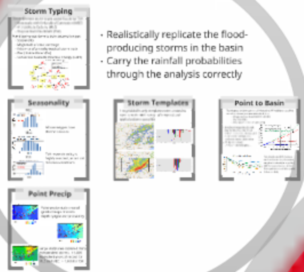
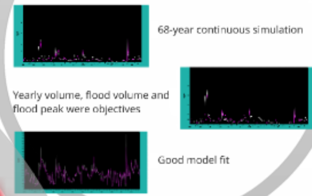
Rainfall



- Realistically replicate the flood-producing storms in the basin
- Carry the rainfall probabilities through the analysis correctly

Runoff

TVA partnered with NWS to calibrate a 140-basin continuous hydrology model, used operationally



68-year continuous simulation

Yearly volume, flood volume and flood peak were objectives

Good model fit

Why Do a PFHA?

How high does the water get?

Does the dam fail? How?

What harm would failure cause?

Probabilistic **F**lood **H**azard **A**nalysis

Fragility Analysis

Consequences Analysis

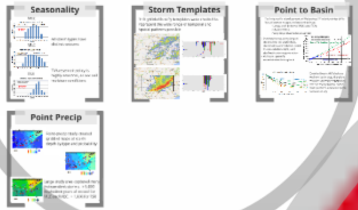
To make better risk decisions

Operations

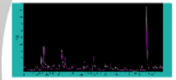
Displaying

Example Hazard Curve

- Carry the rainfall probabilities through the analysis correctly

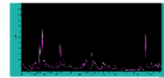


TVA partnered with NWS to calibrate a 140-basin continuous hydrology model, used operationally

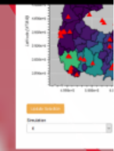


68-year continuous simulation

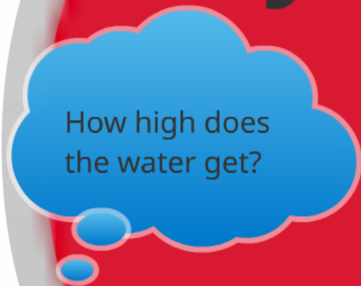
Yearly volume, flood volume and flood peak were objectives



Good model fit



Why Do a PFHA?

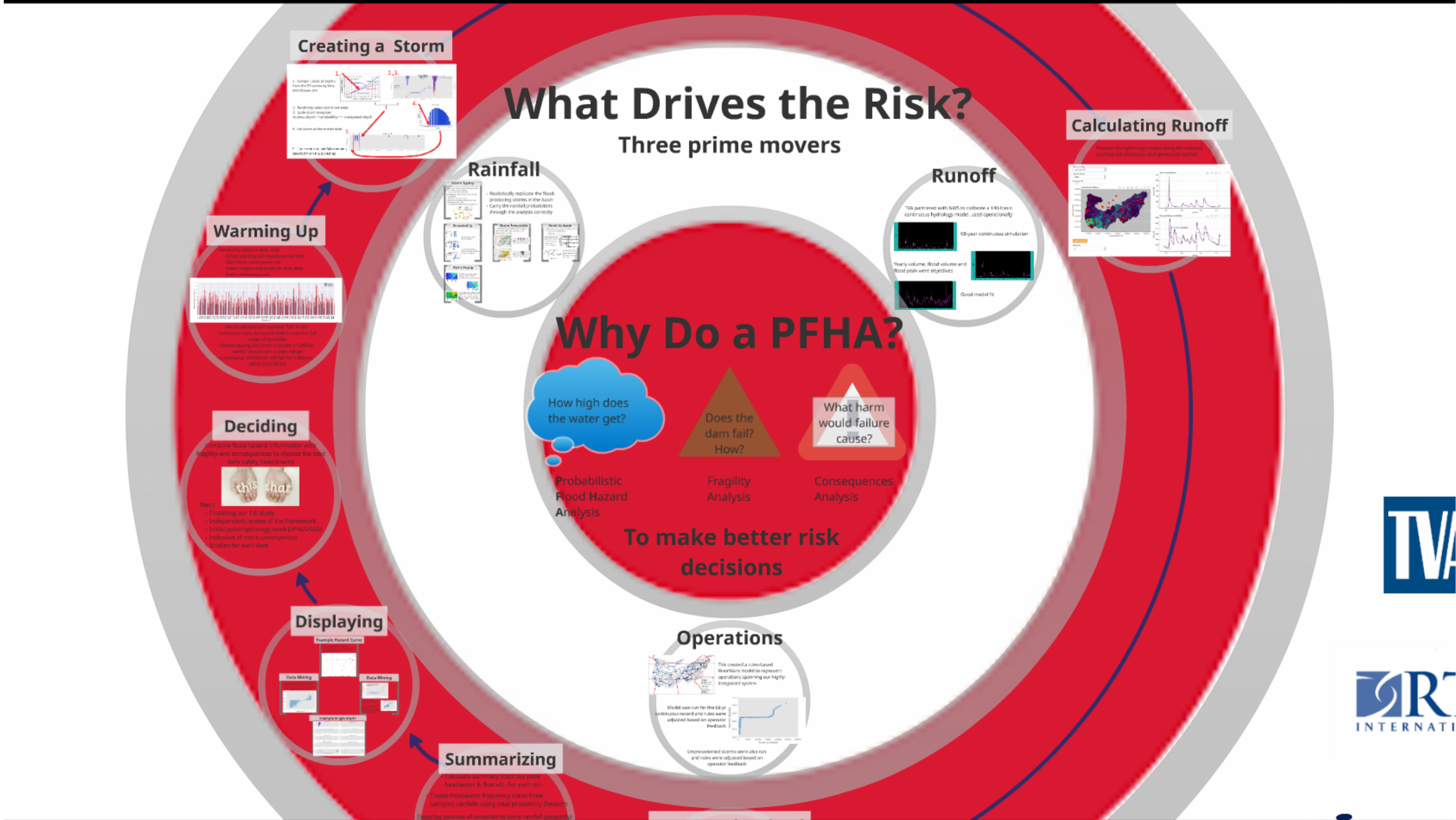


Probabilistic **F**lood **H**azard **A**nalysis

Fragility Analysis

Consequences Analysis

To make better risk decisions



Creating a Storm
What Drives the Risk?
Three prime movers
Calculating Runoff
Rainfall
Runoff
Warming Up
Why Do a PFHA?
How high does the water get?
Does the dam fail? How?
What harm would failure cause?
Probabilistic Flood Hazard Analysis
Fragility Analysis
Consequences Analysis
To make better risk decisions
Deciding
this
that
Displaying
Operations
Summarizing

Rainfall

- Realistically replicate the flood-producing storms in the basin
- Carry the rainfall probabilities through the analysis correctly

Storm Typing

Three different storm types cause floods for TVA:
- Mesoscale with Embedded Convection (MEC)
- Mid-Latitude Cyclone (MLC)
- Tropical Storm Remnant (TSR)

Hand typing was done to train automation per:
- Seasonality
- Magnitude of areal coverage
- Existence of a nearby tropical storm track
- Precipitable Water (Pw)
- Convective Available Potential Energy (CAPE)

Seasonality

MEC

MLC

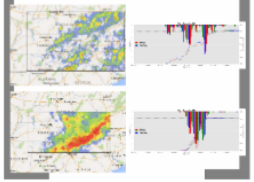
TSR

All storm types have distinct seasons

TVA reservoir policy is highly seasonal, as are soil moisture conditions

Storm Templates

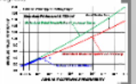
110 gridded hourly templates were created to represent the wide range of temporal and spatial patterns possible

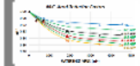


Point to Basin

Techniques for development of Watershed PF relationships differ based on storm type and watershed size:
- Large, well-behaved MLCs and TSRs
- Chaotic MECs
- Very large storms (in progress)

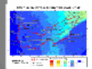
- Involves transposing largest storms into the watershed, station cross-correlation, point to area relationships, and stochastic storm generation
- Ability to quantify uncertainties throughout



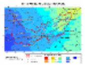


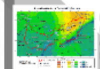
Detailed basin ARFs behave well wrt basin size, therefore we plan to simply interpolate ARF for many basins, rather than perform a detailed point-to-basin study

Point Precip



Point-precip study created gridded maps of storm depth by type and probability





Large study area captured many independent storms. > 5,000 equivalent years of record for MLC and MEC. > 1,000 for TSR

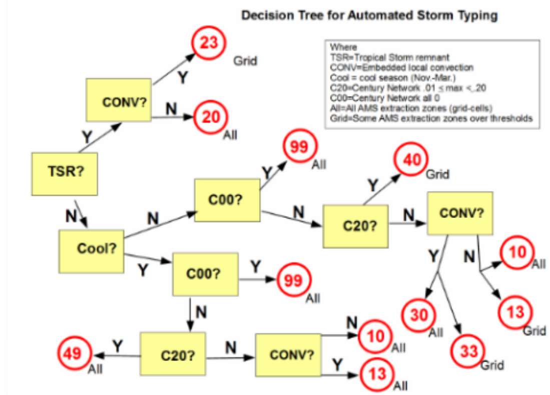
Storm Typing

Three different storm types cause floods for TVA:

- Mesoscale with Embedded Convection (MEC)
- Mid-Latitude Cyclone (MLC)
- Tropical Storm Remnant (TSR)

Hand typing was done to train automation per:

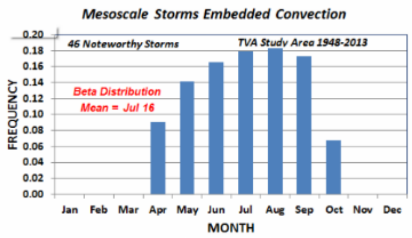
- Seasonality
- Magnitude of areal coverage
- Existence of a nearby tropical storm track
- Precipitable Water (Pw)
- Convective Available Potential Energy (CAPE)



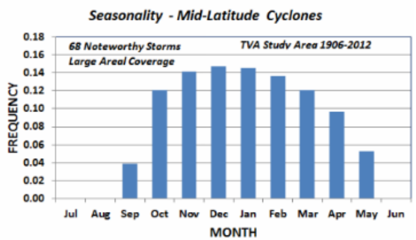
- Rea
pro
- Car
thr

Seasonality

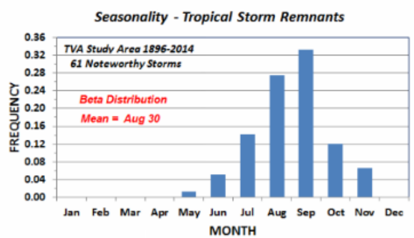
MEC



MLC



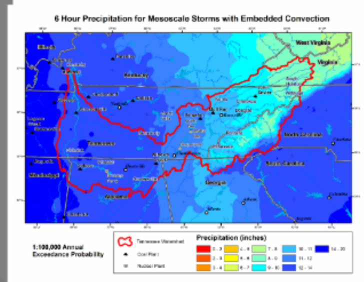
TSR



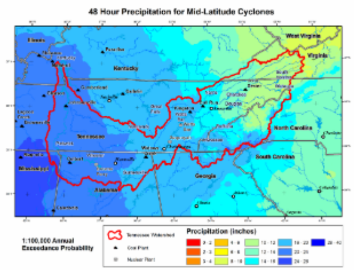
All storm types have distinct seasons

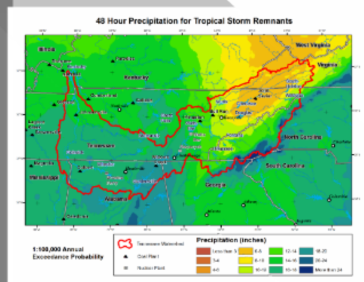
TVA reservoir policy is highly seasonal, as are soil moisture conditions

Point Precip



Point-precip study created gridded maps of storm depth by type and probability

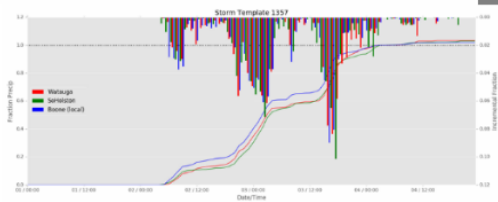


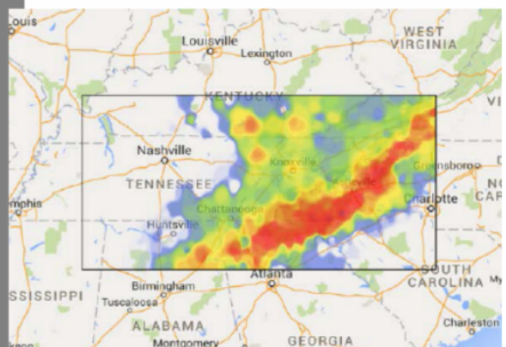


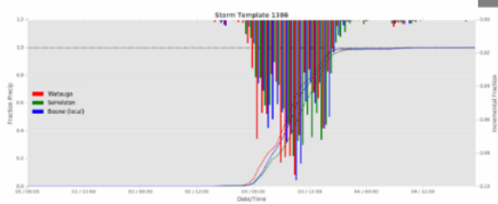
Large study area captured many independent storms. > 5,000 equivalent years of record for MLC and MEC. > 1,000 for TSR

Storm Templates

110 gridded hourly templates were created to represent the wide range of temporal and spatial patterns possible





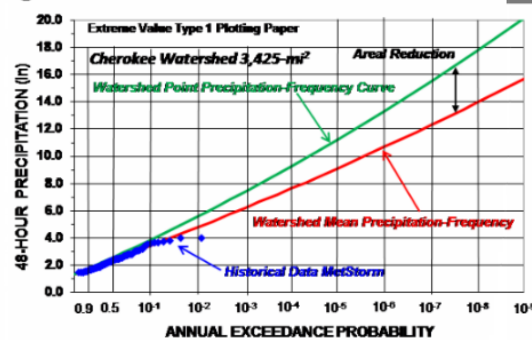


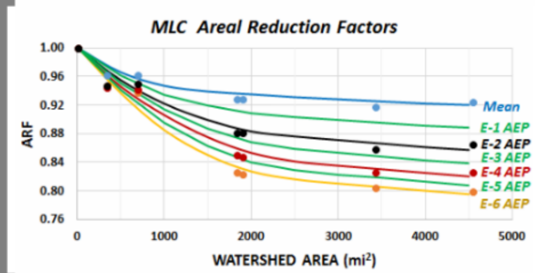
Point to Basin

Techniques for development of Watershed PF relationships differ based on storm type and watershed size:

- Large, well-behaved MLCs and TSRs
- Chaotic MECs
- Very large storms (in progress)

- Involves transposing largest storms into the watershed, station cross-correlation, point to area relationships, and stochastic storm generation
- Ability to quantify uncertainties throughout

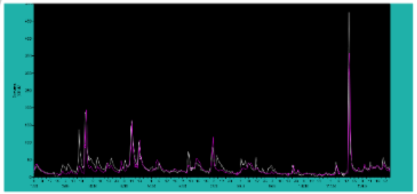




Detailed basin ARFs behave well wrt basin size, therefore we plan to simply interpolate ARF for many basins, rather than perform a detailed point-to-basin study

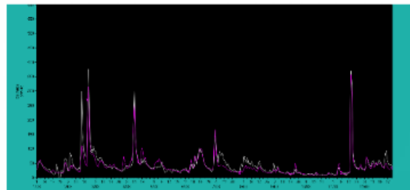
Runoff

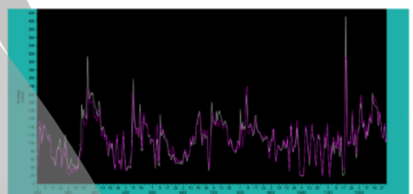
TVA partnered with NWS to calibrate a 140-basin continuous hydrology model, used operationally



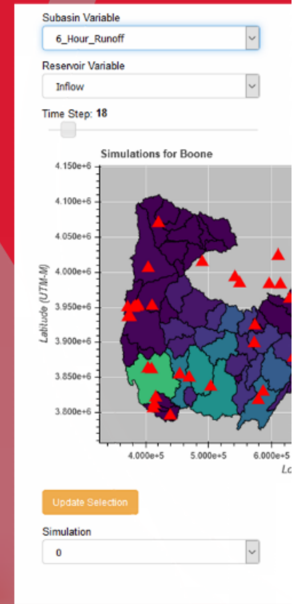
68-year continuous simulation

Yearly volume, flood volume and flood peak were objectives

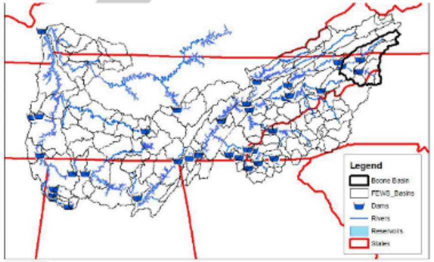




Good model fit

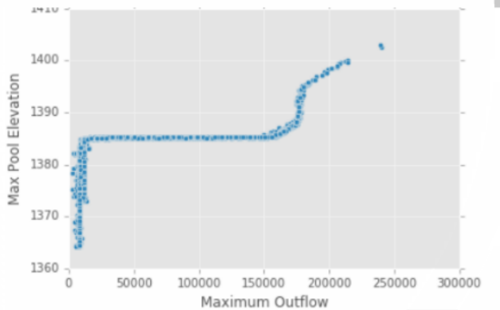


Operations



TVA created a rules-based RiverWare model to represent operations spanning our highly-integrated system

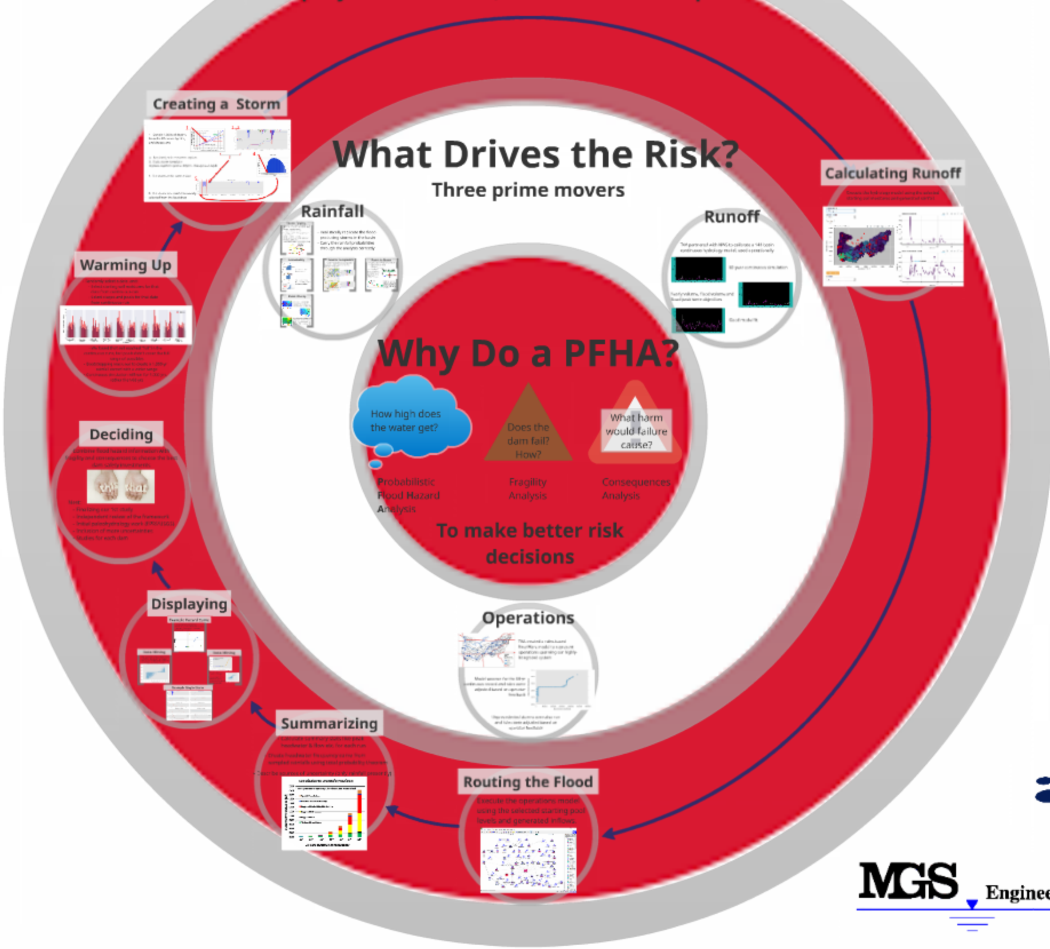
Model was run for the 68-yr continuous record and rules were adjusted based on operator feedback



Unprecedented storms were also run and rules were adjusted based on operator feedback

How do the Prime Movers Interact?

Uniquely for each storm, therefore model all possibilities



TVA

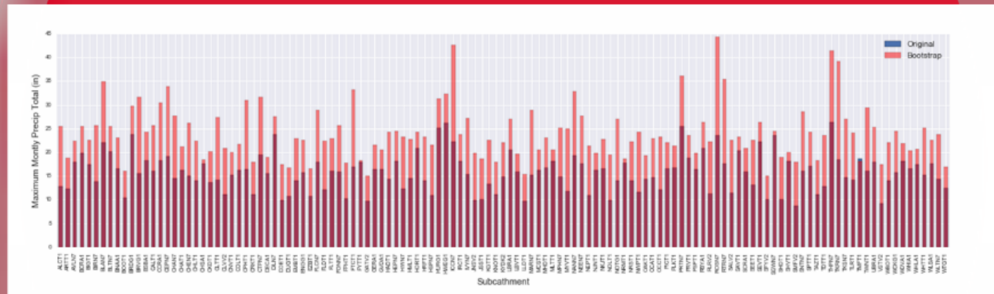
RTI INTERNATIONAL

METSTAT

MGS Engineering Consultants, Inc.

Warming Up

- Randomly select a date, and:
  - Select starting soil moistures for that date from continuous-run
  - Select stages and pools for that date from continuous-run

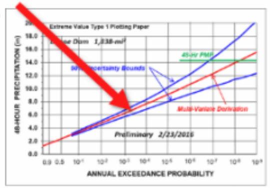


- We found that soil reached "full" in the continuous runs, but pools didn't cover the full range of possibles
- Bootstrapping was used to create a 1,000-yr rainfall record with a wider range
- Continuous simulation will run for 1,000 yrs, rather than 68 yrs

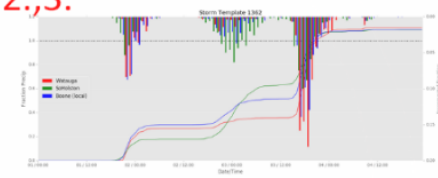
Creating a Storm

1. Sample 1,000s of depths from the PF curves by bins, and choose one

1.

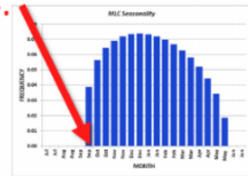


2.,3.



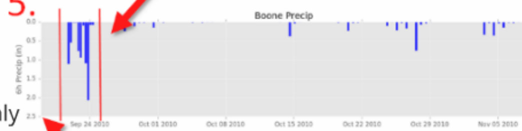
2. Randomly select storm template
3. Scale storm template:
in place depth==>probability==> transposed depth

4.



4. Set storm at the correct date

5.



5. Cut storm into rainfall randomly selected from the bootstrap

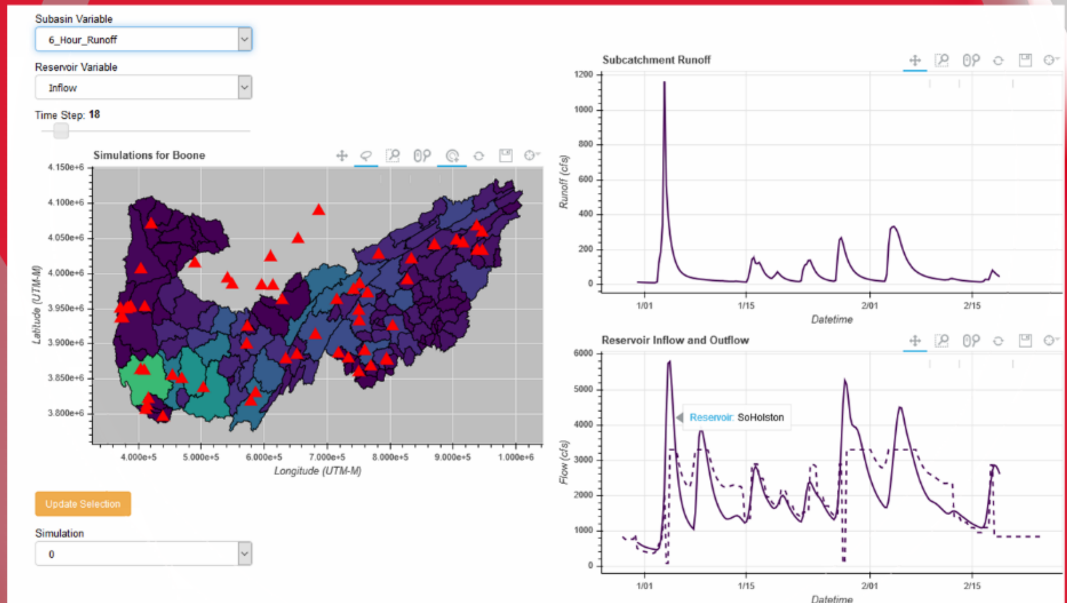
Rainf

Storm Typing

Three different storm types cause floods for TVA:
- Mesoscale with Embedded Convection (MEC)
- Mid-Latitude Cyclone (MLC)
- Tropical Storm Remnant (TSR)

Calculating Runoff

Execute the hydrology model using the selected starting soil moistures and generated rainfall.

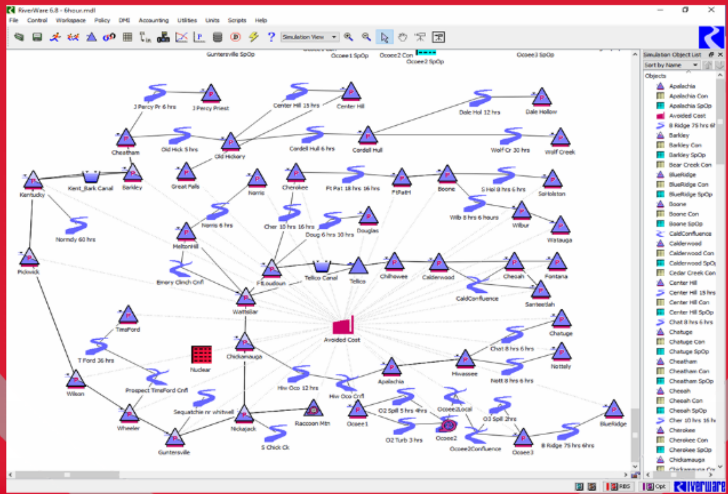


)asin
nally

s simulation

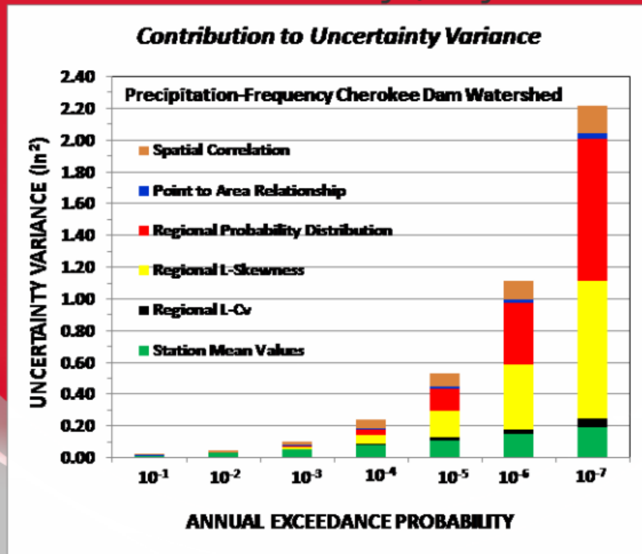
Routing the Flood

Execute the operations model using the selected starting pool levels and generated inflows.



Summarizing

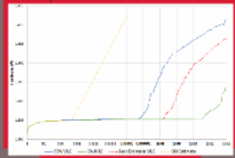
- Calculate summary stats like peak headwater & flow etc. for each run
- Create headwater frequency curve from sampled rainfalls using total probability theorem
- Describe sources of uncertainty (only rainfall presently)



Displaying

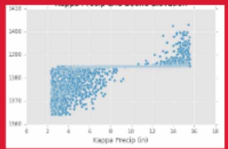
Example Hazard Curve

- 1E-6 was conservative for PMF level
- This dam stayed "in control" for storms much larger than those observed in our history
- Gate operation is critical



Data Mining

- Interface provides summary stats that can be "drilled" for individual-storm information
- Here we determined that all storms less than 10" basinwide keep the dam "in control".

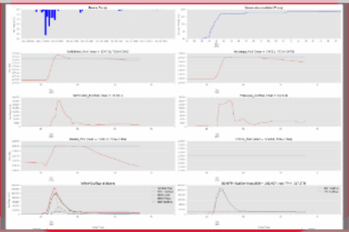


Data Mining

Plots are easy to customize for insight.

Here we found that the downstream dam only ever loses control after the upstream dam does

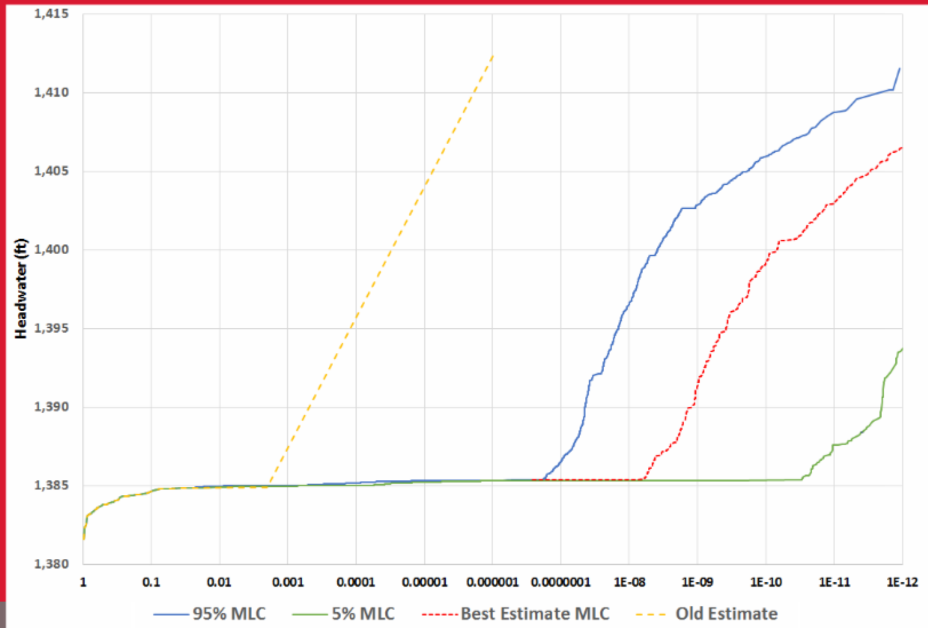
Example Single Storm

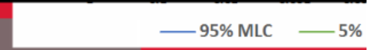


Summ

Example Hazard Curve

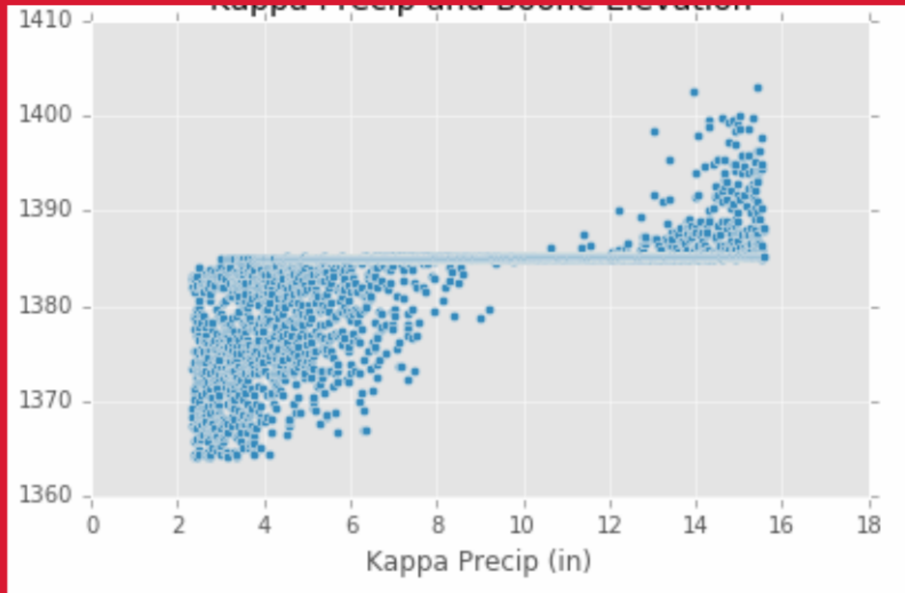
- 1E-6 was conservative for PMF level
- This dam stayed "in control" for storms much larger than those observed in our history
- Gate operation is critical





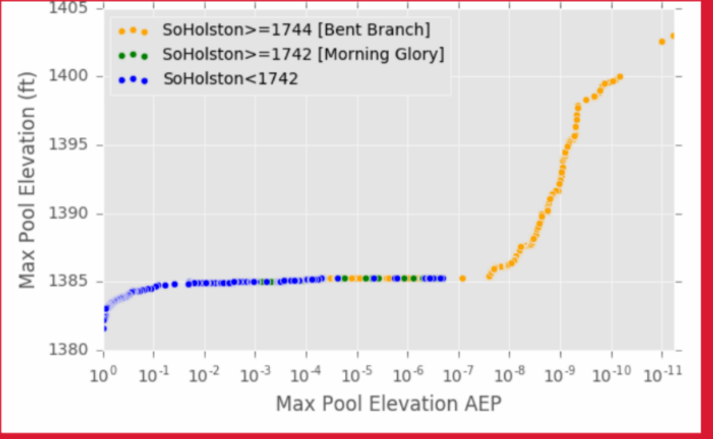
Data Mining

- Interface provides summary stats that can be "drilled" for individual-storm information
- Here we determined that all storms less than 10" basinwide keep the dam "in control".



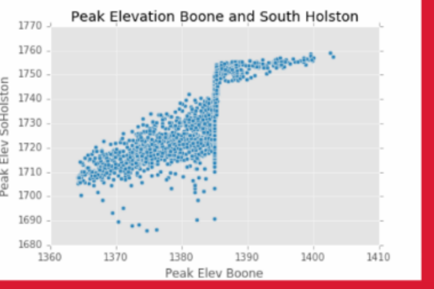
LC - - - Old Estimate

Data Mining

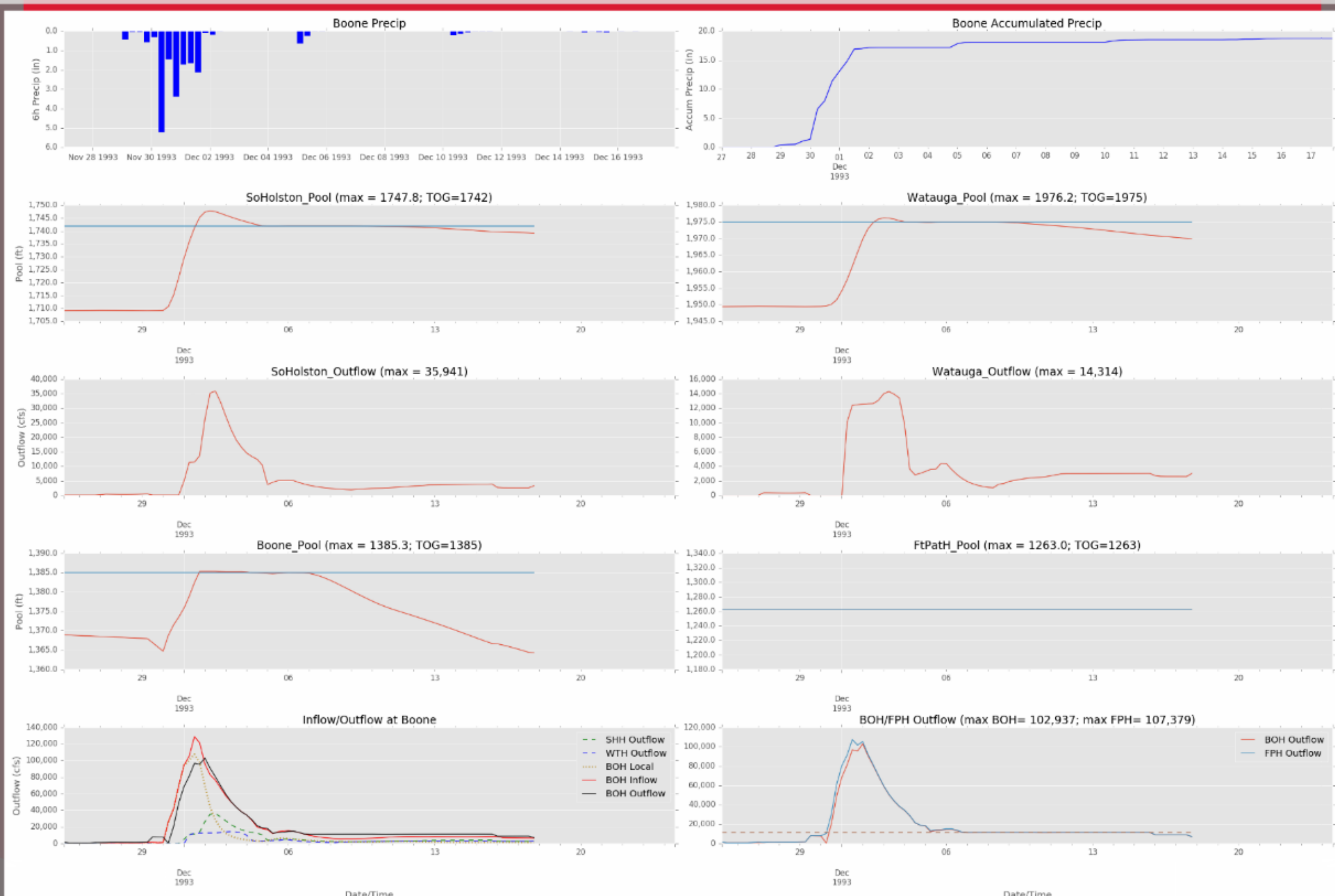


Plots are easy to customize for insight.

Here we found that the downstream dam only ever loses control after the upstream dam does



Example Single Storm



Deciding

Combine flood hazard information with fragility and consequences to choose the best dam safety investments

Next:

- Finalizing our 1st study
- Independent review of the framework
- Initial paleohydrology work (EPRI/USGS)
- Inclusion of more uncertainties
- Studies for each dam