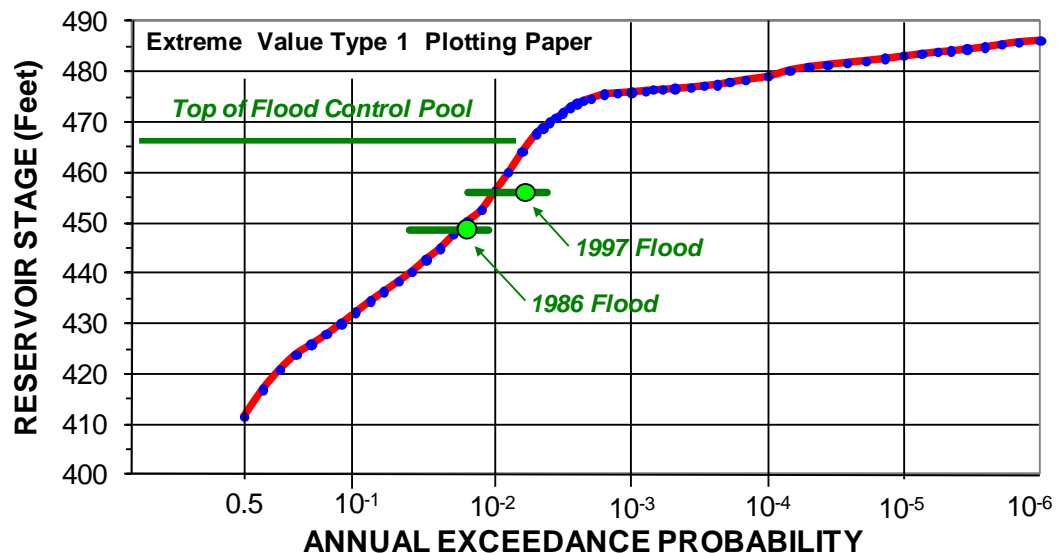
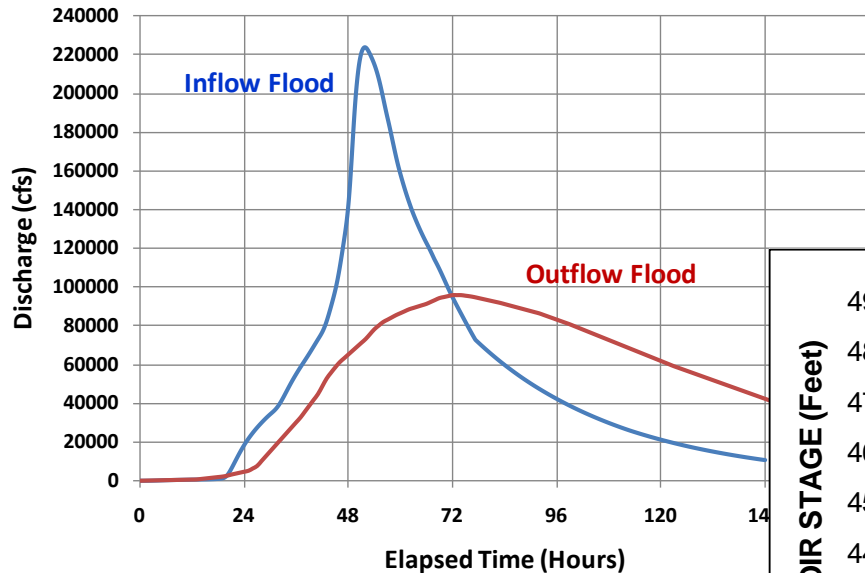


# PMP/PMF – Stochastic Flood Analysis

## Comparison of Methodologies

Western  
Hydropower Dam Owners  
Workshop  
July, 2011

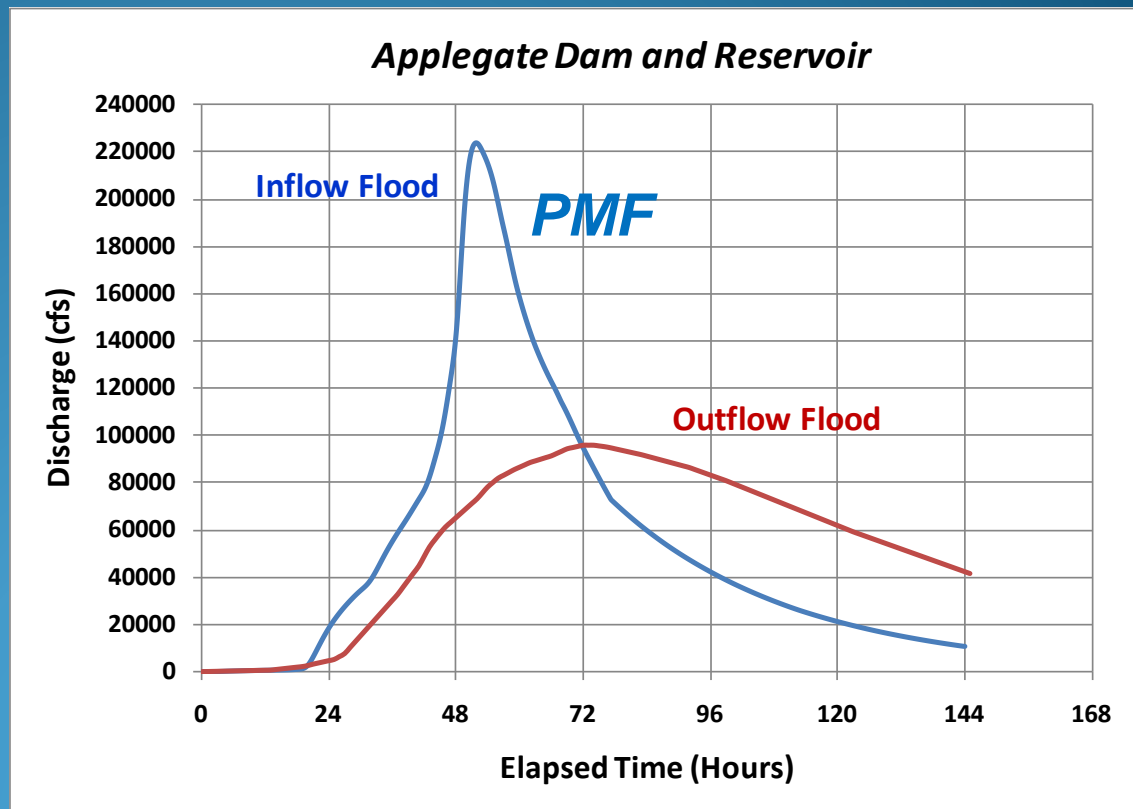
*Applegate Dam and Reservoir*



# ***Deterministic PMF...***

*A single flood hydrograph is developed  
for assessing the hydrologic and hydraulic adequacy  
of a dam and reservoir project*

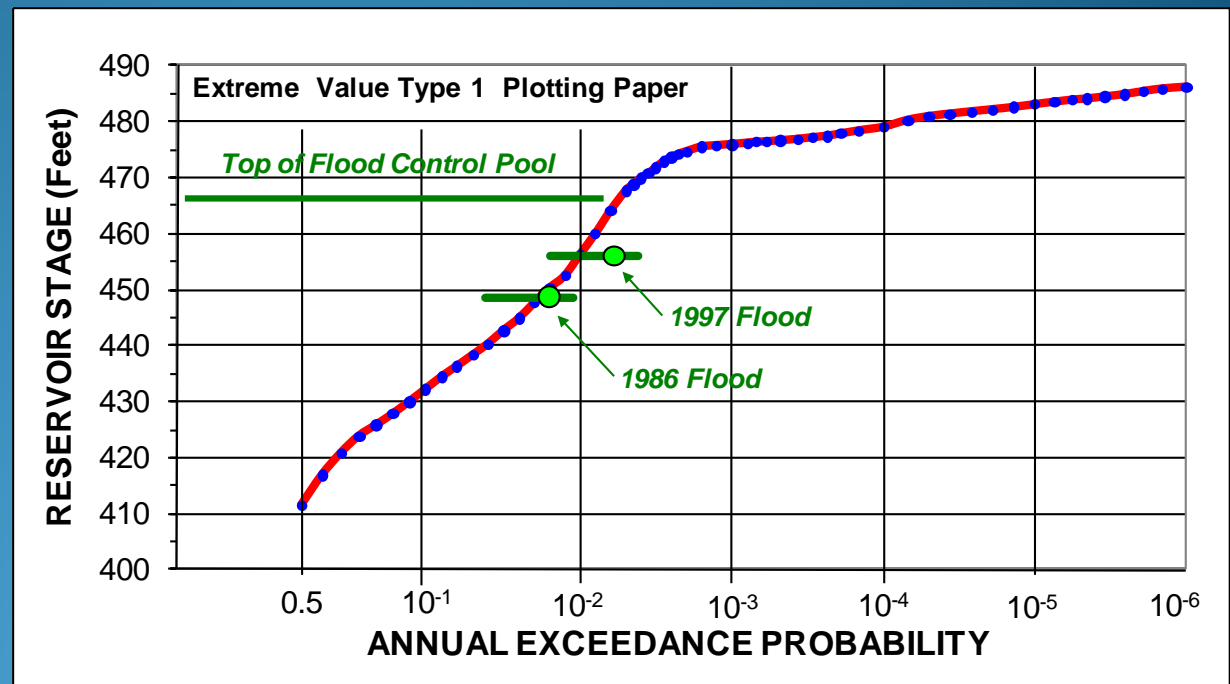
*Sensitivity Analyses  
sometimes used  
to further assess  
project adequacy*



# Stochastic Flood Analysis...

*Multi-thousand flood hydrographs computed to develop flood-frequency relationships for peak inflow, runoff volume, maximum reservoir level and maximum spillway releases based on diversity of storms/floods representative of basin*

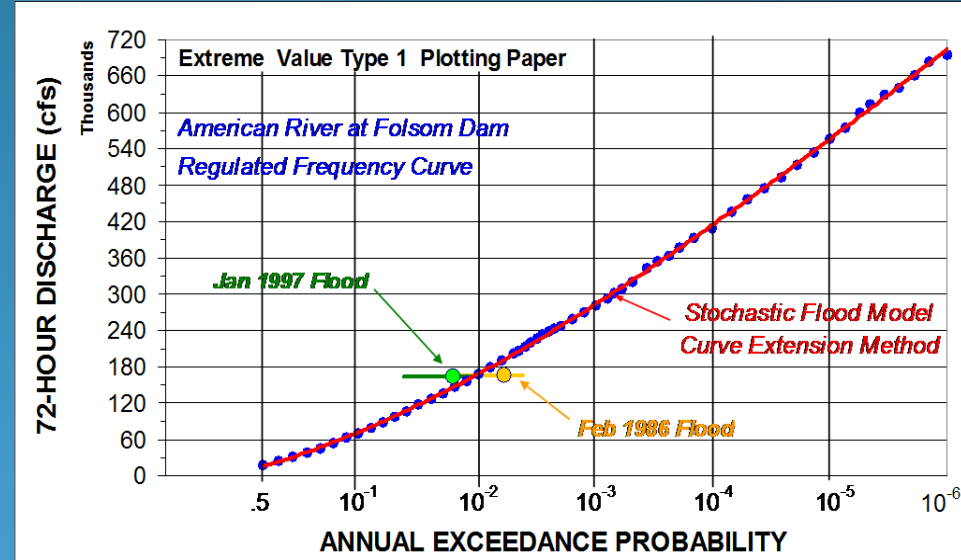
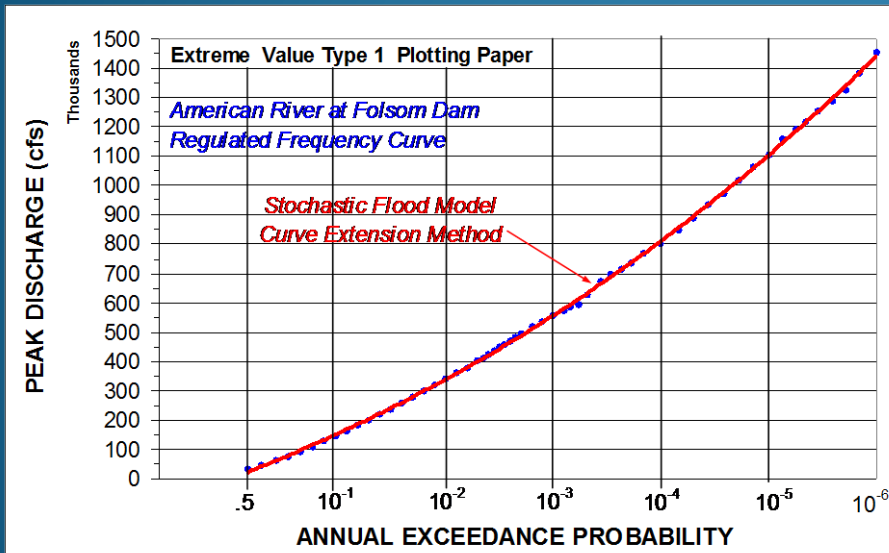
*Robust examination of reservoir response to wide range of flood characteristics*



*Hydrologic Hazard Curve for Max Reservoir Level is Primary Deliverable*

# Stochastic Flood Analysis...

*Flood-frequency relationships developed  
for any flood characteristics of interest  
using flood hydrographs generated from stochastic simulations*

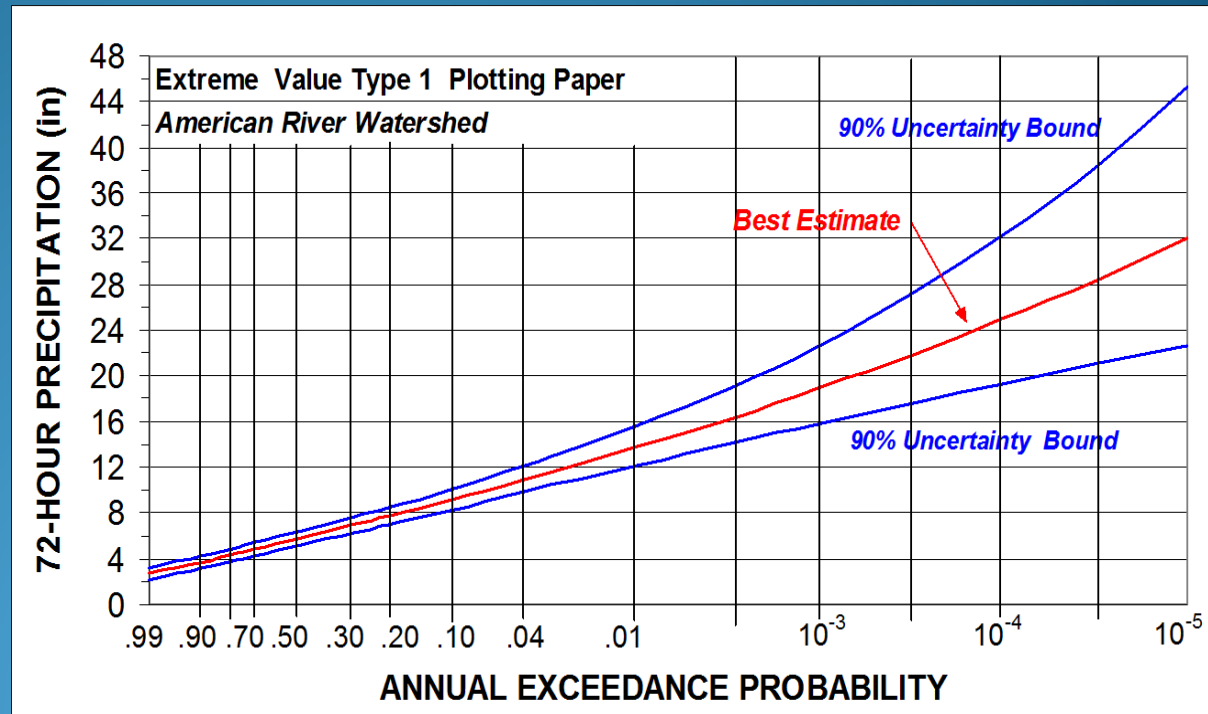


*Other flood-frequency characteristics can be computed such as:  
duration of spillway operation or dam overtopping at certain thresholds*

# Compare Storm Magnitudes ...

| <i>PMP/PMF</i> | <i>Stochastic Flood Analysis</i>   |
|----------------|--|
| 72-Hour PMP    | Full Range of Storm Magnitudes<br>Basin-Average 72-hr<br>Precipitation-Frequency Curve |

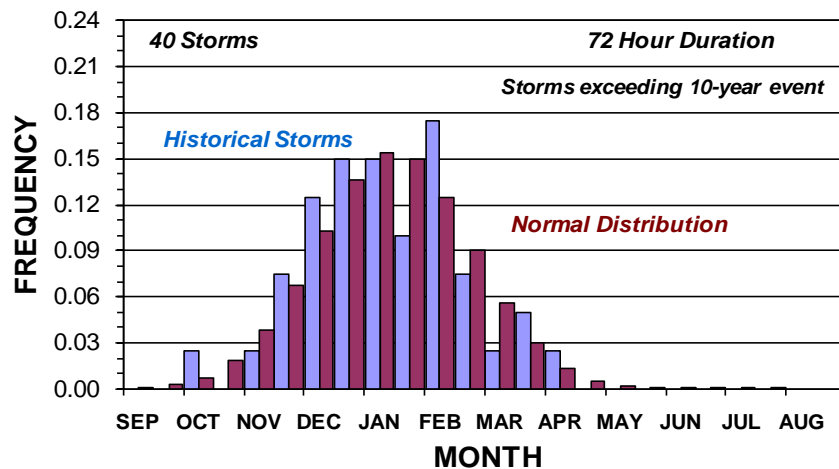
*PMP can be viewed  
as one extreme  
storm among  
a range of extreme  
storms*



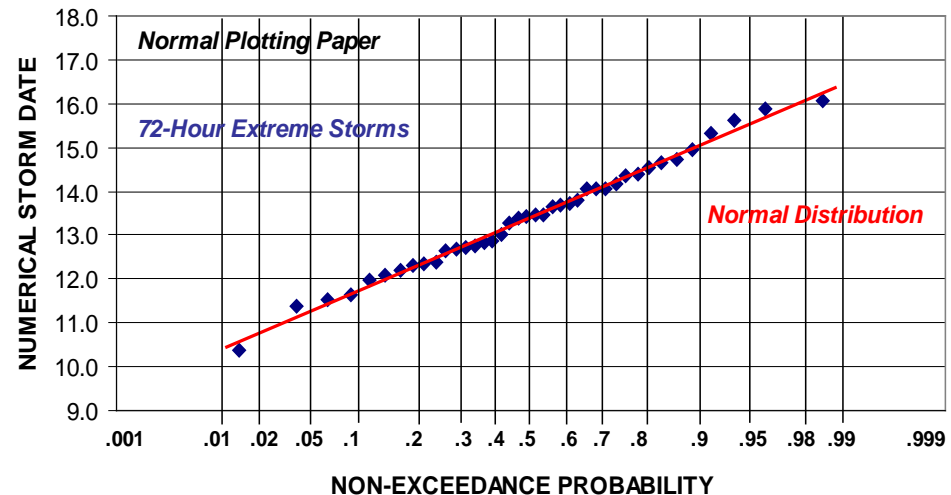
# Compare Storm Seasonality ...

| <i>PMP/PMF</i>                        | <i>Stochastic Flood Analysis</i>                               |
|---------------------------------------|--|
| Month yielding largest flood from PMP | Storm/Flood Dates for full range observed in historical record |

**WEST FACE SIERRA MOUNTAINS**



**American River Watershed**





# Compare Storm Temporal Patterns ...

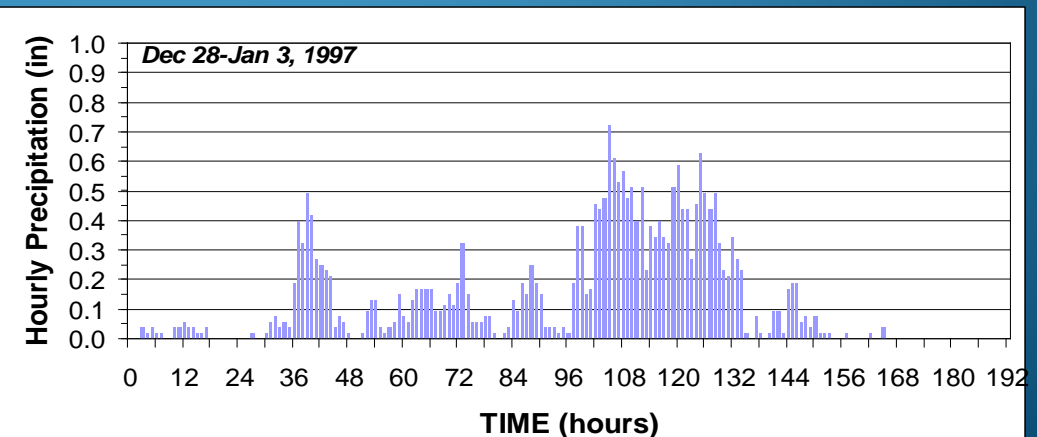
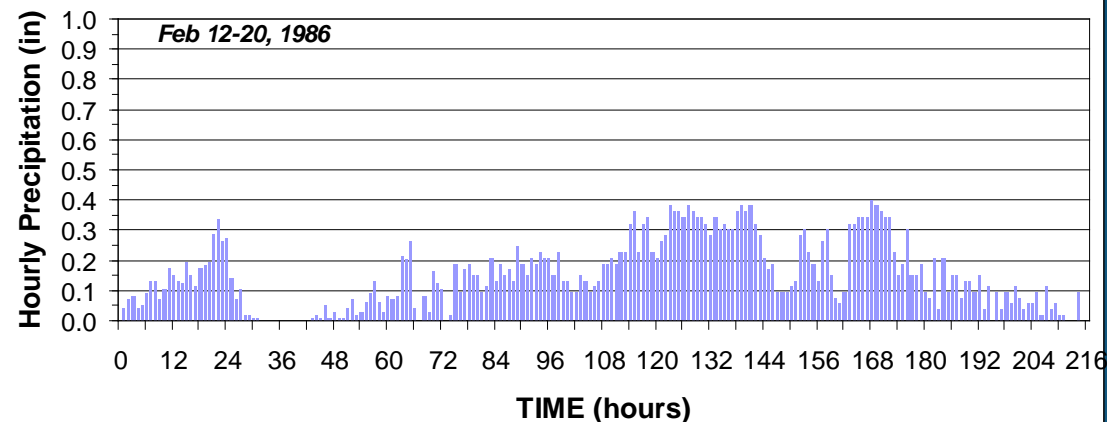
| <i>PMP/PMF</i>               | <i>Stochastic Flood Analysis</i>                      |
|------------------------------|---|
| 1 Synthetic temporal pattern | Suite of temporal patterns based on historical storms |

*Suite of Historical Storms  
(Commonly 12-24 storms)*

*Each prototype storm has  
separate temporal pattern*

*Storms scaled by selected  
72-hour precipitation from  
precipitation-frequency  
relationship*

*Note: storm duration  
not limited to 72-hours*

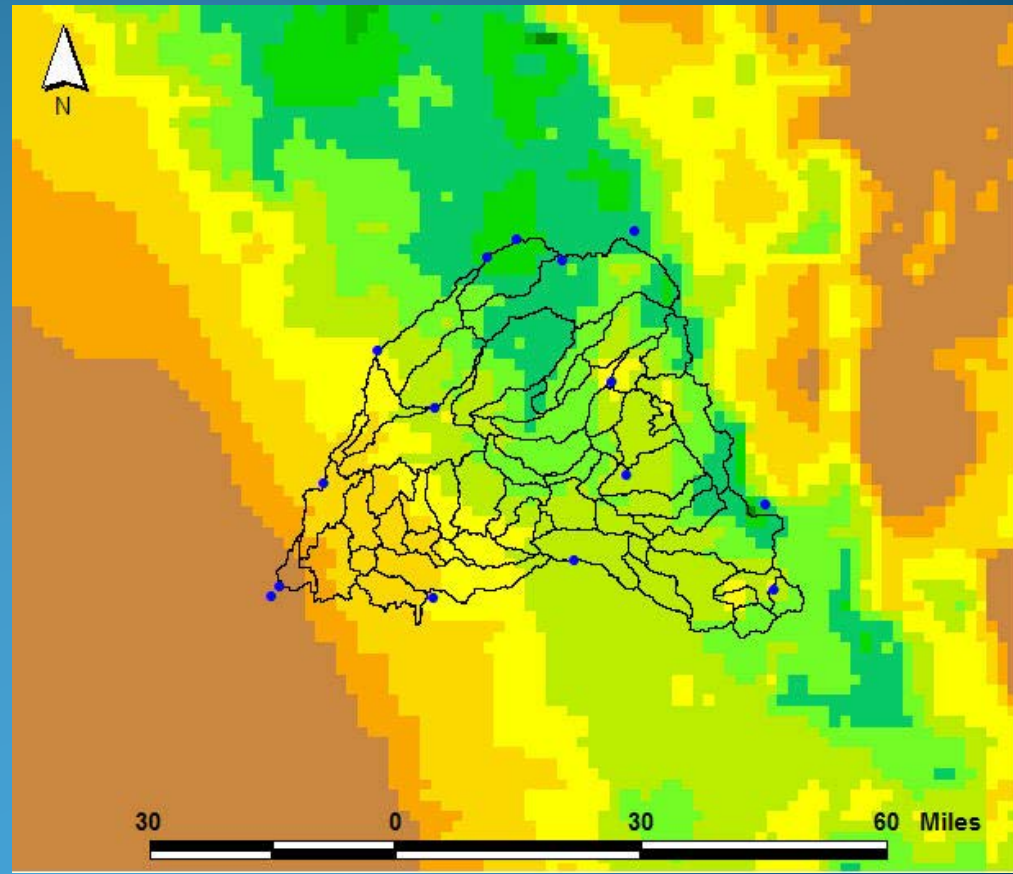


# Compare Storm Spatial Distributions ...

| <i>PMP/PMF</i>       | <i>Stochastic Flood Analysis</i>                     |
|----------------------|--|
| "Critical Centering" | Suite of spatial patterns based on historical storms |

*Suite of Historical Storms*

*Each prototype storm  
has unique spatial  
and temporal pattern*



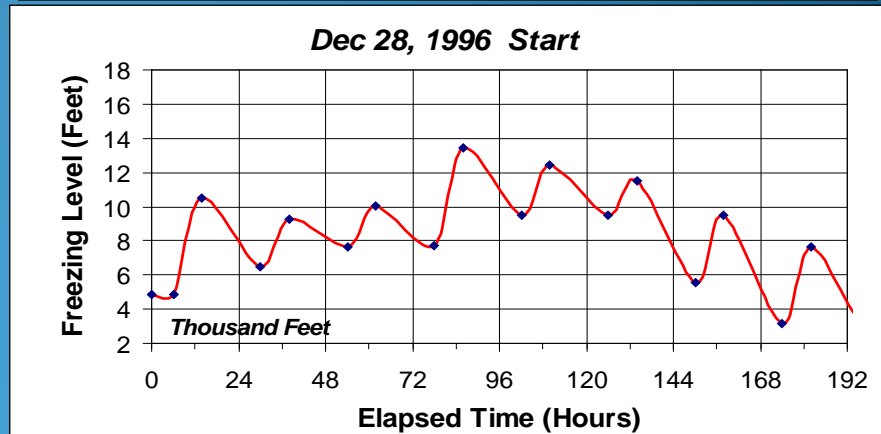
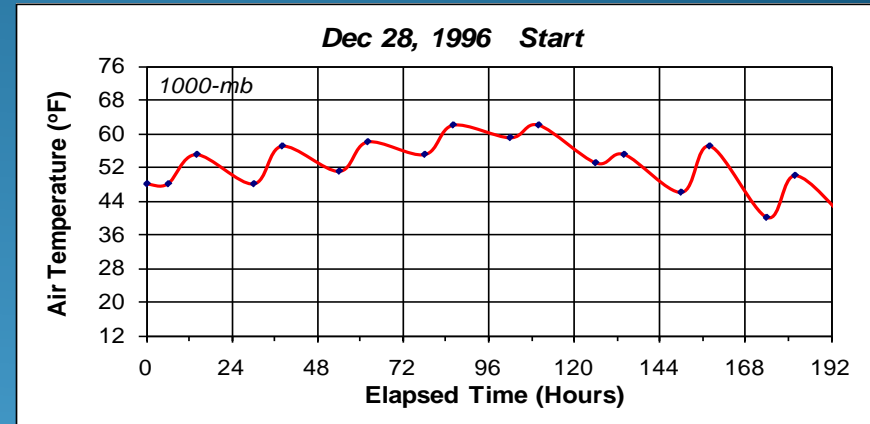


# Compare Air Temperature Temporal Pattern...

| <i>PMP/PMF</i>    | <i>Stochastic Flood Analysis</i>  |
|-------------------|---|
| Synthetic pattern | Separate temporal pattern for each prototype storm based on historical storms |

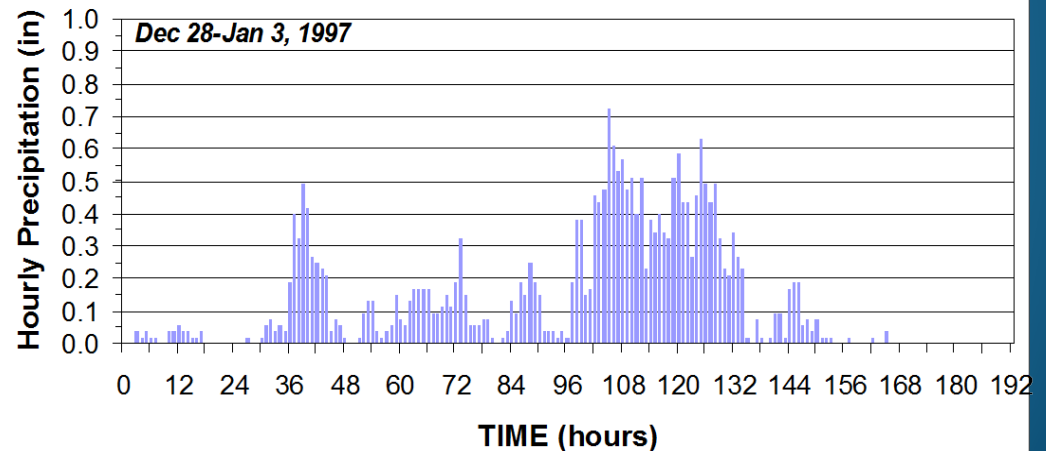
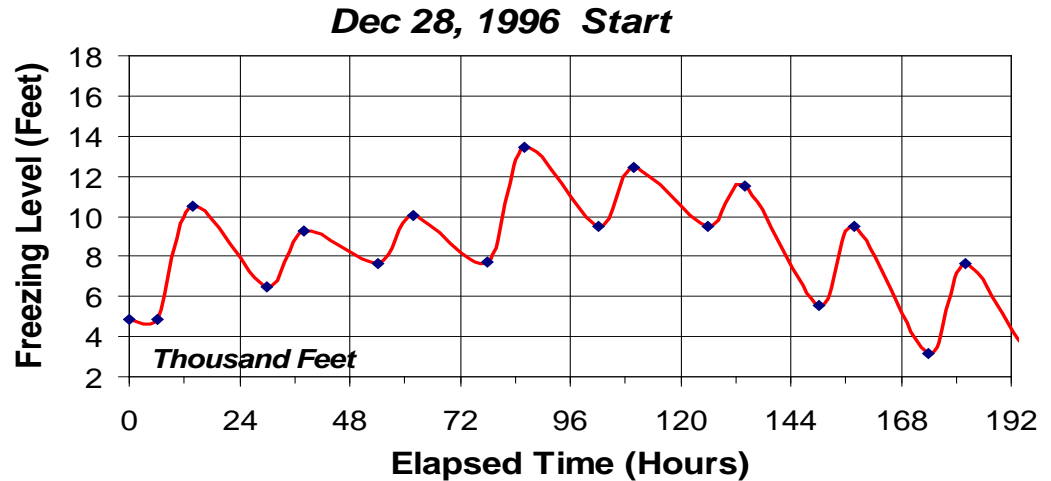
*1000-mb Temperature and Freezing Level are variables*

*Patterns are scaled by values of 1000-mb Temperature and Freezing Level chosen by Monte Carlo methods*



# Compare Air Temperature Temporal Pattern...

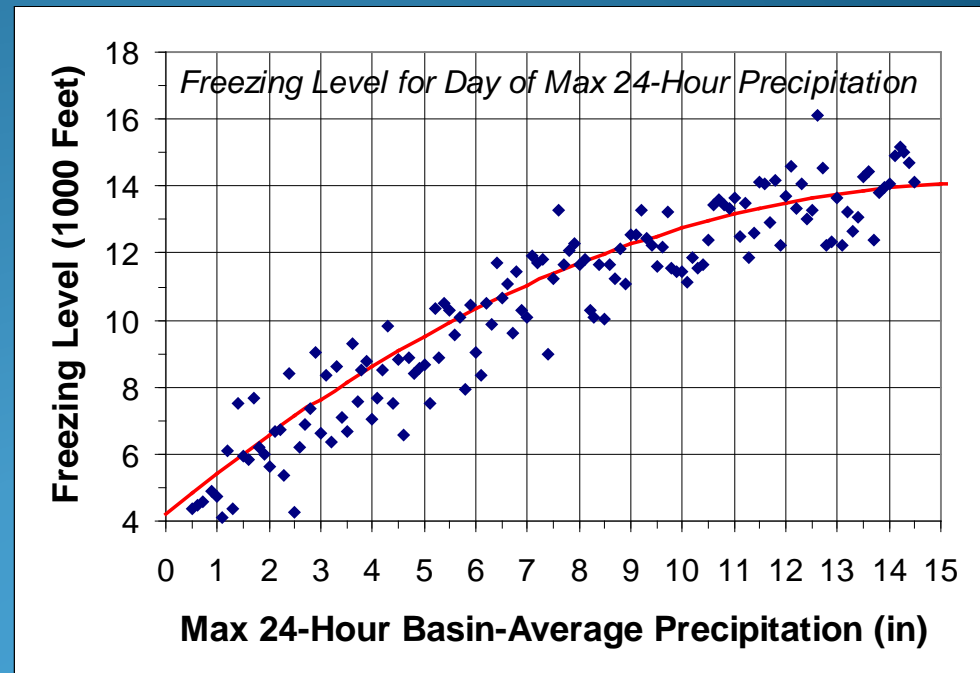
*High Freezing Levels  
for Extreme Storms*



# Compare Freezing Level ...

| <i>PMP/PMF</i>   | <i>Stochastic Flood Analysis</i>   |
|--|--|
| Dependent on<br>air temperature lapse rate<br>set by analyst | Freezing level is stochastic variable<br>based on radiosonde data<br>for historical storms |

*Freezing level is correlated  
with storm magnitude  
and 1000-mb dewpoint*

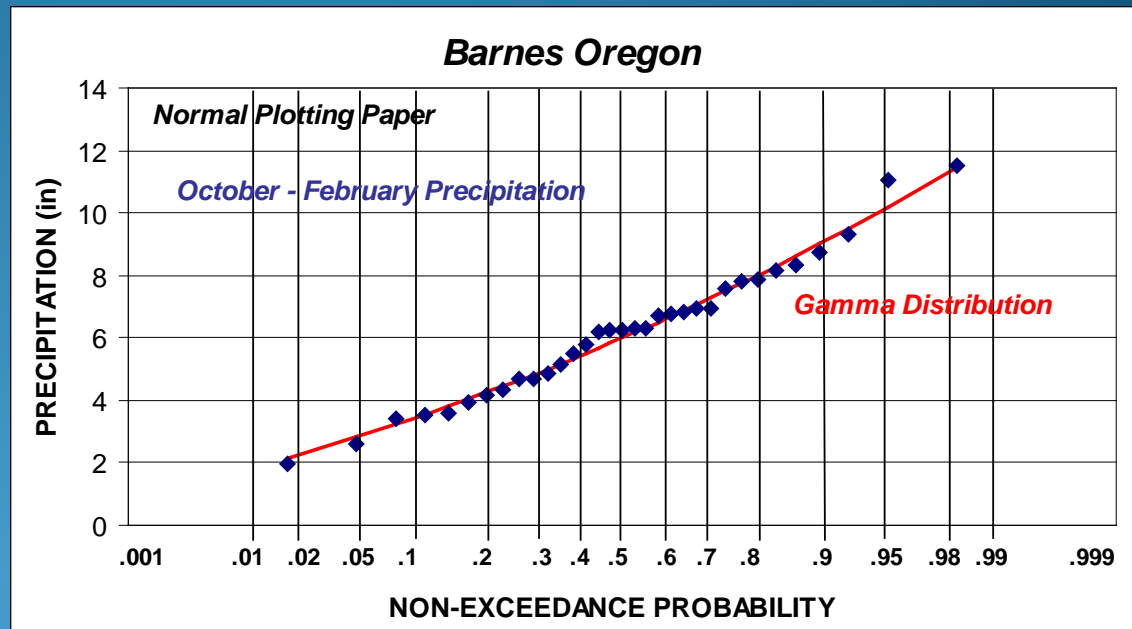


*Example of 500-simulations – Sierra Mountains CA*

# Compare Antecedent Soil Moisture ...

| <i>PMP/PMF</i>            | <i>Stochastic Flood Analysis</i>  |
|---------------------------|---|
| Wet antecedent conditions | Full range of soil moisture conditions observed in historical record varies by date (month) |

*Antecedent precipitation  
used for soil moisture  
accounting and setting  
antecedent snowpack*



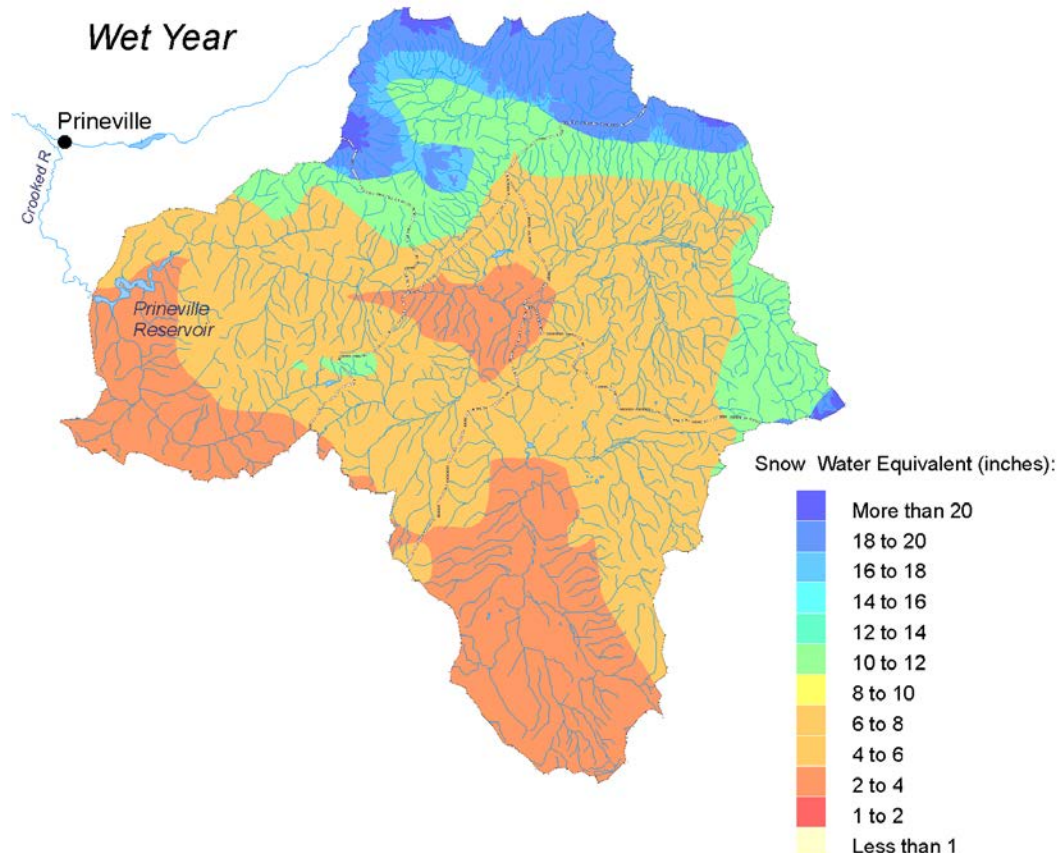
*Example: End-of-February storm date  
in semi-arid climate, Oregon*

# Compare Antecedent Snowpack...

| <i>PMP/PMF</i>        | <i>Stochastic Flood Analysis</i>                                |
|-----------------------|---|
| Conservative Snowpack | Full range of snowpack conditions observed in historical record |

*Snowpack depth and density varies spatially by date, elevation and antecedent precipitation*

*Example:  
End-of-February storm date  
in semi-arid climate, Oregon*





## Compare Soil - Runoff Characteristics...

| <i>PMP/PMF</i>                                  | <i>Stochastic Flood Analysis</i>  |
|---|---|
| Soil Moisture Deficit = 0<br>Minimum loss rates | Soil moisture deficit<br>and soil loss rates<br>dependent on soil moisture conditions |

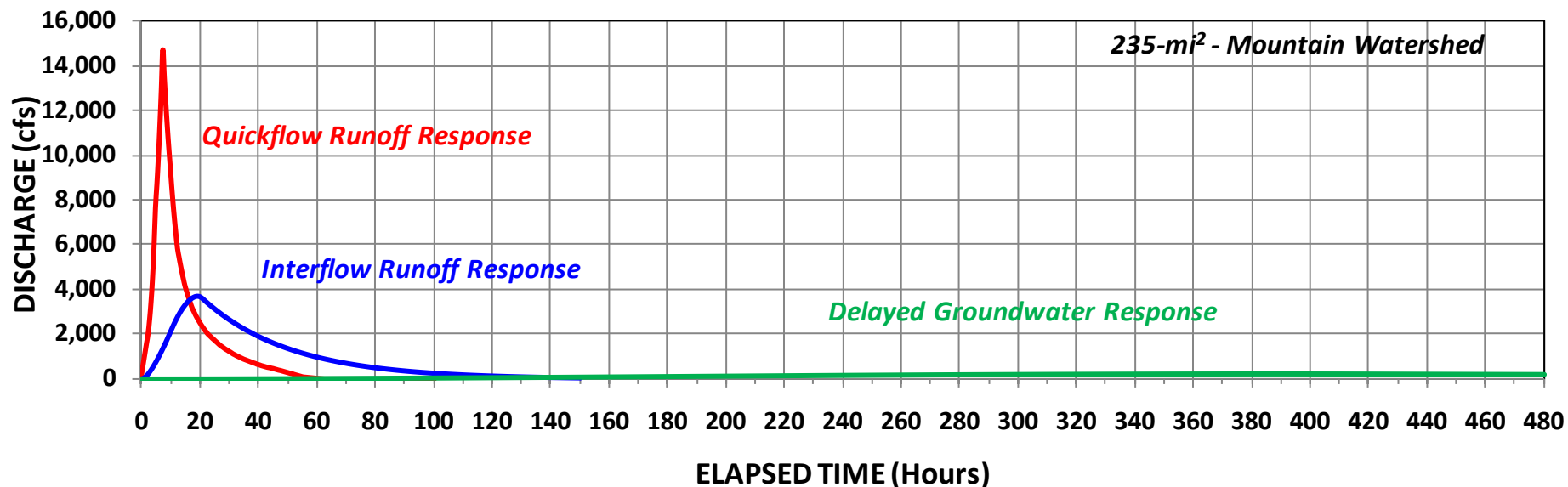
*Soil moisture conditions dependent upon soil moisture  
accounting based on storm date, antecedent  
precipitation and evapo-transpiration*

# Compare Runoff Response...

| <i>PMP/PMF</i>                         | <i>Stochastic Flood Analysis</i>                          |
|--|---|
| Commonly “surface” response is modeled | Surface Runoff (quickflow) and Interflow Runoff Responses |

*Slower interflow response common in forested mountain watersheds with some quickflow response for extreme storms*

**Characteristic Streamflow Responses to Runoff Generation**



## *Compare Initial Reservoir Level ...*

---

| <i>PMP/PMF</i>               | <i>Stochastic Flood Analysis</i>                           |
|------------------------------|--|
| Conservative reservoir level | Based on historical reservoir levels for chosen storm date |

*Historical reservoir level data inherently reflects reservoir operations in addition to seasonal climatic variables*

*Stochastic simulations will mimic seasonal variability in reservoir level exhibited in historical record*

## *Compare Flood Computations...*

| <i>PMP/PMF</i>                                  | <i>Stochastic Flood Analysis</i>                |
|---|---|
| Watershed Model<br>and rainfall-runoff modeling | Watershed Model<br>and rainfall-runoff modeling |

*Distributed rainfall-runoff modeling  
preferred for stochastic method*

*where runoff computed on  
land segments  
smaller than sub-basin level*

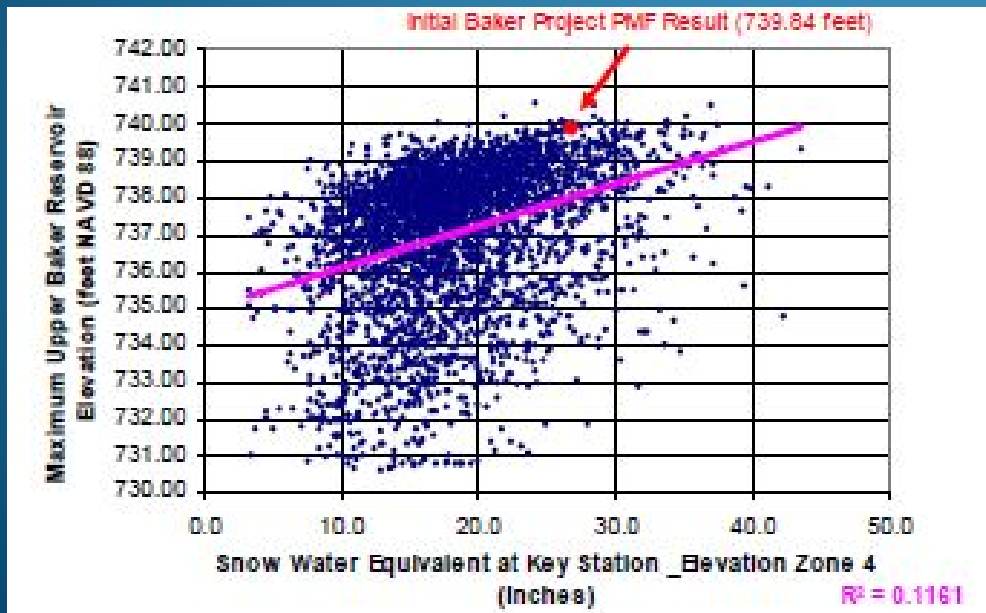
# Compare Calibration of Watershed Model...

| <i>PMP/PMF</i>                        | <i>Stochastic Flood Analysis</i>  |
|---------------------------------------|---|
| Calibrated to large historical floods | <p>Calibrated to large historical floods and other storm/flood events to assess model parameters over wide range of climatic conditions</p> <p>Also Calibrated to historical flood-frequency relationship for project inflows</p> <p><i>2 Additional Levels of Calibration for Watershed Model and SEFM</i></p> |



# Compare Sensitivity Analysis ...

| <i>PMP/PMF</i>         | <i>Stochastic Flood Analysis</i>   |
|------------------------|--|
| One-at-a-Time approach | Global Sensitivity Analysis<br>is standard output<br>from stochastic simulations |



*Global sensitivity analysis  
can account for interaction  
and dependencies between  
inputs/model parameters*

*Scatter due to numerous other  
hydrometeorological inputs  
affect maximum reservoir level*

## ***Compare Uncertainty Analysis ...***

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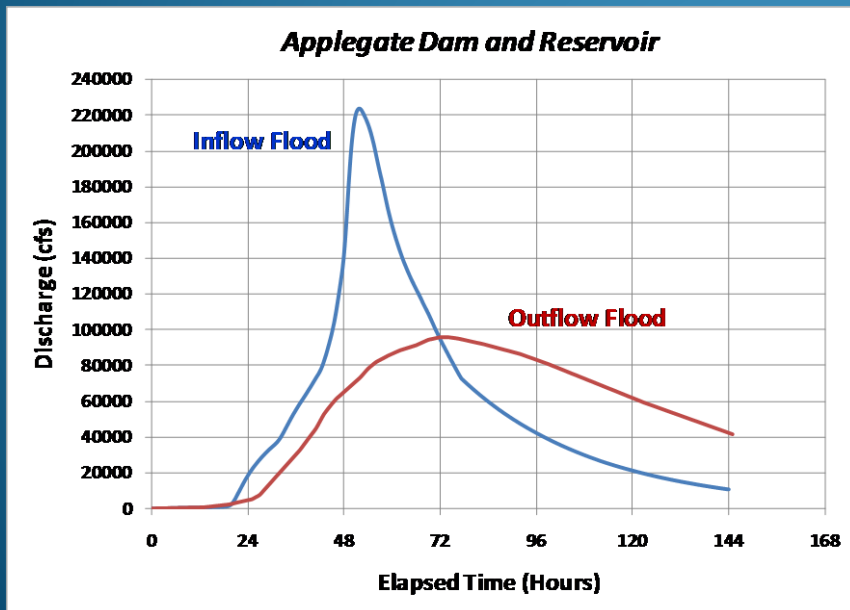
| <b><i>PMP/PMF</i></b>   | <b><i>Stochastic Flood Analysis</i></b> |
|-------------------------|---|
| Not Done – Feasibility? | Optional                                |

*Uncertainty analyses can be conducted  
and uncertainty bounds can be developed  
for flood-frequency relationships*

# Summary ...

## Deterministic PMP/PMF

*uses a single flood hydrograph (PMF)  
and sensitivity analyses  
to assess hydrologic and hydraulic adequacy  
of a dam and reservoir project*



*based on  
conservative selections  
of hydrometeorological inputs  
and watershed parameters  
(policies and guidelines)*

# Summary ...

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## Stochastic Flood Analysis

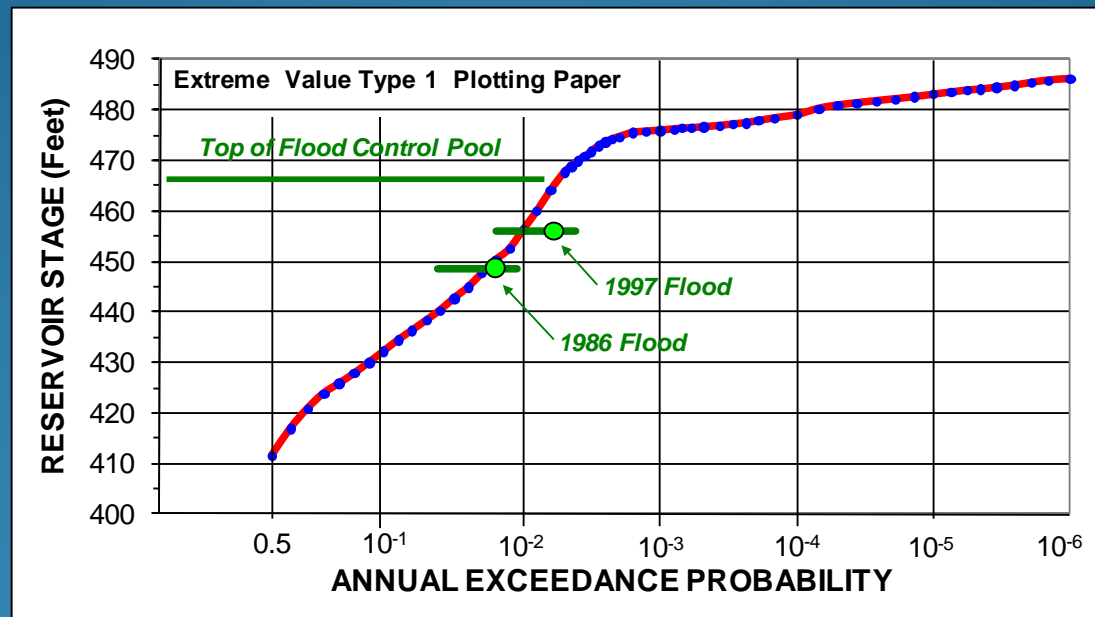
*Produces flood-frequency relationships  
based on simulation of multi-thousand flood hydrographs  
produced by combinations of hydrometeorological conditions  
consistent with the historical record*

*Hydrometeorological inputs are simulated by Monte Carlo methods  
which preserves the seasonal characteristics  
and dependencies between parameters  
exhibited in the historical record*

# Summary ...

## Stochastic Flood Analysis

*Robust examination of reservoir response  
to diversity of flood characteristics*



*The focus is on assessing  
the magnitude and frequency of extreme floods  
and providing information for Risk-Informed Decision-Making*



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*End of Slides*