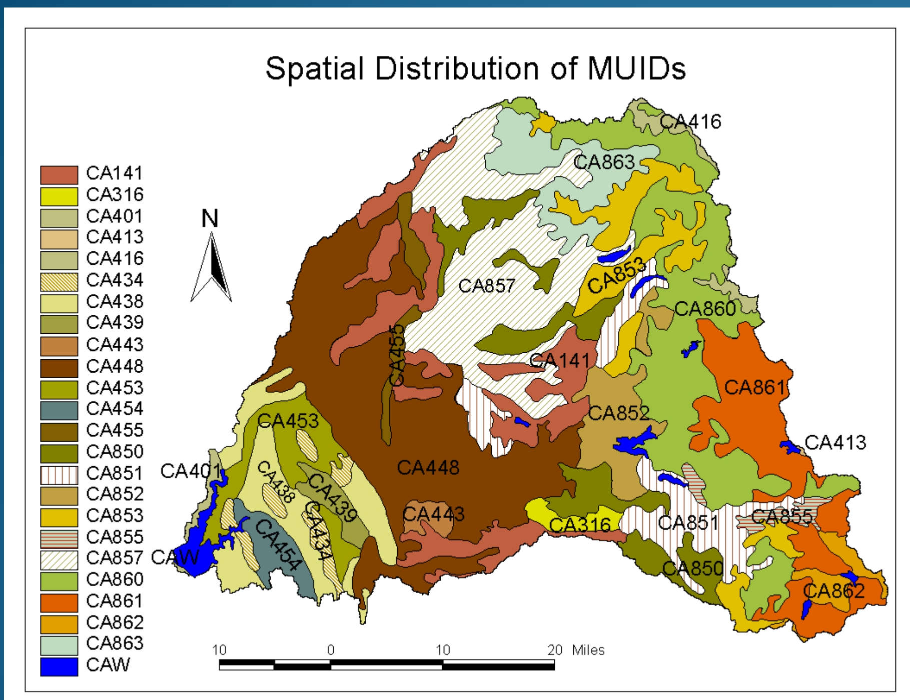
Elevation varies from

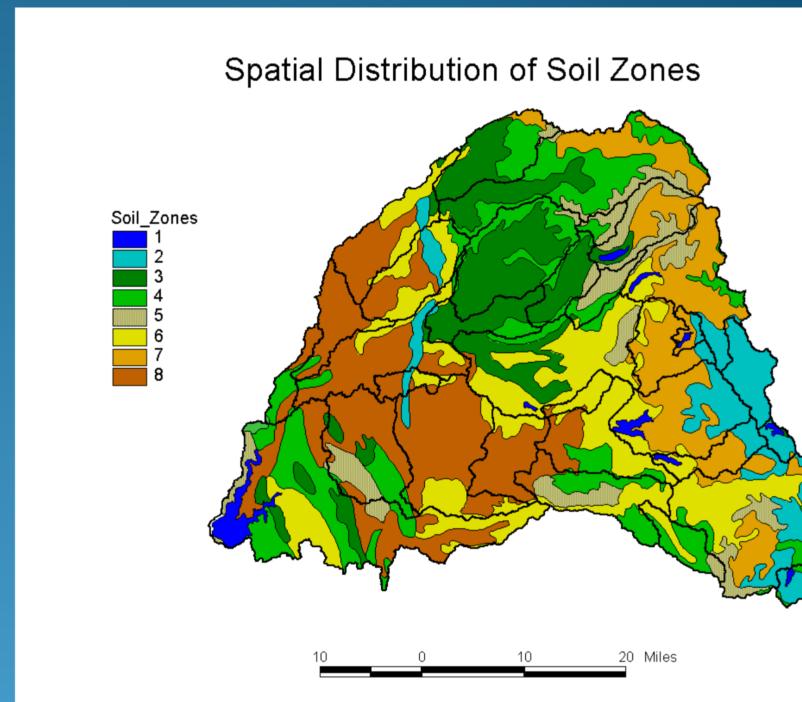
300-feet (zone 1)

to 12,000-feet (zone 9)

Distributed Rainfall-Runoff, Snowmelt Modeling

7 Zones for Describing Soil Characteristics





Soil Characterization from NRCS

Merged to produce 7 Soil Zones with similar hydrologic characteristics

Distributed Rainfall-Runoff, Snowmelt Modeling

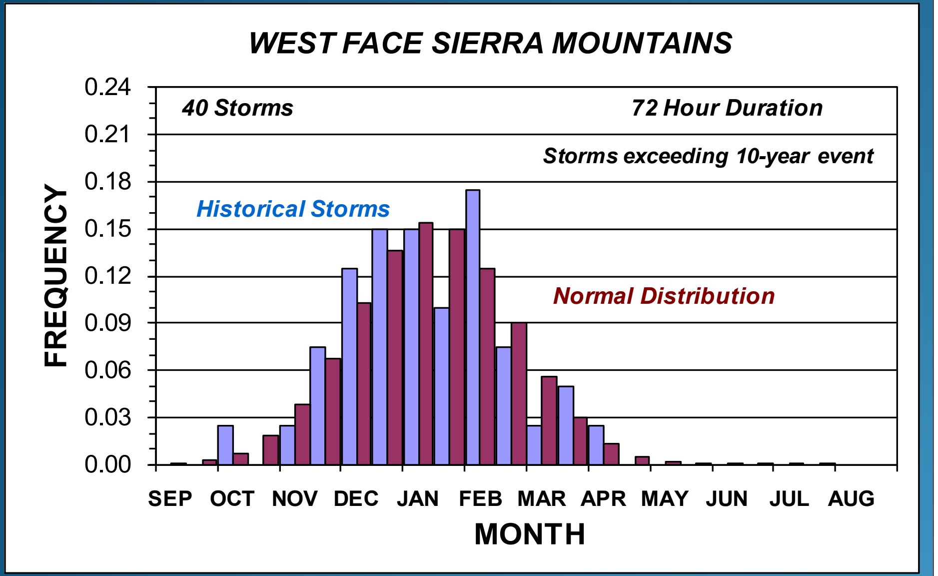
Hydrologic Runoff Units (HRUs) are polygons of land formed from the intersection of Zones of Mean Annual Precipitation, Elevation and Soil Type

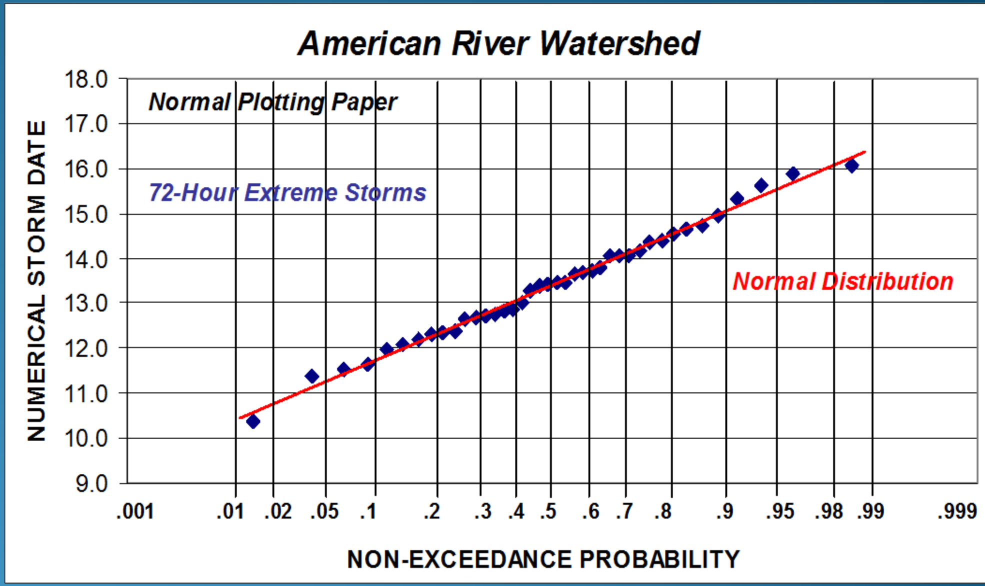
263 unique HRUs in American River Watershed for:

- ***Soil moisture accounting***
- ***Snow-water accounting***
- ***Spatial allocation of snowpack***
- ***Rainfall-runoff modeling***
- ***Snowmelt modeling***

Stochastic Hydrometeorological Inputs

Seasonality of Storms



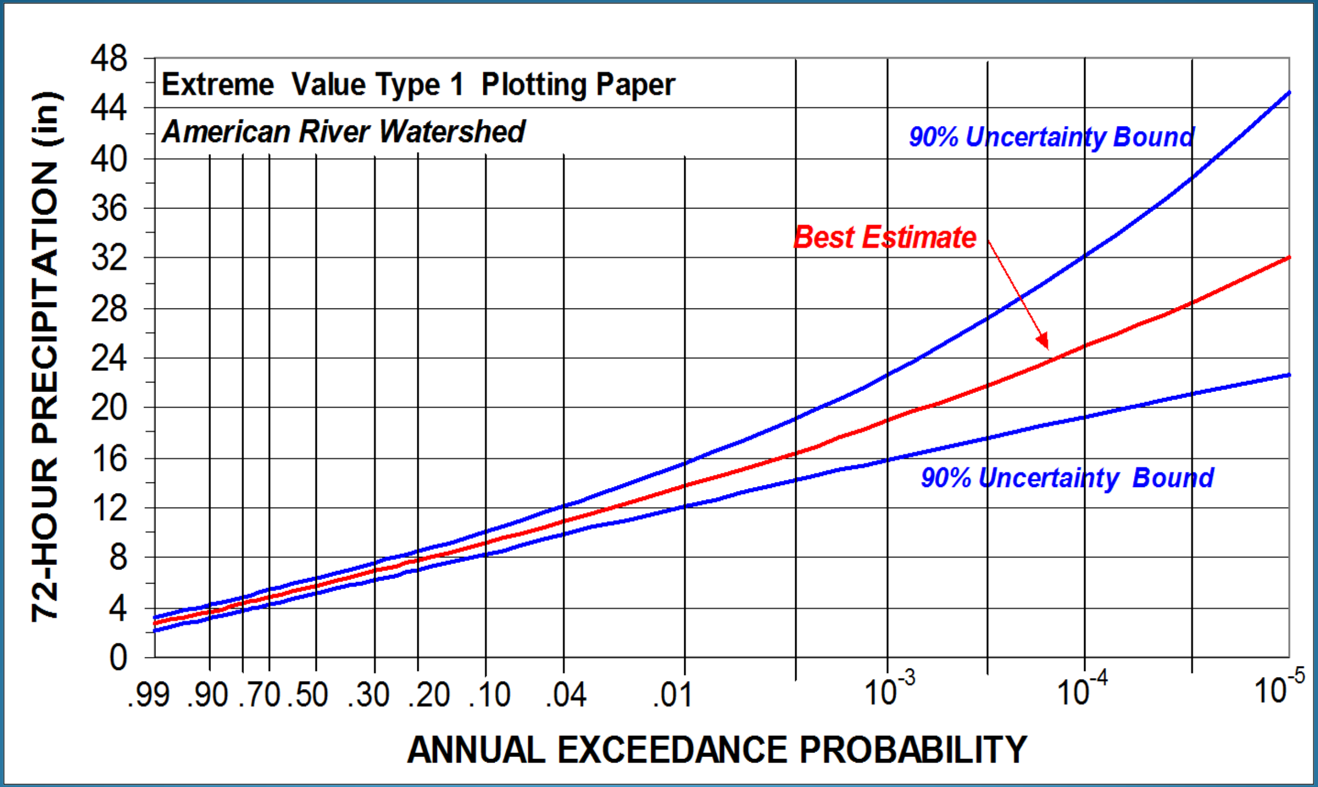


Studies in western US and British Columbia

Show Storm Seasons to be Normally Distributed

Stochastic Hydrometeorological Inputs

Magnitude of 72-Hour Precipitation Annual Maxima



Precipitation-Frequency for American River Watershed 1,862-mi²

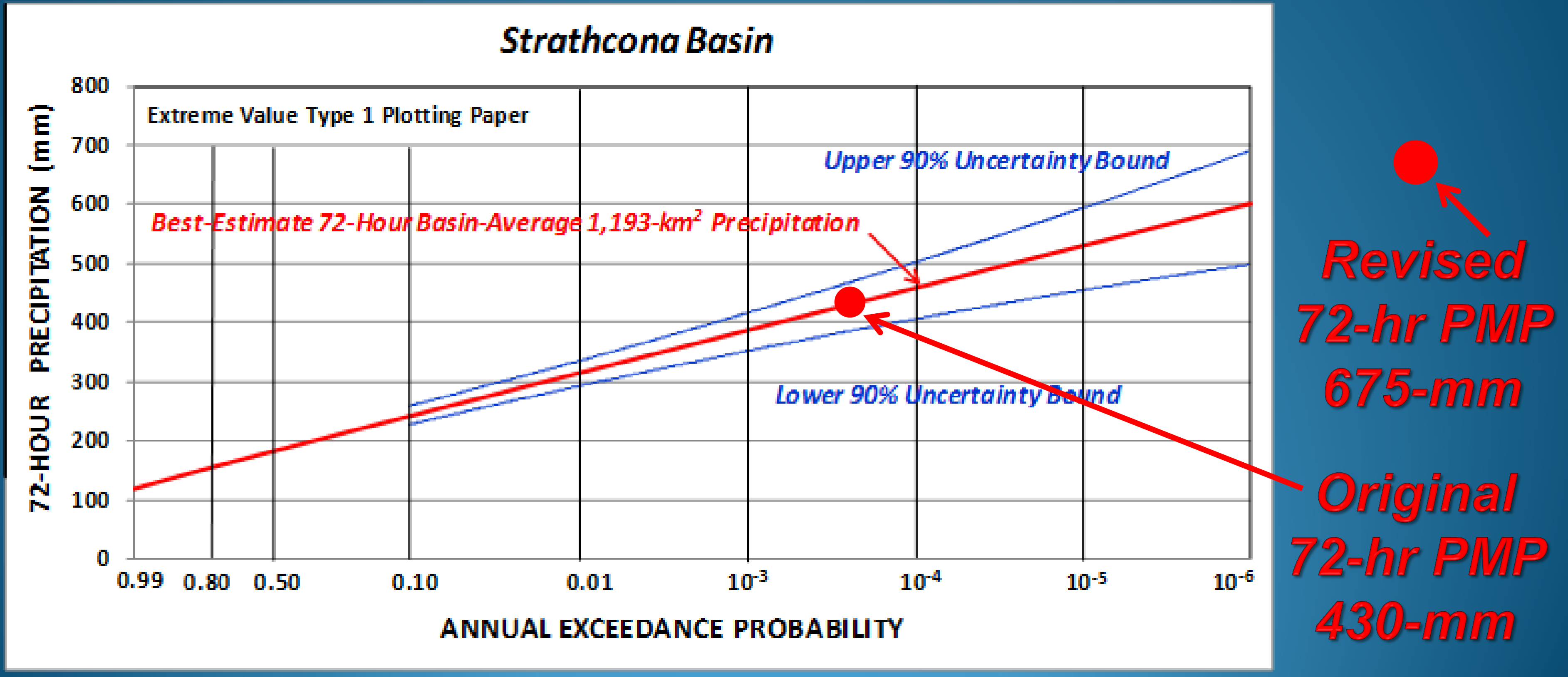
Slightly More Positive Skew than Extreme Value Type 1

Stochastic Hydrometeorological Inputs

Regional Frequency Analysis of 72-Hour Precipitation

143 stations
6,600 station-years of record

Vancouver Island, BC
Olympic Mountains, WA

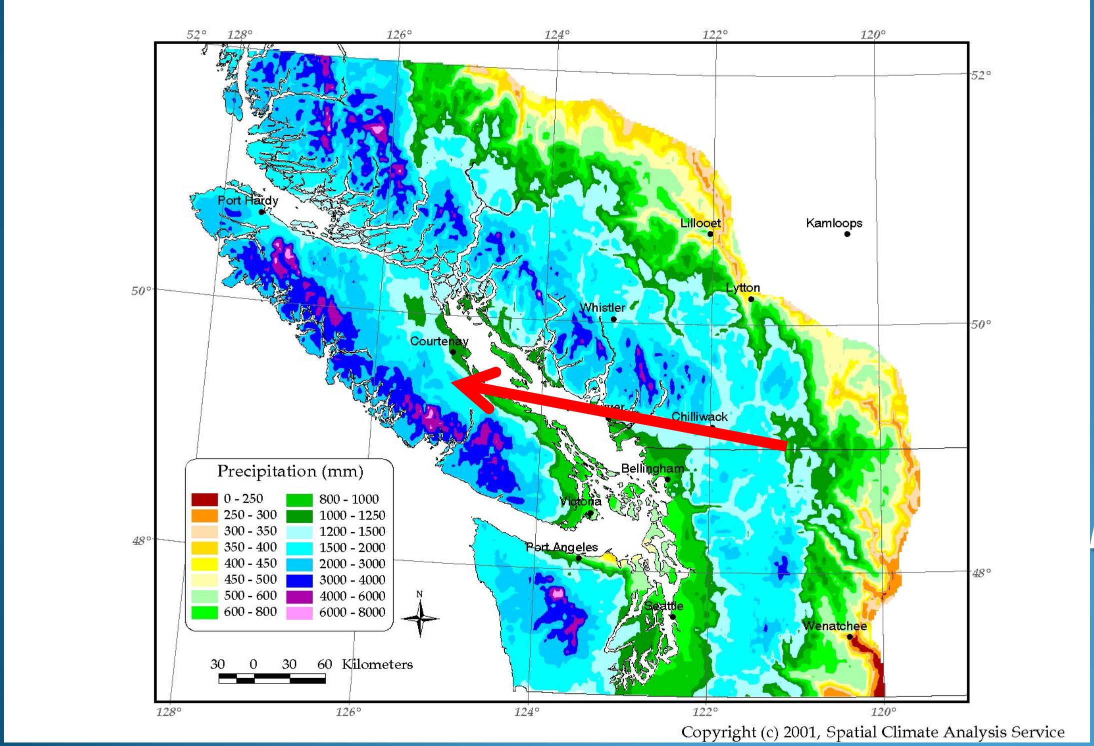


PMP Estimate Revised – Dam Goes from "Safe" to "Unsafe" ?

Stochastic Hydrometeorological Inputs

Large Storms occur on Campbell River Watershed when Moist Inflow Winds are from the East and ESE

Orographic Precipitation occurs from Upslope Winds on what is typically the Leeward Mountain Face



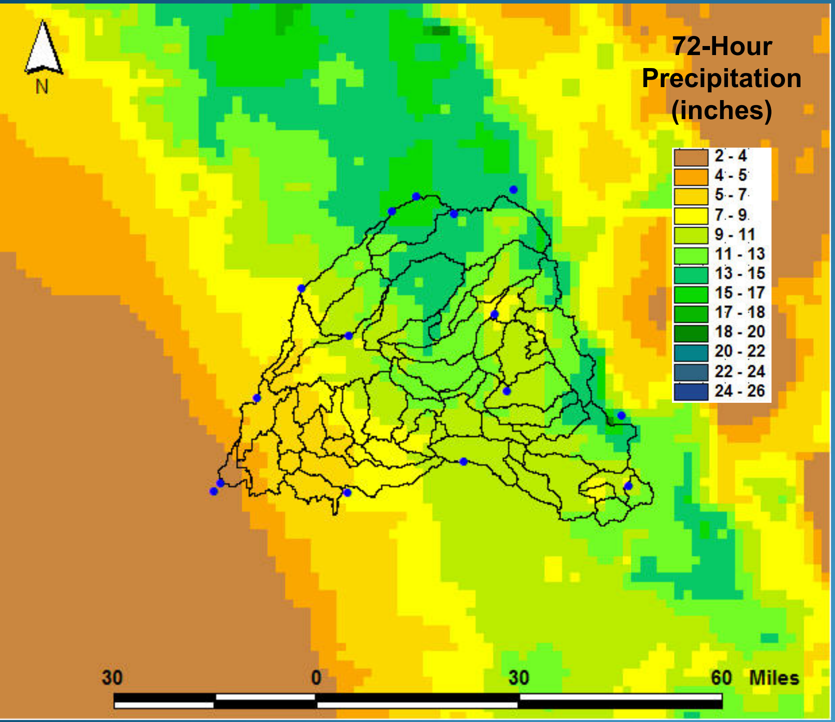
<u>Duration of Heavy Precipitation</u> dependent upon sustaining moist inflow winds from East and ESE

Duration of Upslope Winds is Transient Condition During Storm Passage

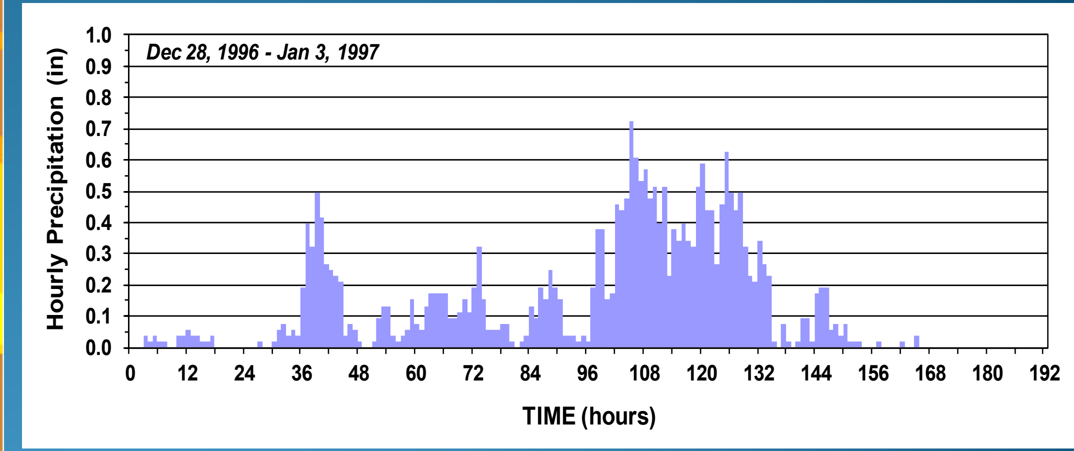
<u>Result</u>: Large Volume Storms/Floods are Rare for Campbell River Watershed Relative to Windward Face

Stochastic Hydrometeorological Inputs

Scalable Spatial and Temporal Storm Patterns



American River Watershed, CA

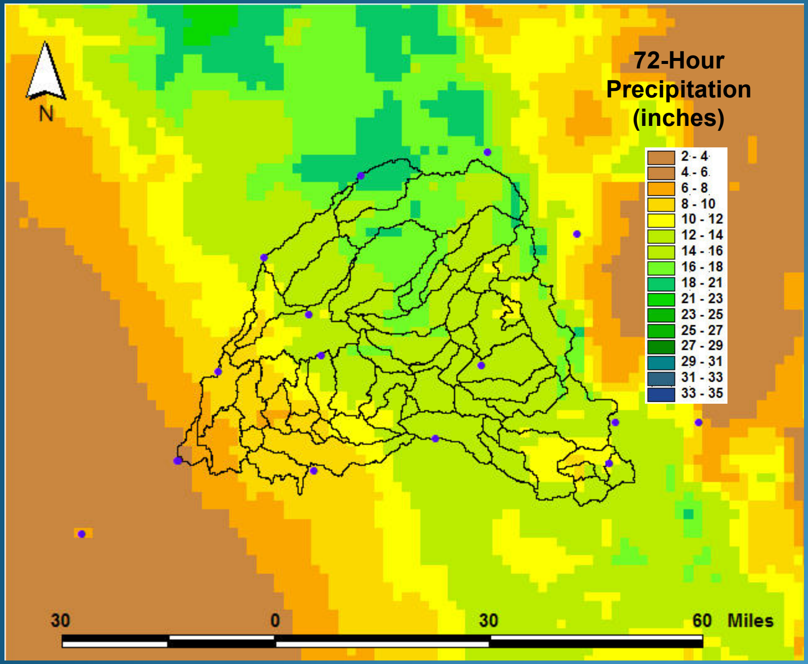


Total storm duration not limited to 72-hours

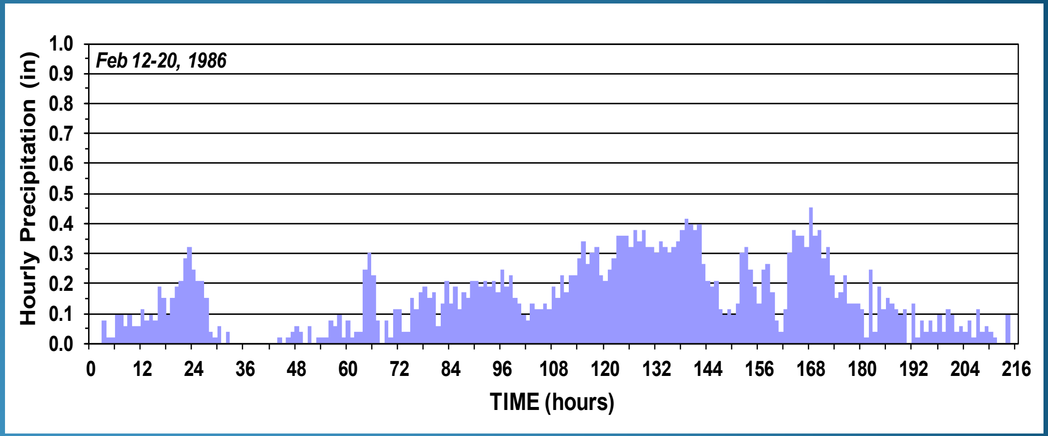
Each of 33 sub-basins has a separate temporal pattern, scalable by the selected 72-hour basin-average precipitation

Stochastic Hydrometeorological Inputs

Scalable Spatial and Temporal Storm Patterns



American River Watershed, CA

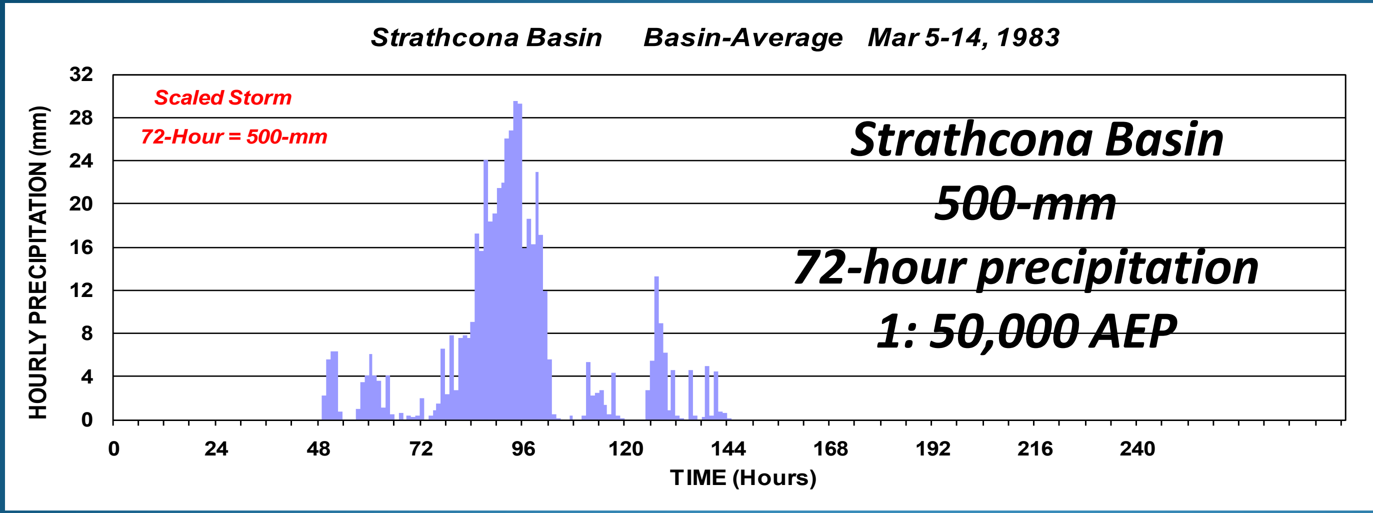


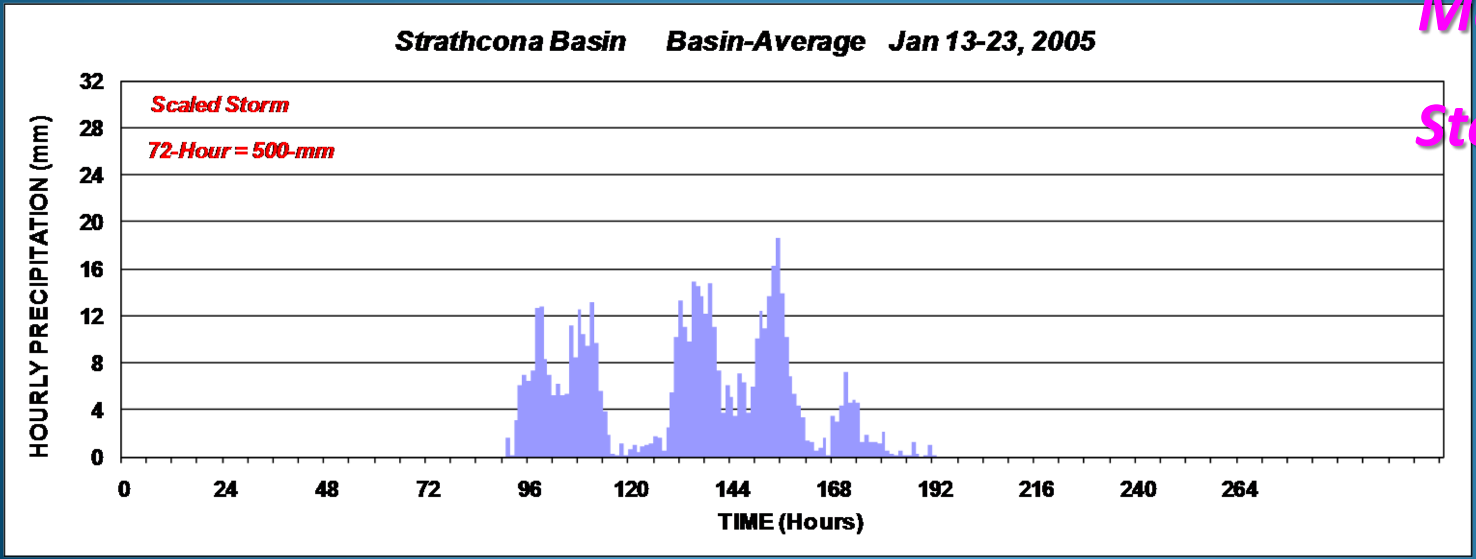
24 Prototype Temporal and Spatial Templates

developed from historical storms observed on the watershed

Stochastic Hydrometeorological Components

15 Historical Storms used to Develop Suite of Scalable Storm Templates for Strathcona Basin

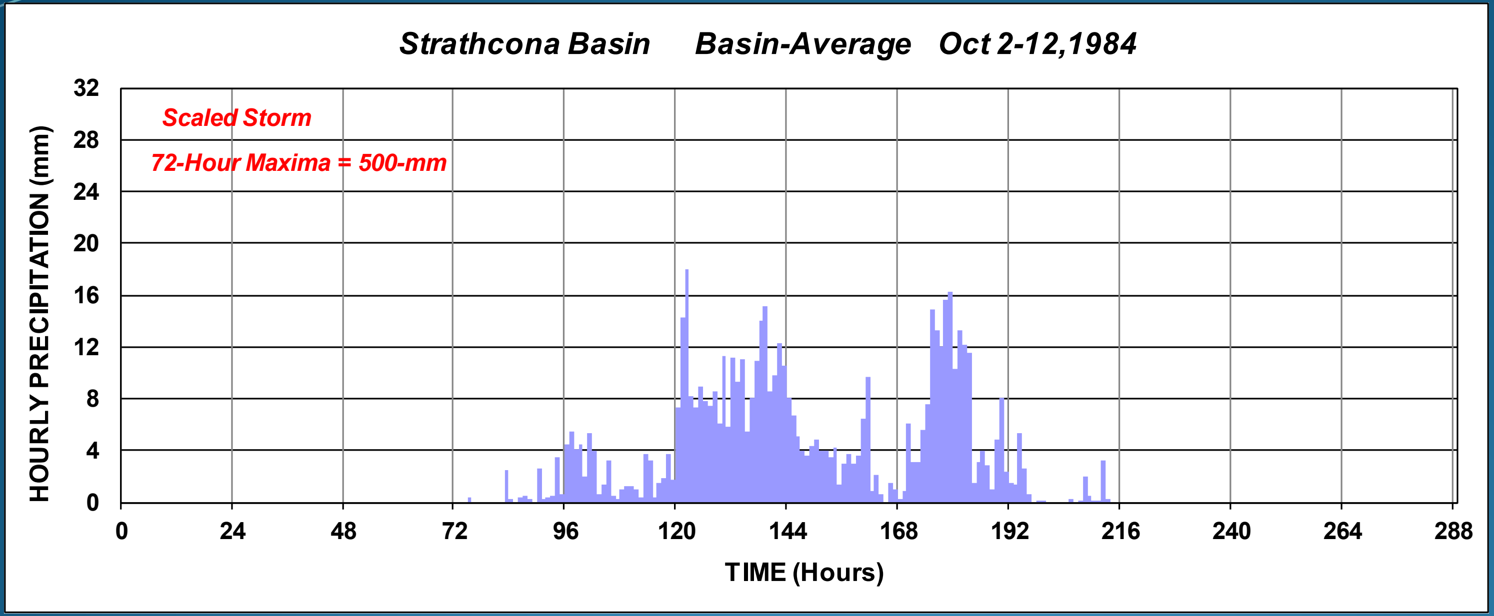


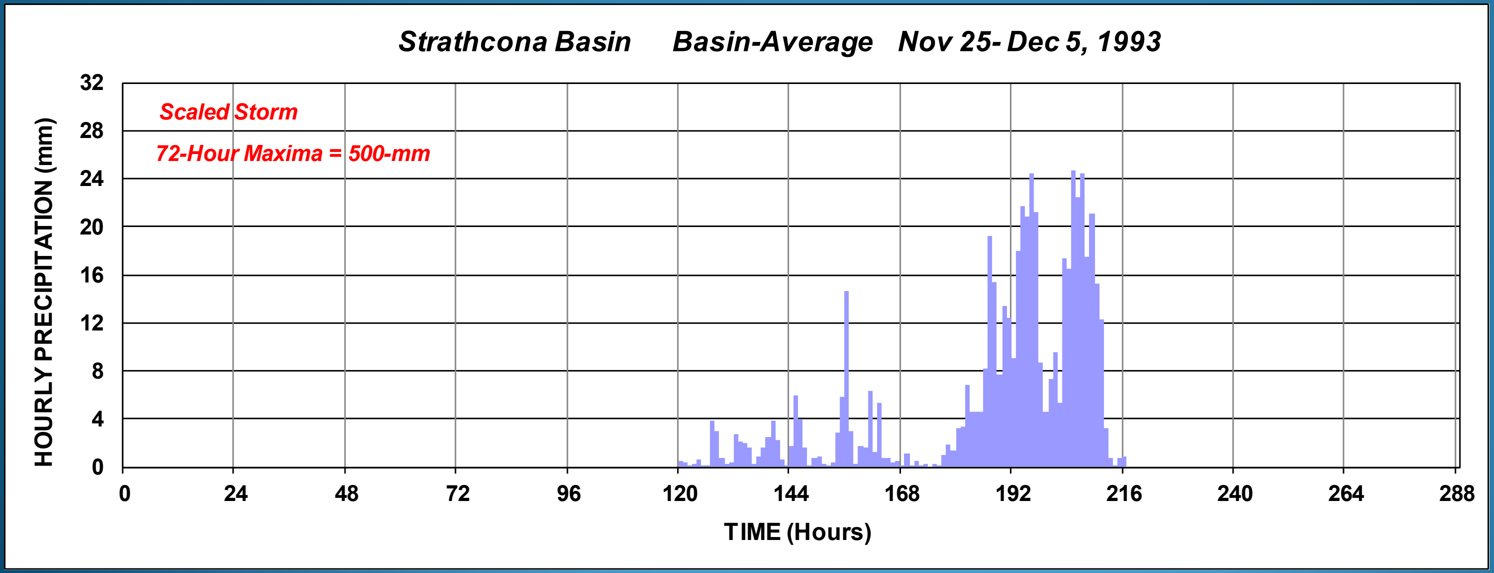


Note Diversity:

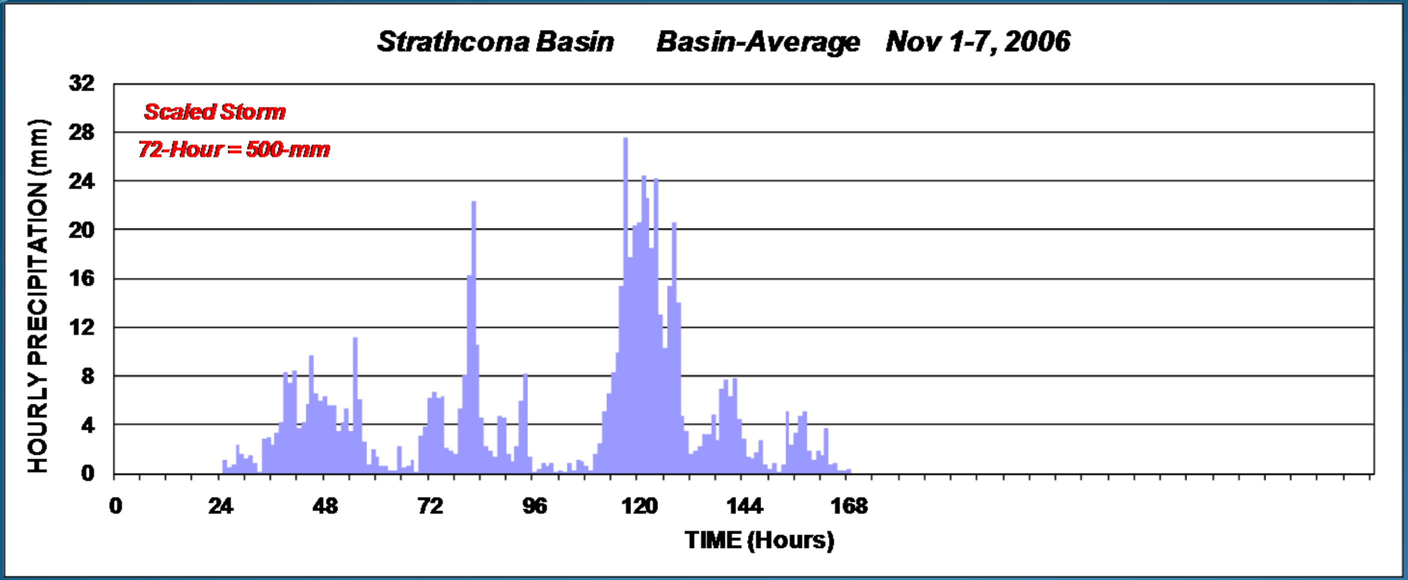
- Temporal Patterns
- Multi-Pulse Storms
- Max Intensities
- Storm Duration

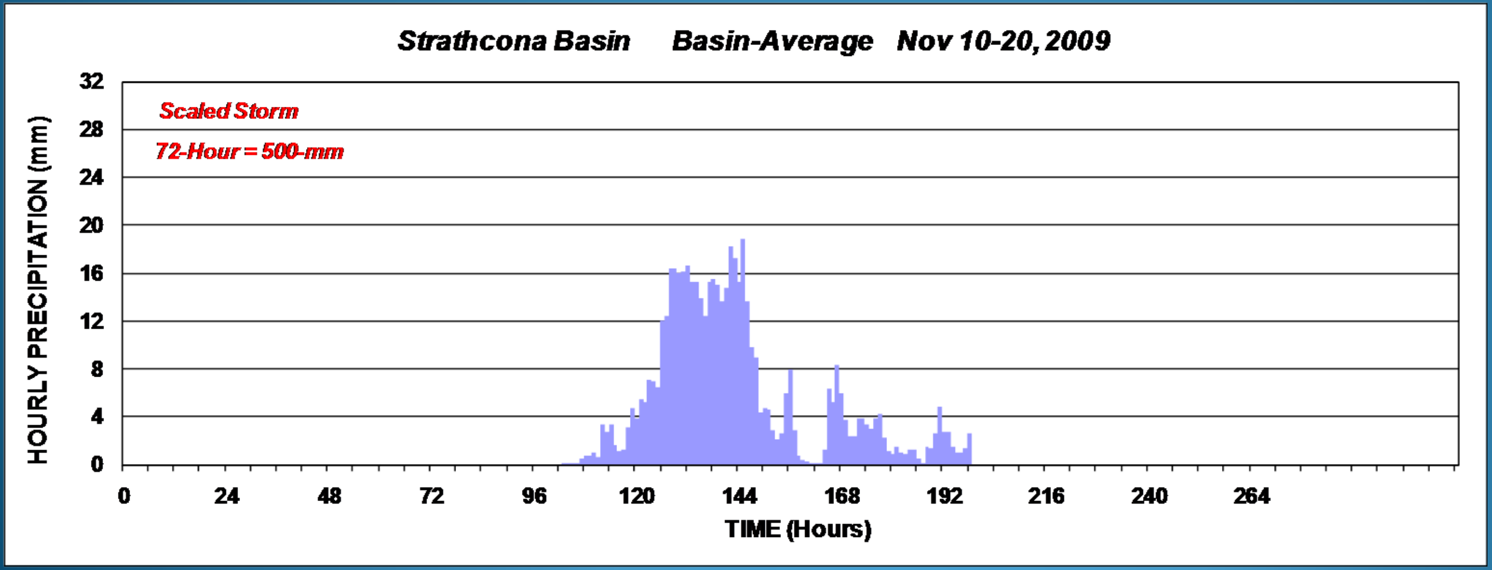
Stochastic Hydrometeorological Components



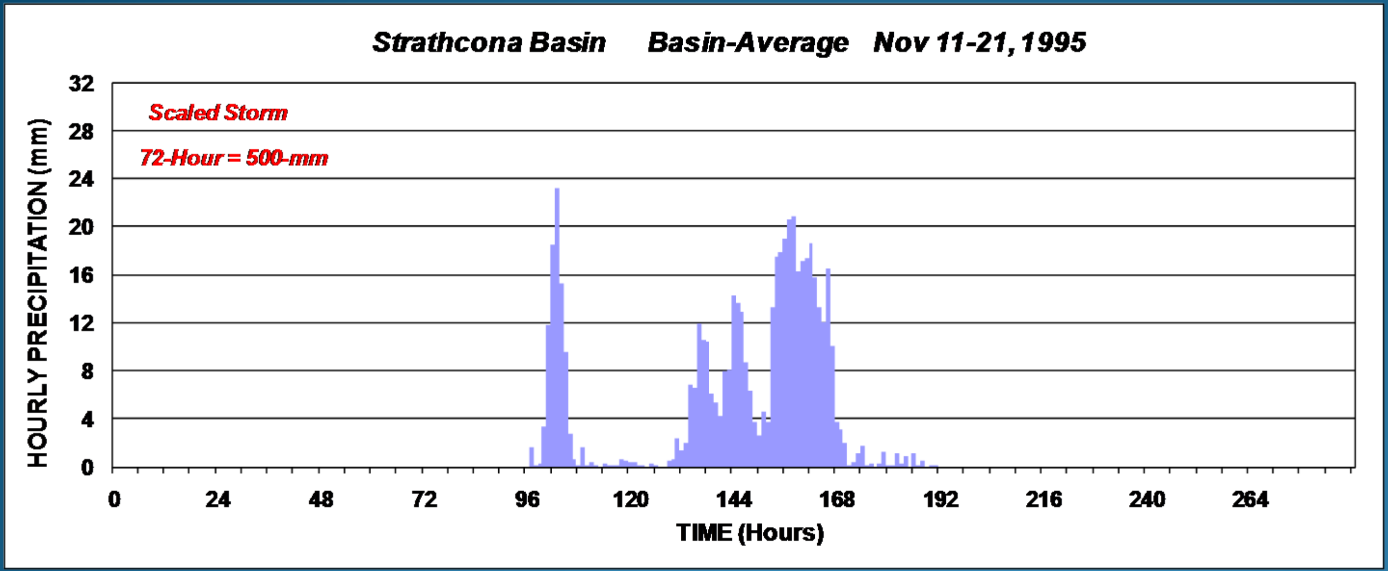


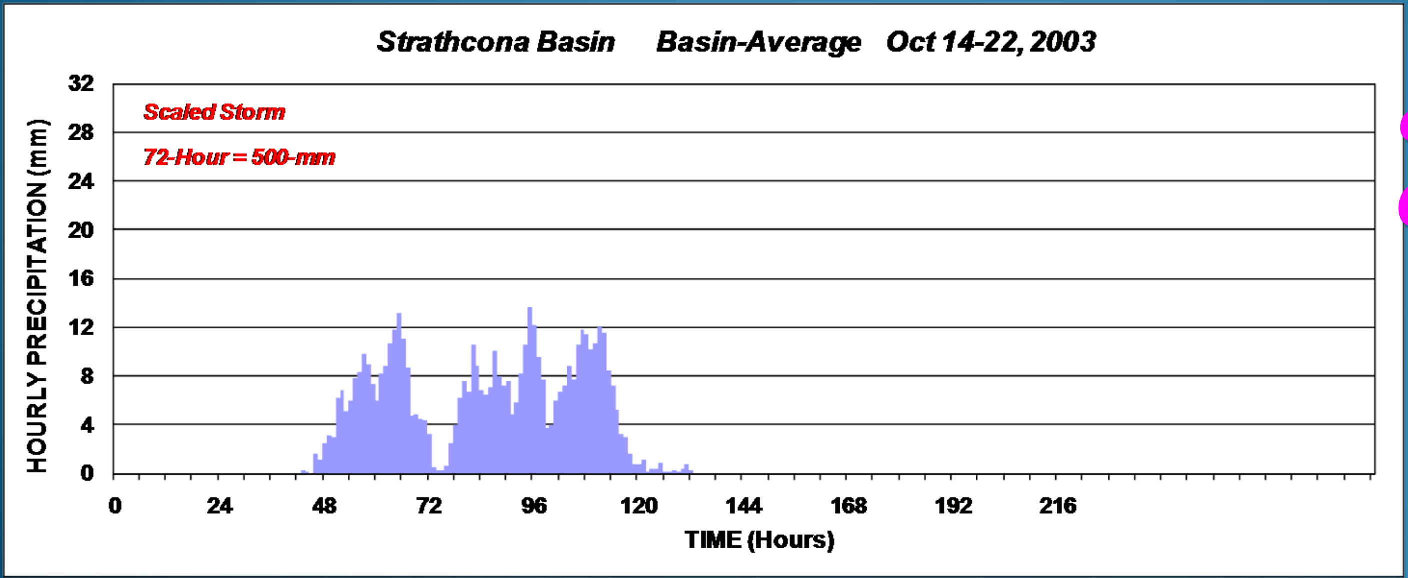
Stochastic Hydrometeorological Components





Stochastic Hydrometeorological Components





Diversity of Storm Temporal Patterns Provides for Robust Assessment of Inflow Flood Characteristics and Reservoir Responses

Summary …

SEFM provides a Hydrological Tool

for Developing Flood-Frequency Relationships

(Hydrologic Hazard Curves) for Flood Discharges,

Runoff Volumes and Maximum Reservoir Level

and for

Assessing the Annual Exceedance Probability (AEP)

of Extreme Floods including IDFs and the PMF

SEFM Description and Examples…

End-of-Slides