

# Overview of the TVA PFHA Calculation System

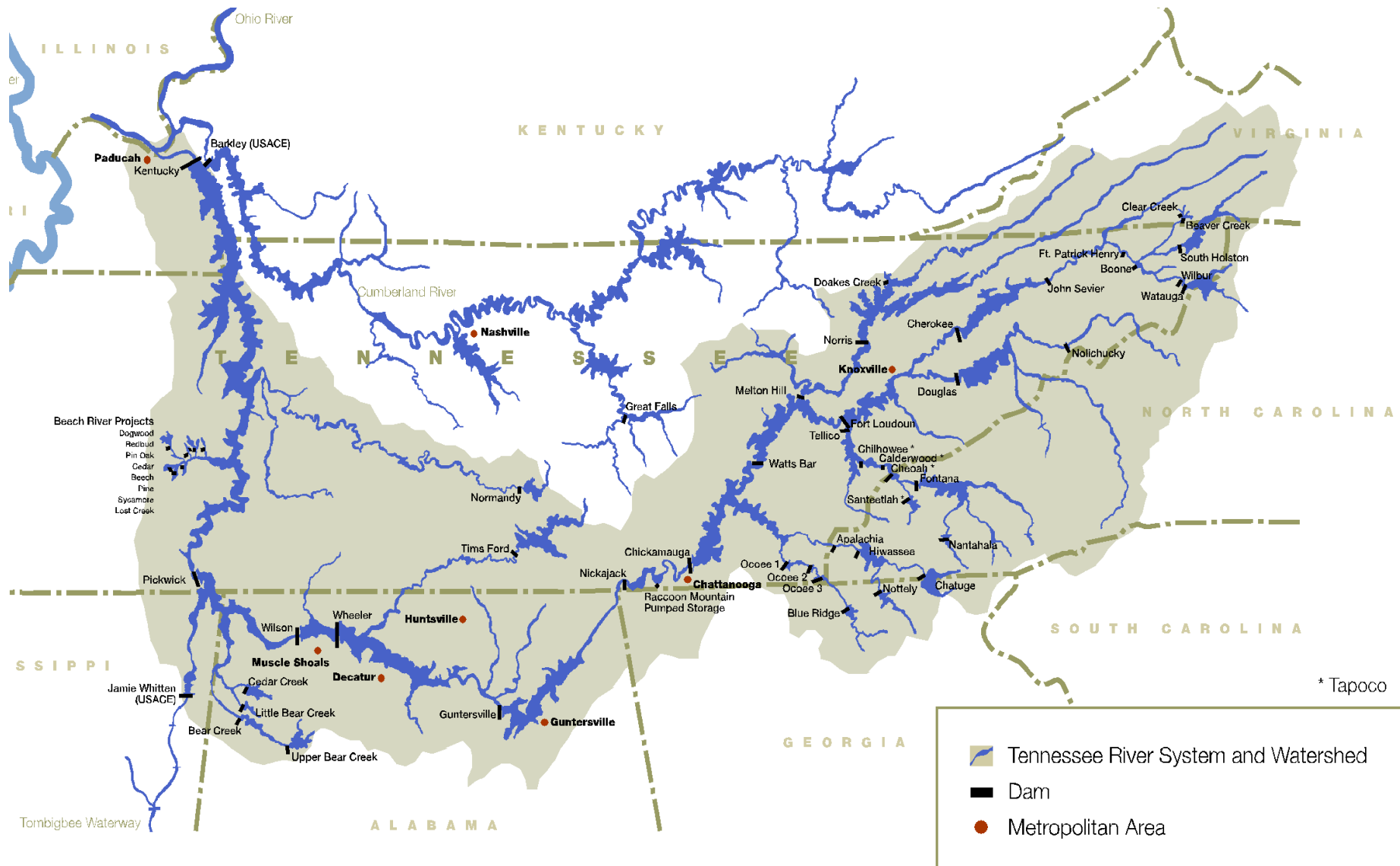
Shaun Carney (RTI International)

Curt Jawdy (TVA)



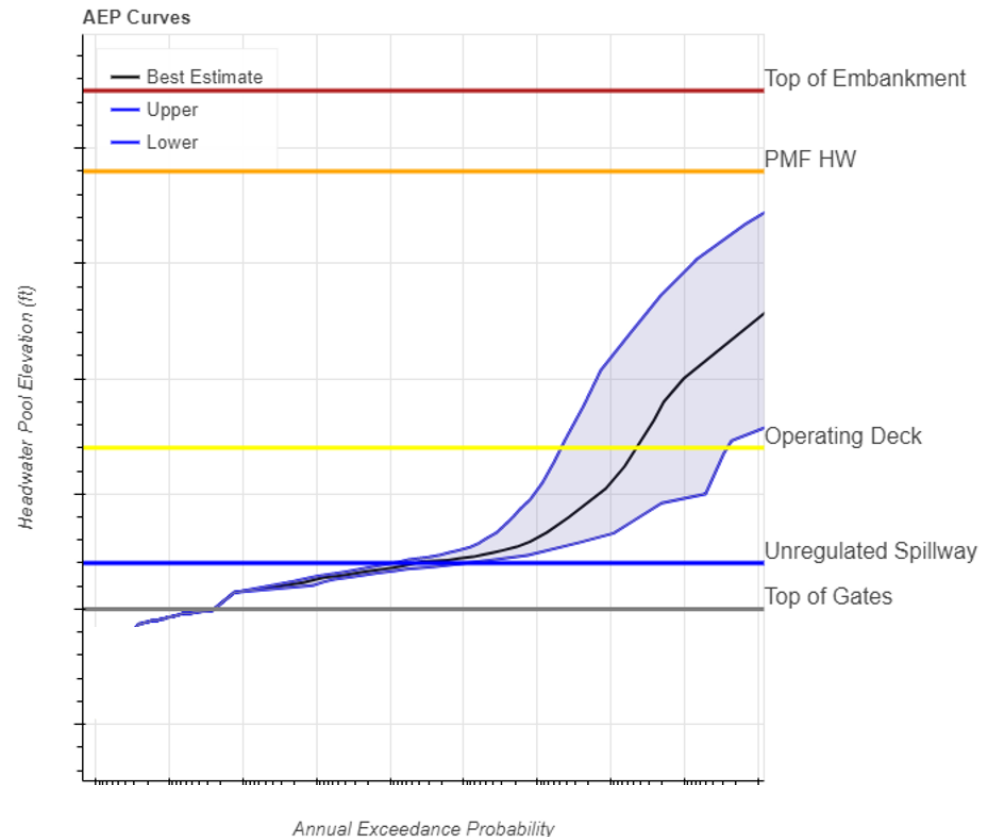
# TVA Dams

- 49 dams, of which over 30 are operated as a large system



# Probabilistic Flood Hazards Analysis at TVA

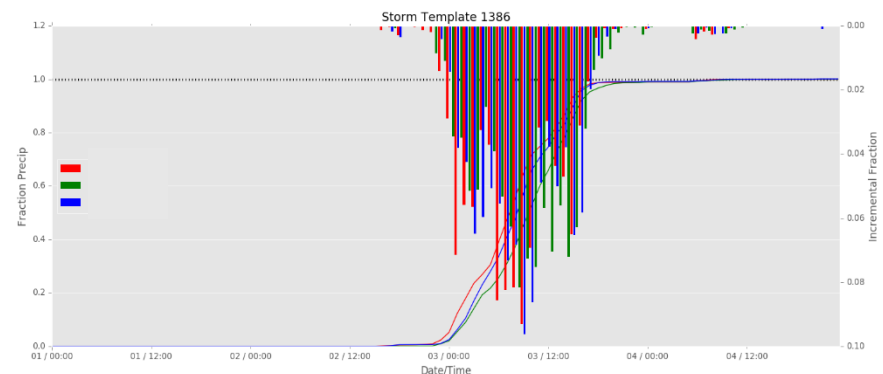
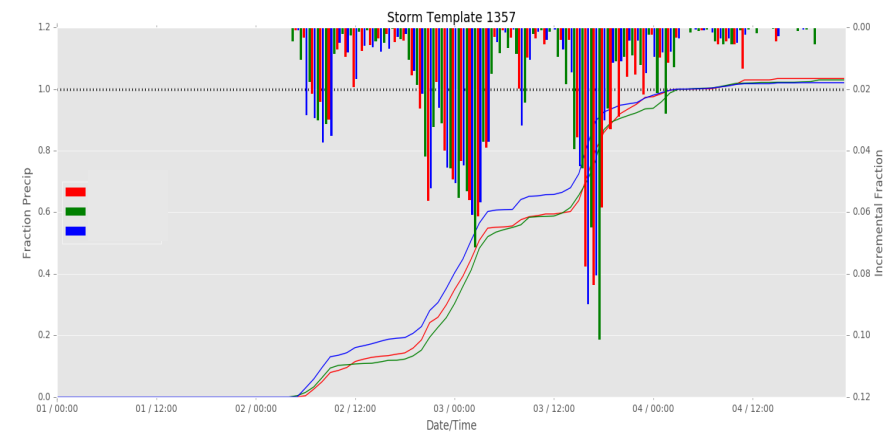
- Began development in 2014
- Application of the Stochastic Event Flood Model (SEFM)
- Applied for 20 unique dams to date
- Supports Risk-Informed Decision Making (RIDM) for dam safety decisions



*Note axes are intentionally not labeled throughout the presentation to prevent sharing TVA sensitive information*

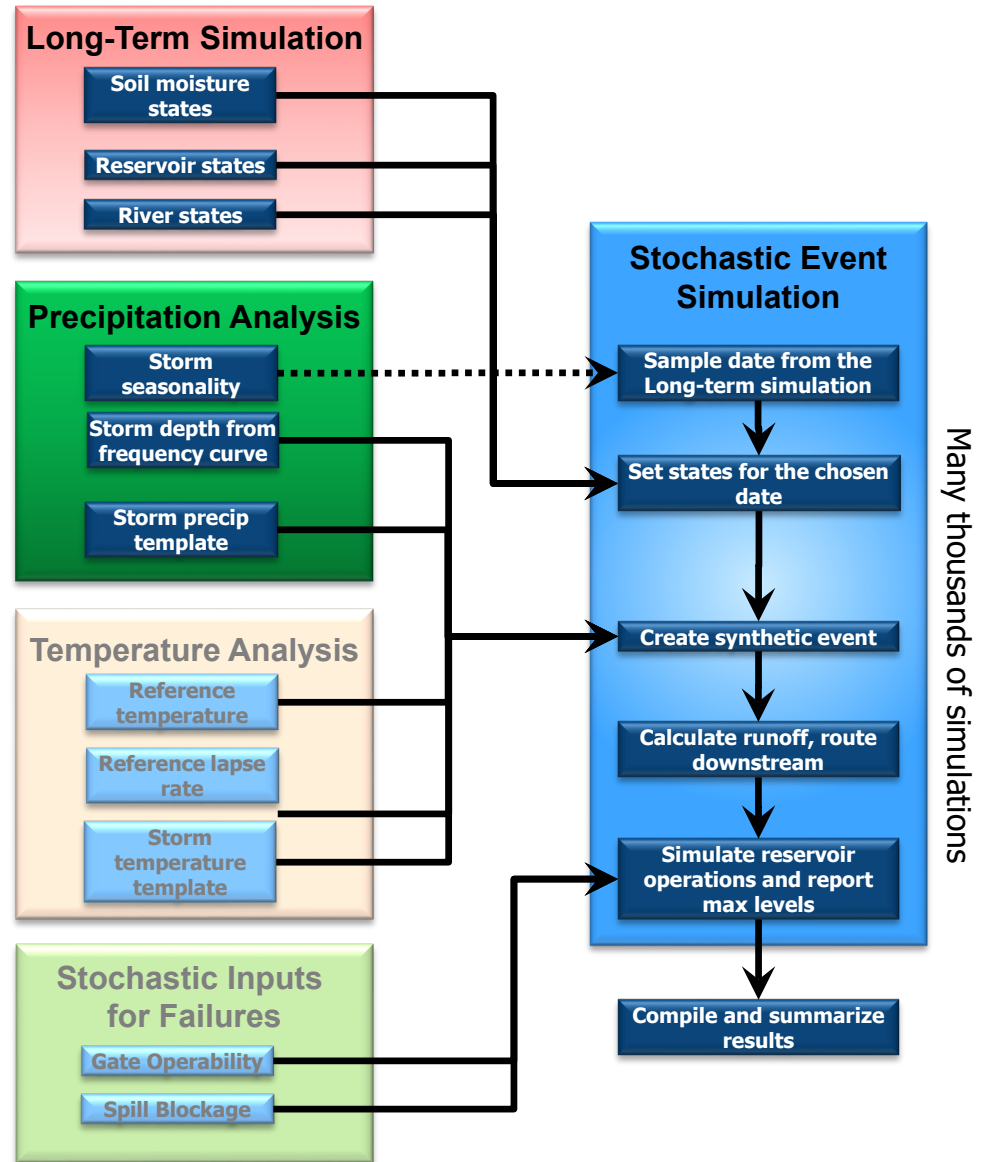
# Stochastic Simulations

- Generate thousands of realistic storms and starting conditions
- Simulate hydrologic and reservoir operational response to storms
- Aggregate statistics from each storm to make hazard curves



# Stochastic Flood Simulation Summary

- Create realistic extreme storms
- Simulate watershed and reservoir system response
- Repeat thousands of times
- Compute statistics from results
- Basins with snow require temperature inputs for snow models
- Next fiscal year will incorporate gate failures for TVA



# MGS Engineering Stochastic Event Flood Model Varieties



## **SEFM Commercial**

- All-in-one software package
- Multiple hydrologic models
  - UBC model
  - SAC-SMA/modified SAC-SMA
- Custom reservoir model with basic operations

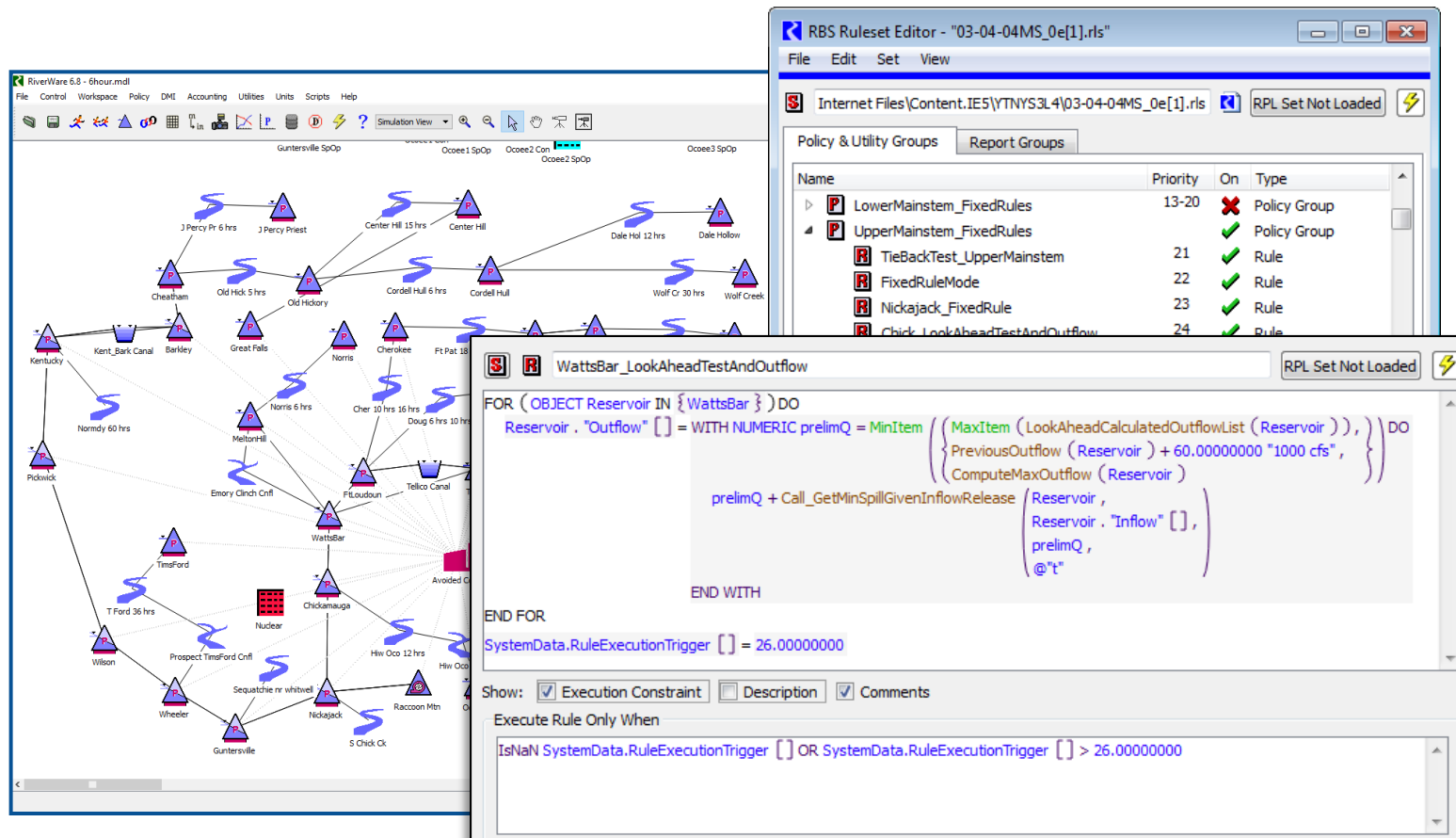


## **SEFM Sampling Modules**

- Standalone process executables
- Intended to embed in more complex applications
- Modules
  - Statistical pre-processor
  - Stochastic input time series generation
  - Statistical post-processor

# RiverWare Model

- Rule-based model represents operating policy during extreme events
- Allows complex operating rules
- Includes approximated inflow forecasts
- Capability to modify gate availability, outlet capacity
  - Use a scalar input to control



# TVA PFHA System

- Storm Transposition Tool
  - Produce representative storm templates
- Execution framework
  - Long-term, stochastic simulations
- Data management
  - 49 dams, 3 storm types, uncertainty
  - Summary statistics, time series
  - Configuration, inputs
- Analysis Tools
  - Hazards curve comparison
  - Assessment of influences on results
  - Drill-down capabilities



# Unique Aspects of the TVA PFHA Calculations

- Precipitation-frequency assessed uniquely per storm type
  - Assess, combine hydrologic hazards from each type
- Statistical methods applied to produce 1000-year synthetic precipitation
  - Preserve spatial/temporal characteristics of events
  - More diverse combinations of events/reservoir conditions for stochastic events
- Intelligent sampling
  - Stratified sampling of precipitation
  - Convergence-based sampling with Neyman's optimal allocation to improve sampling efficiency
- Uncertainty limited to precipitation-frequency
  - Other projects consider additional sources

# TVA PFHA System: Current Work

- Improved data storage
  - Scenario input settings
  - Models at time of scenario execution
    - Hydrologic models
    - RiverWare models, rule sets
- Improved run management across multiple servers
- Improved performance for reporting tools
- Goal: better traceability of work



# TVA PFHA System Interface

- Model Controllers
  - Set up inputs for scenarios
  - Execute and monitor simulations
- Hazards Curve Explorer
  - Merge results from multiple storm types
  - Compare hydrologic hazard curves (e.g. different operating policies)
- Scenario Explorer
  - Understand drivers of hydrologic hazard curves
- Simulation Explorer
  - Review simulation-specific settings
  - View time series outputs for individual simulations

# Model Controller

[Long-Term Model Controller](#)[Stochastic Model Controller](#)[Hazards Curve Explorer](#)[Scenario Explorer](#)[Simulation Explorer](#)[Precipitation Explorer](#)[Troubleshooting/Log Files](#)

## Stochastic Model Controller

This tab is used to create and execute stochastic scenarios. Once runs are completed, they can be further explored on the following tabs. While models are running, previously completed runs can be viewed and explored.

Make selections in the General Scenario Parameters, Stochastic Simulation Inputs, and Stochastic Sampling Inputs sections. The stochastic simulations may be executed for a fixed number of simulations, or until the hydrologic hazard curves converge (controlled by the Sampling Execution Run Mode).

[REFRESH PAGE](#)[Run Selected for Stochastic Model](#)

### General Scenario Parameters

Long-term continuous run:

(RW Model Segment~Watershed Model~MAP~WSM Model~RW Model~FailureMode)

Beech~Base~HistoricalMAP~Beech~Base~Base~NoFail

Reservoir

Beech

Storm Type

MEC

Precip-Frequency Parameters

Beech\_MEC\_10\_Percent

Seasonality

MEC\_Seasonality

Storm Template Folder

Base

Storm Template Weighting

Base

Database write-mode

Custom

Generate AEP curves for the selected reservoir(s):

Beech  
Cedar  
Dogwood  
LostCreek

Select AEP Parameter

AEP Curves

Annual Exceedance Probability

[Check and Re-run Failed RiverWare Simulations](#)

# Hazards Curve Explorer

Long-Term Model Controller   Stochastic Model Controller   Hazards Curve Explorer   Scenario Explorer   Simulation Explorer   Precipitation Explorer   Troubleshooting/Log Files

## Hazards Curve Explorer

This tab is used to visualize the various AEP curves available from the executed scenarios and generate combined AEP curves.

AEP Scenario Comparison   Merge Storm Types   Produce AEP and Duration Curves

### AEP Scenario Comparison

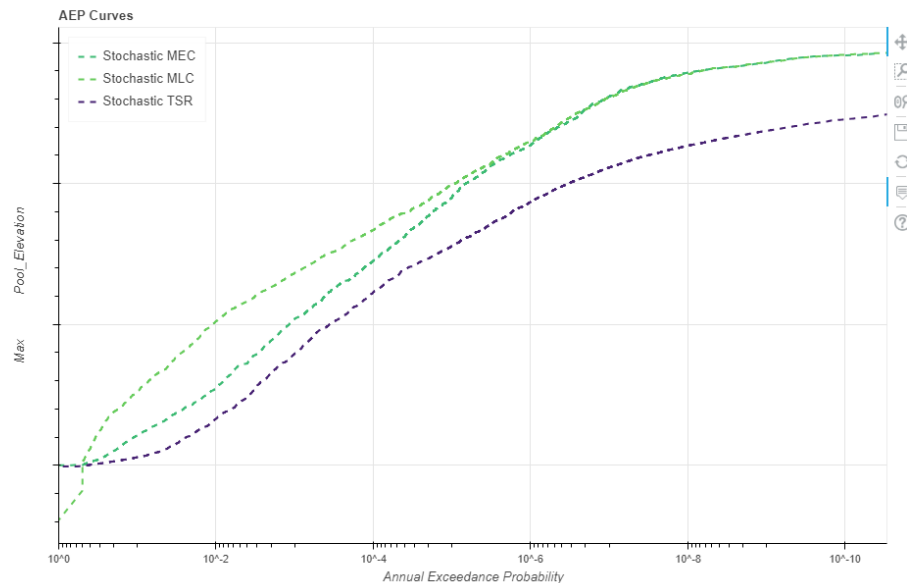
Add lines to plot below by selecting scenarios and AEP lines based on the multi-selects (Ctrl+Click), and clicking *Update AEP Plot*. Hide lines on plot by clicking on an entry in the legend. The plot legend can be updated by typing in the *Plot Legend* column.

Select AEP Line

Stochastic  
Long-Term

| # | Watershed Model | MAP               | Dam   | Storm Type | Kappa             | Seasonality | Templates | Template Weighting | WSM Model | RW Model | Failure Mode | Plot Legend |
|---|-----------------|-------------------|-------|------------|-------------------|-------------|-----------|--------------------|-----------|----------|--------------|-------------|
| 0 | Base            | HistoricalMAP_... | Beech | MEC        | Beech_MEC_10_P... | MEC_Sea...  | Base      | Base               | Base      | Base     | NoFail       | Scenario: 0 |
| 1 | Base            | HistoricalMAP_... | Beech | MEC        | Beech_MEC_90_P... | MEC_Sea...  | Base      | Base               | Base      | Base     | NoFail       | MEC         |
| 2 | Base            | HistoricalMAP_... | Beech | MEC        | Beech_MEC_Best... | MEC_Sea...  | Base      | Base               | Base      | Base     | NoFail       | Scenario: 2 |
| 3 | Base            | HistoricalMAP_... | Beech | MLC        | Beech_MLC_10_P... | MLC_Sea...  | Base      | Base               | Base      | Base     | NoFail       | Scenario: 3 |
| 4 | Base            | HistoricalMAP_... | Beech | MLC        | Beech_MLC_90_P... | MLC_Sea...  | Base      | Base               | Base      | Base     | NoFail       | MLC         |
| 5 | Base            | HistoricalMAP_... | Beech | MLC        | Beech_MLC_Best... | MLC_Sea...  | Base      | Base               | Base      | Base     | NoFail       | Scenario: 5 |
| 6 | Base            | HistoricalMAP_... | Beech | TSR        | Beech_TSR_10_P... | TSR_Sea...  | Base      | Base               | Base      | Base     | NoFail       |             |
| 7 | Base            | HistoricalMAP_... | Beech | TSR        | Beech_TSR_90_P... | TSR_Sea...  | Base      | Base               | Base      | Base     | NoFail       | TSR         |
| 8 | Base            | HistoricalMAP_... | Beech | TSR        | Beech_TSR_Best... | TSR_Sea...  | Base      | Base               | Base      | Base     | NoFail       | Scenario: 8 |

Update AEP Plot



# Scenario Explorer

Long-Term Model Controller

Stochastic Model Controller

Hazards Curve Explorer

Scenario Explorer

Simulation Explorer

Precipitation Explorer

Initial Conditions Explorer

Filter Data:

X Axis

Max Pool Elevation

Loc/Stat

Dam B

Y Axis

Max Pool Elevation

Loc/Stat

Dam A

Color

Max Pool Elevation

Precipitation

Initial Pool Elevation

Max Pool Elevation

Max Outflow

Max Inflows AEP

Max Outflow AEP

Max Pool Elevation AEP

None

Enter Color Threshold 2 ... (> threshold 1)

Enter Color Threshold 3 ... (> threshold 2)

Size

None

Loc/Stat

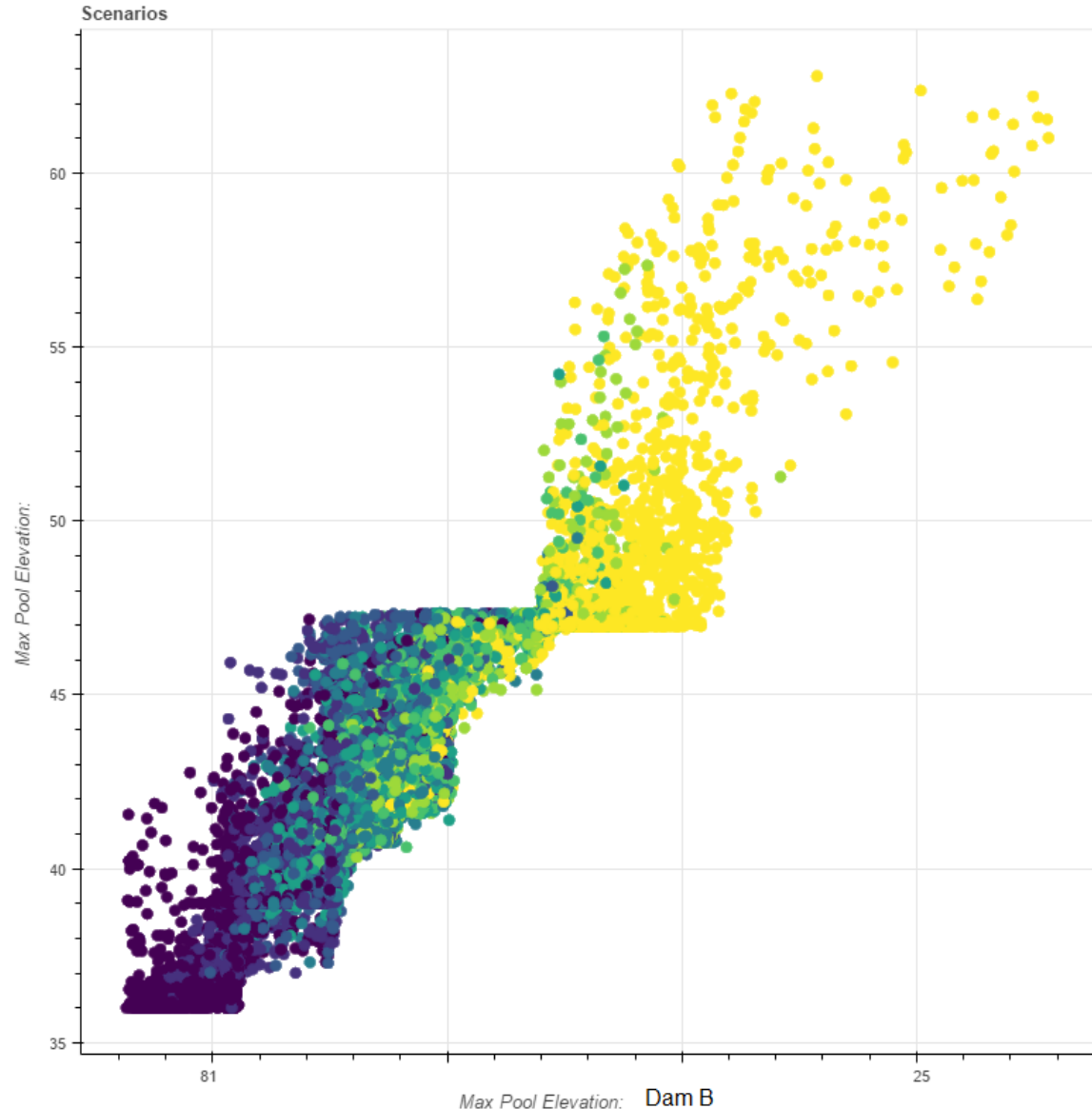
None

Size Thresholds:

Enter Size Threshold 1 ...

Enter Size Threshold 2 ... (> threshold 1)

Enter Size Threshold 3 ... (> threshold 2)



# Simulation Explorer

Simulation Explorer

Simulation Explorer

Update Selection

Update Selection

Simulation

Simulation

37129

Export Riverware

Summary

Time Series

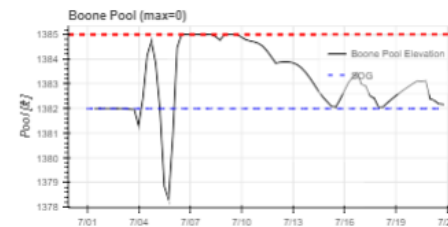
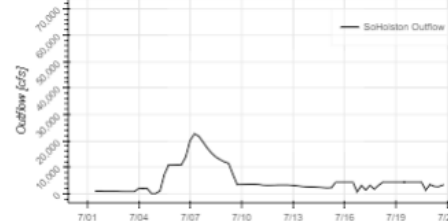
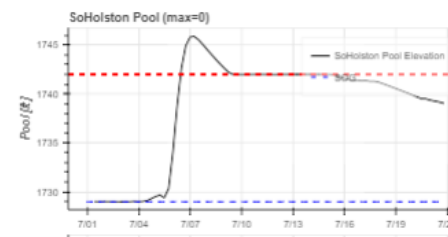
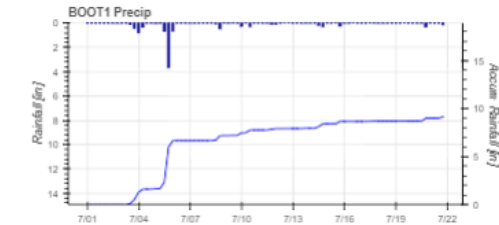
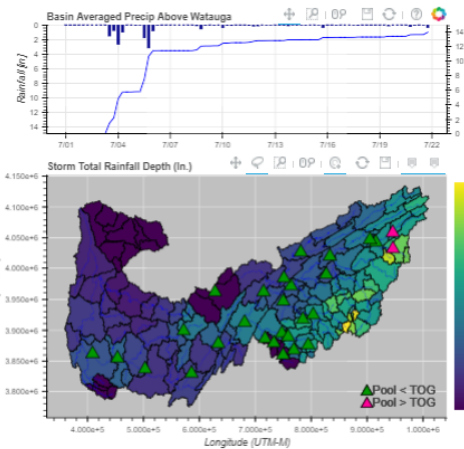
Simulation Explorer

This page allows for the exploration of a single simulation from the currently selected scenario(s). From the previous Scenario Explorer tab, select the simulations of interest using the less tool. Choosing Update Selection will change the Simulation drop-down menu to contain only those selected simulations. This tab contains two sub-tabs: Summary, and Time Series.

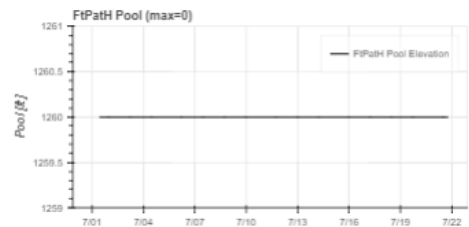
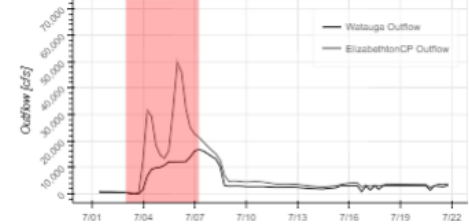
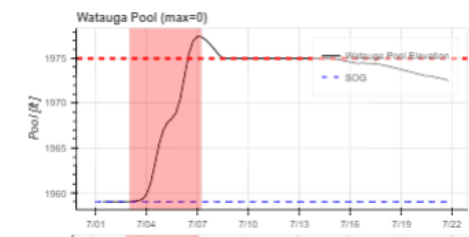
The Summary tab shows a summary table of the selected simulation. The table includes meta-data about the storm dates, precipitation bin, storm template, etc., used during the hazards run for the selected simulation. Two precipitation plots are shown to provide a summary of the spatial and temporal patterns of the storm. Reservoirs are shown on the spatial plot as triangles and are highlighted in red if at some point in the simulation they exceeded Top of Gates.

The Time Series tab shows results from the RiverWare simulations. Currently there are 7 plot layouts set up for certain Reservoir systems (i.e. South Holston, Main Stem, etc.). Clicking on the buttons will toggle the different plot layouts (\*\*NOTE: This may take a moment for a new plot layout to load into the interface, please wait). Some plots in the plot layouts may appear empty if those data are missing from a certain scenario run. The plots are linked for zooming and panning and the time-slider can be used to display a vertical line on all of the plots. Changing simulations in the drop-down menu above will automatically update the plots with new data.

| #  | Attribute                      | Value                              |
|----|--------------------------------|------------------------------------|
| 0  | SimNumber                      | 37129                              |
| 1  | StormDate                      | 07/01/2004                         |
| 2  | Precip Bin Number              | 38                                 |
| 3  | Incremental Prob of Precip Bin | 3.62E-04                           |
| 4  | Kappa Precip AEP               | 2.54E-03                           |
| 5  | Kappa Precip (Inches)          | 7.76                               |
| 6  | Storm Temporal Pattern         | storm2sdfm_watugaTSR_4892_1407.tsr |
| 7  | Max Watauga Outflow AEP        | 5.09E-05                           |
| 8  | Max Watauga Outflow            | 16786.59                           |
| 9  | Max Watauga Outflow AEP        | 4.99E-05                           |
| 10 | Max Watauga Outflow            | 16915.06                           |
| 11 | Max Watauga Pool Elevation AEP | 5.11E-05                           |
| 12 | Max Watauga Pool Elevation     | 1977.45                            |
| 13 | Max Watauga Pool Elevation AEP | 1.00                               |
| 14 | Max Watauga Pool Elevation     | 1648.00                            |

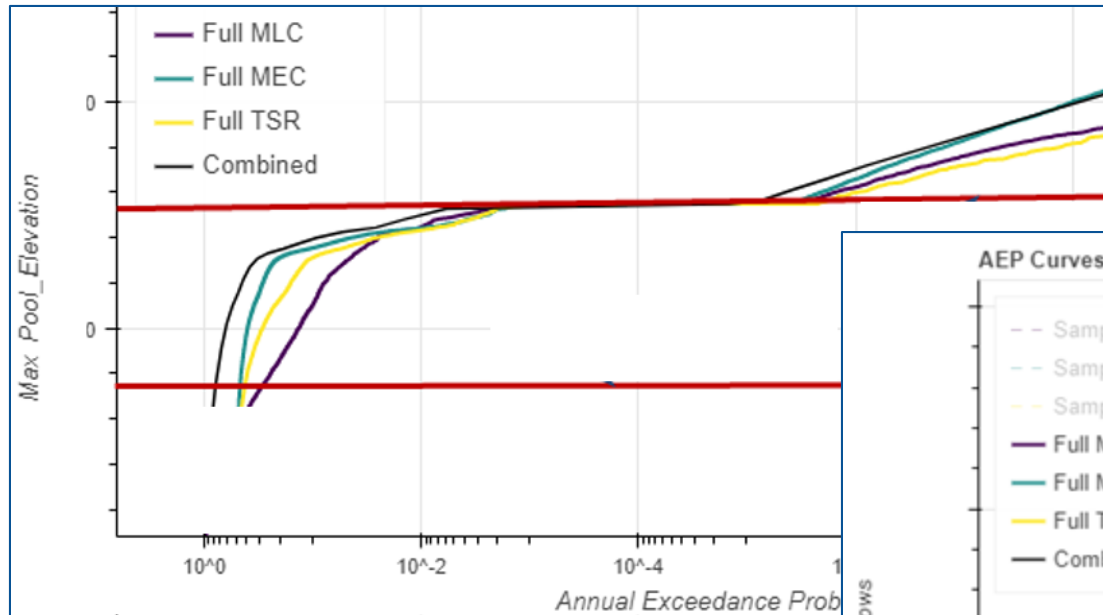


--- Top of Gates  
--- Flood Trigger  
--- Spillway Crest

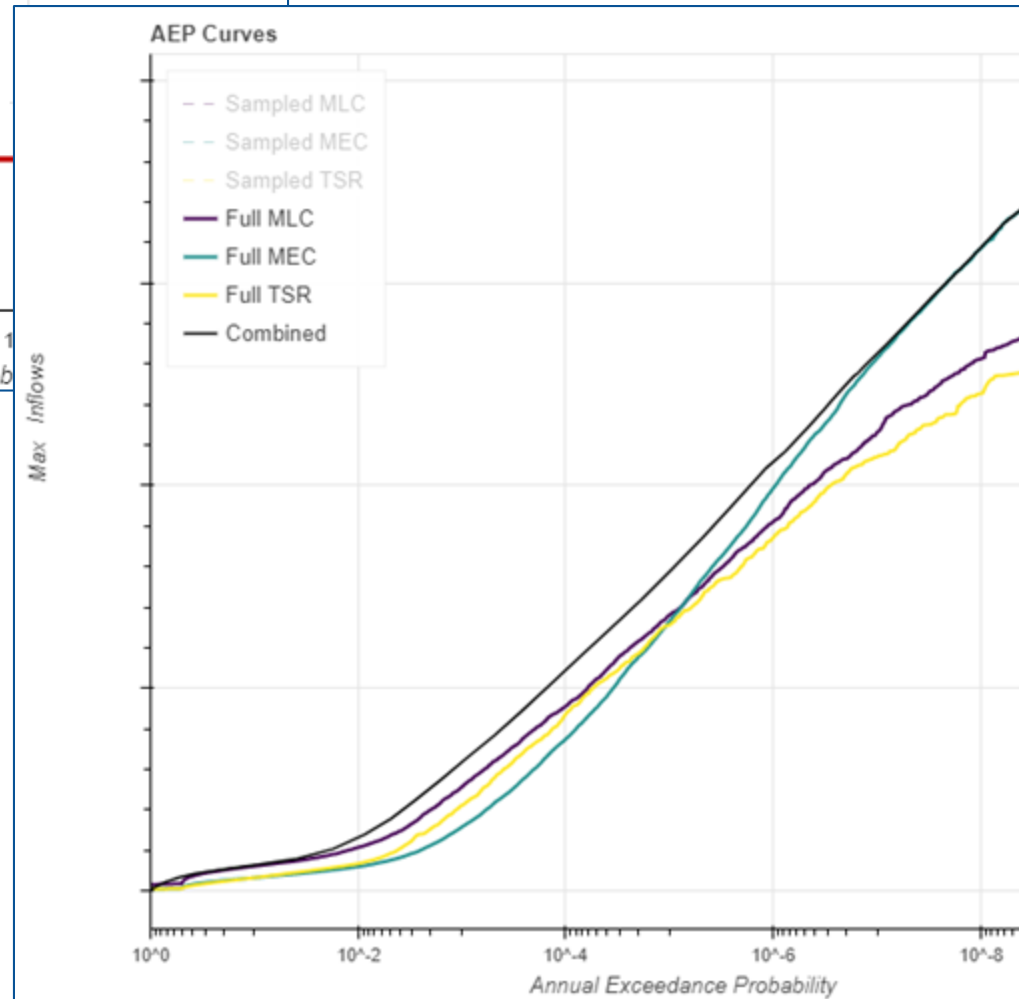


# Analysis Applications

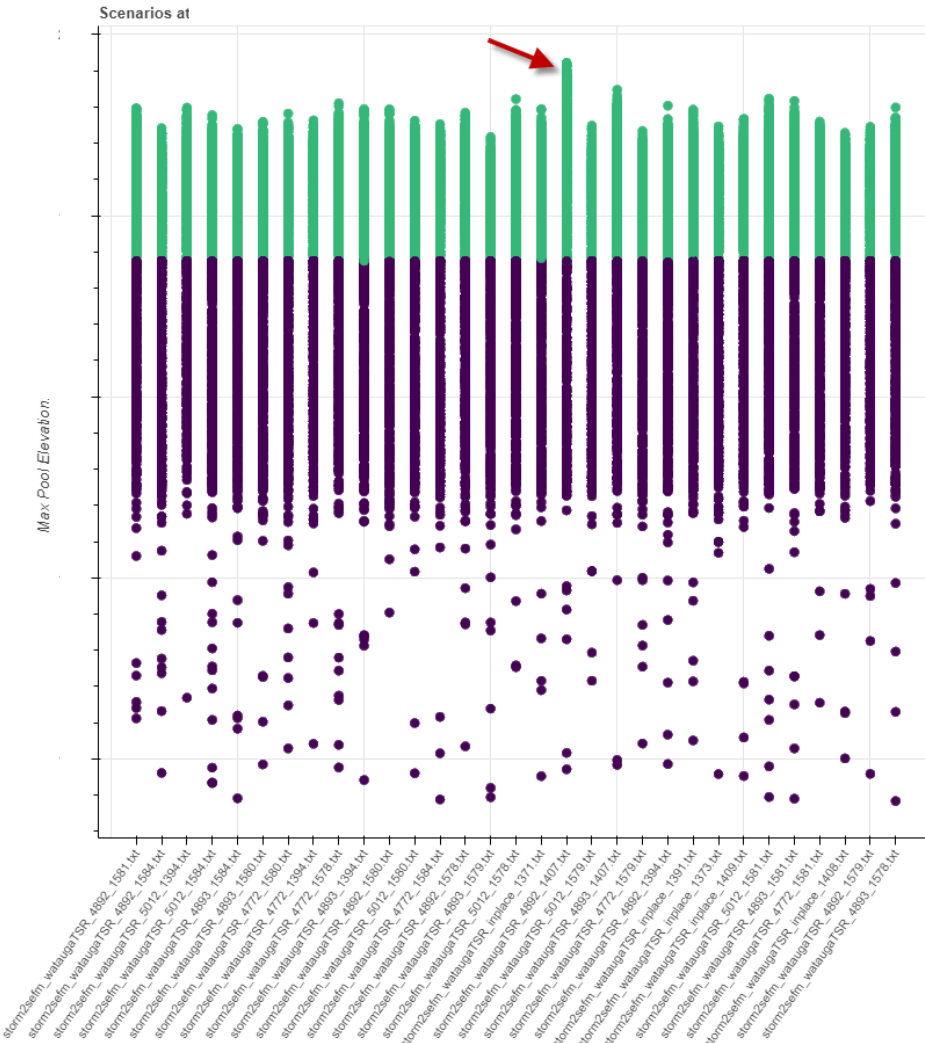
# Influence of Different Storm Types



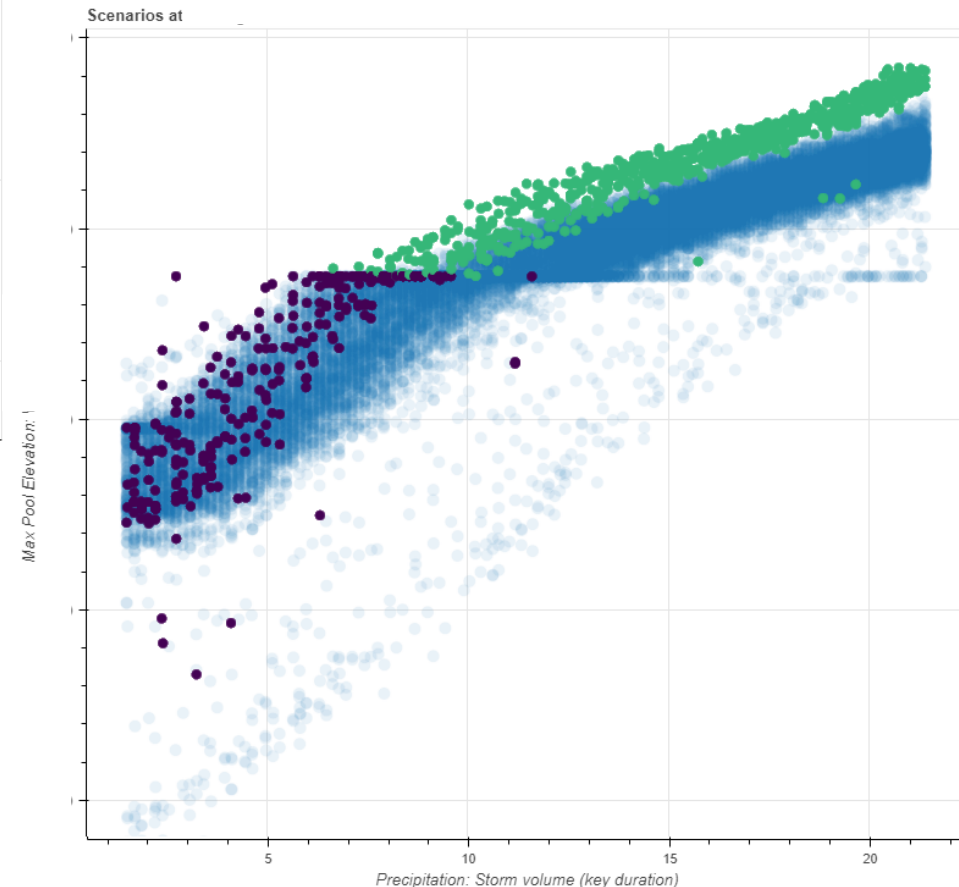
- Different storm types control for different AEP ranges



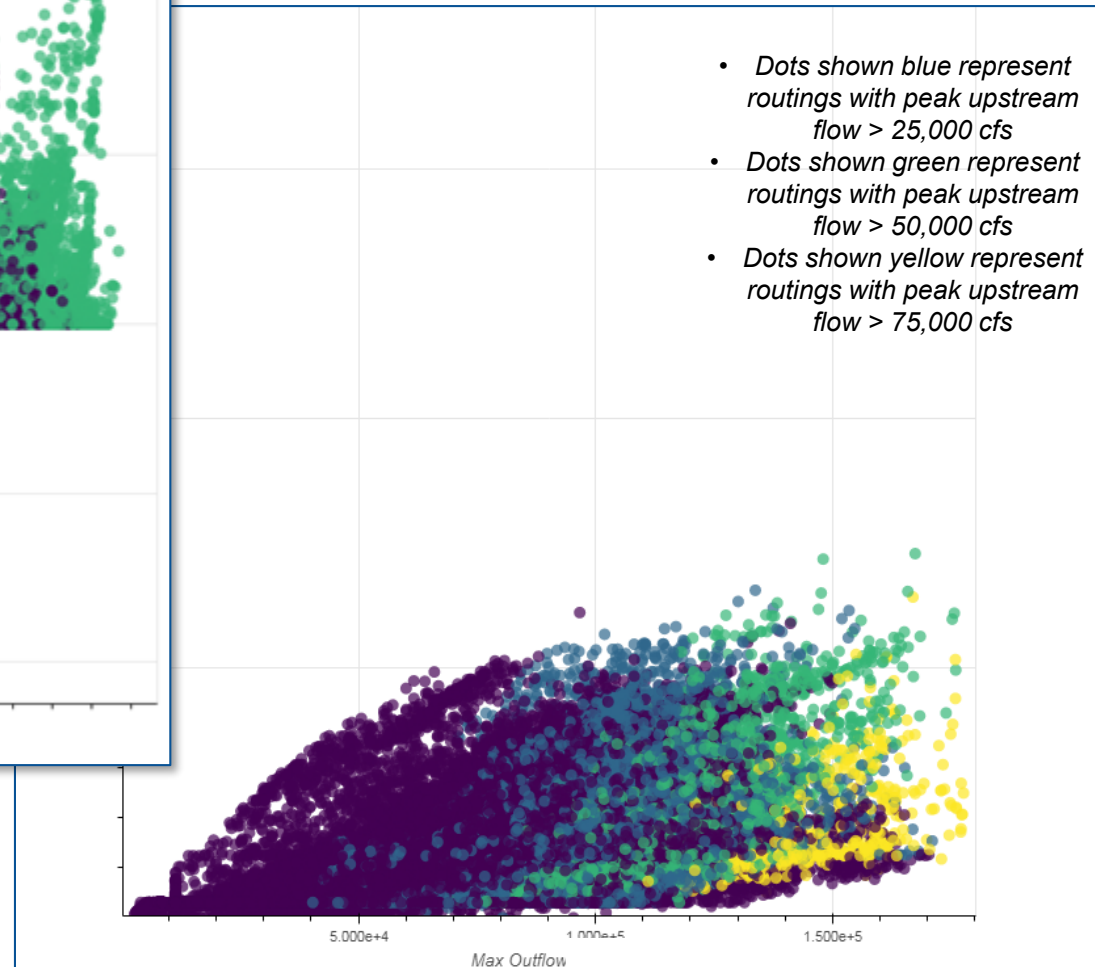
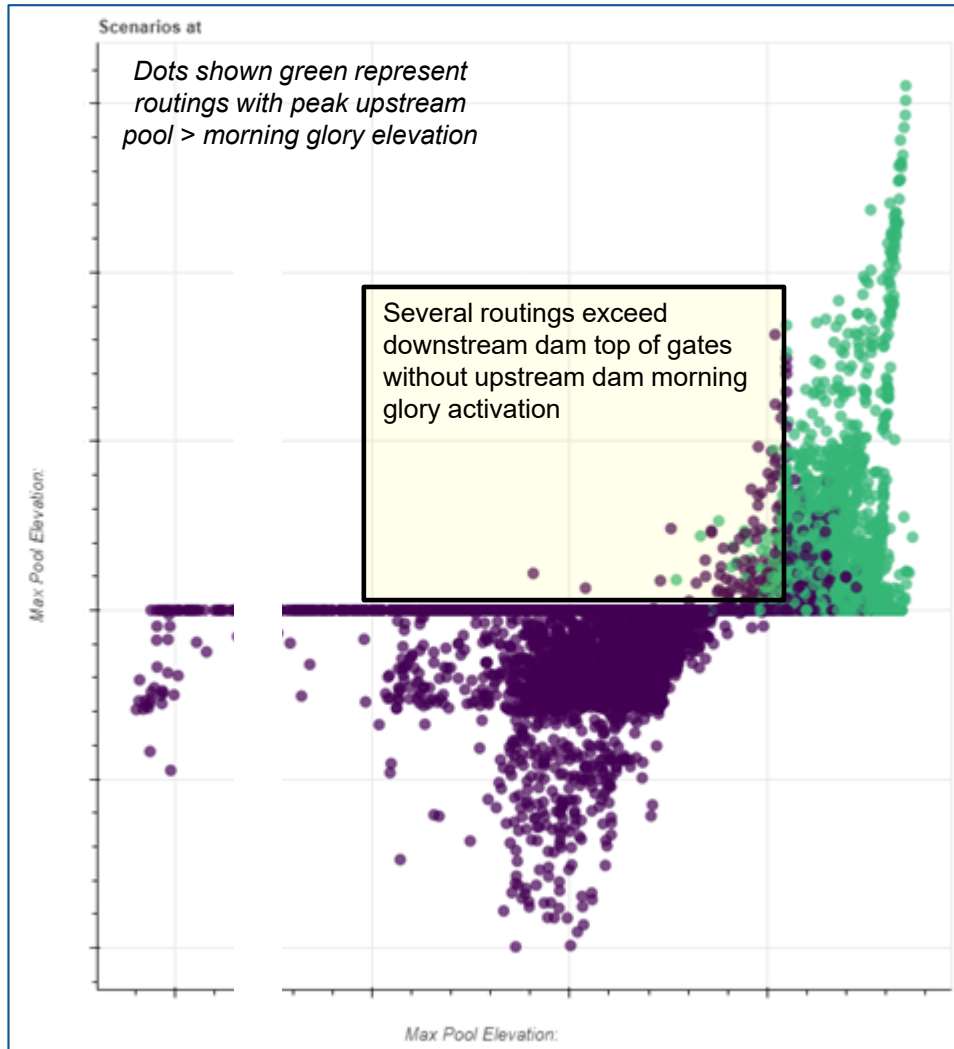
# Influence of Storm Patterns



- Storm pattern can have a significant impact



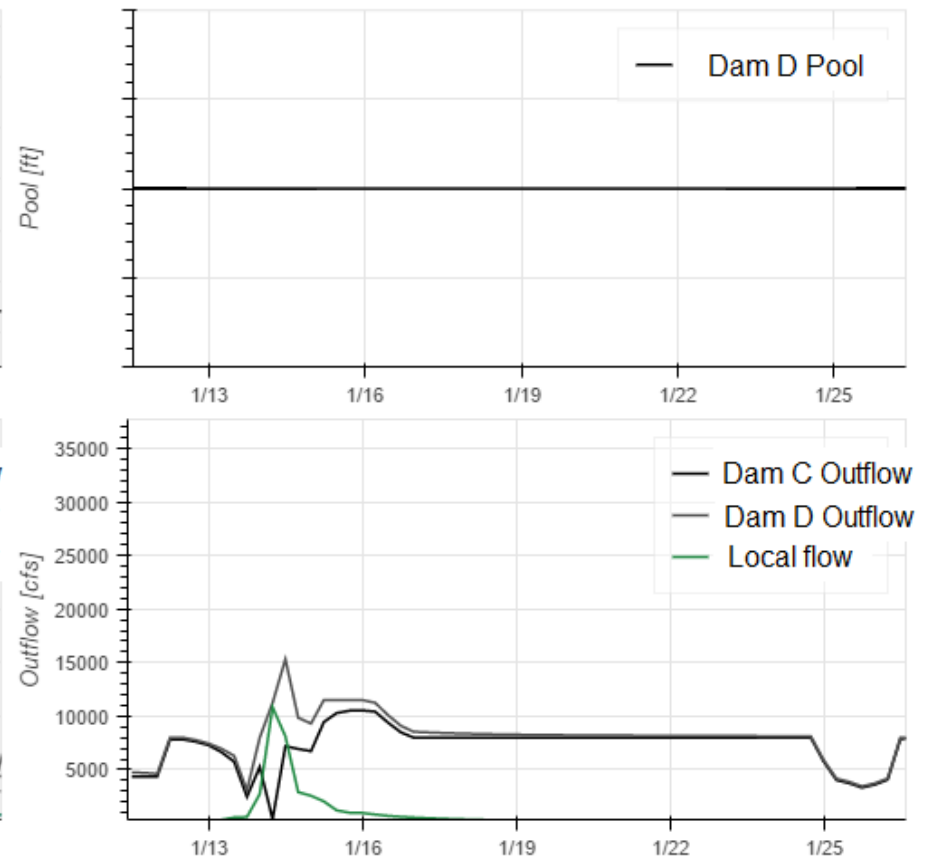
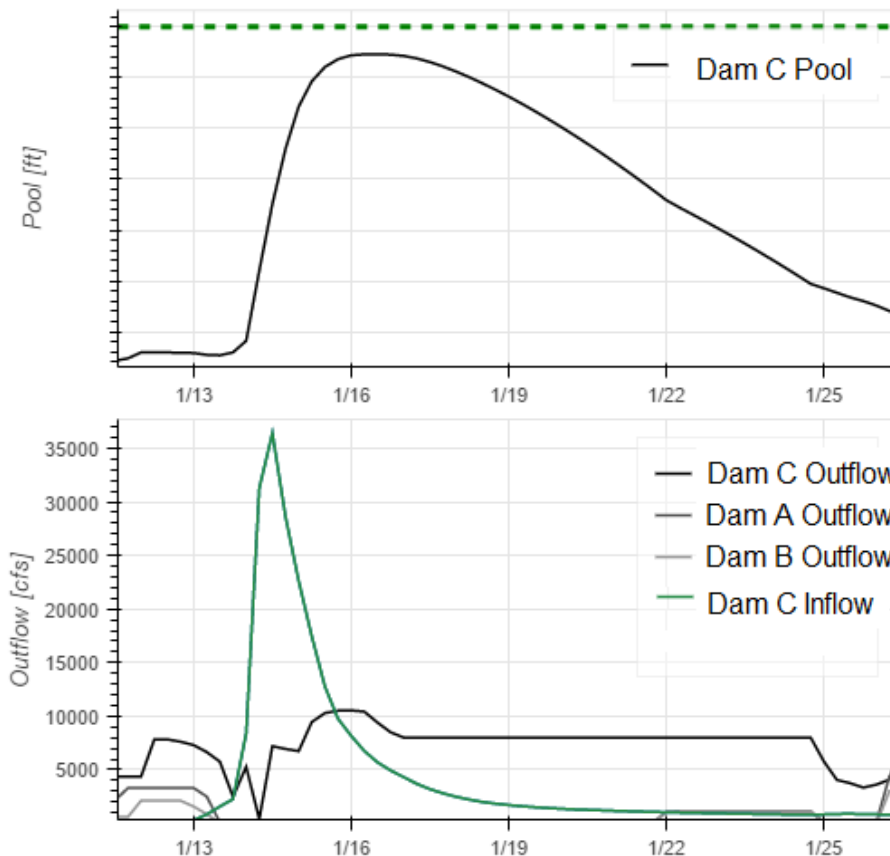
# Influence of Other Reservoirs



# Compare Interim Risk Reduction Operating Policies

- Two different policy alternatives
  - Protect downstream
  - Keep headwater low

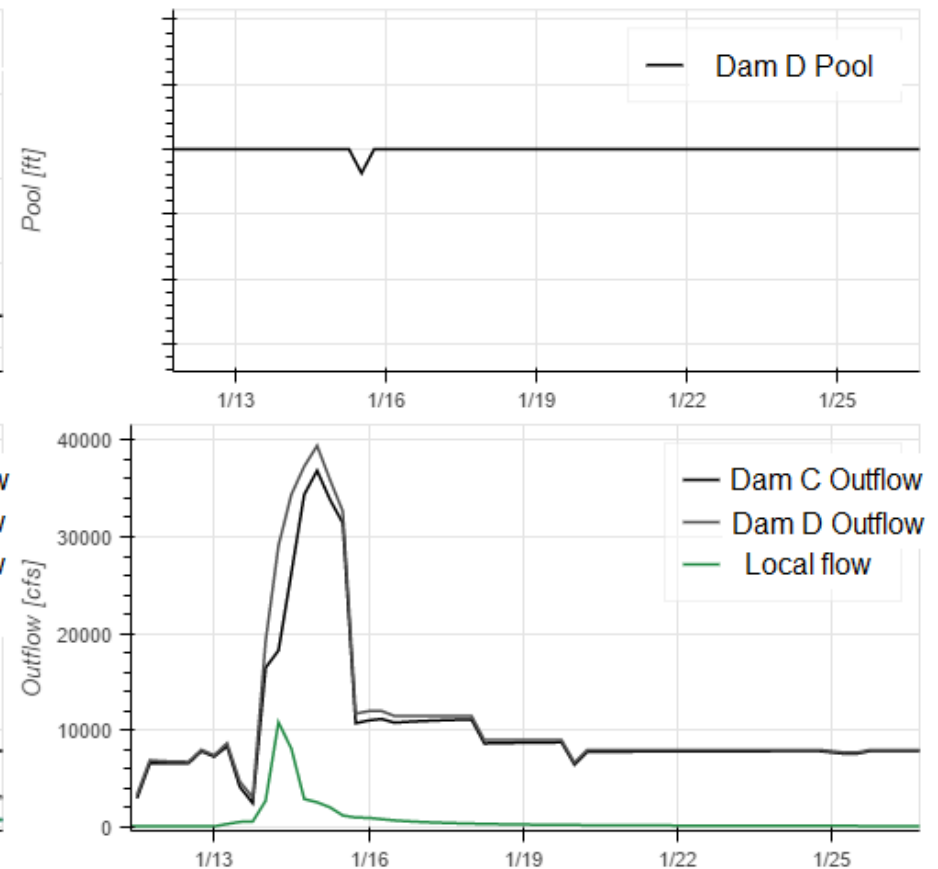
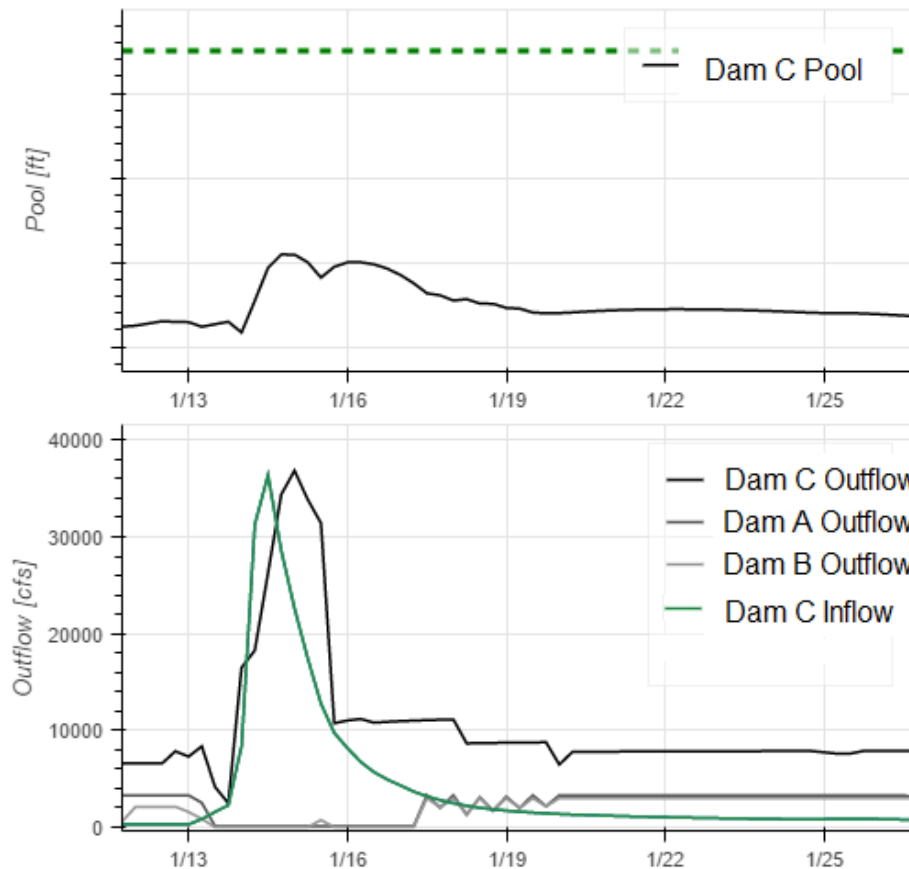
## Protect downstream



# Compare Interim Risk Reduction Operating Policies

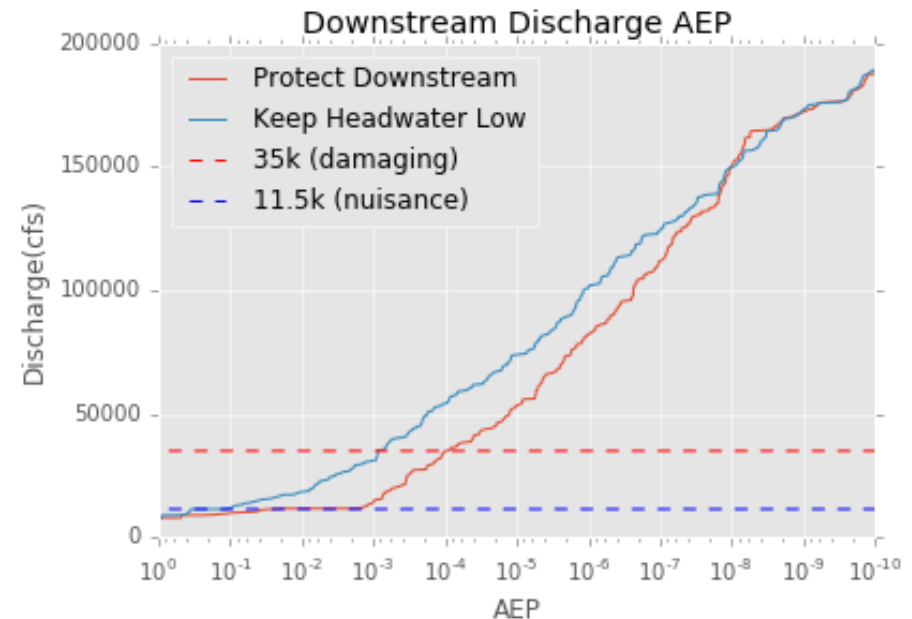
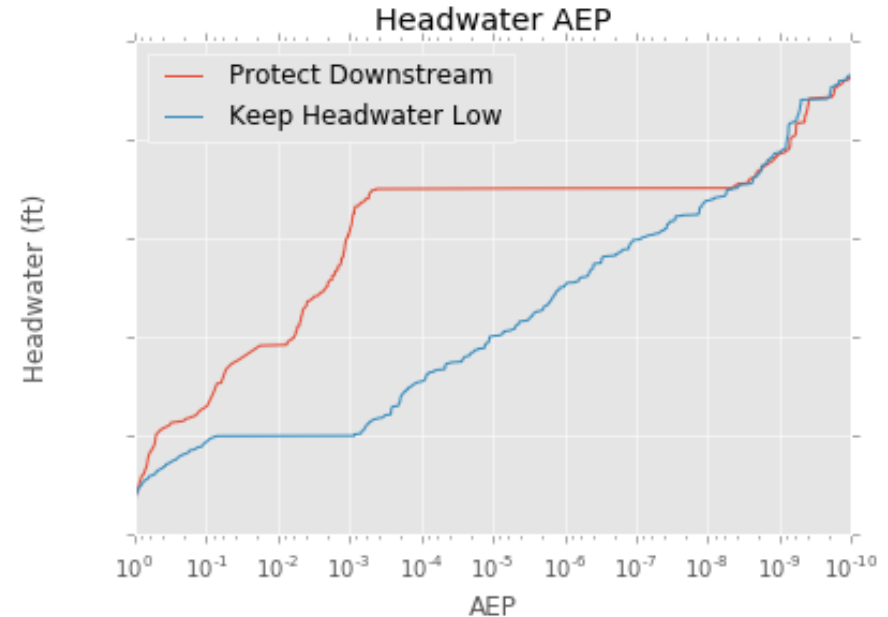
- Two different policy alternatives
  - Protect downstream
  - Keep headwater low

Keep headwater low

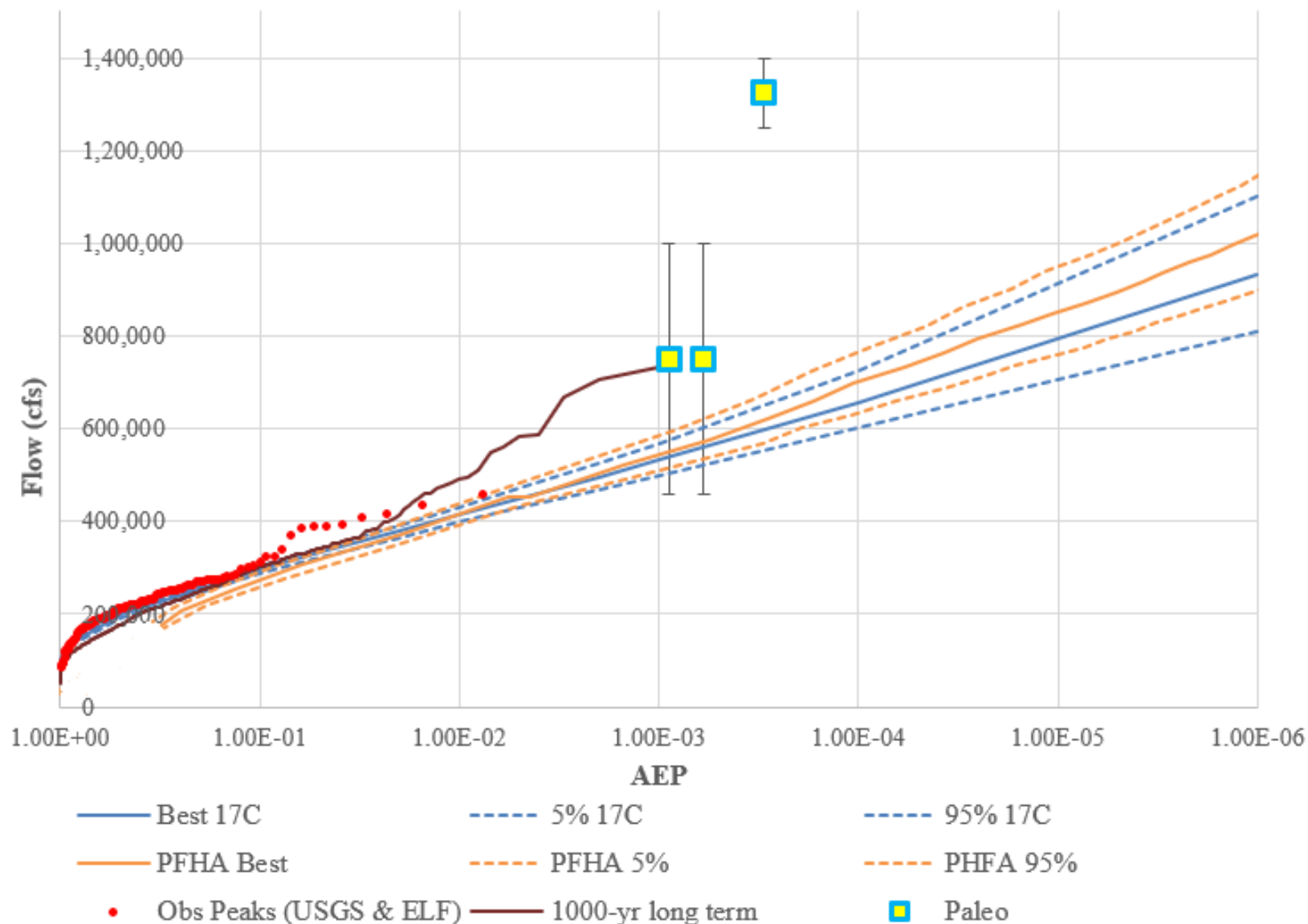


# Compare Interim Risk Reduction Operating Policies

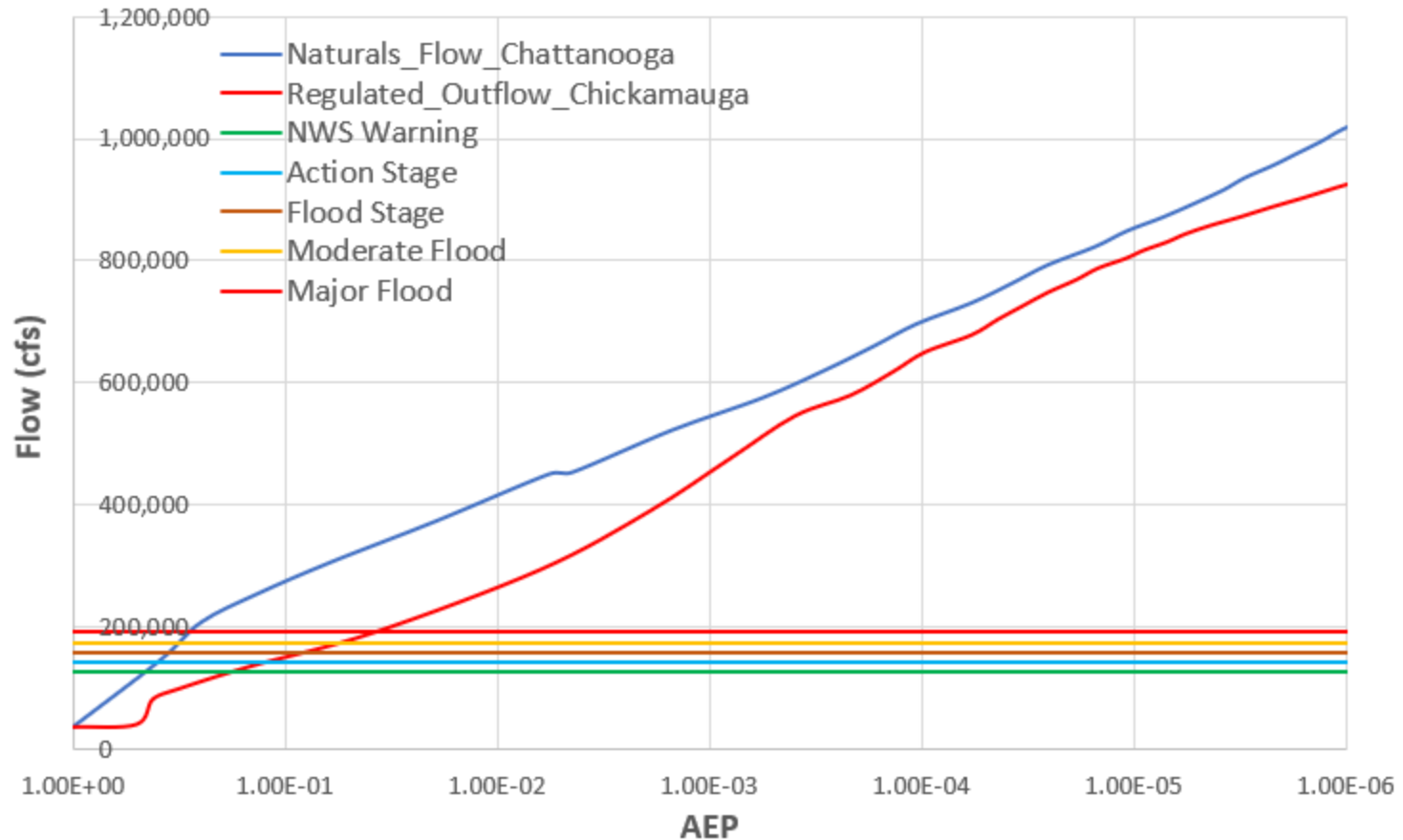
- Two different policy alternatives
  - Protect downstream
  - Keep headwater low



# PFHA vs. Flow-Based with Paleo Flow Frequency



# Regulated vs. Unregulated Flow Frequency



# More Information

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