A Hydrological Tool for Analysis of Extreme Floods

Stochastic Event Flood Model (SEFM)

Stochastic Modeling 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
  10,000 simulations in 1-hour

- Availability of 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
  30+ 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
History of SEFM ...

BC Hydro
Mica Dam, 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
Current Projects 2011 - SEFM ...

BC Hydro
Campbell River System, Vancouver Island BC
3 dams in series 1,500-km² watershed

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
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**
conducted 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, UBC, 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**
5) Compute Multi-Thousand Flood Annual Maxima using Hydrologic Model and Input Datasets – Conduct Sufficient Simulations to Exceed Flood Magnitudes of Interest for a Particular Project

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**
  - including variable duration of total storm
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
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.
SEFM – Output…

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

Hydrologic loading for extreme floods are of primary interest
Folsom Dam – SEFM Example...

American River Watershed 1,862-mi²

33 sub-basins

5 major dams upstream of Folsom Lake
Distributed Rainfall-Runoff, Snowmelt Modeling

11 Zones of Mean Annual Precipitation

Mean Annual Precipitation varies from 20-inches (zone 1) to 72-inches (zone 11)
Distributed Rainfall-Runoff, Snowmelt Modeling

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 watershed for:

- Soil moisture accounting
- Snow-water accounting
- Spatial allocation of snowpack
- Rainfall-runoff modeling
- Snowmelt modeling
Stochastic Hydrometeorological Inputs

Seasonality of Storms

Storm Dates were drawn from a Normal Distribution based on the historical occurrence of large storms on the west face of the Sierra Mountains in California.
500,000 flood simulations conducted based on representative sample of 500,000 72-hour precipitation annual maxima developed from regional frequency analysis and site-specific storms on the American River watershed.
Stochastic Hydrometeorological Inputs

Spatial and Temporal Distribution of Precipitation

24 Prototype Temporal and Spatial Templates
developed from historical storms observed on the watershed
scaled by 72-Hour precipitation selected for that simulation
Stochastic Hydrometeorological Inputs

Spatial and Temporal Distribution of Precipitation

Total storm duration not limited to 72-hours

24 Prototype Temporal and Spatial Templates developed from historical storms observed on the watershed scaled by 72-Hour precipitation selected for that simulation
Stochastic Hydrometeorological Inputs

Air Temperature Temporal Patterns for Snowmelt Computation

1000-mb Air Temperature (sea-level) and Freezing Levels are scaled based on behavior observed in large historical storms.
Stochastic Hydrometeorological Inputs

Display of 24 Prototype Temporal Patterns

American River.pdf
Stochastic Hydrometeorological Inputs

Snowpack Characteristics

Historical monthly snowpack data used to develop relationships for spatially allocating snowpack (tracks snow-free ground as well as snow-on-ground)

Snowpack varies by month, elevation, and antecedent precipitation prior to storm date
Stochastic Hydrometeorological Inputs

Storage in Upstream Reservoirs

Floodwater storage available in 5 upstream reservoirs affected flood control at Folsom Dam.

Stochastic routine developed to account for seasonal floodwater storage and correlated behavior between historical reservoir operation at 5 upstream reservoirs.
Stochastic Hydrometeorological Inputs

Initial Reservoir Storage at Folsom Lake

Seasonal historical reservoir levels and prior Rule Curves were analyzed at Folsom Lake and used to stochastically select initial reservoir levels for flood simulations.
Calibration of Watershed Model

Multiple Calibration Events

HEC-1 Watershed Model calibrated using 4 storm/flood events and 12 flood hydrographs
SEFM calibrated to match historical 3-day discharge frequency curve at Folsom Dam site
Stochastic Simulation Procedure

Simulations are conducted representing 500,000 annual maxima floods.
Information provided for reservoir response of common through rare floods as well as for Dam Safety and Overtopping
Outputs from SEFM – Folsom Dam

72-Hour Maximum Discharge

American River at Folsom Dam
Regulated Frequency Curve

Jan 1997 Flood
Feb 1986 Flood

Extreme Value Type 1 Plotting Paper

72-HOUR DISCHARGE (cfs)

720
660
620
580
540
500
460
420
380
340
300
260
220
180
140
100
60
20
0

ANNUAL EXCEEDANCE PROBABILITY

.5
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6

Thousands
Outsputs from SEFM – Folsom Dam

Maximum Reservoir Discharges

Information provided for likelihood of downstream flooding due to release of floodwaters.
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

Discussion