# Stochastic Hydrology in the Tennessee Valley

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February 24, 2021

# Agenda

Some History

PFHA and Dam Safety

Where are we?

What do we do?

How do we use it?

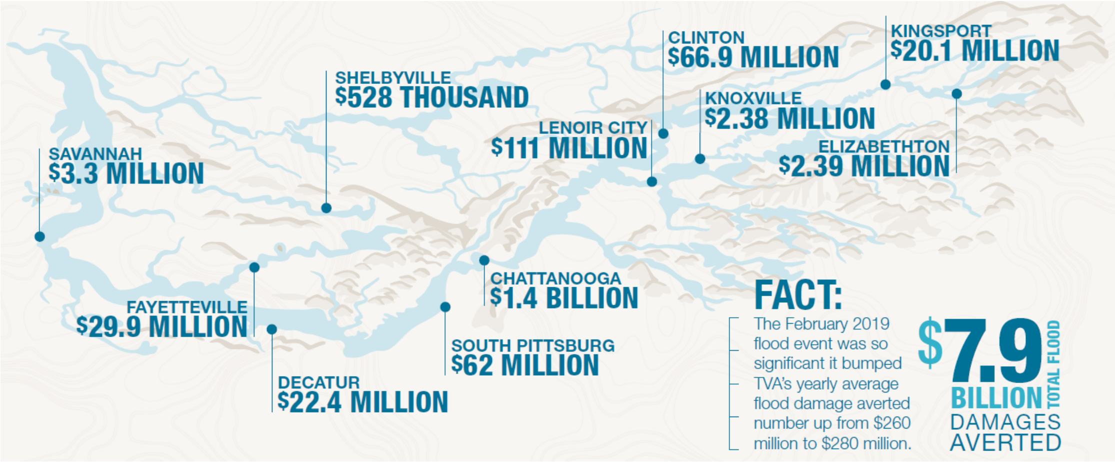
What have we learned?

Where are we going?

# TVA's Statutory Responsibility

An Act to provide for :

1. Improved navigability
2. Flood control
3. Reforestation and proper use of marginal lands
4. Agricultural and industrial development of the valley
5. National defense
6. "other purposes"



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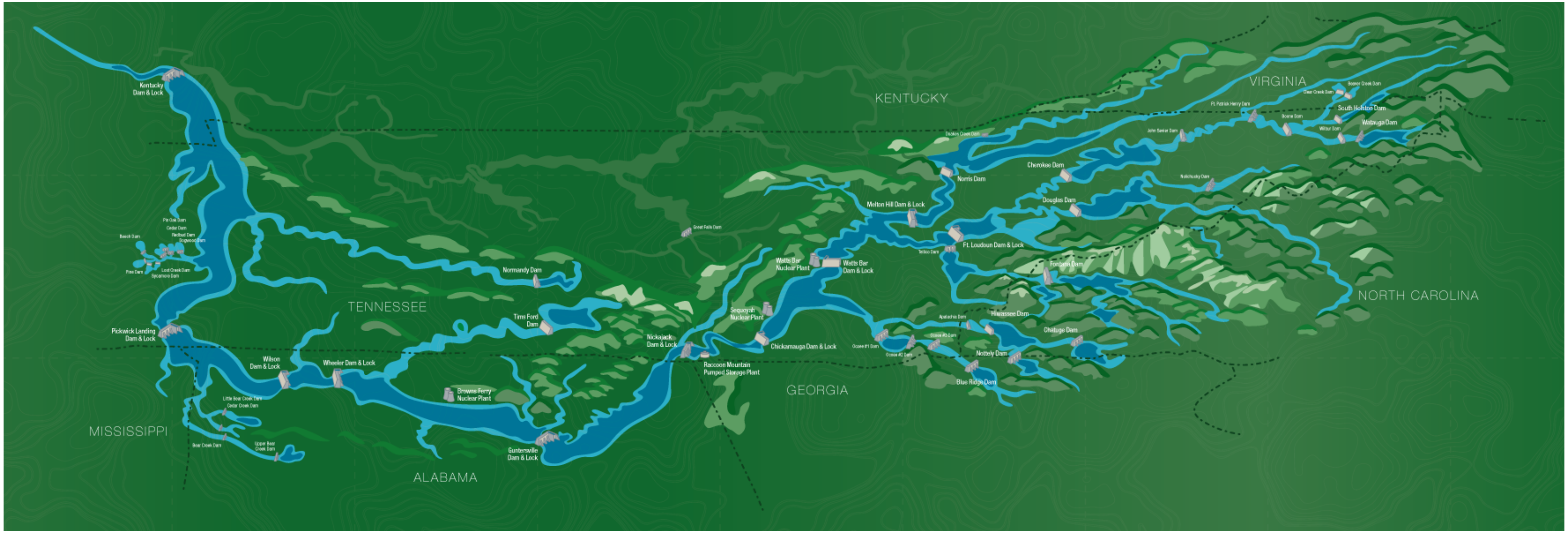
# The TVA Reservoir System



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# TVA Dam Safety – It's all about Risk

Risk is everywhere. Risk is fine. But you MUST:

Identify the risk → Quantify the risk → Modify the risk

RIDM allows dam safety to prioritize investments across the portfolio to those projects that provide the greatest risk benefit.

We need to understand *probabilities* of extreme loadings

We need a method that is consistent and repeatable

# PFHA Program – Where we are

| PHASE 1: Development | PHASE 2: Implementation | PHASE 3: Production |
|---|---|---|
| FY14 – FY16 | FY17 ~FY21 | ~FY22 and Beyond |

**PHASE 1: Development** (FY14 – FY16)

Project Inception
Storm Typing
Regional Point Precipitation Frequency Analysis
Detailed Watershed Studies
Storm Transposition Tool Development
RiverWare Model Development

**PHASE 2: Implementation** (FY17 ~FY21)

First Pilot Studies for Risk Assessment (FY17)
Framework Peer Review
Site-specific Study Independent Review
Incorporation of Paleoflood Data
Incorporation of Dendrochronology Data
Enhancements to Front end/Back end
Application of PFHA to Interim Risk Reduction Measures
Evaluation of Policy Alternatives with PFHA

**PHASE 3: Production** (~FY22 and Beyond)

Mature Product
Routine studies and updates
Expansion of PFHA into other operational areas
Ongoing routine maintenance


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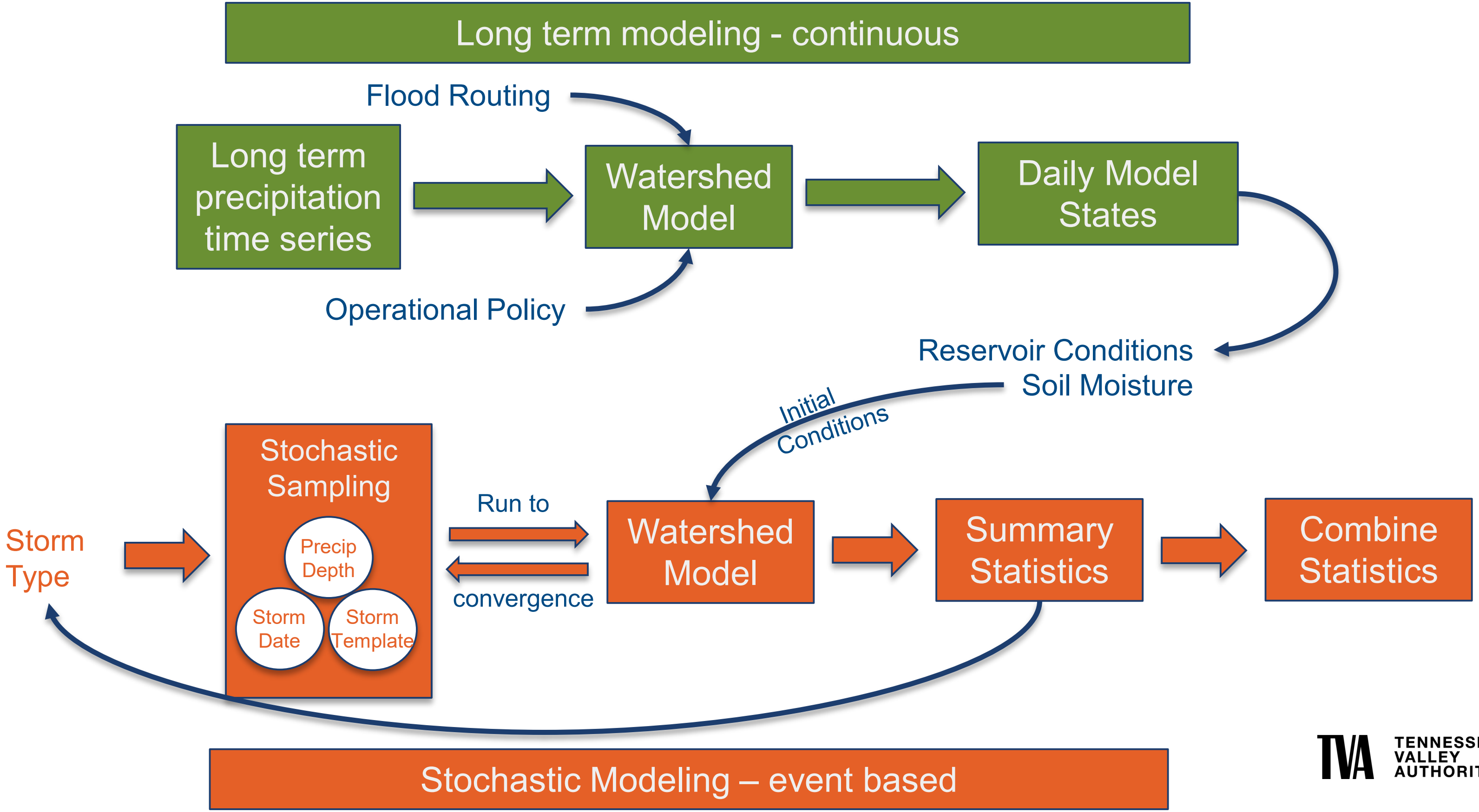
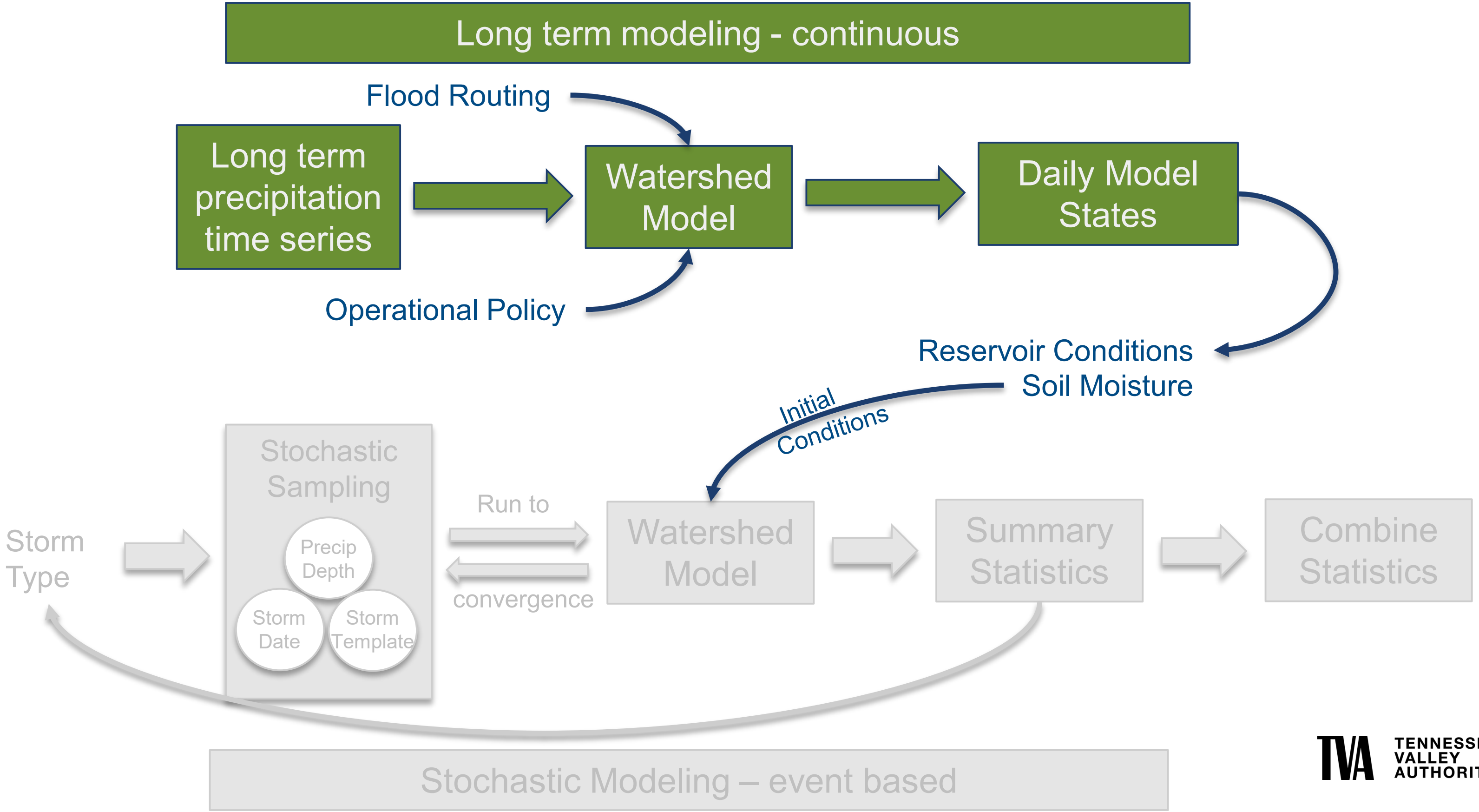
# The TVA Framework

# PFHA Simulation Roadmap



# PFHA Simulation Roadmap



# Long term simulation

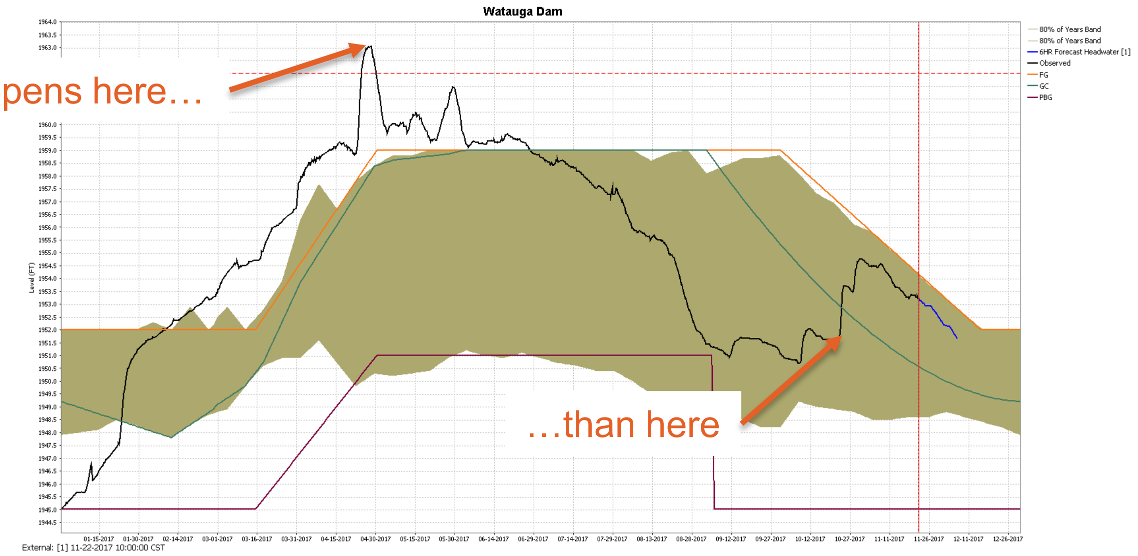
**The Goal:**

To provide a representative range of initial watershed conditions for stochastic events.

To represent sequences of storms that may cause flooding issues.

*The worst case scenario may not be an exceptionally rare storm, but an unfortunately timed storm of moderate intensity*

It’s worse if a storm happens here…



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# Long term simulation

**The Solution:**

Simulate a long term watershed and reservoir model using resampled historical precipitation

*But… resampled historical precip may not provide sufficient variability of wetter and drier periods*

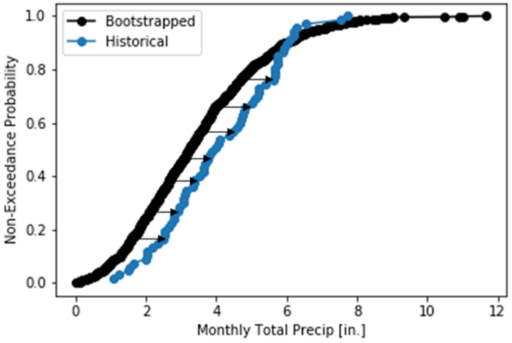
**Use an Alternating Renewal Method:**

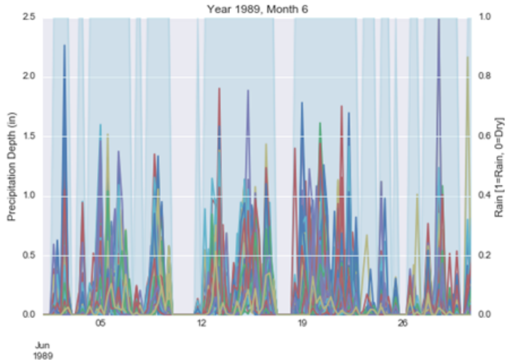
Fit distributions to seasonal rainfall statistics (depth, duration, etc.)

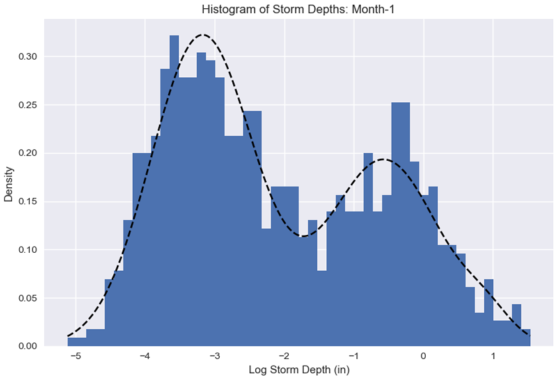
Resample the distributions to capture distribution tails

Synthesize a 1,000 year precipitation time series

Bias correct the middle 90% of the data



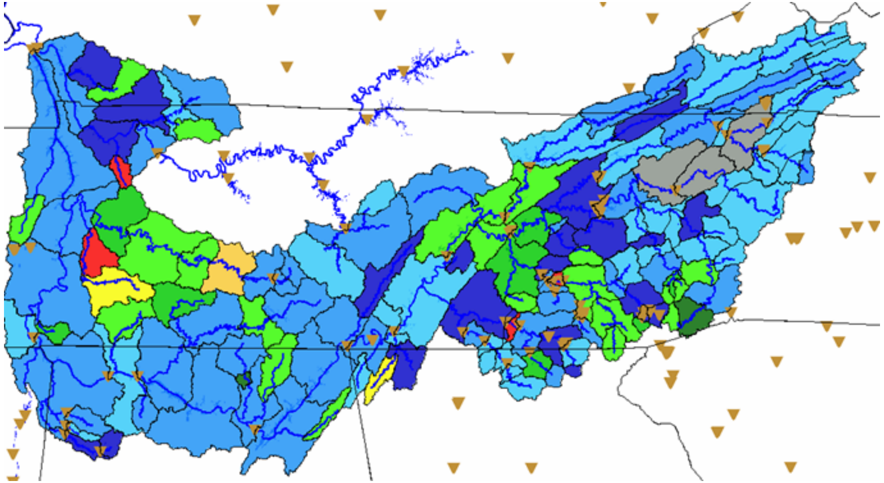
# Long term simulation

**Watershed Modeling:**

Drop the rainfall on the TVA Operational forecast model

- 127 auto-calibrated basins, used in daily operations
- Runoff modeling using SAC-SMA

Route the runoff to RiverWare control points





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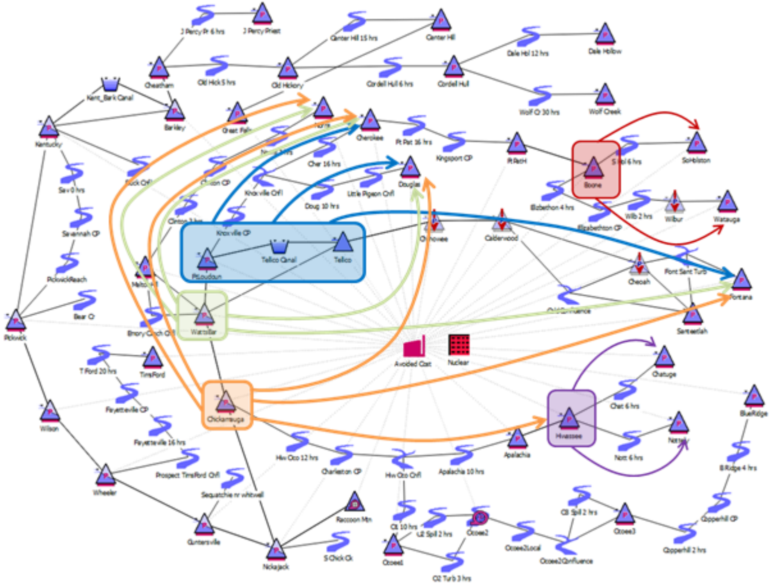
# Long term simulation

**Operations Modeling:**

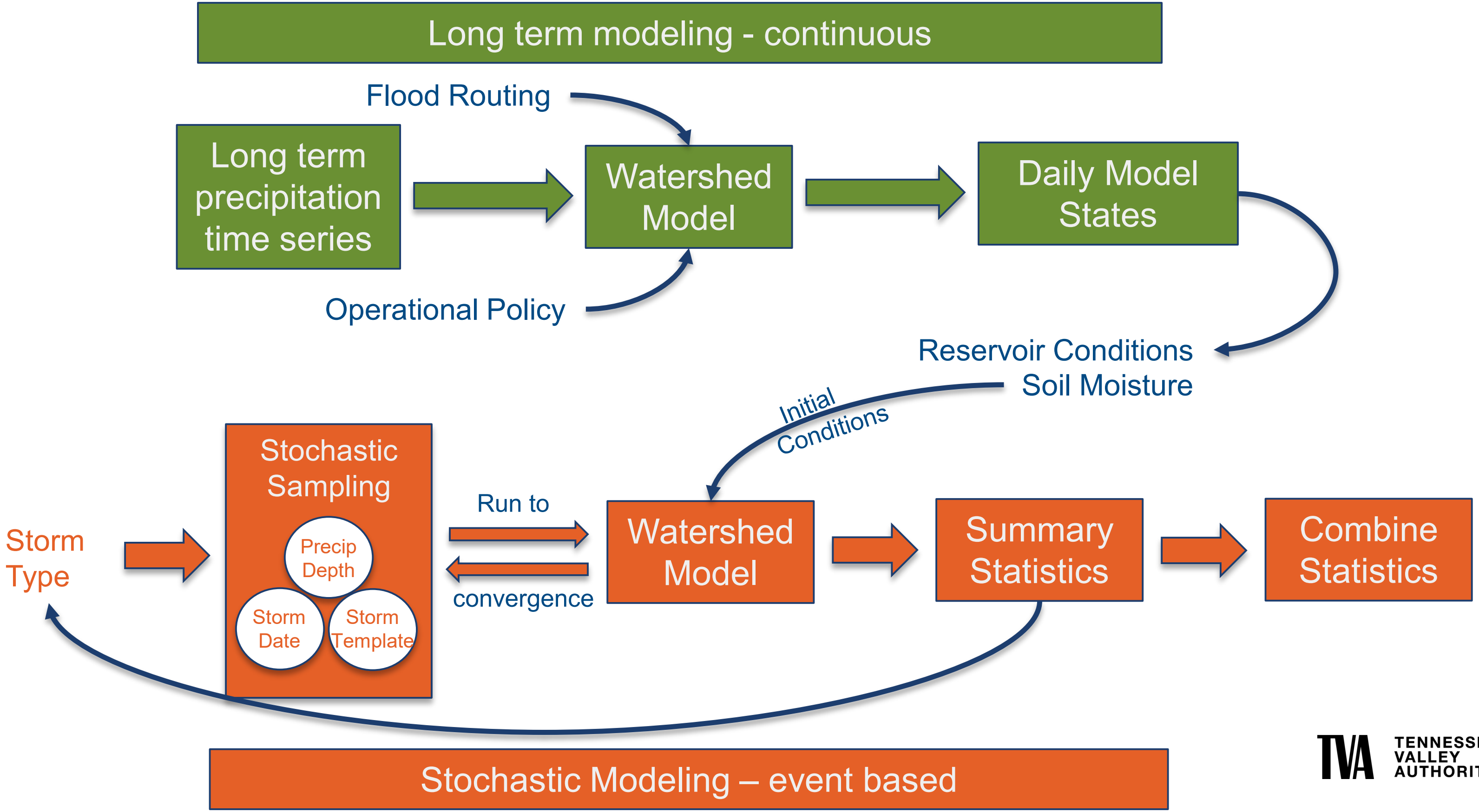
Simulate the entire reservoir system using RiverWare

- Flood operations and routine daily operations are complex
- RiverWare rules based simulation approximates:
  - *Turbine releases*
  - *Environmental releases*
  - *System operating guide constraints*
  - *Flood operations*
  - *Tieback operations*
- There are 79 rules and hundreds of functions



Record the model states – these provide initial conditions for the stochastic sampling

# PFHA Simulation Roadmap



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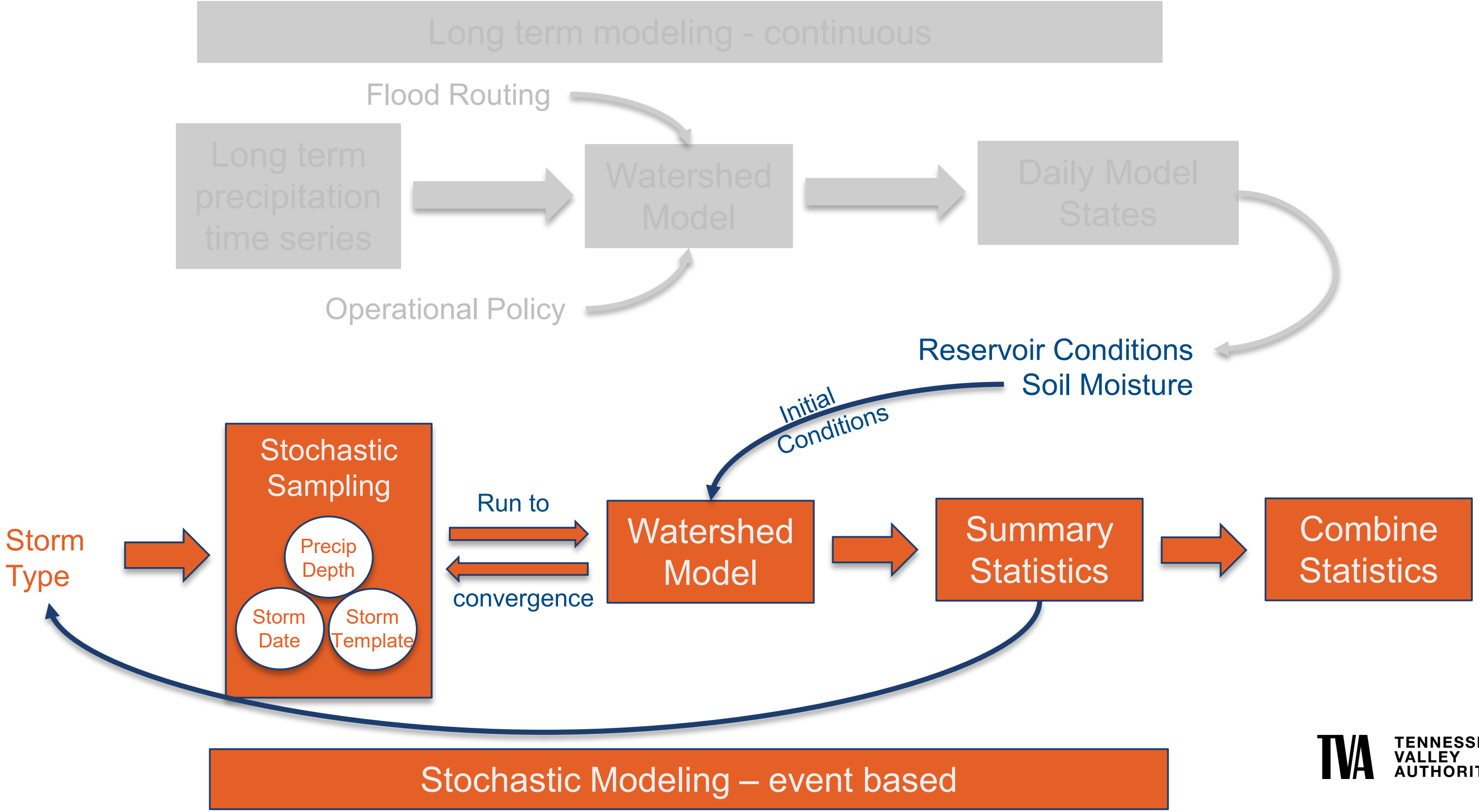
# PFHA Simulation Roadmap



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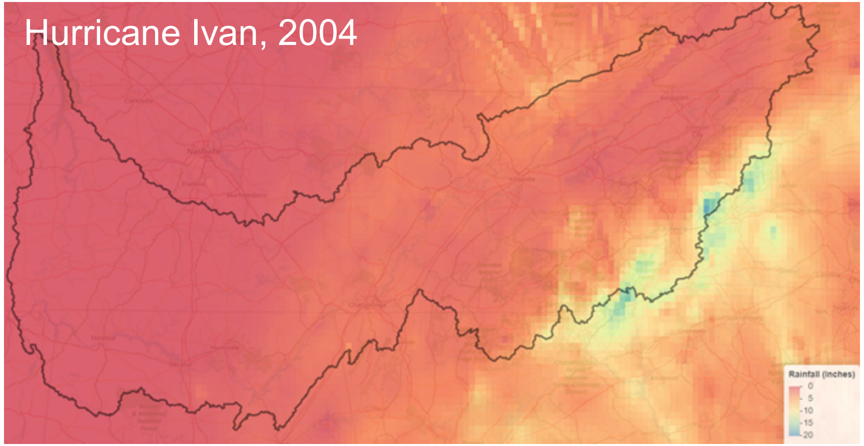
# Storm Typing

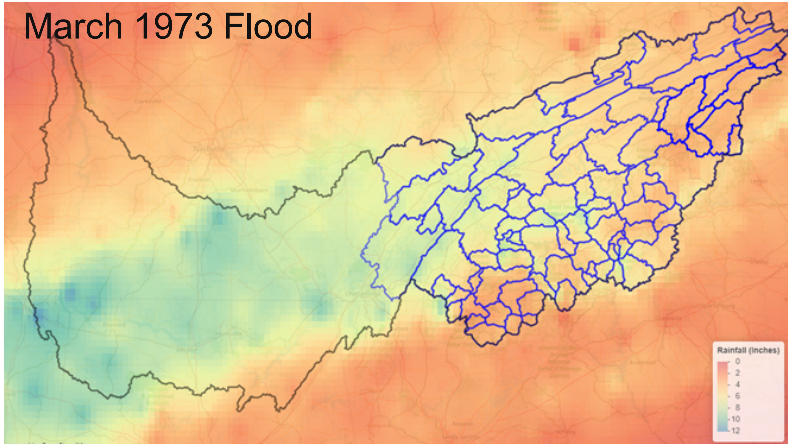
The Tennessee Valley is subject to mixed populations of storms and floods

Different types of storms have different spatial and temporal characteristics, which cause floods with differing impacts

Separating the storm types reduces uncertainty in the PF relationships

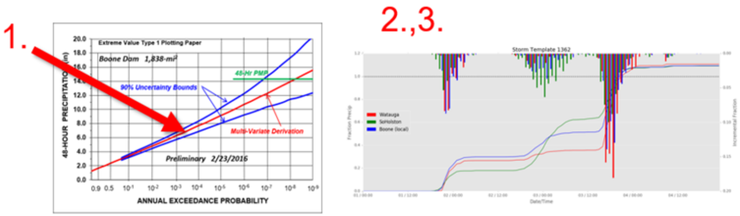
The tropical storm remnant PF analysis was the first ever conducted in the US specific to TSRs



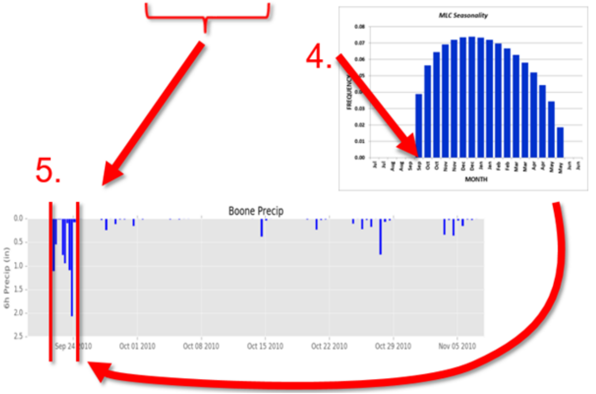



# Stochastic Simulation

***Stochastic event generation routine:***




1. Pick storm depth from precip-frequency
2. Pick storm template
3. Scale storm template by sampled depth
4. Pick storm date from seasonality
5. Insert storm into long-term rainfall time series




Simulate stochastic events until the headwater frequency curve converges

Intelligent sampling allocates additional samples to precipitation bins where it matters

Simulate a stochastic event for each storm type

Combine the frequency statistics for each of the three storm types into a single hazard curve



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# Current Work

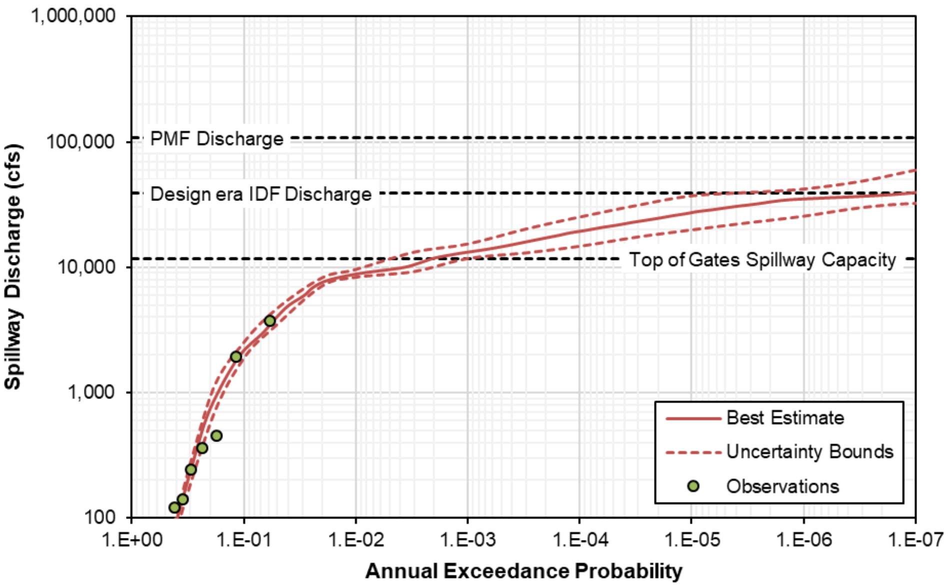
# Practical Application – Dam A

**The issue:**

- Screening level analysis highlighted concerns with the spillway
- Baseline risk assessment identified an actionable level of risk
- The primary risk driving failure mode has a hydrologic loading
- Inflow hydrology is dominated by regional winter storms on the common end
- Summer thunderstorm complexes can be severe and drive risk for rare probabilities

**The question:**

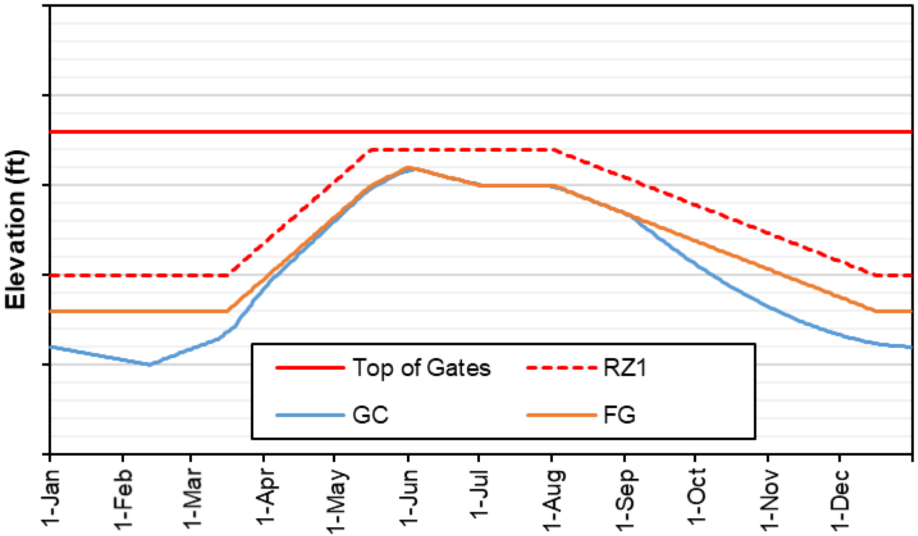
- What can we do to modify our risk profile, and how much does it buy us?



# Dam A – operating policy

**Operational Constraints:**

- Limited pool control
- Turbines are not always available
- Discharges will be curtailed during rain events to help downstream
- Dam is tied in to operations downstream, and can be called on to change discharges
- Pool is low in the winter to control flooding
- Pool is high in the summer to facilitate recreation and water supply



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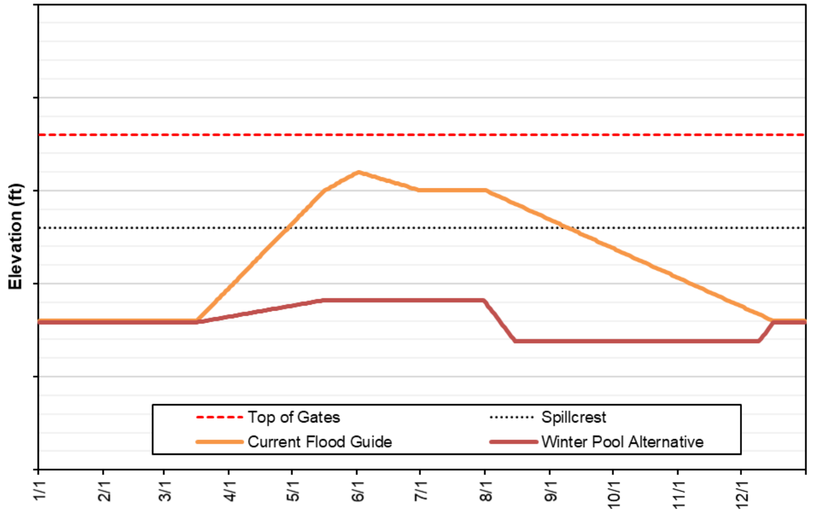
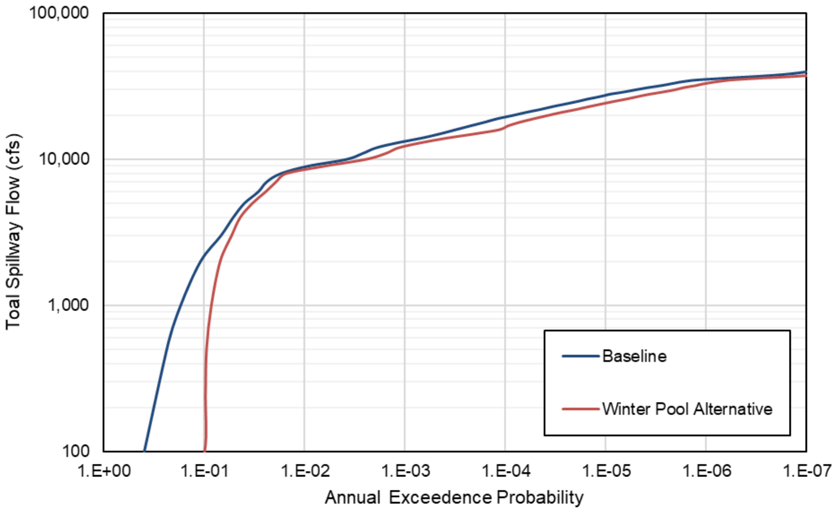
# Dam A – operating policy

**What if we just go to winter pool(ish) all year?**



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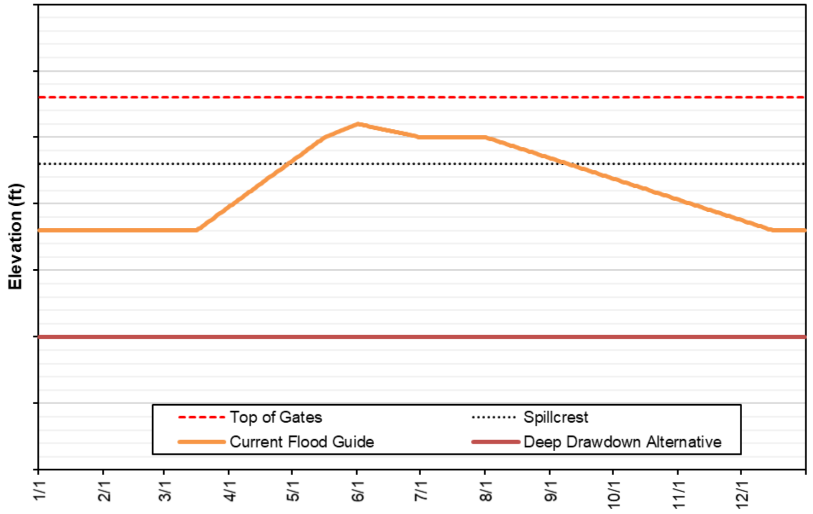
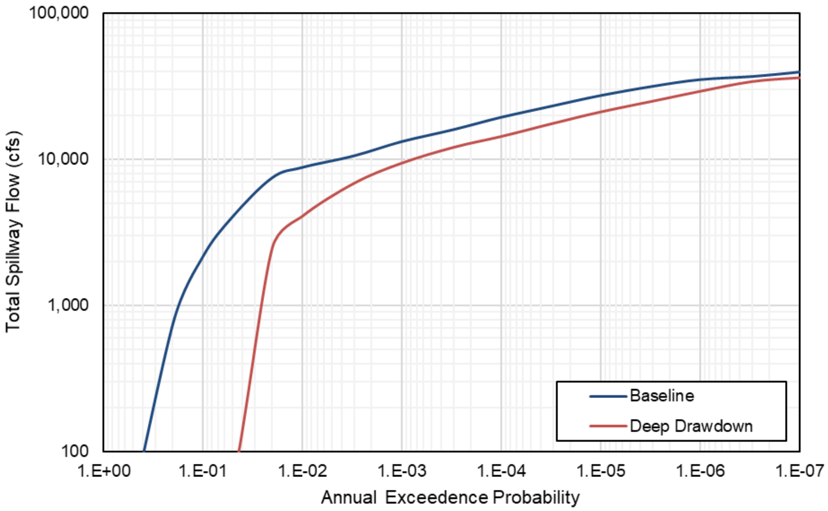
# Dam A – operating policy

**What if we draw down even further?**



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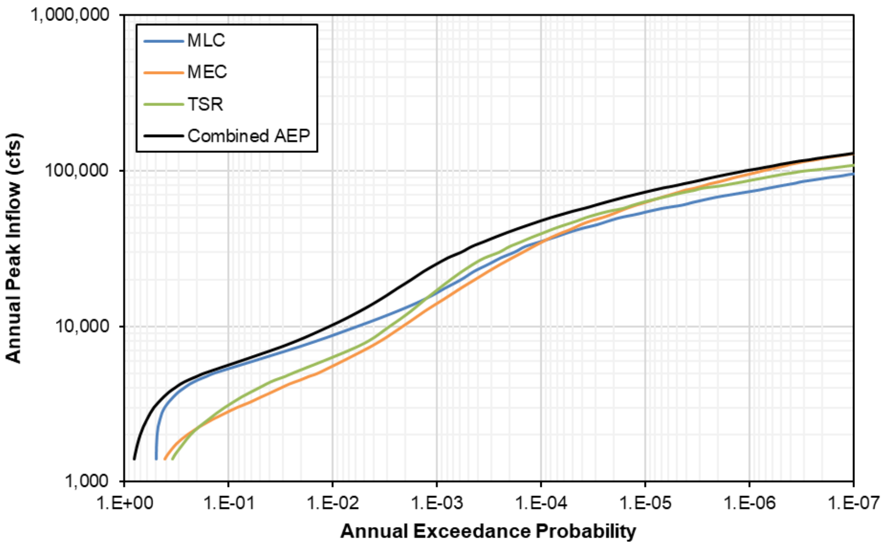
# Practical Application – Dam B

**The issue:**

- Screening level analysis highlighted several potential risk drivers
- Risk analysis showed a secondary risk driver was due to hydrologic loads on the spillway
- Inflow hydrology can be dominated by different types of storms on different parts of the curve
- The auxiliary spillway may be more resilient than the primary, but requires a higher headwater to use

**The questions:**

- What can we do to modify our risk profile, and how much does it buy us?



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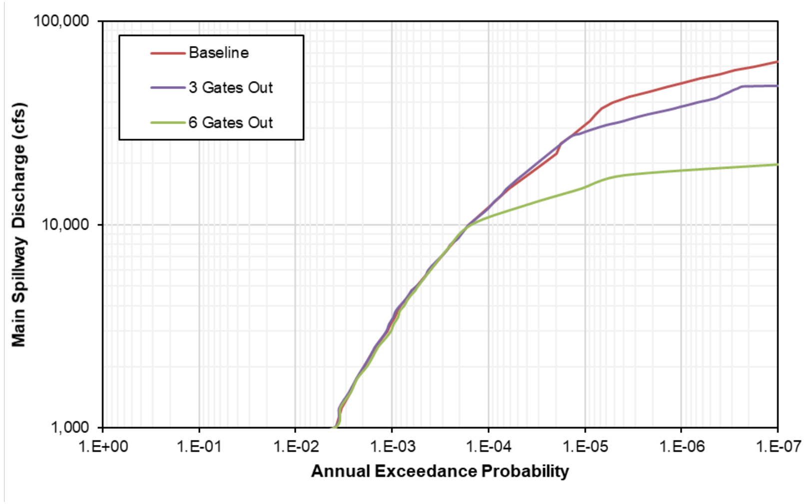
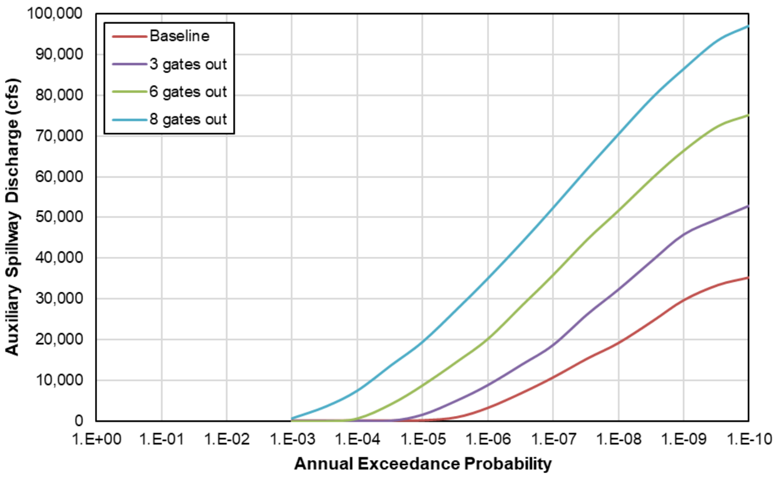
# Dam B – Risk modification alternatives

**Can we permanently tag out some of the main spill gates?**



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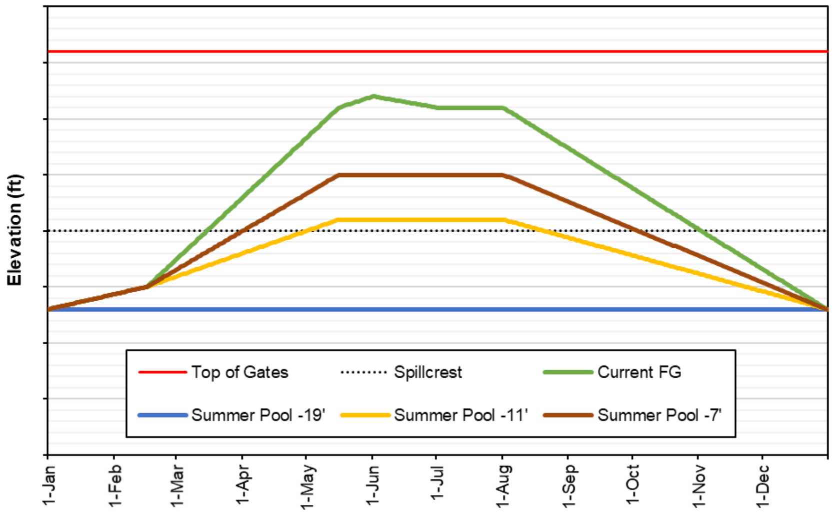
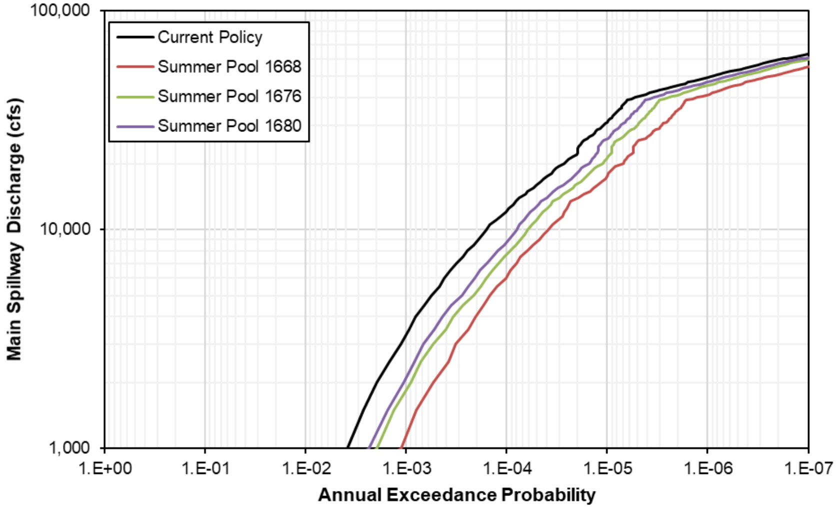
# Dam B – Risk modification alternatives

**What if we lower the pool?**

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# Lessons Learned

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# Lessons Learned

- Look at the data!
  - We have a black box. Black boxes are dangerous.
  - At Fontana Dam – 765,000 stochastic events, and they are all meaningful
  - How do you know you're right?
- Paleoflood and dendrochronology data is *indispensable*
- Solicit input from across the organization – don't work in a vacuum
- Let the questions drive the software development
- There is a huge range of potential applications

# Future Work

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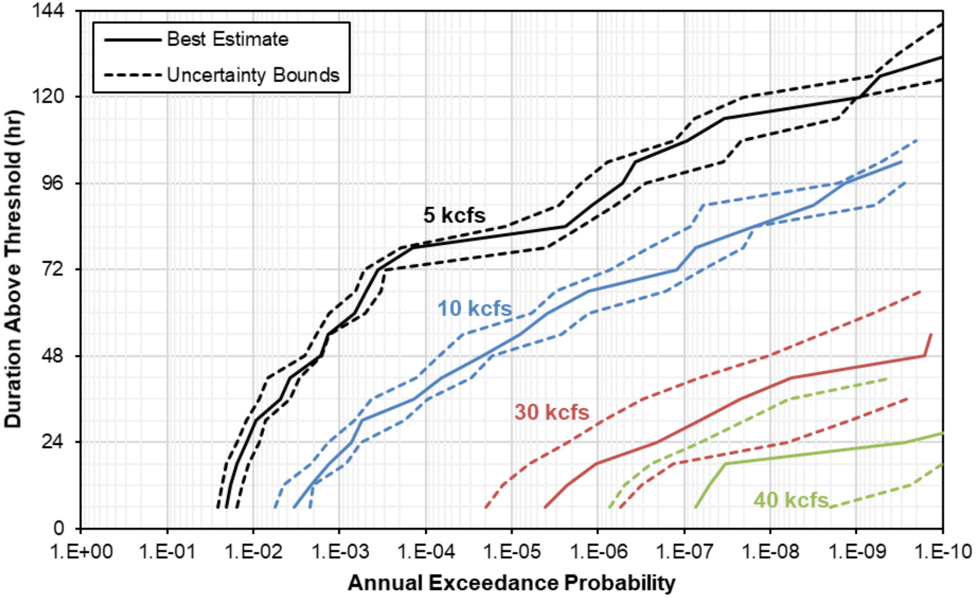
# Future Work

- Using the PFHA system to evaluate multivariate hydrologic frequency



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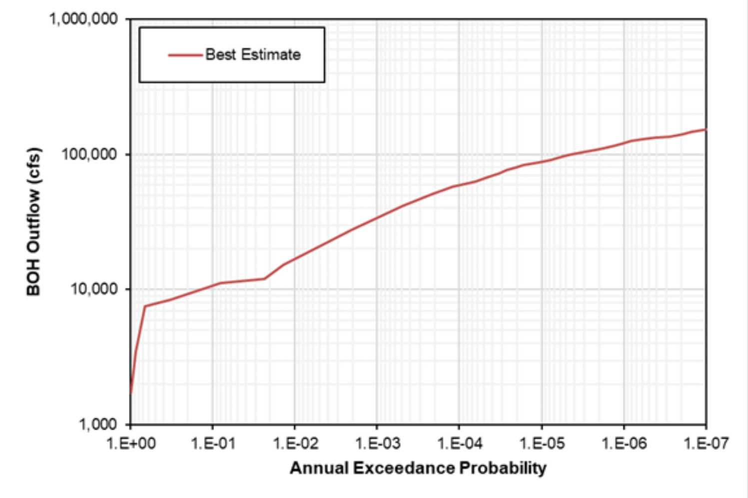
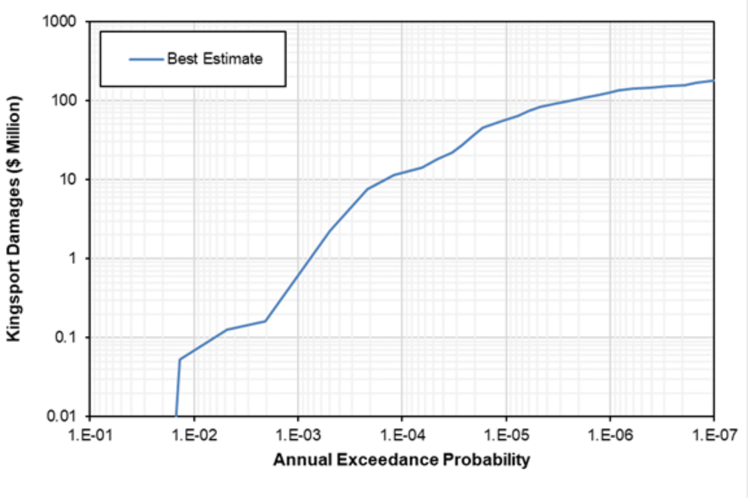
# Future Work

- Accounting for climate change and non-stationarity in the PF analysis
- Assessing transference of risk from one project to another
- Evaluating individual policy changes for River Management and communicating with stakeholders
- Optimizing system wide, multiple purpose operations

# Future Work

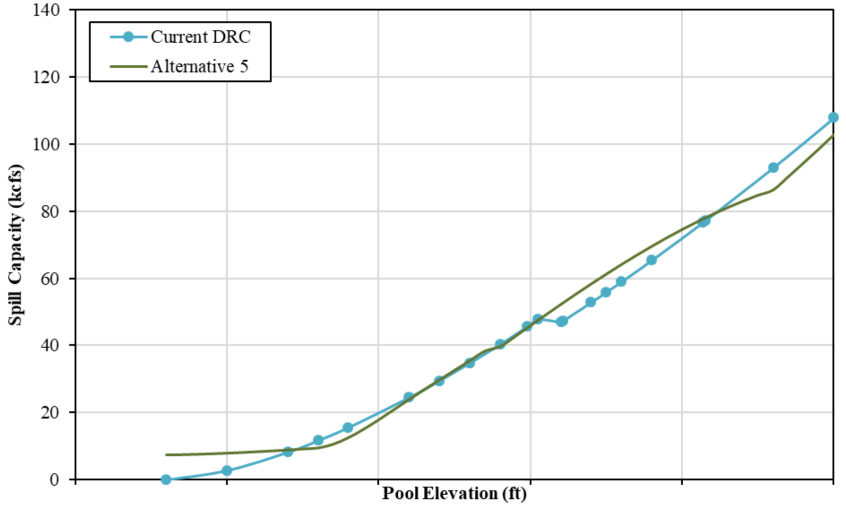
- Leveraging PFHA in economic analyses
- Quantifying the economic benefit of the reservoir system compared to natural conditions

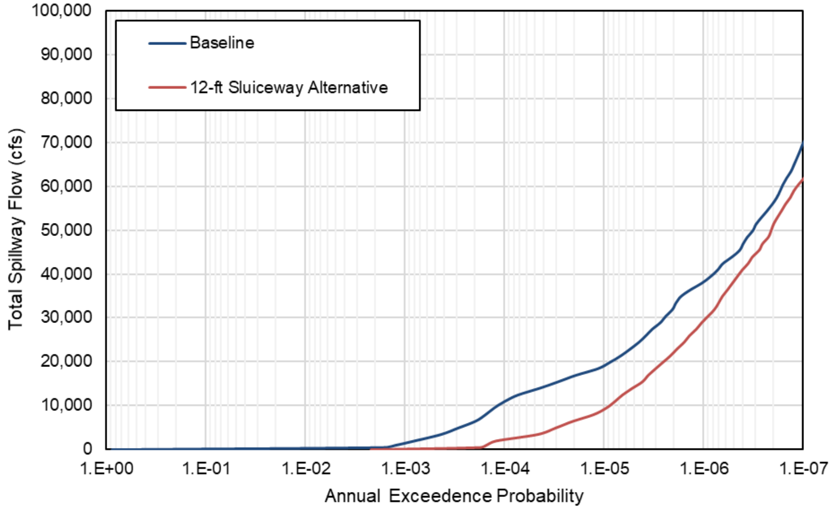


# Future Work

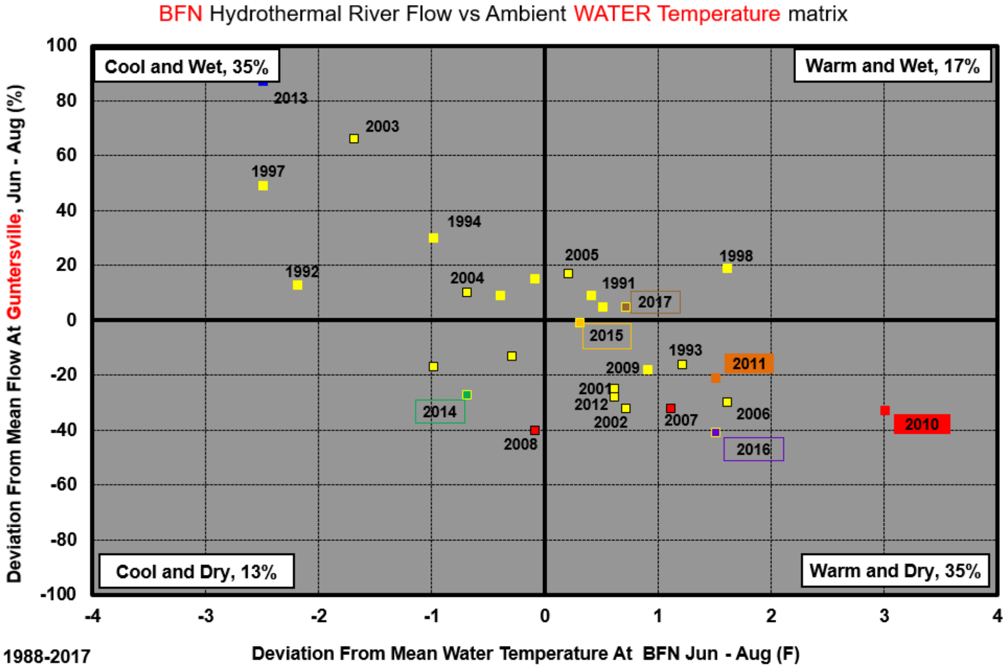
- Using PFHA to inform the design process and evaluate infrastructure alternatives



# Future Work

- Using the PFHA framework and dendrochronology analysis to evaluate operational resiliency and quantify the economic benefit of water reliability.



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# Future Work

- Incorporating *watershed scale* paleoflood data to better inform, refine, or validate PF relationships
  - FY19-20 – completed paleoflood studies immediately downstream from Guntersville Dam (big, main river project)
  - FY21 – Paleo study at Douglas Dam (French Broad River)
  - FY22 – Paleo study at Ocoee Dams 1&2 (Ocoee River)
  - FY23 – Paleo study at Norris Dam (Clinch River)
  - Go see Rachel Lombardi’s presentation later today! Ask her lots of hard questions!

# Further Information

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