

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 Decision Making 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-km² 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-mi² watershed

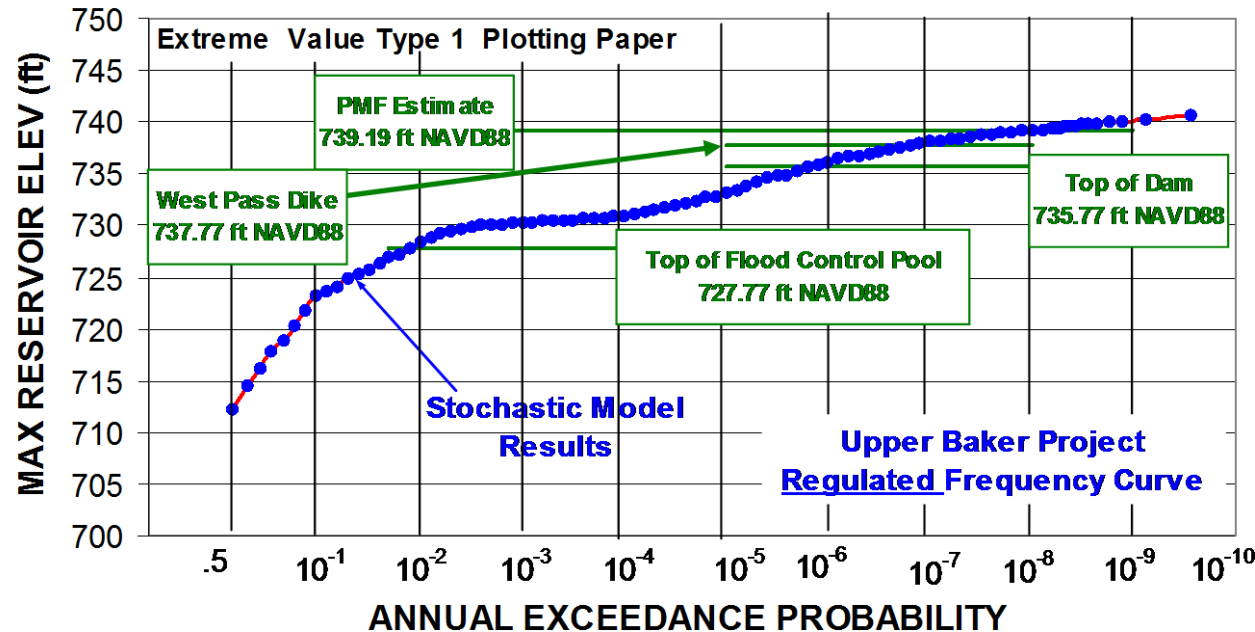
BC Hydro

Bridge River System, Coastal Mountains, BC

3 dam system - 3,500-km² watershed

SEFM – Primary Deliverable ...

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



Integrates

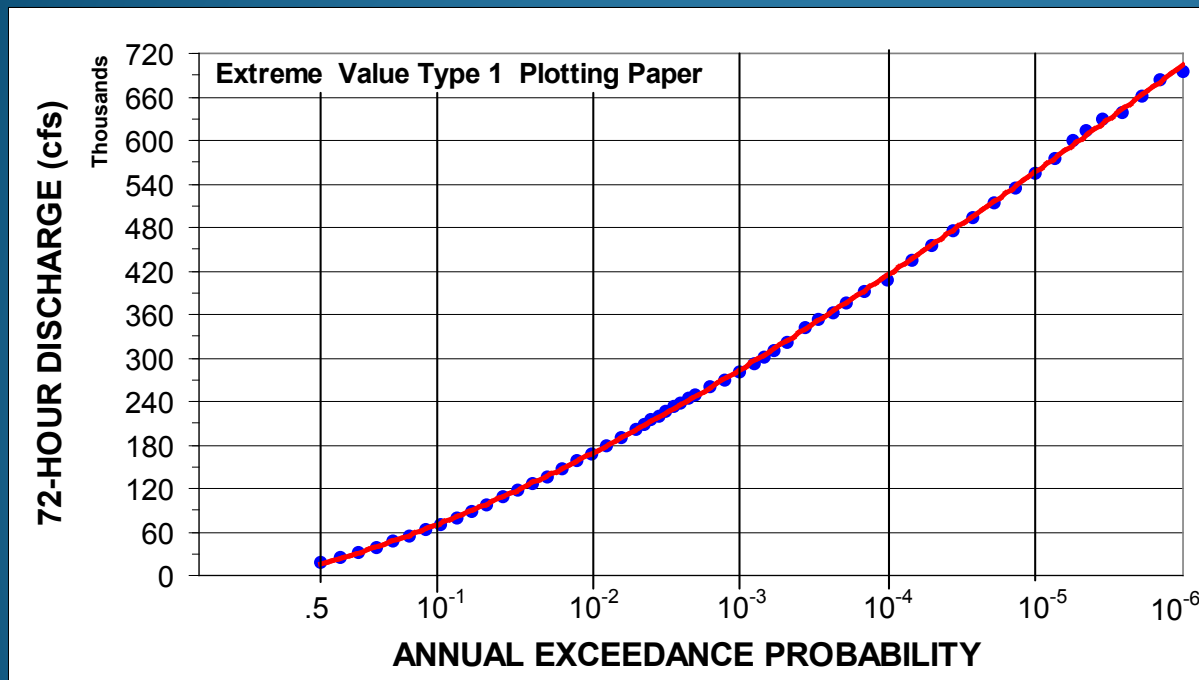
- Frequency Information
- Flood Peak Discharge
- Runoff Volume
- Hydrograph Shape
- Initial Reservoir Level
- Reservoir Operations

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 ...

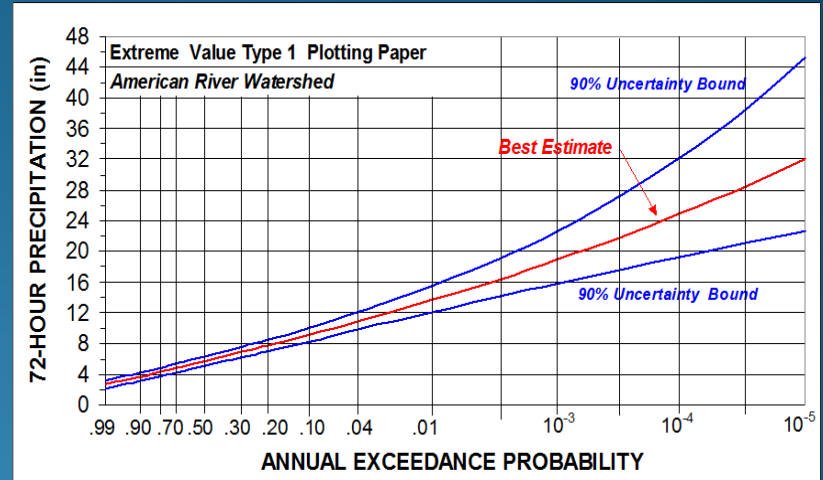
- 1) *Use Deterministic Rainfall-Runoff Model
HEC-1, UBCWM, WATFLOOD, (HEC-HMS in future)*
- 2) *Treat Hydrometeorological Inputs as Variables*
- 3) *Stochastically Generate Multi-Thousand Years of Storms
and Dates of Storm Occurrence*
- 4) *Select Hydrometeorological Inputs to Accompany Storms
and Maintain Seasonal Characteristics and Dependencies*

Stochastic Approach ...

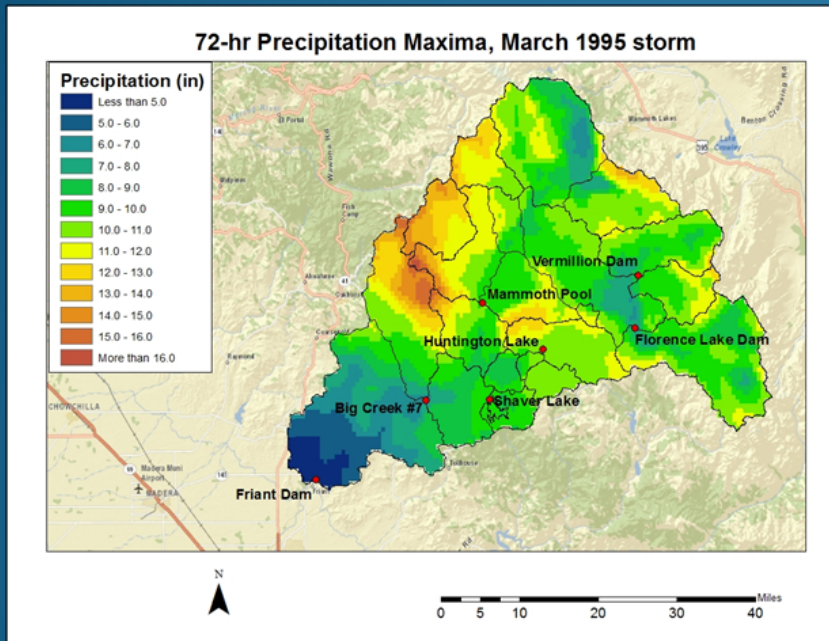
- 5) *Compute Multi-Thousand Flood Annual Maxima using Hydrologic Model and Input Datasets – Conduct Sufficient Simulations to Exceed Flood Magnitudes of Interest*
- 6) *Rank Flood Outputs in Descending Order of Magnitude and Assign Exceedance Probabilities using a Plotting Position Formula*
- 7) *Construct 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 ...

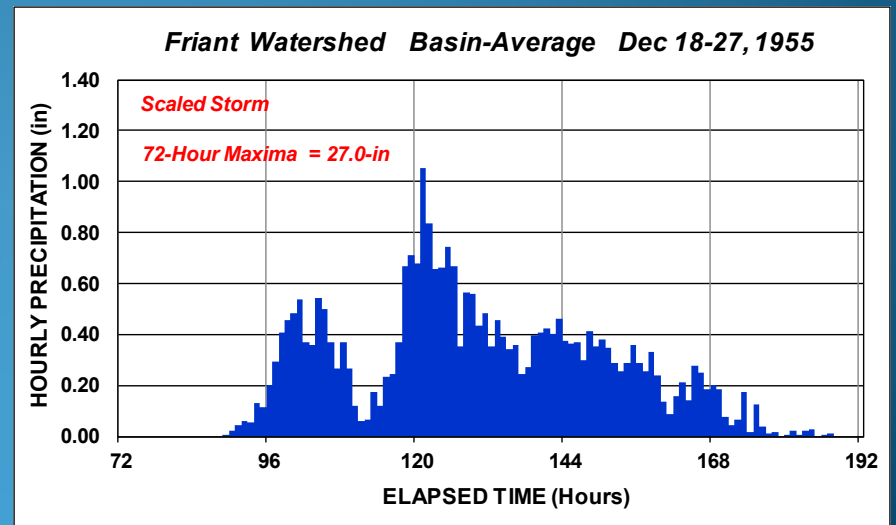
Magnitude of Basin-Average Precipitation (24-hr, 72-hr)



Spatial Distribution of Precipitation over Watershed



Temporal Distribution of Precipitation over Watershed variable storm duration



Stochastic Simulation Hydrometeorological Variables ...

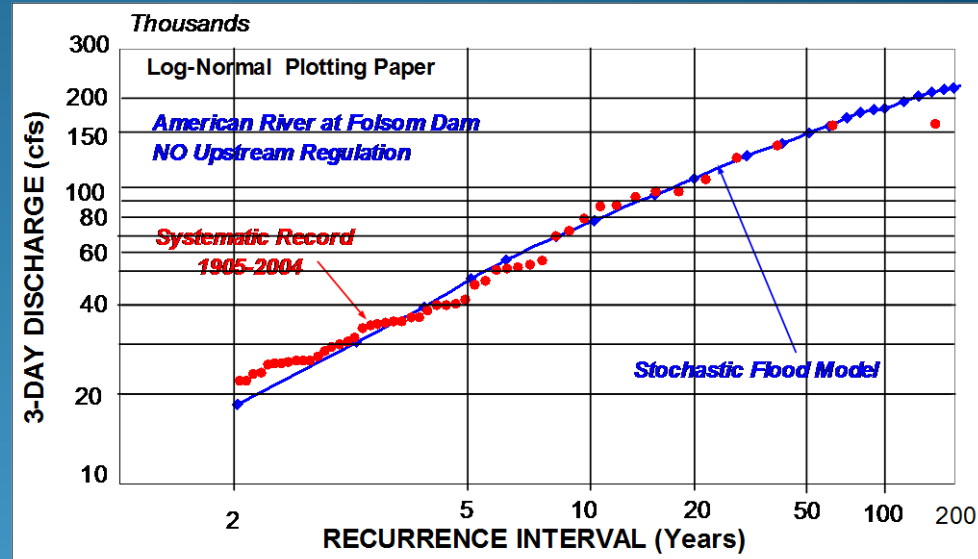
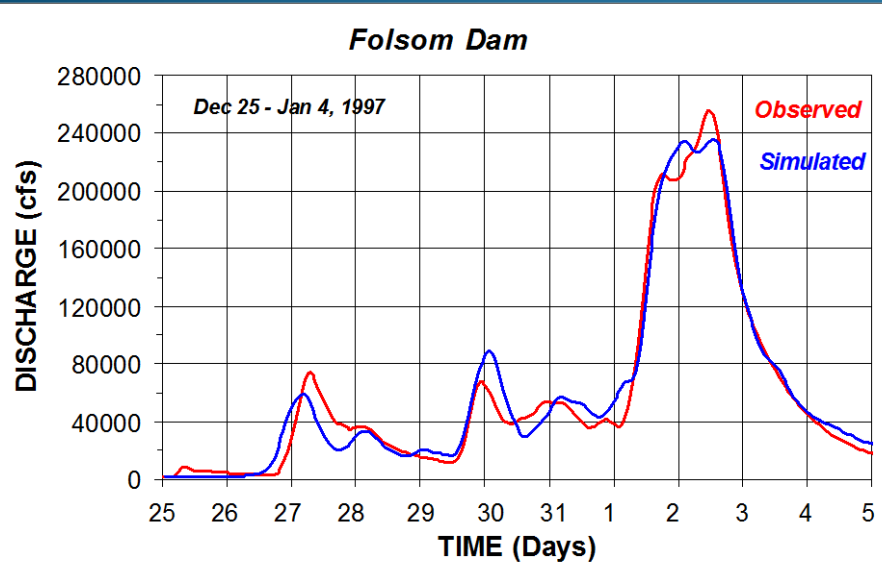
- *Antecedent Precipitation – Spatially Distributed*
 - *Antecedent Snowpack
(spatially distributed snow depth and density)*
 - *Antecedent Soil-Moisture
(spatially distributed by soil type)*
- *Freezing Level and Air Temperature Temporal Pattern*
- *Initial Streamflow*
- *Initial Reservoir Level*

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

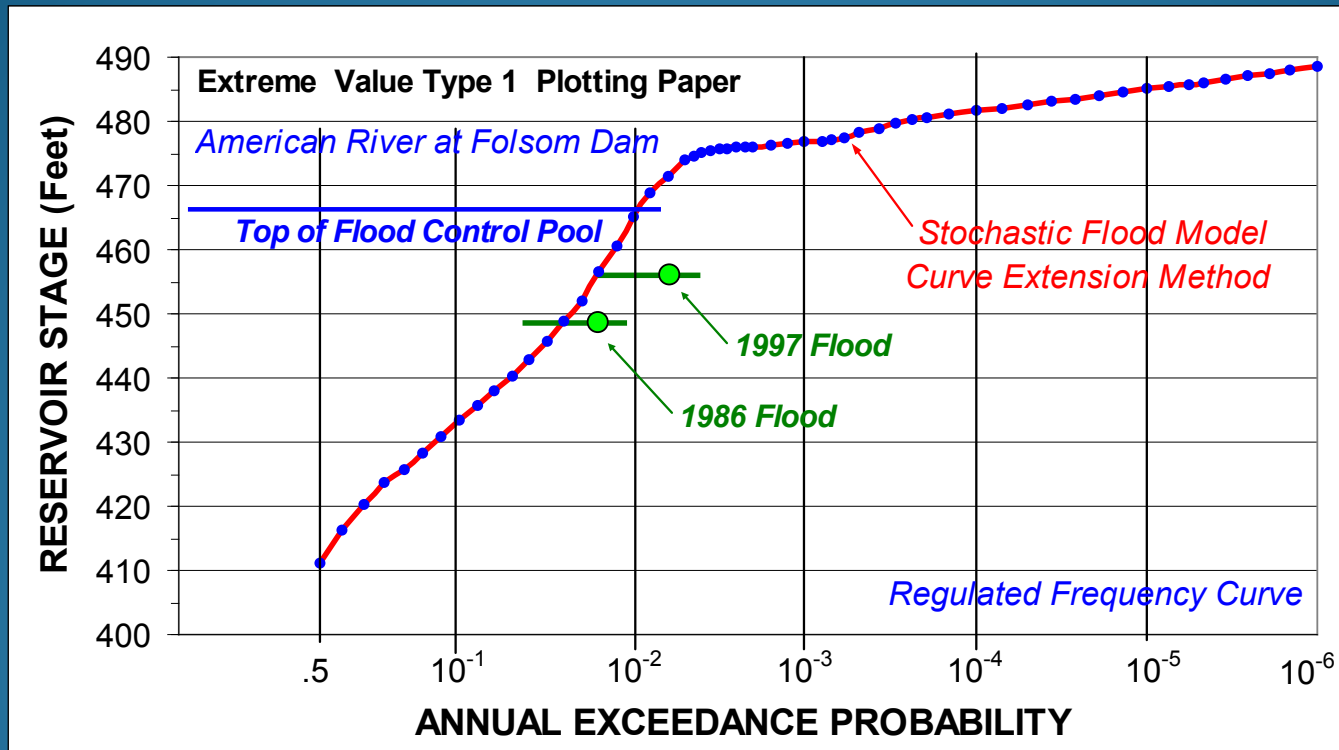
Each flood simulation represents an annual maxima flood based on historical behavior of the hydrometeorological inputs and the observed flood response of the watershed

*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...

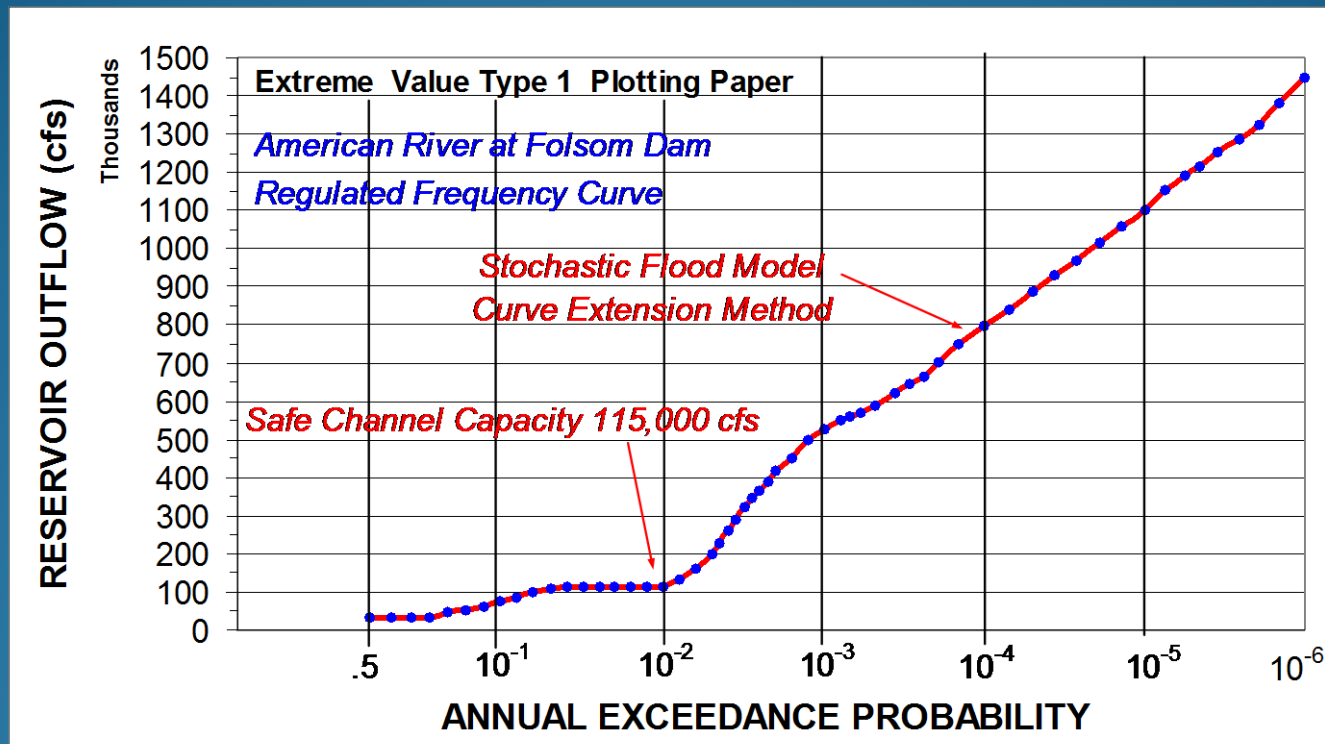
Primary Outputs are Magnitude-Frequency Curves (Hydrologic Hazard Curves)



Hydrologic loading for extreme floods are of primary interest

SEFM – Example Output...

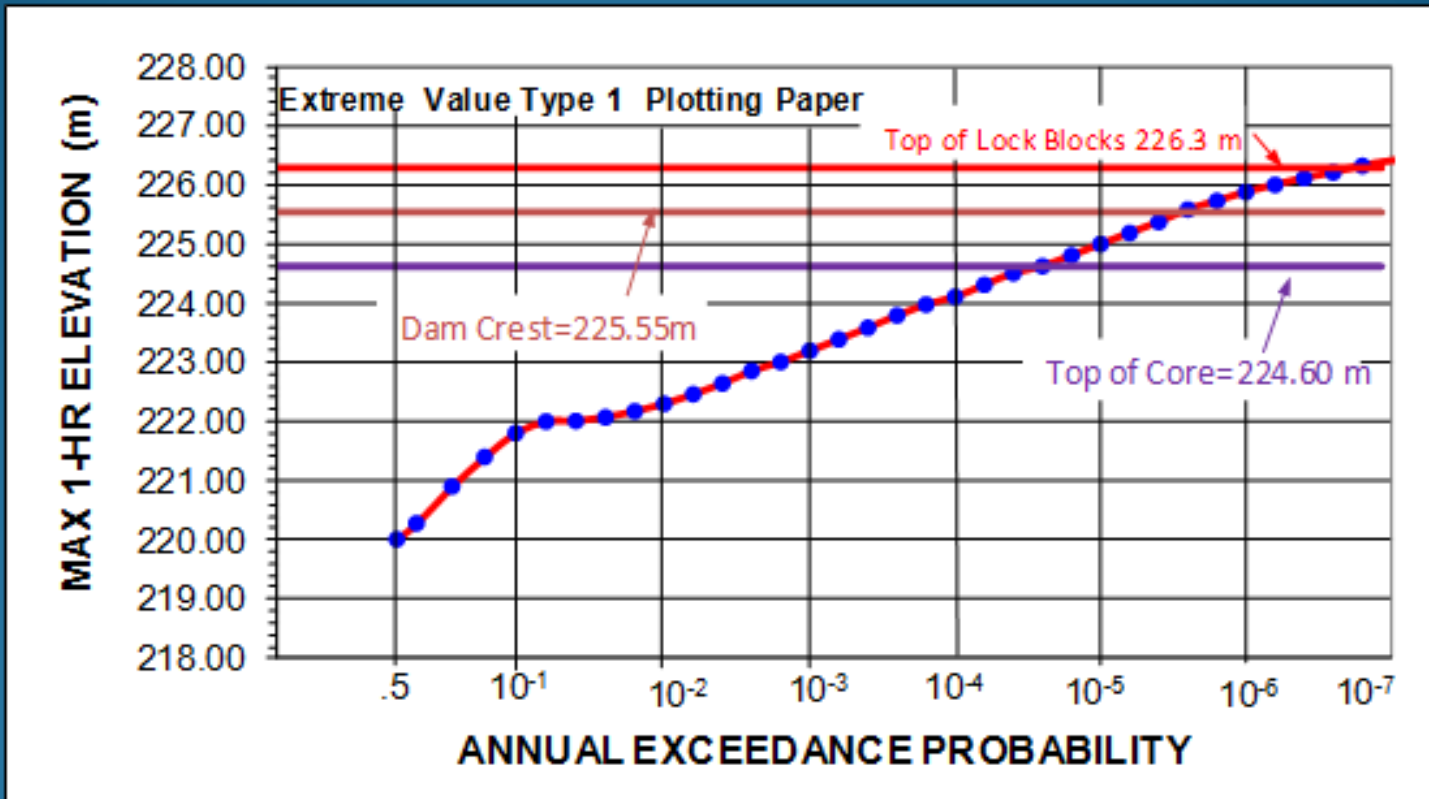
**Safe Channel Capacity within the Levee System
is a Concern in the Sacramento Valley**



***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 ...

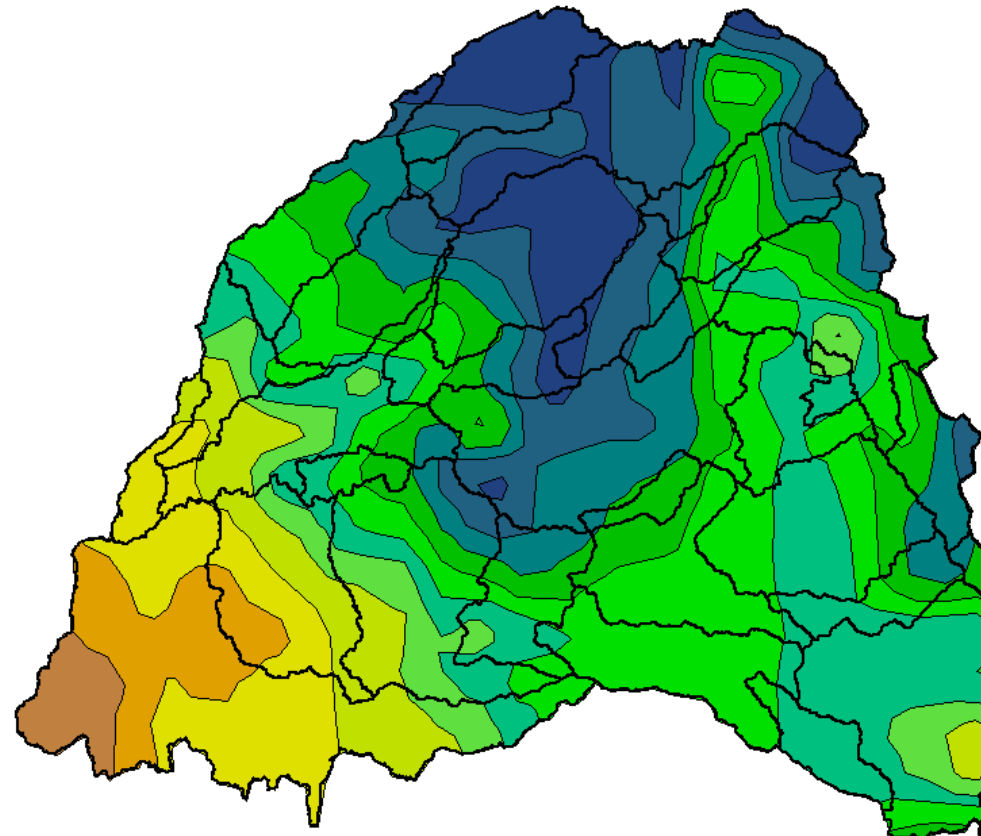
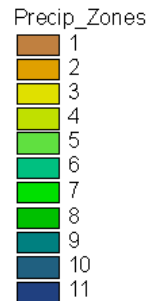
- ***Watershed Layout for Distributed Rainfall-Runoff Modeling***
- ***Seasonality of Storms***
- ***Precipitation-Frequency Relationships for Watershed***
- ***Diversity of Temporal Patterns for Storms***

Distributed Rainfall-Runoff, Snowmelt Modeling

11 Zones of Mean Annual Precipitation

American River, CA

Spatial Distribution of Annual Precipitation Zone



***Mean Annual Precipitation
varies from
20-inches (zone 1)
to 72-inches (zone 11)***

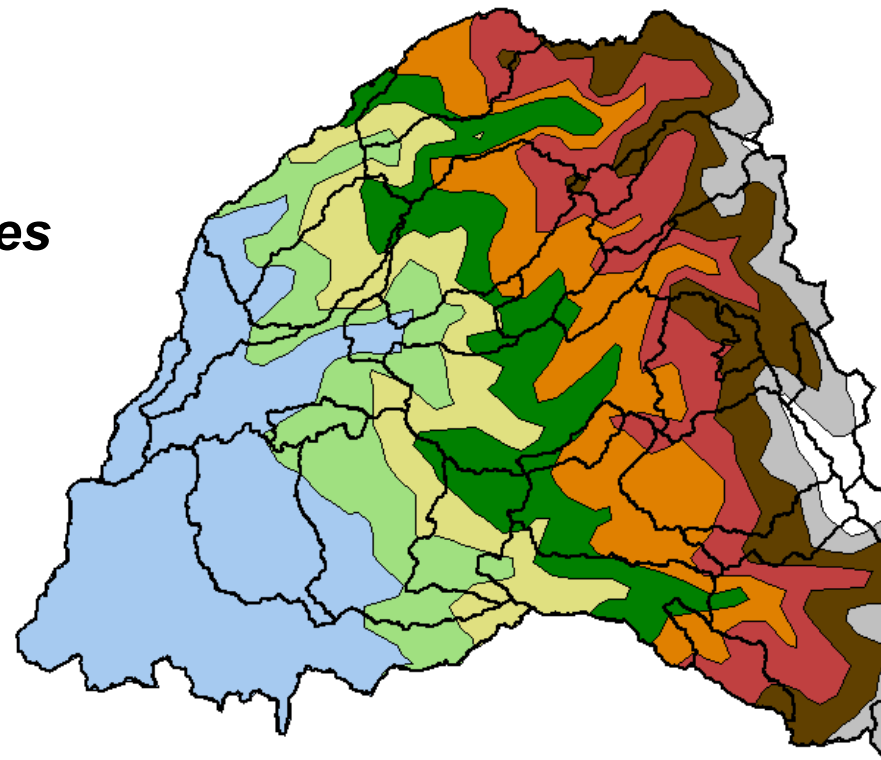
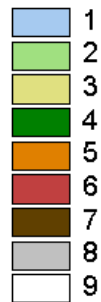
Distributed Rainfall-Runoff, Snowmelt Modeling

American River, CA

Spatial Distribution of Elevation Zones

9 Elevation Zones

Elevation_Zones

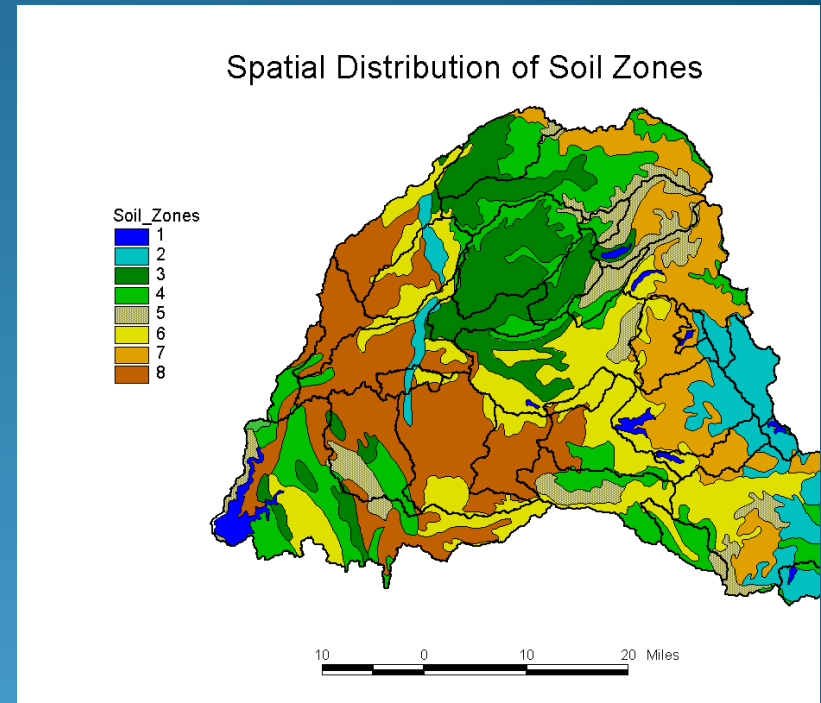
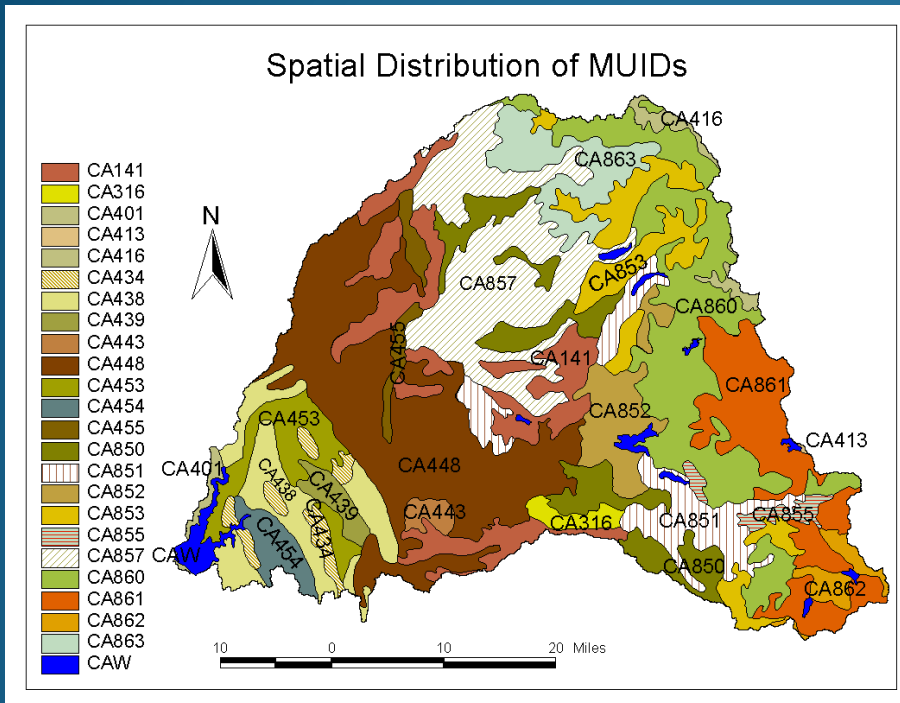


10 0 10 20 Miles

***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

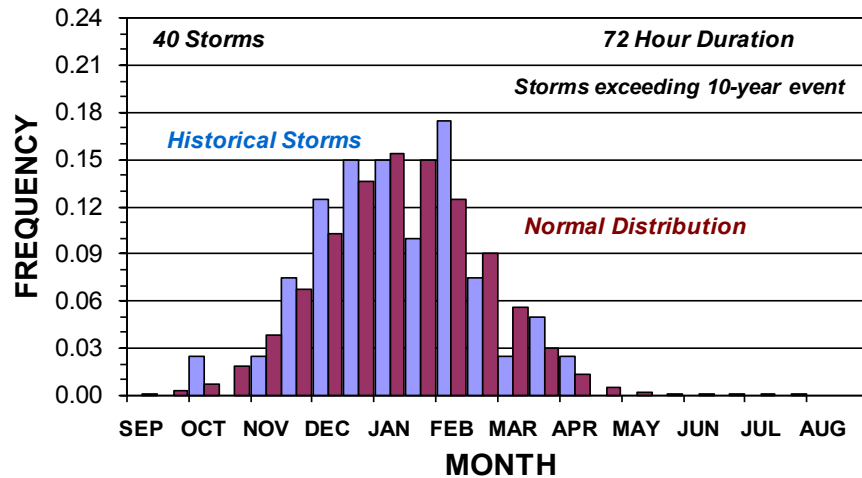
263 unique HRUs in American River Watershed for:

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

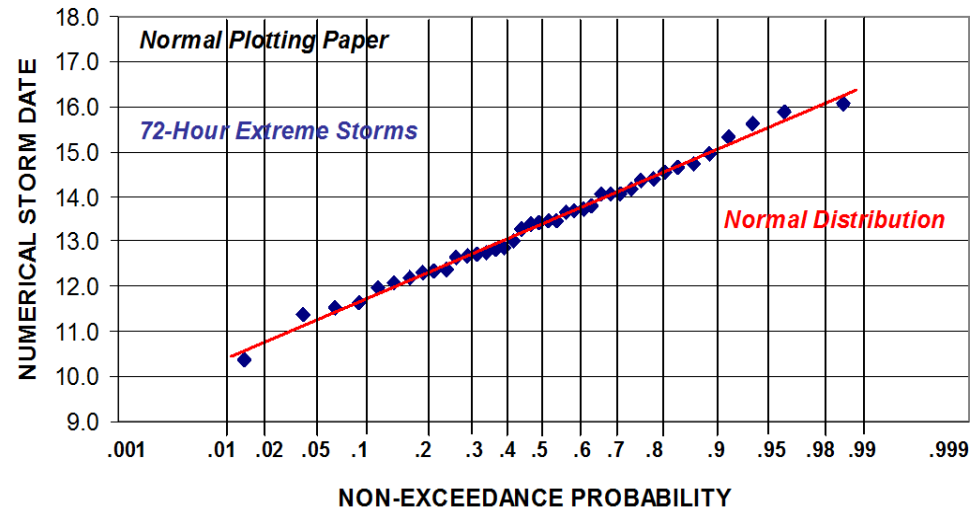
Stochastic Hydrometeorological Inputs

Seasonality of Storms

WEST FACE SIERRA MOUNTAINS



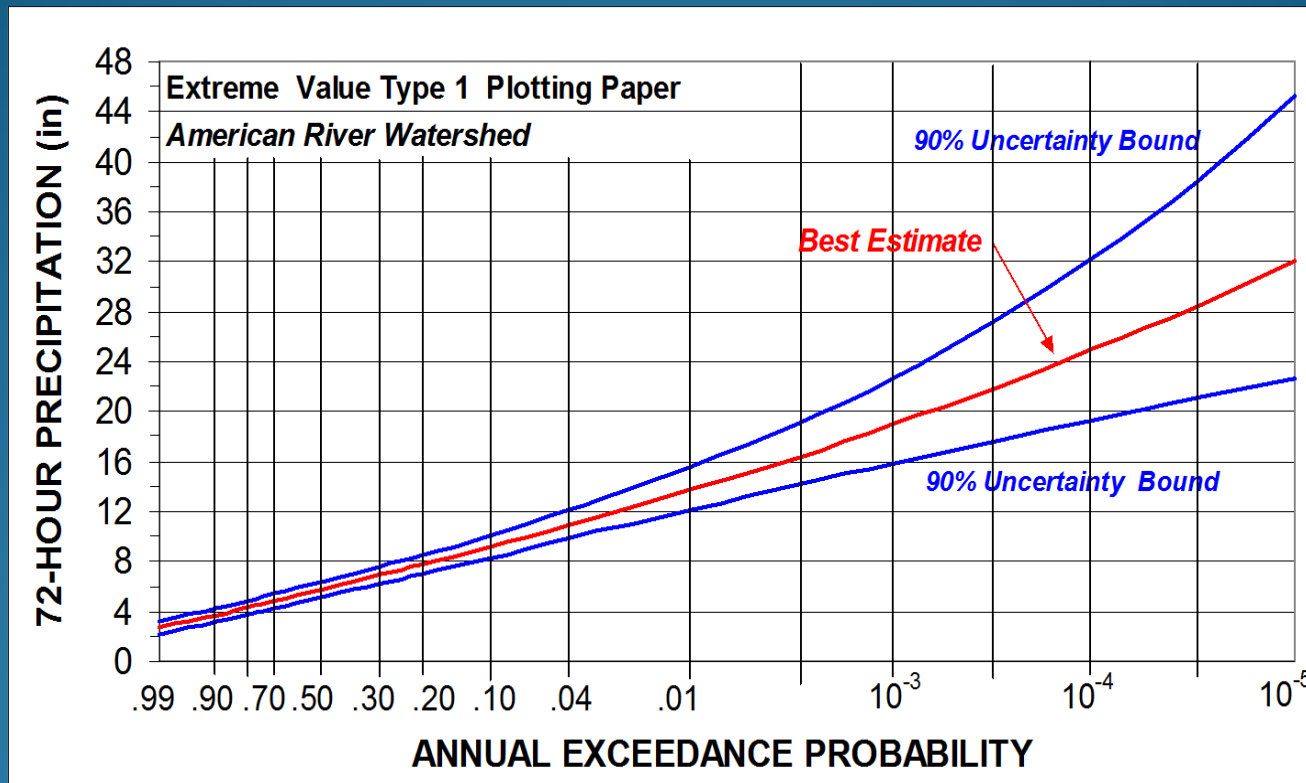
American River Watershed



*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*

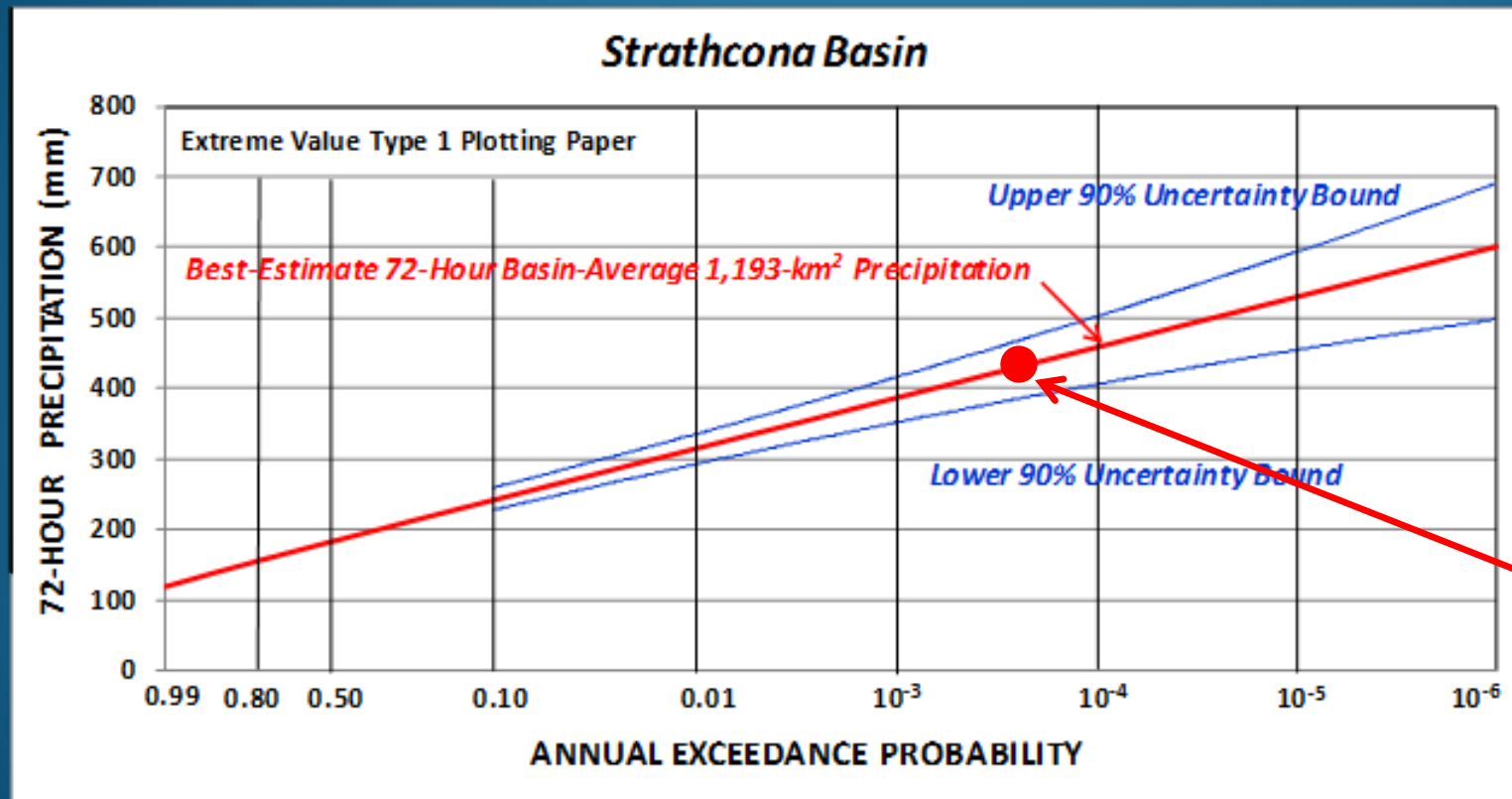
Stochastic Hydrometeorological Inputs

Regional Frequency Analysis of 72-Hour Precipitation

143 stations

6,600 station-years of record

Vancouver Island, BC
Olympic Mountains, WA



Revised
72-hr PMP
675-mm

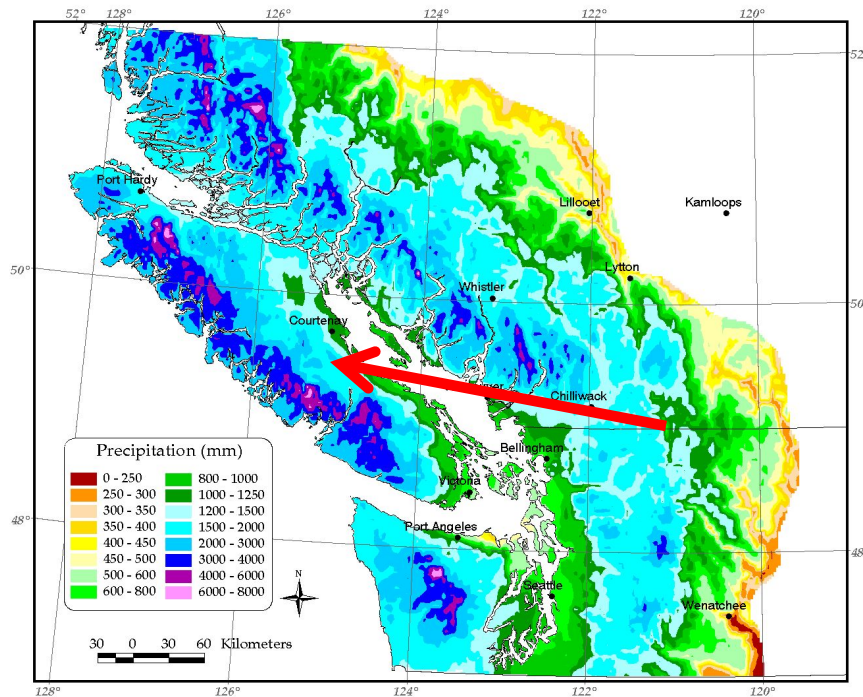
Original
72-hr PMP
430-mm

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



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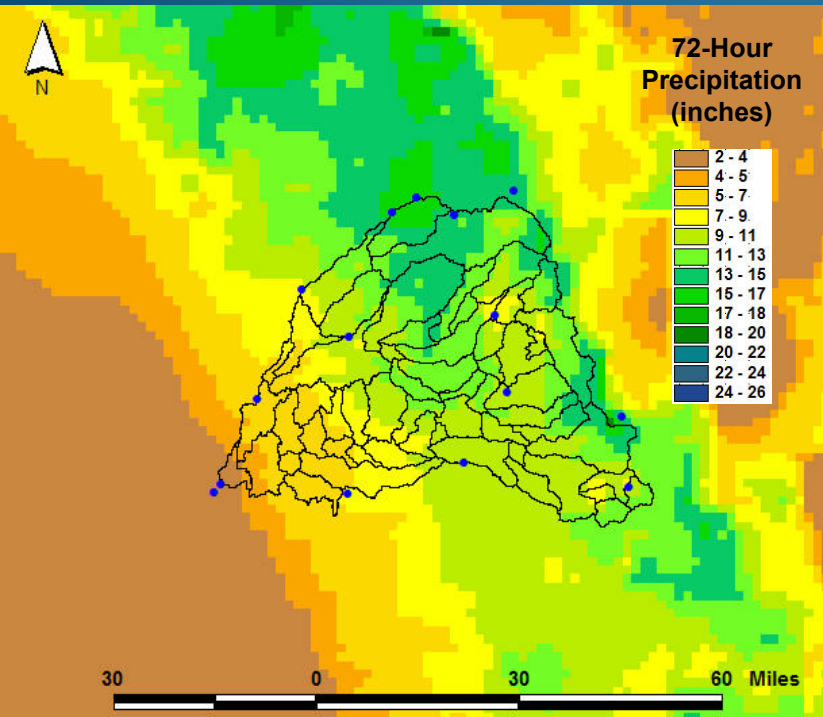
Duration of Heavy Precipitation dependent upon sustaining moist inflow winds from East and ESE

Duration of Upslope Winds is Transient Condition During Storm Passage

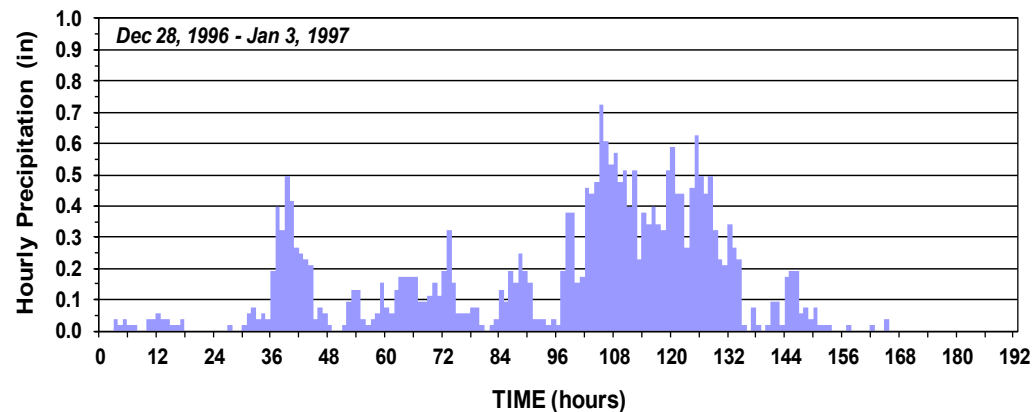
Result: Large Volume Storms/Floods are Rare for Campbell River Watershed Relative to Windward Face

Stochastic Hydrometeorological Inputs

Scalable Spatial and Temporal Storm Patterns



American River Watershed, CA

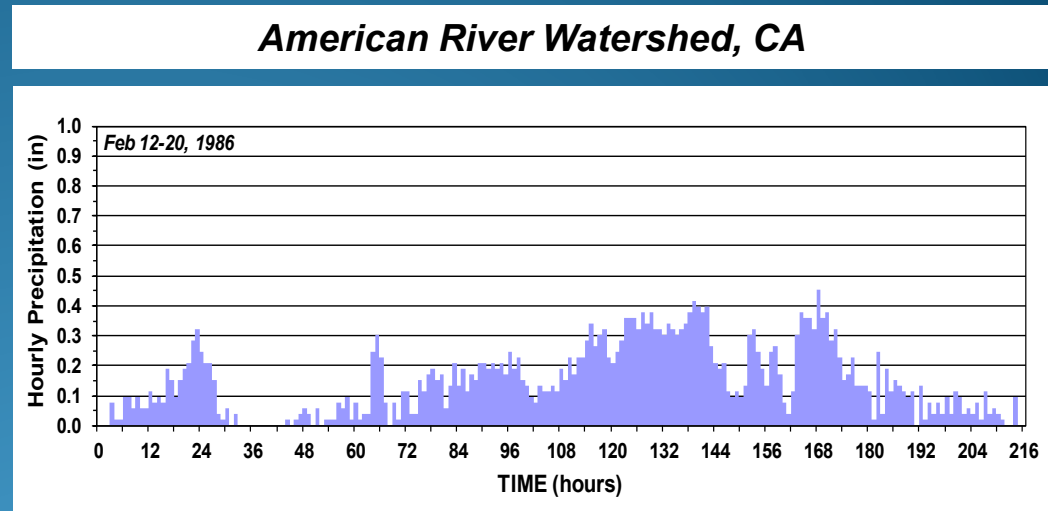
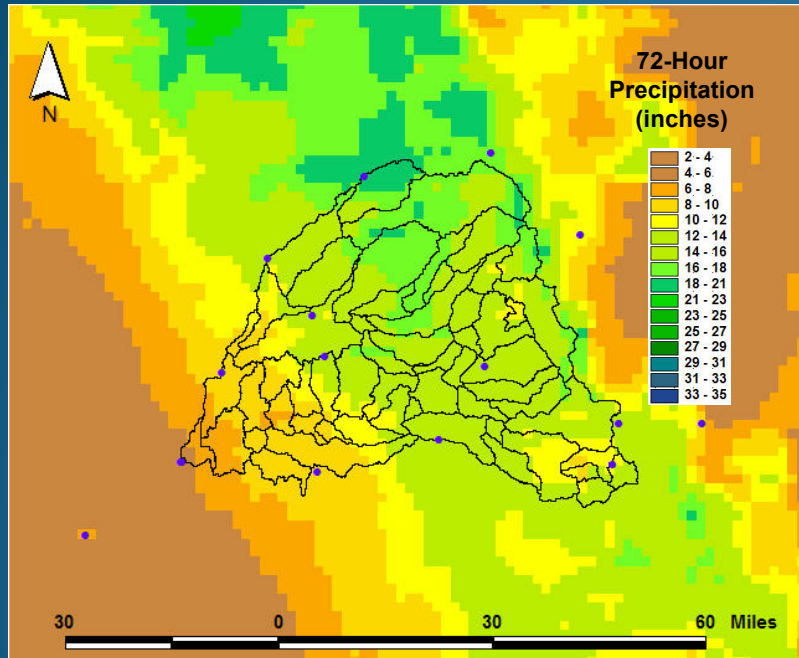


Total storm duration not limited to 72-hours

*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



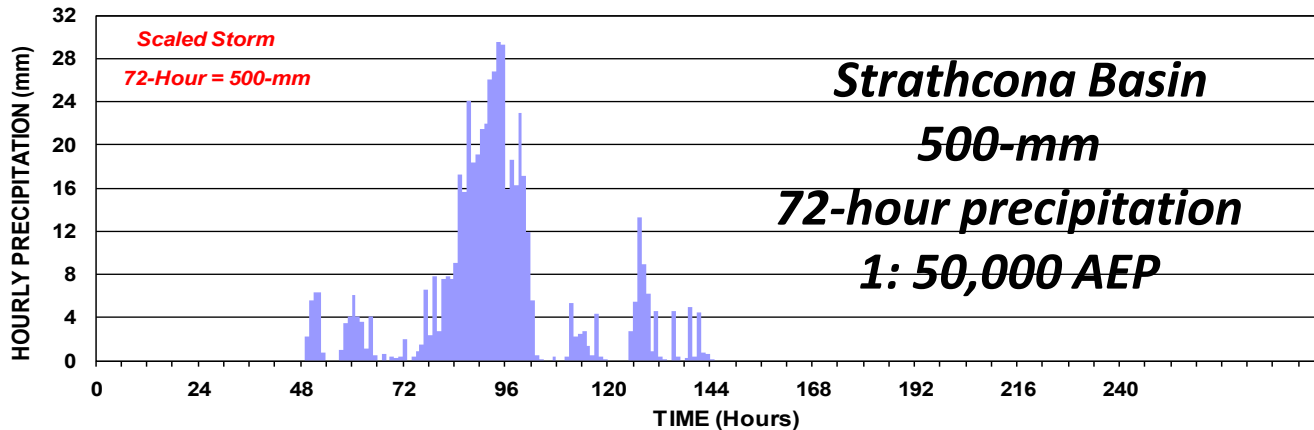
24 Prototype Temporal and Spatial Templates

developed from historical storms observed on the watershed

Stochastic Hydrometeorological Components

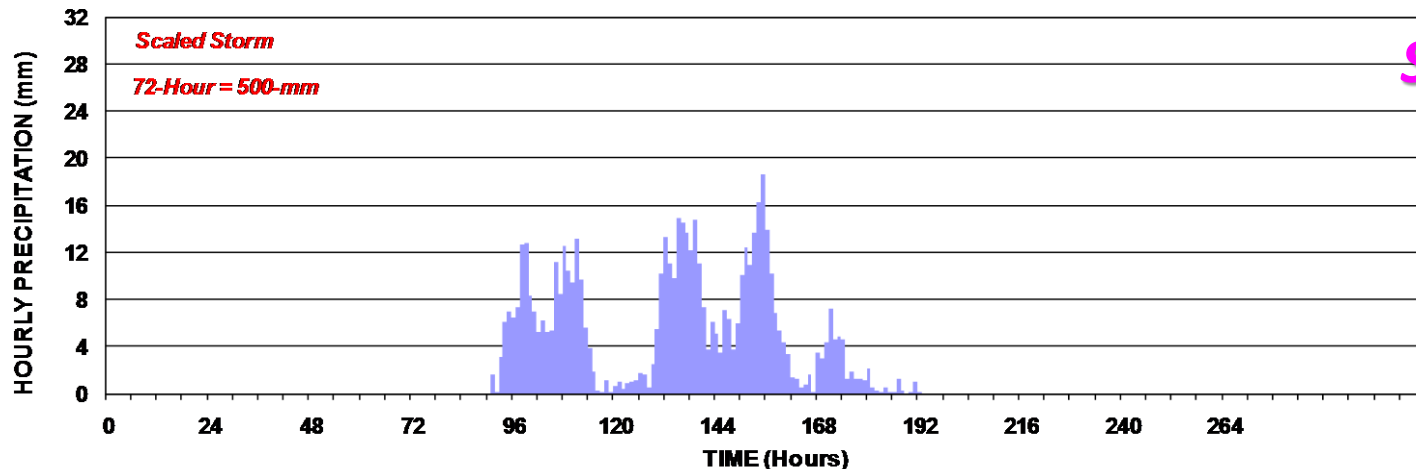
15 Historical Storms used to Develop Suite of Scalable Storm Templates for Strathcona Basin

Strathcona Basin Basin-Average Mar 5-14, 1983



Note Diversity:
Temporal Patterns
Multi-Pulse
Storms

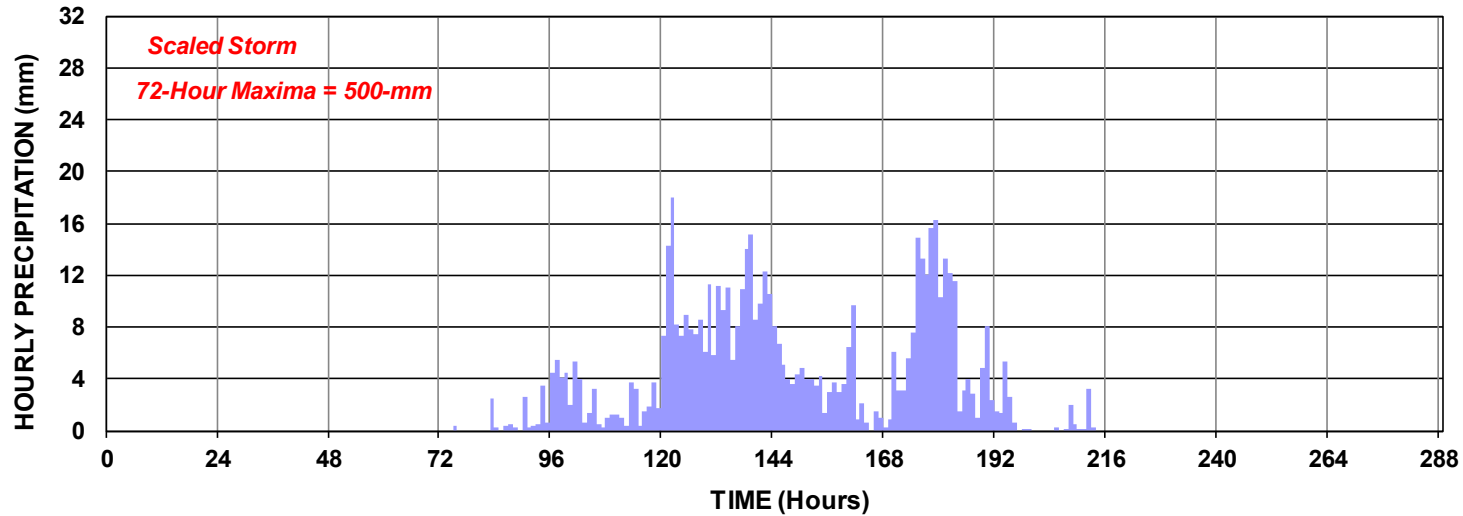
Strathcona Basin Basin-Average Jan 13-23, 2005



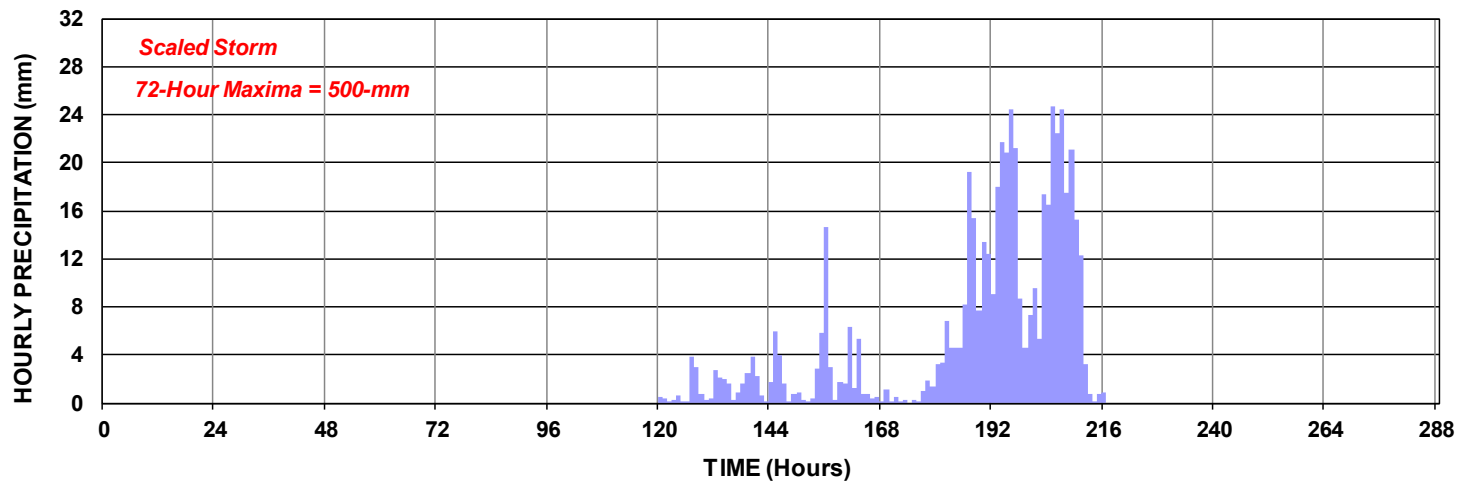
Max Intensities
Storm Duration

Stochastic Hydrometeorological Components

Strathcona Basin Basin-Average Oct 2-12, 1984

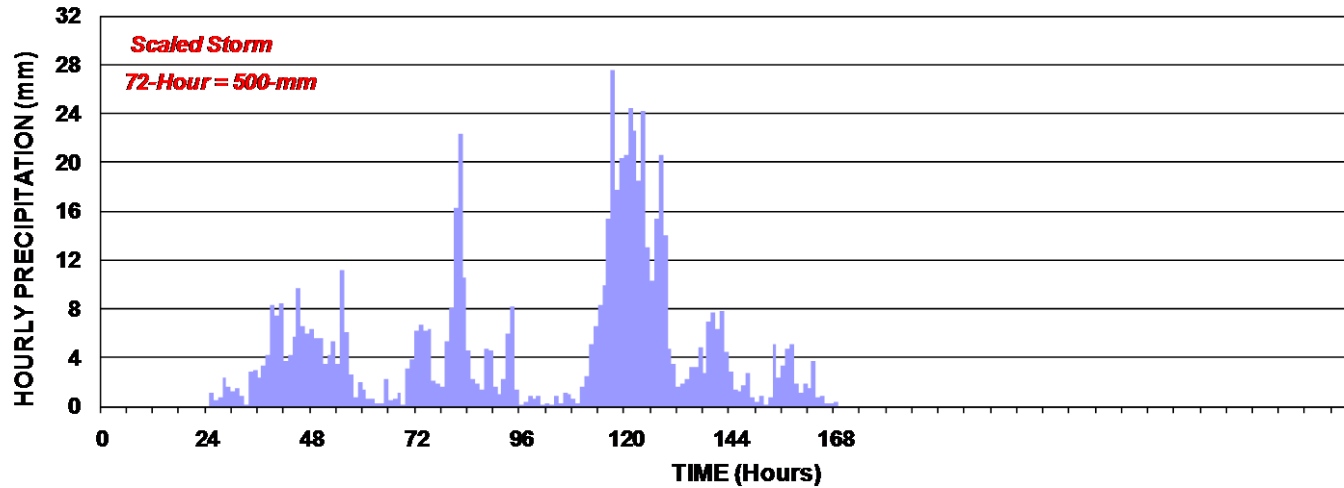


Strathcona Basin Basin-Average Nov 25- Dec 5, 1993

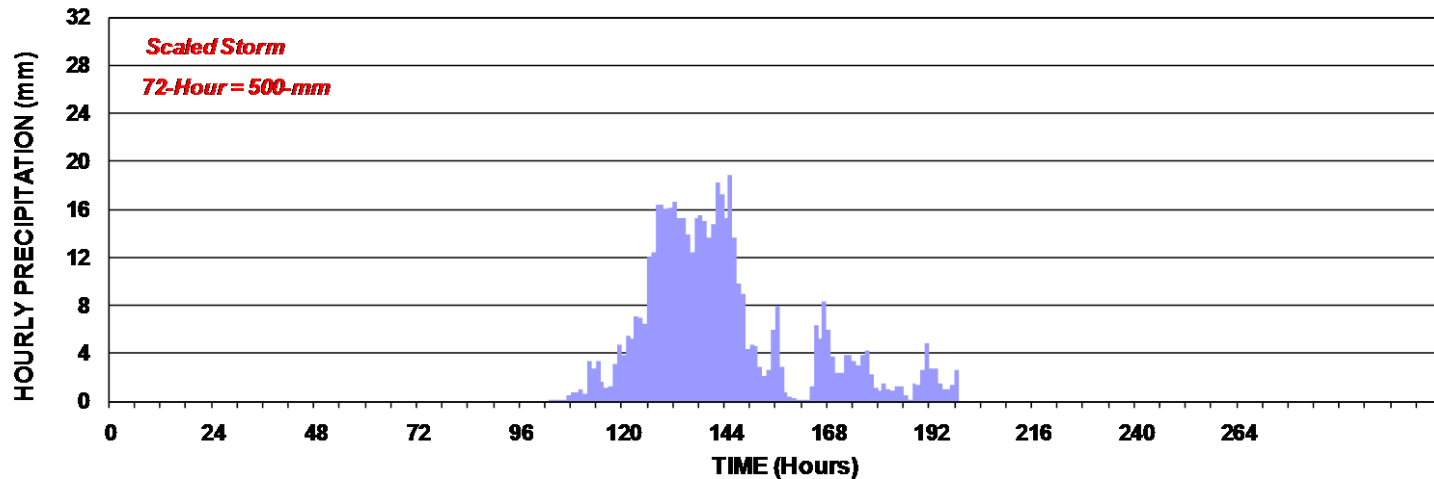


Stochastic Hydrometeorological Components

Strathcona Basin Basin-Average Nov 1-7, 2006

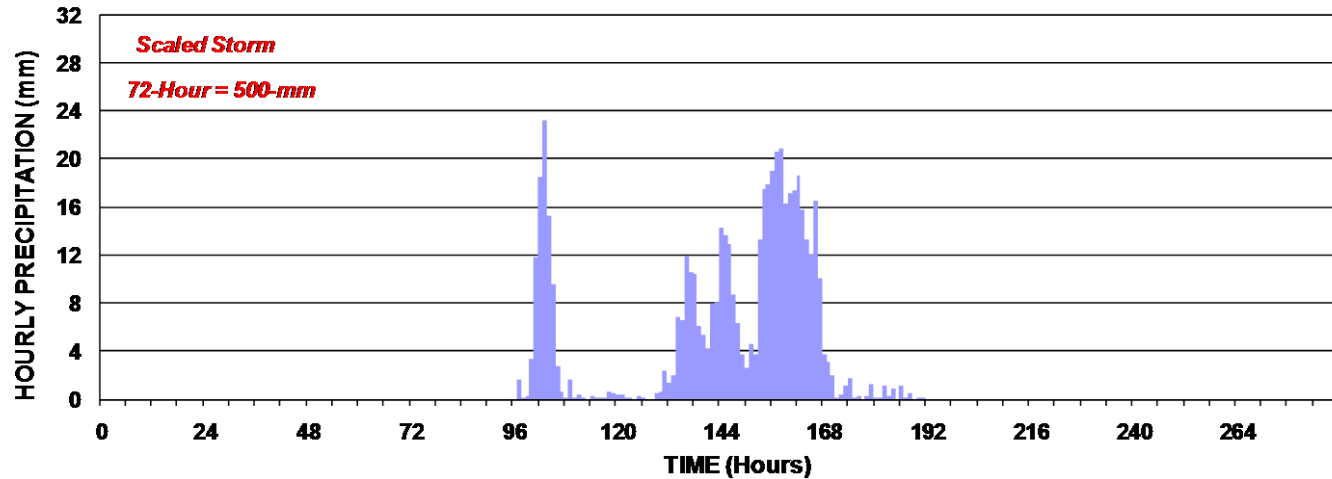


Strathcona Basin Basin-Average Nov 10-20, 2009

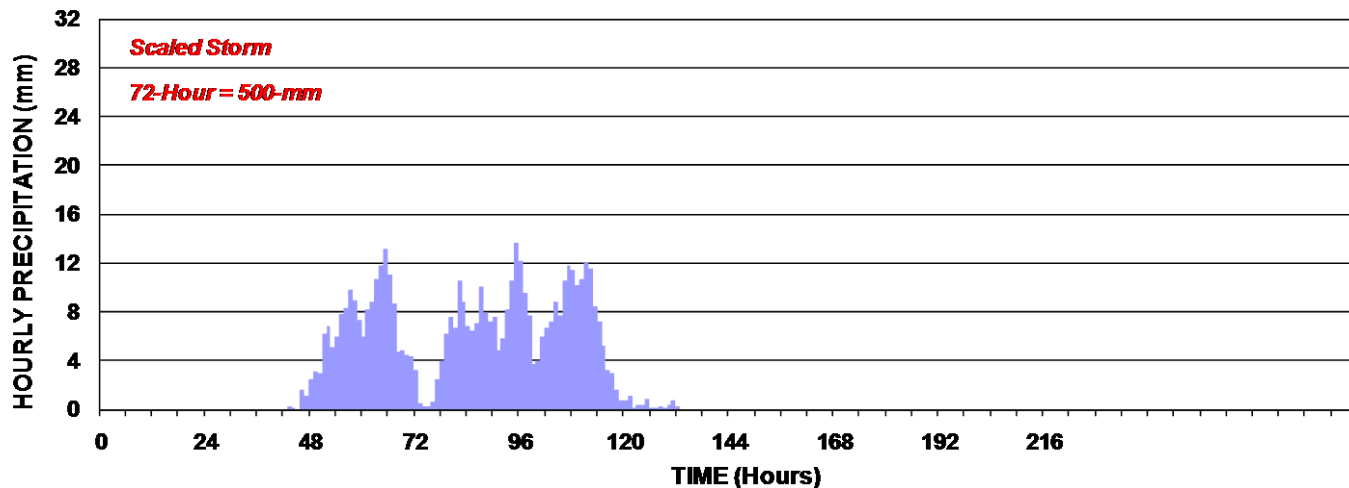


Stochastic Hydrometeorological Components

Strathcona Basin Basin-Average Nov 11-21, 1995



Strathcona Basin Basin-Average Oct 14-22, 2003



**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 IDF's and the PMF*

SEFM Description and Examples...

End-of-Slides