Massachusetts Climate and Hydrologic Risk Project

Part 2

Presented by: Gregory Stewart PE, USGS

Jonathan Lamontagne PhD, Tufts

Massachusetts Climate and Hydrologic Risk Project: Overview

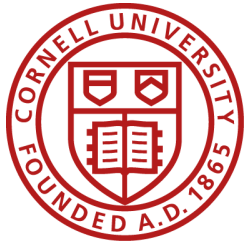
Planners are concerned with how climate and hydrologic extremes and their frequency will change over time

- Increases in rainfall intensity
- Increases in frequency of flooding
- Decreases in annual minimum streamflows

Exacerbate vulnerabilities in infrastructure

- Transportation
- Flood Control
- Water Supply
- Power Supply
- Drainage and Sewer Systems

Cooperative project:



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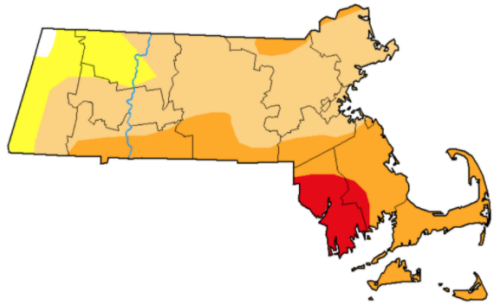
Planners are concerned with extremes

Parts Of Massachusetts Facing 'Extreme' Drought Conditions

September 17, 2020 | By Colin Young, State House News Service



WBUR, 2020

A map from the U.S. Drought Monitor as of Sept. 17. Areas in red indicate "extreme" drought, and those in yellow are facing "severe" conditions. (Screenshot via U.S. Drought Monitor)

New England Deluged by Worst Flooding in Decades

After days of record rainfall in Maine, Massachusetts and New Hampshire, thousands of residents have evacuated their homes. In Peabody, Mass., north of Boston, a couple relied on the buddy system.
Brian Snyder/Reuters

By Katie Zezima

May 16, 2006

NYT, 2006

BOSTON, May 15 — After days of record rainfall, rivers in Maine, Massachusetts and New Hampshire have spilled over their banks,

Boston's Epic Cold Snap Ties a Century-Old Record

It hasn't been this cold for this long since 1918.

by SPENCER BUELL • 1/2/2018, 11:22 a.m.

Get a compelling long read and must-have lifestyle tips in your inbox every Sunday morning — great with coffee!

EMAIL ADDRESS

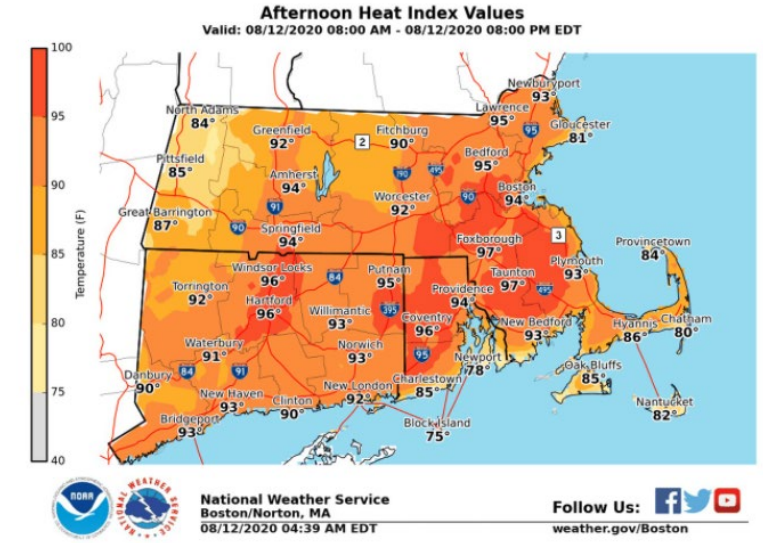
Boston Magazine, 2018

photo via AP/Bill Sikes

The extreme, bone-chilling cold that has swept the region over the past

Boston has had 11 days of heat wave weather this summer so far

By Caroline Enos Globe Correspondent, Updated August 12, 2020, 3:41 p.m.



Most parts of Eastern Massachusetts, Connecticut, and Rhode Island hit 90 degrees while under a heat advisory Wednesday. NATIONAL WEATHER SERVICE

Boston Globe, 2020

Of particular concern is how the frequency and intensity of these extremes may change over time.

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Massachusetts Climate and Hydrologic Risk Project: Overview

Stochastic Weather Generator (SWG, Cornell University):

- Tool for generating simulations of climate realizations for selected warming conditions

Deterministic Model (USGS):

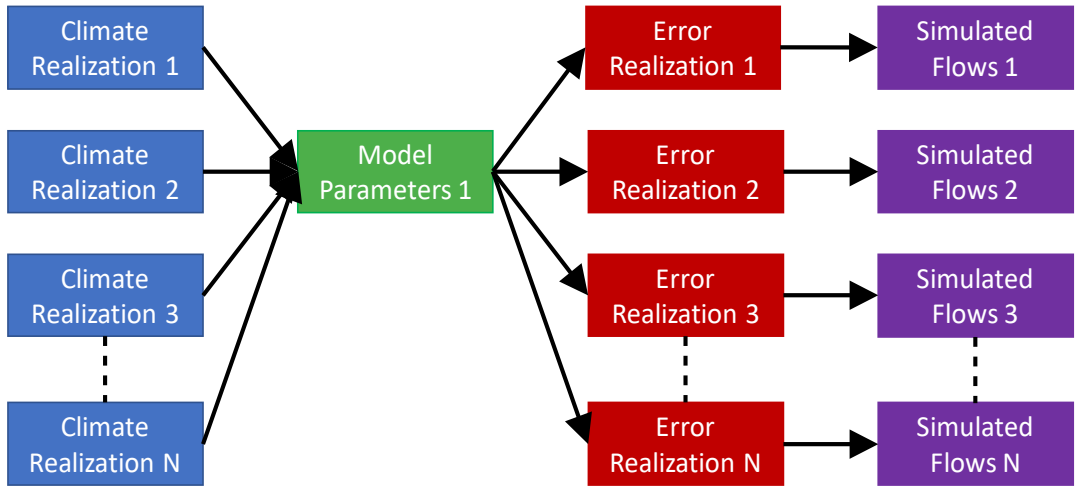
- SWG data input to a calibrated watershed model

Stochastic Watershed Model (SWM, Tufts University):

- Tool for correcting errors inherent with deterministic models

Visualization of results (USGS):

- Online Tool for viewing results



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Massachusetts Climate and Hydrologic Risk Project: Stakeholder team

- Project stakeholder team was developed and conduct bi-weekly meetings
- Project team members take turns presenting

Members from the project team:

- MA DCR
- USGS
- Tufts
- Cornell
- MA EOEEA

Additional members from:

- MA DEP
- MA DOT
- MA FWE
- Umass
- MIT

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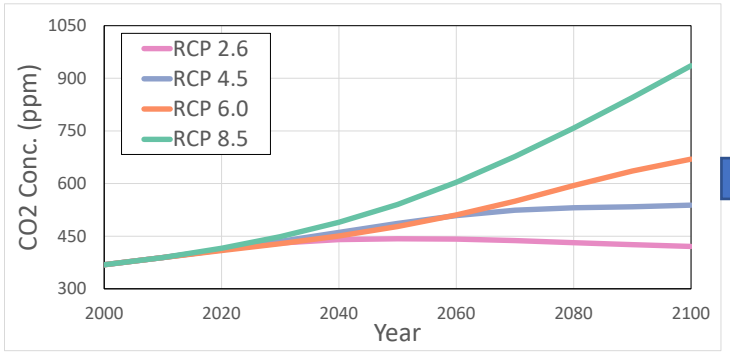
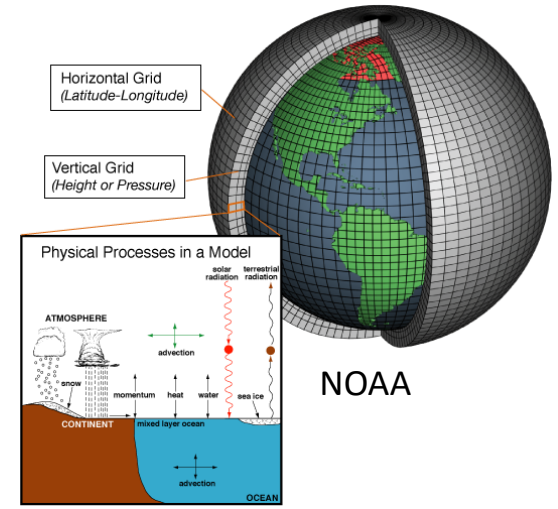
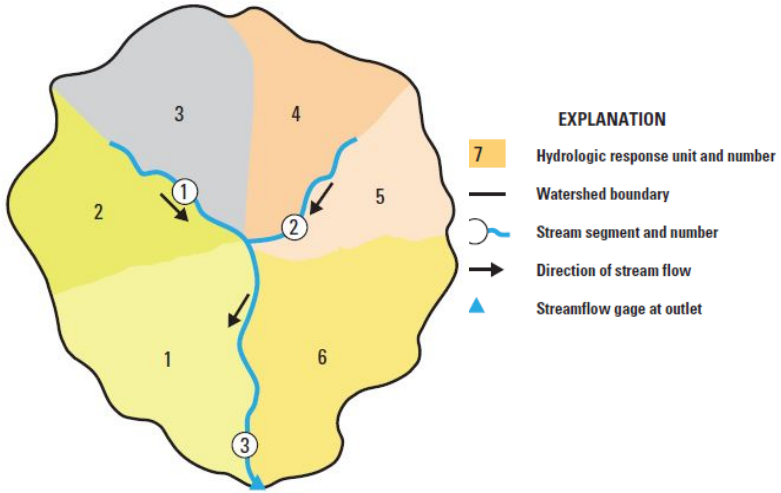
Scientists use models to estimate future risks





NOAA



Emissions Scenarios:

Emissions response to socio-economic change.

Global Climate Models:

Climate response to emissions.

Watershed Models:

Hydrologic response to climate and weather.

Each link in the chain contains uncertainty that propagates.

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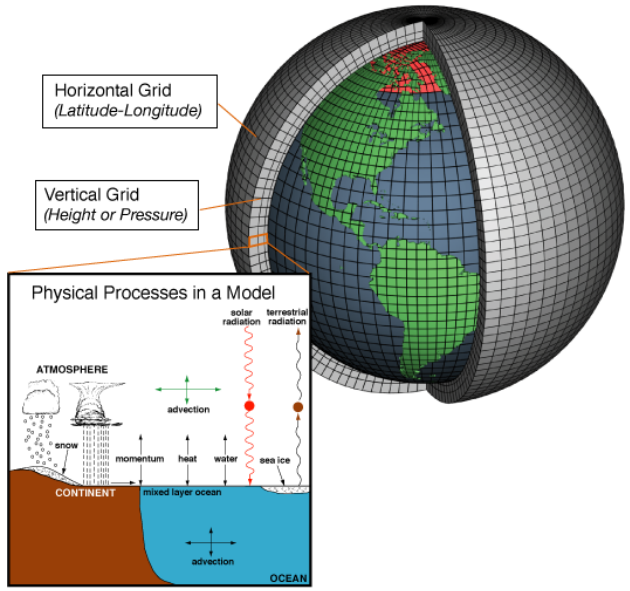
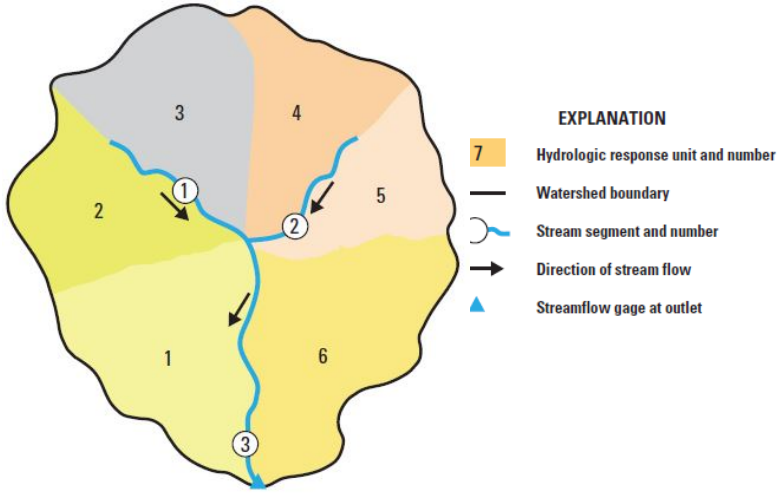
Commonly used models are ill-suited to quantify local hydro-climatic risk



Global Climate Models:
Designed to capture large-scale signals of climate change.

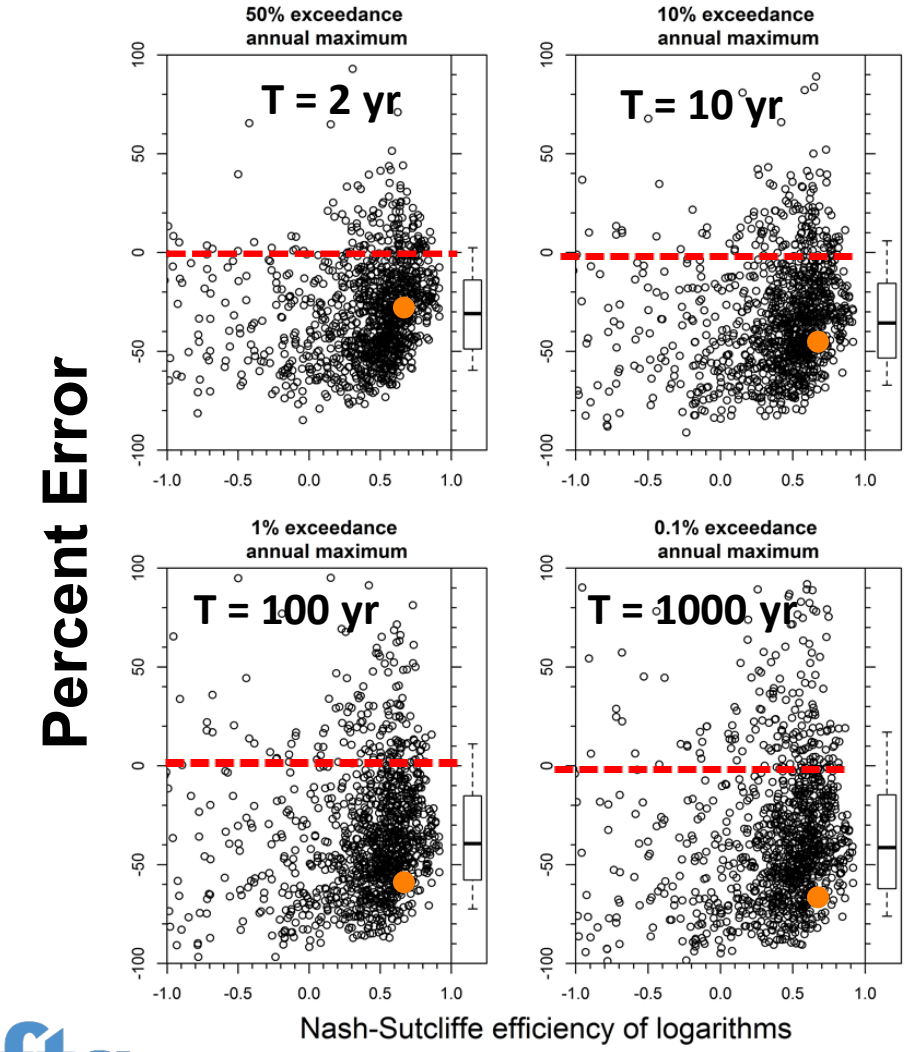
Errors and uncertainties arise when downscaling to state, basin scale.



Watershed Model:
Designed and calibrated to capture flows on average.

Models generally underestimate extreme events.

Watershed models misrepresent the extremes planners most care about



Farmer and Vogel [2016] looked at 1,225 U.S. basins.

Consistent, substantial underestimation of design floods.

100-year flood $\geq 40\%$ too small in 50% of sites

Squannacook is consistent with this pattern.

T=2 flood 33% too small, T=1000 flood 66% too small

Low flow statistics also underestimated.

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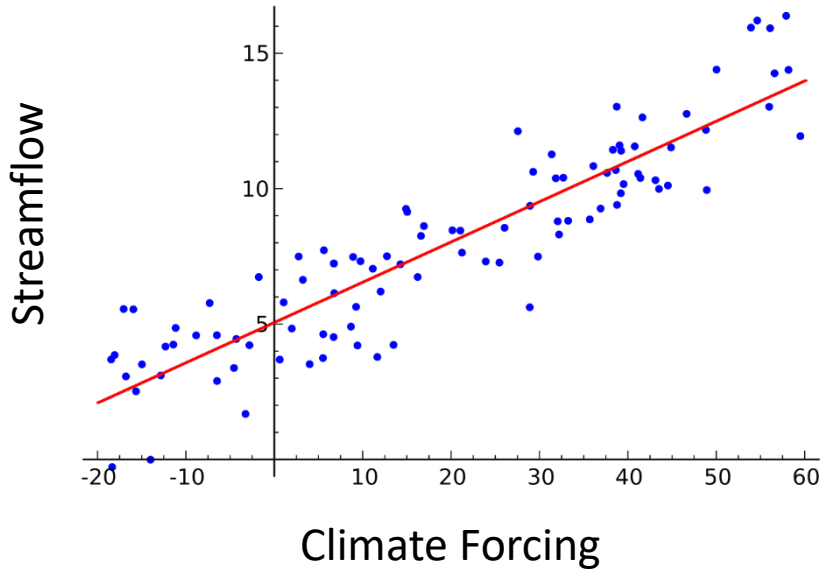
Watershed models misrepresent extremes because they are missing variability



Observation = Simulation + Error

$$O = S + e$$

$$var(O) = var(S) + var(e)$$

100% = 70% + 30%

If model is a linear regression, and we have an $R^2 = 0.7$, variance of model outputs will have 30% too little variance, underestimate extremes.

Models have a deterministic part (S) and a stochastic part (e), most applications discard the stochastic part.

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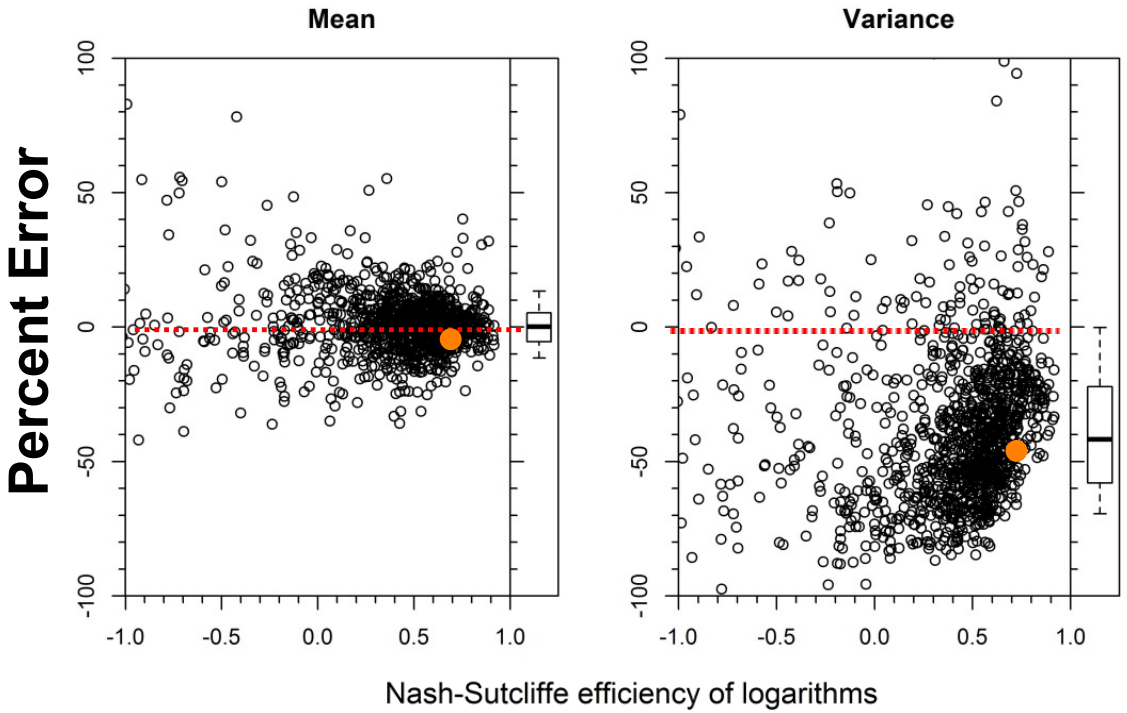
Watershed models misrepresent extremes because they discard variability in error



Farmer and Vogel [2016] observed same phenomena across U.S. watersheds.

Squannacook pilot basin consistent with national trend:

- Little error in average flow
- Variance is 50% too small

Our approach: Add variability to PRMS to correct bias in design flows.

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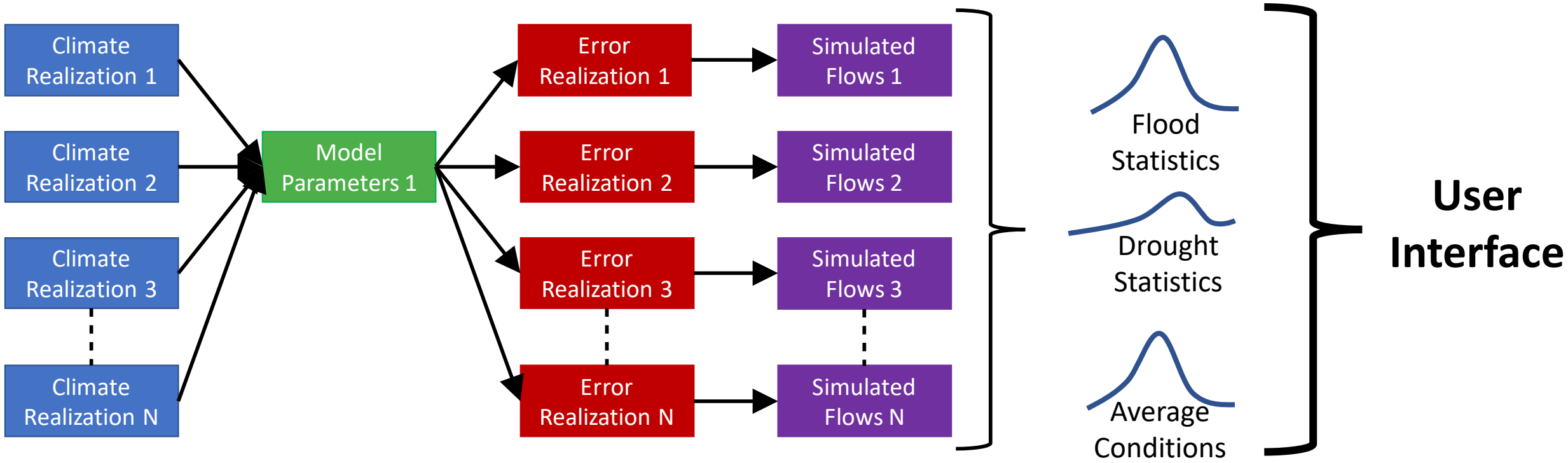
Summary: MA Hydro-Climate Risk Approach



Climate realizations generated by the **SWG** force the **deterministic PRMS** model.

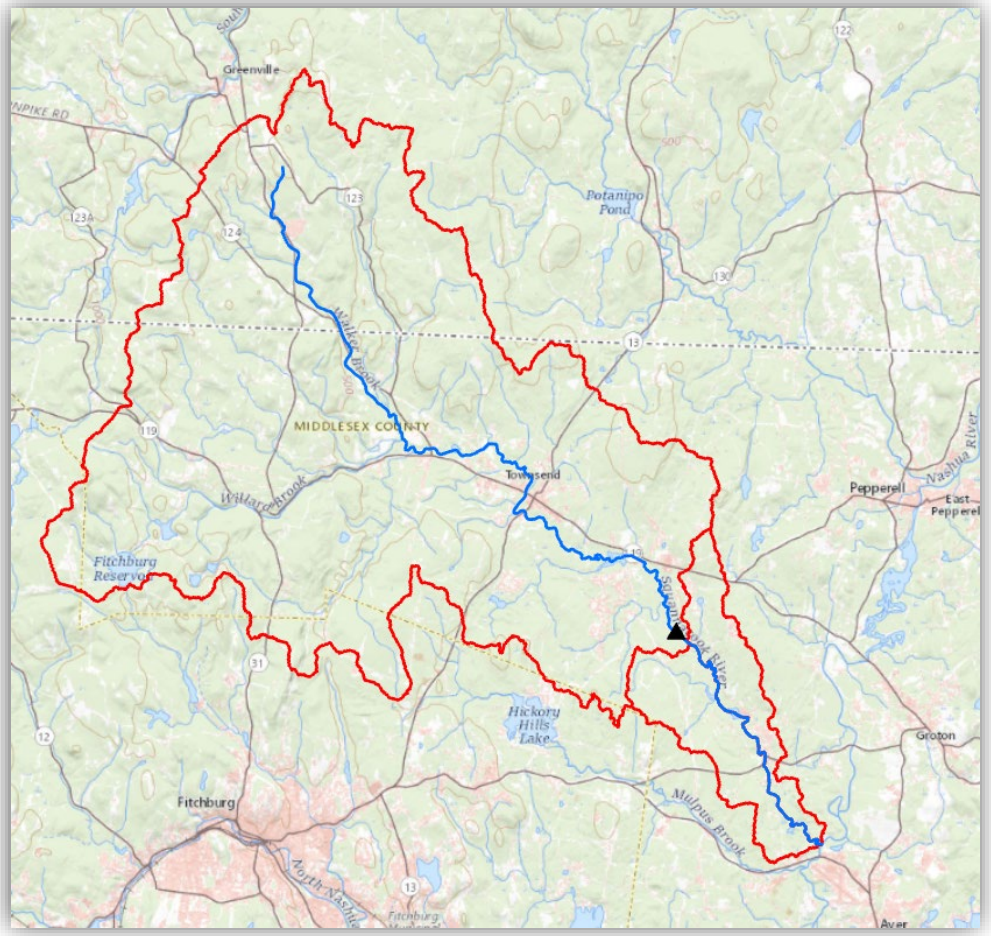
The **SWM** adds variability to **PRMS** output, create **database of simulated flows**.

Distribution of **design events** reflecting climate change computed from **database.**

Massachusetts Climate and Hydrologic Risk Project: Pilot Watershed

Squannacook River Watershed in north-central Massachusetts was selected as pilot watershed

- Long-term gage: 72 years of continuous record from the USGS streamgage in West Groton (drainage area at gage is 66.8 mi^2)
- Minor water withdrawals and a minor diversion in the headwaters
- Mean watershed elevation is near the mean for the state and climate is not significantly impacted by the coast



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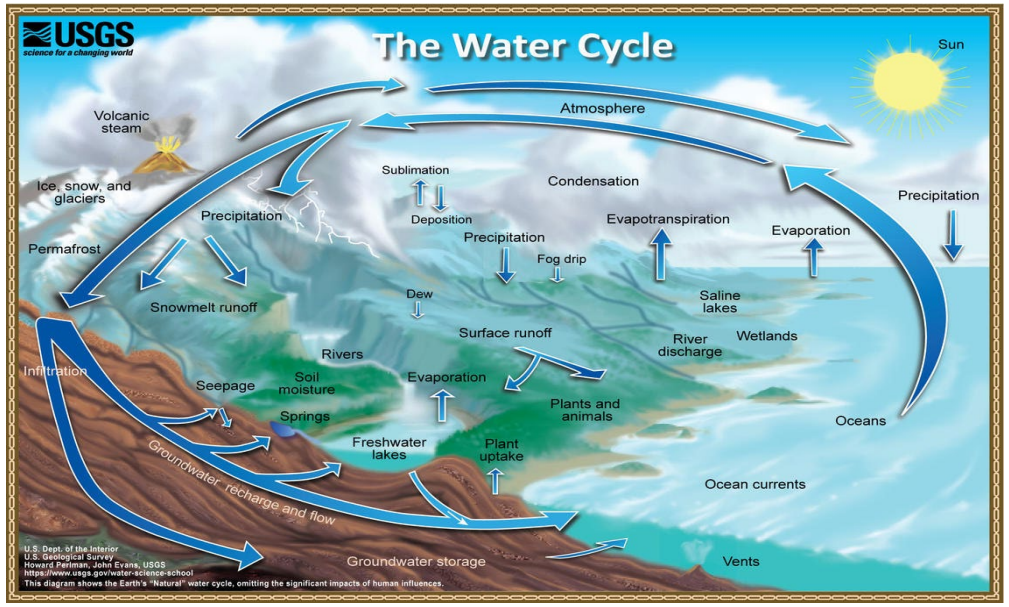
Massachusetts Climate and Hydrologic Risk Project: Deterministic Model

USGS Precipitation-Runoff Modeling System (PRMS) was selected for the project

- Simulates hydrologic processes:
  - Evaporation, transpiration
  - Runoff
  - Infiltration
  - Interflow
- Accounts for physical effects:
  - Plant canopy
  - Snowpack
  - Soil zone
- Tracks energy and water budgets
- Operates on a daily time step
- Data inputs are daily precipitation, minimum temperature, and maximum temperature



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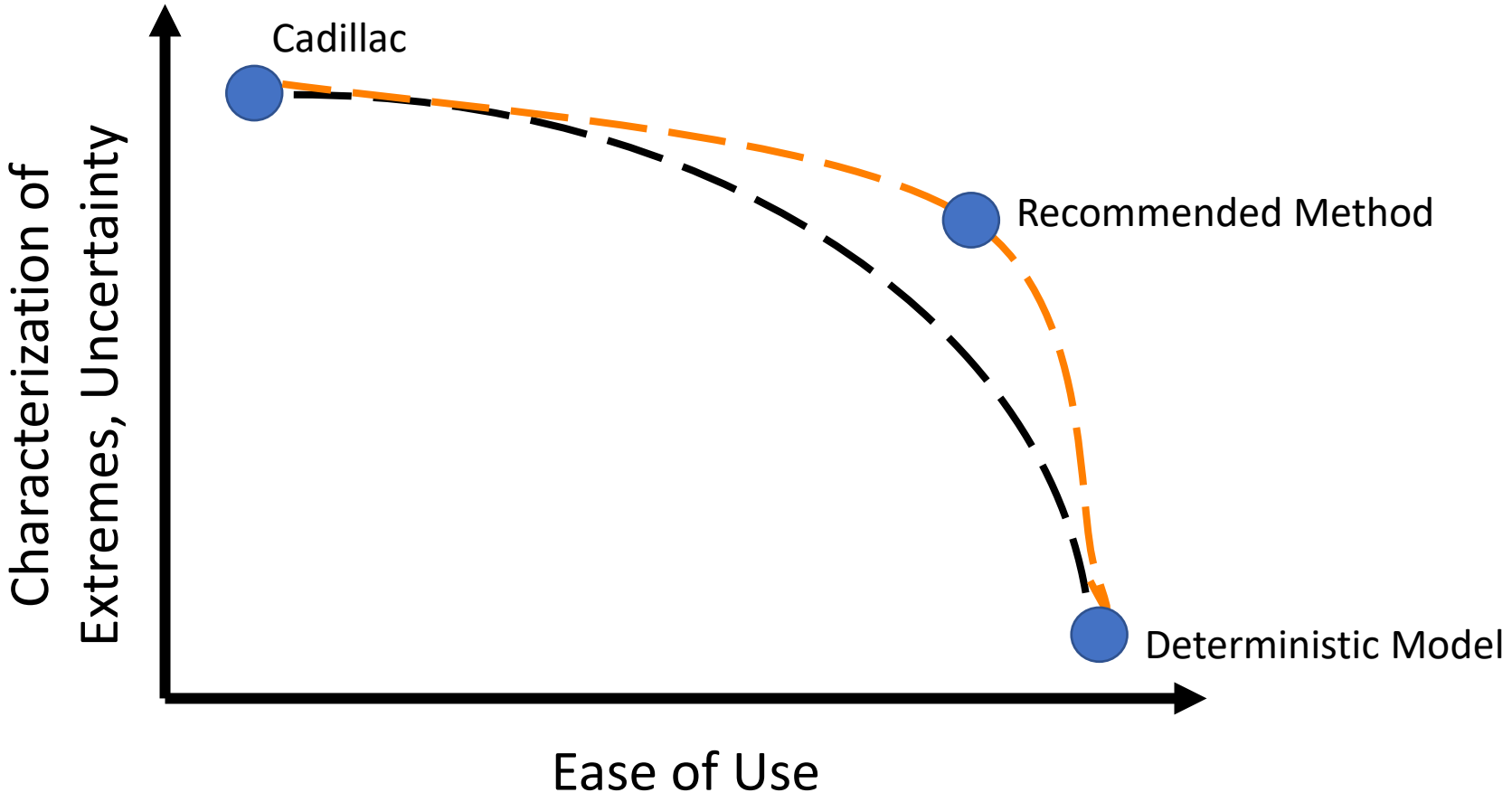
Project aims to balance generalizability and ability to capture extremes, uncertainty



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Result 1: Replicating historical design events

Historical S_t and O_t

$$\lambda = \ln\left(\frac{S_t}{O_t}\right)$$

$$\lambda_t = AR(p) + \epsilon_t$$

Randomly generated residual: $\tilde{\varepsilon}_t$

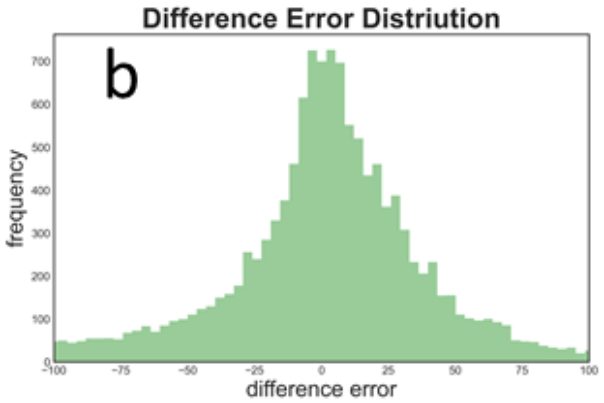
$$\tilde{\lambda}_t = \widetilde{AR}(p) + \tilde{\varepsilon}_t$$

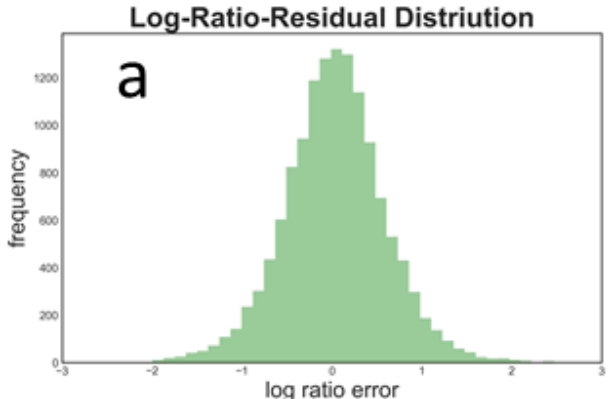
$$\tilde{S}_t = TBCF * \frac{S_t}{\exp(\tilde{\lambda}_t)}$$

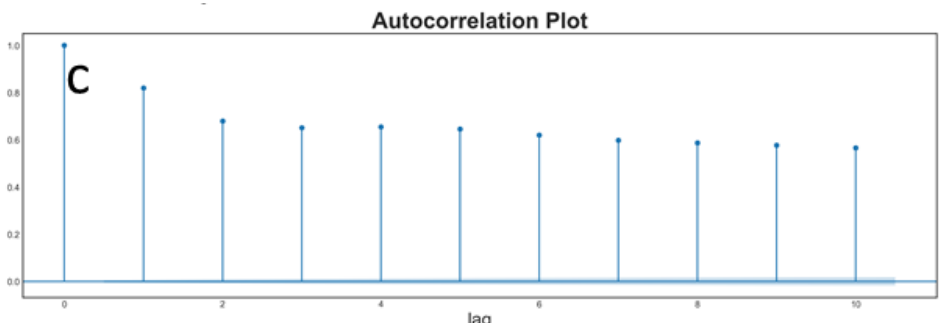
Simple Bootstrapping

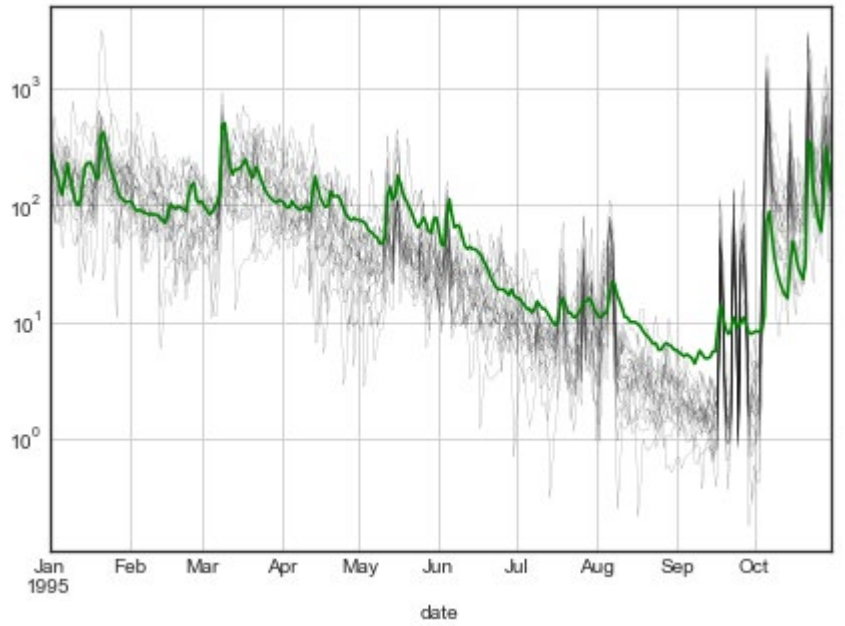
kNN Bootstrapping

AR model uncertainty

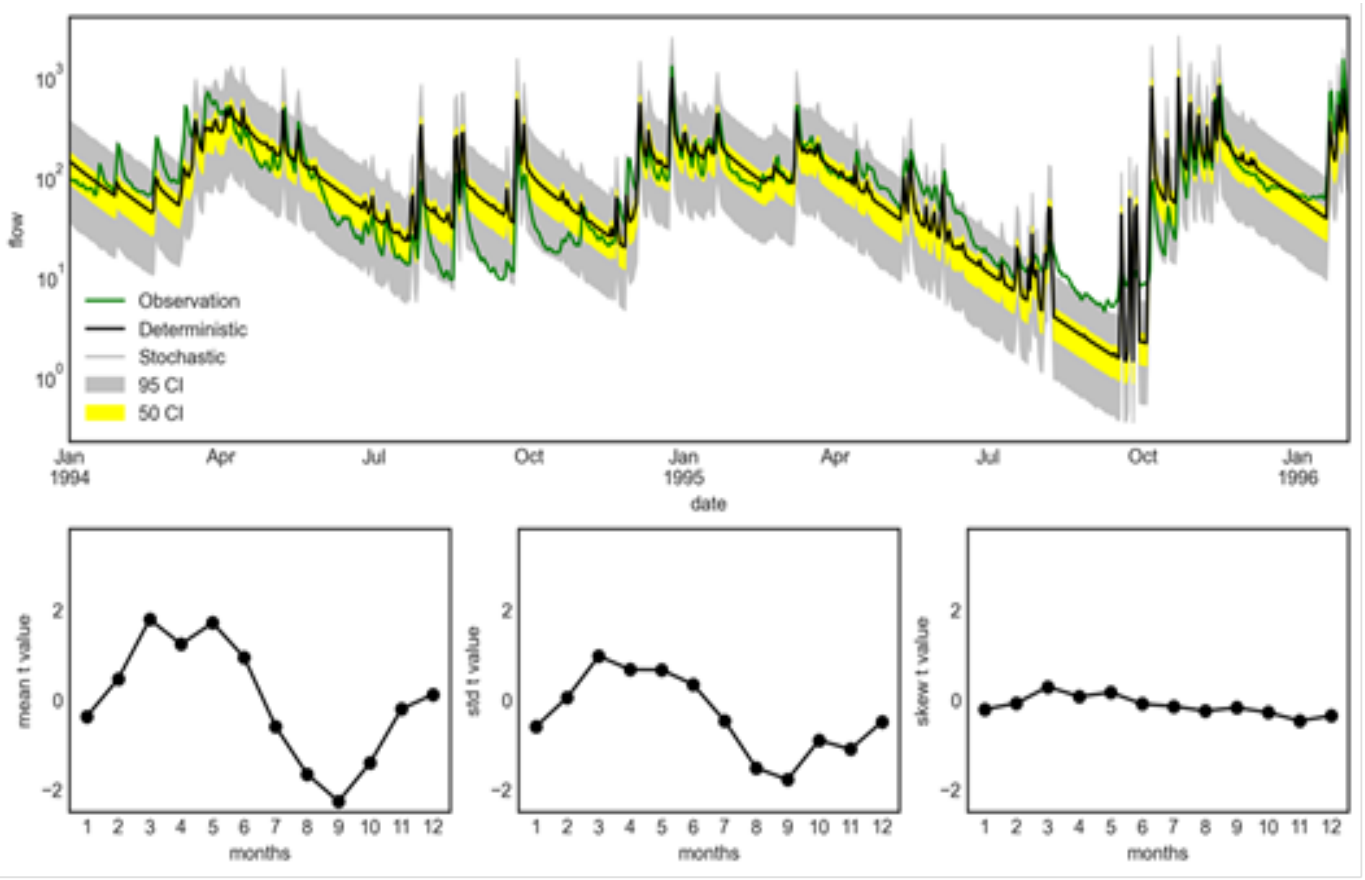


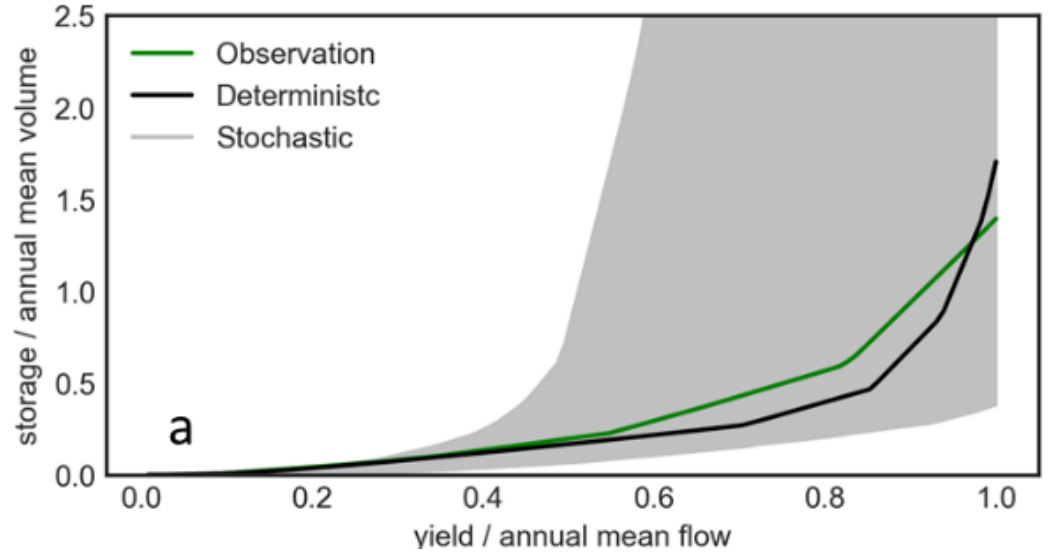


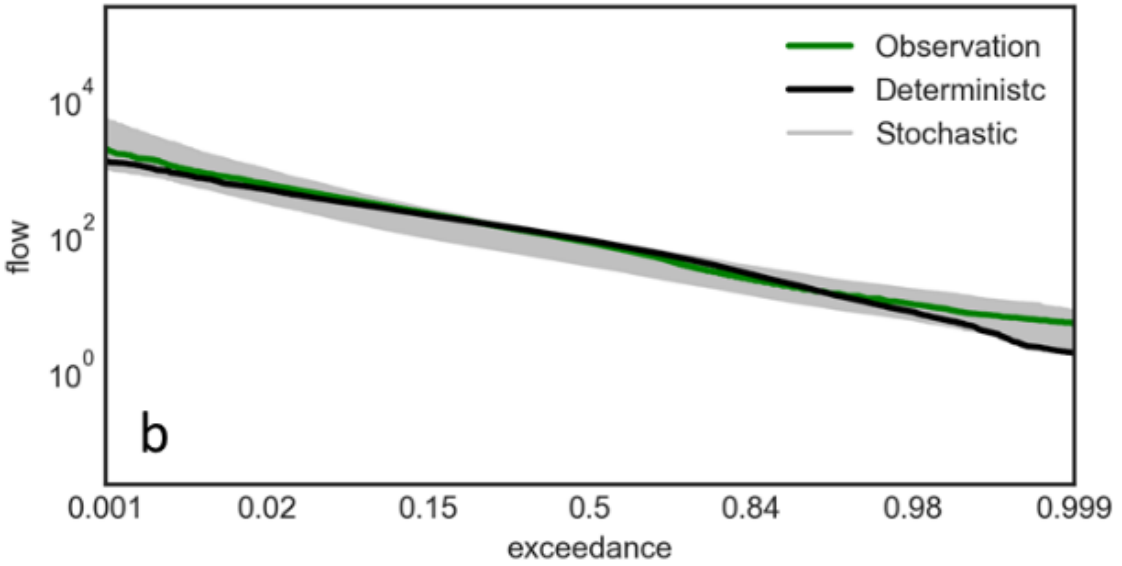




SWM effectively captures historical hydrologic conditions







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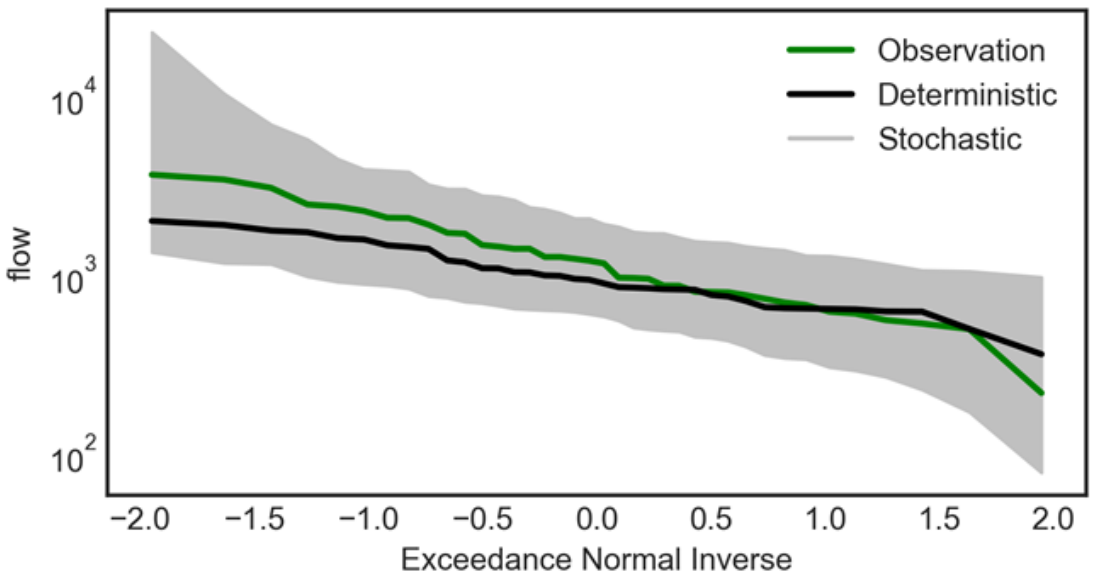
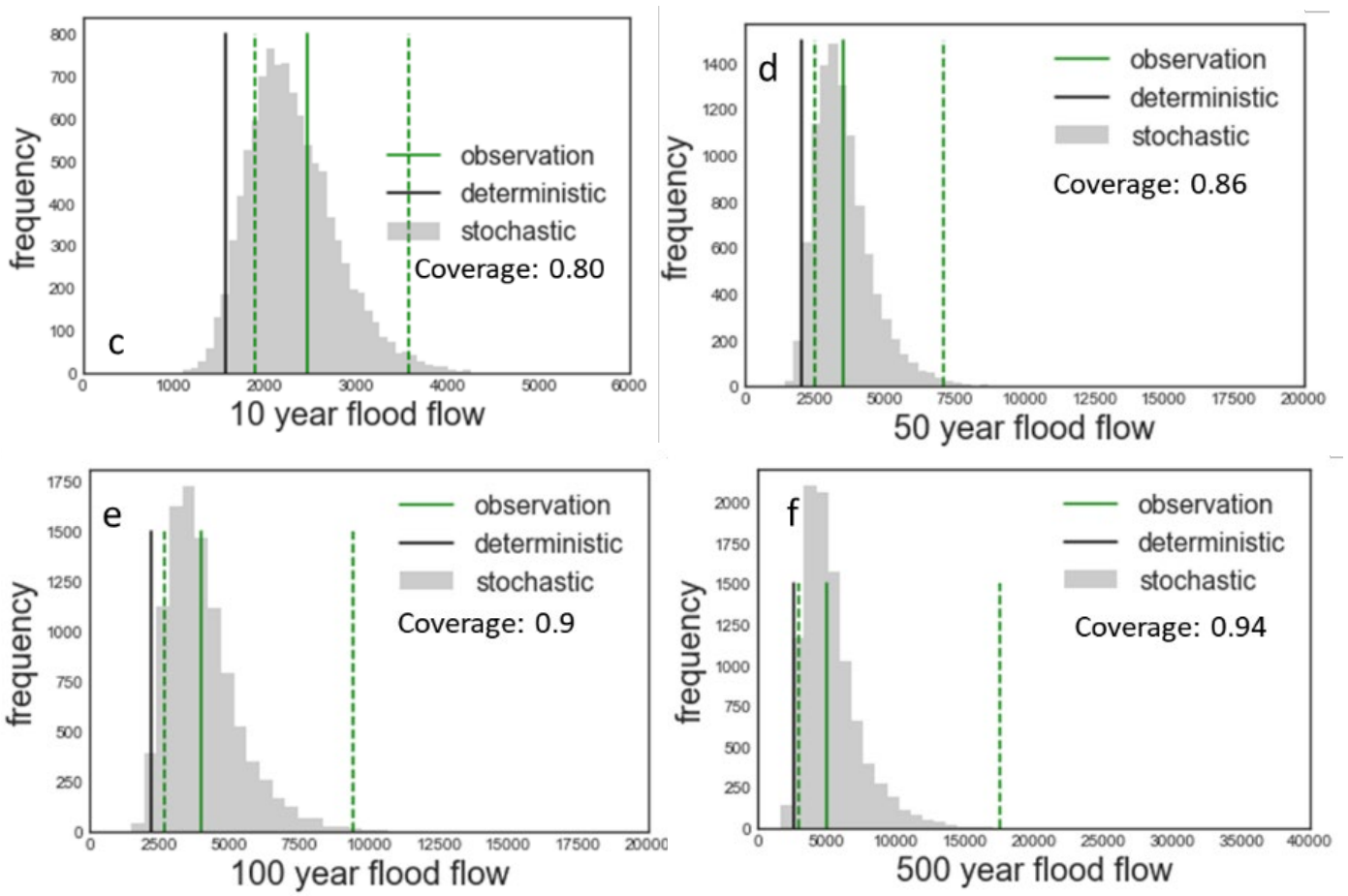
SWM accurately captures historical design floods and their uncertainty





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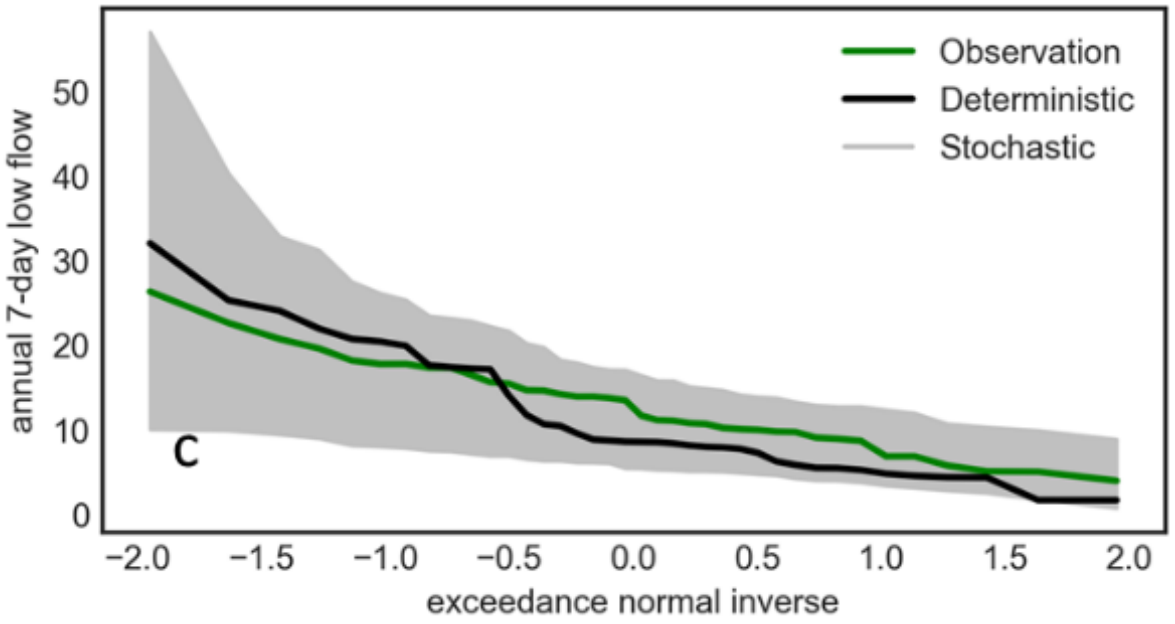
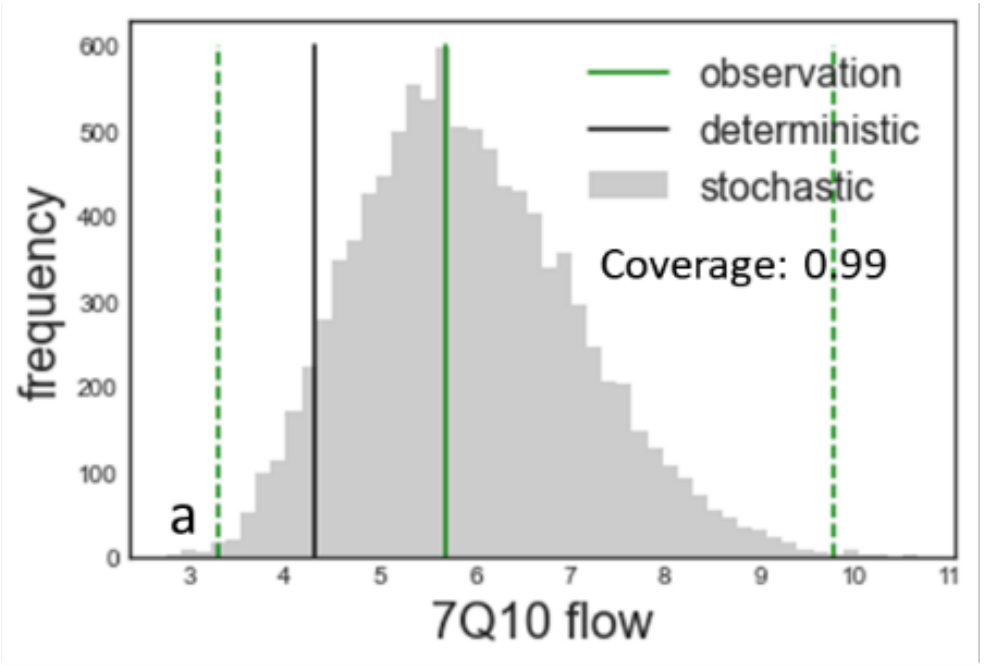
Modified SWM accurately captures design low flows and their uncertainty





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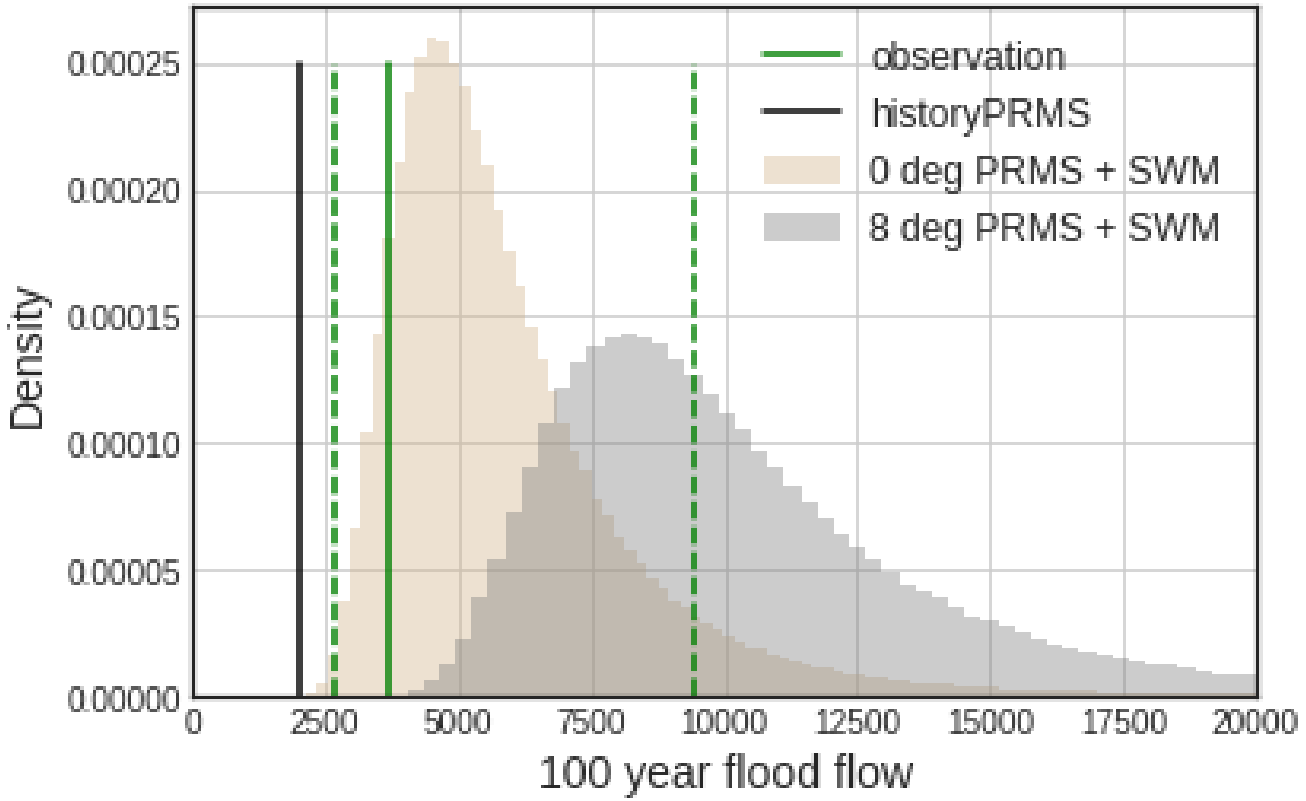
Pilot Result 2, future:
Extreme events under climate change



1. Now provide distributions of design stats, not point estimate.
2. For 0 degrees warming (beige), consistent with B17B (green).
3. Warming (grey) shifts distribution larger, extends fat tail.

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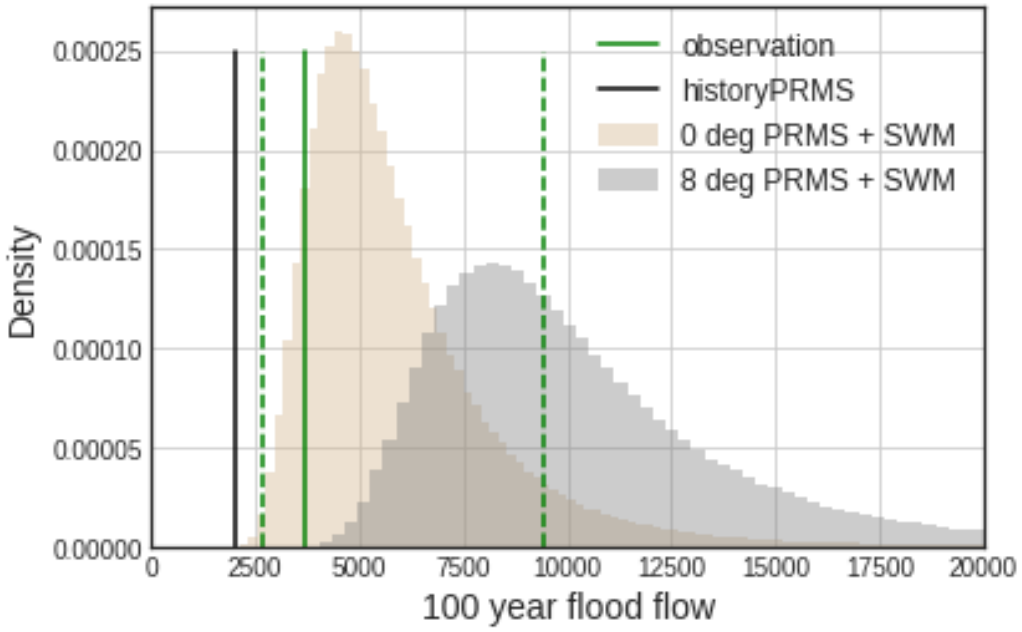
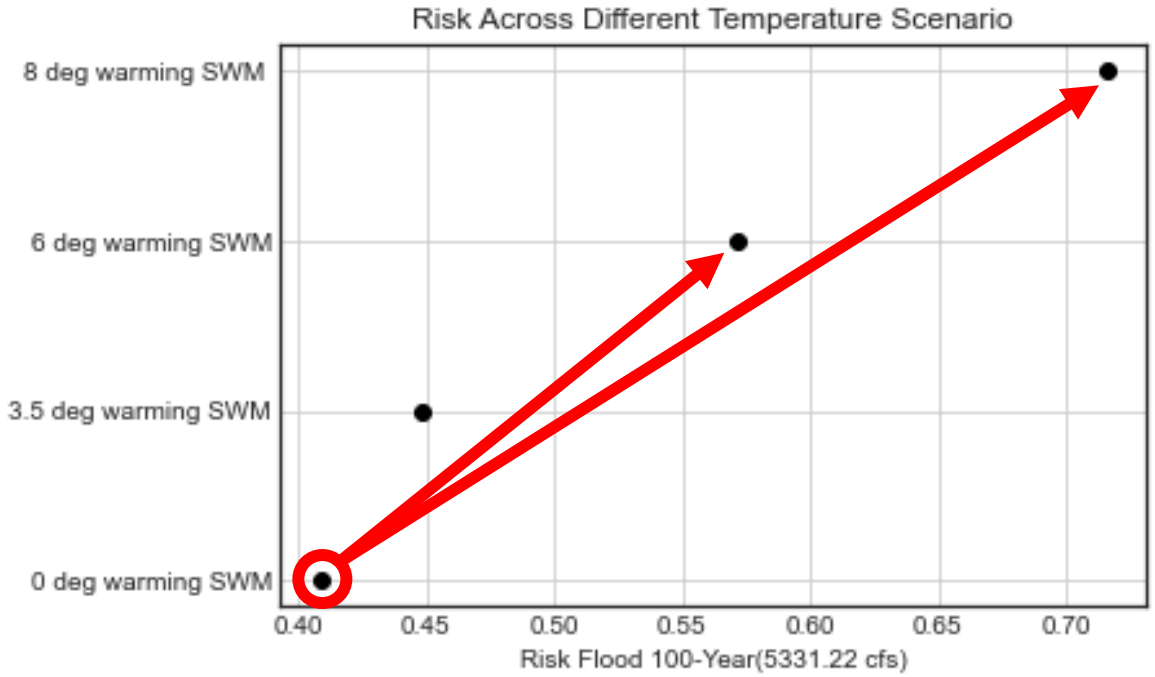
Warming conditions substantially increase risk of extreme floods





Risk: Probability the design event will be exceeded over a design life/planning period.

6 degrees increases 100-year flood risk over 50-year design life from 40% to 57%.

8 degrees increases risk over 50-year design life from 40% to 72%.

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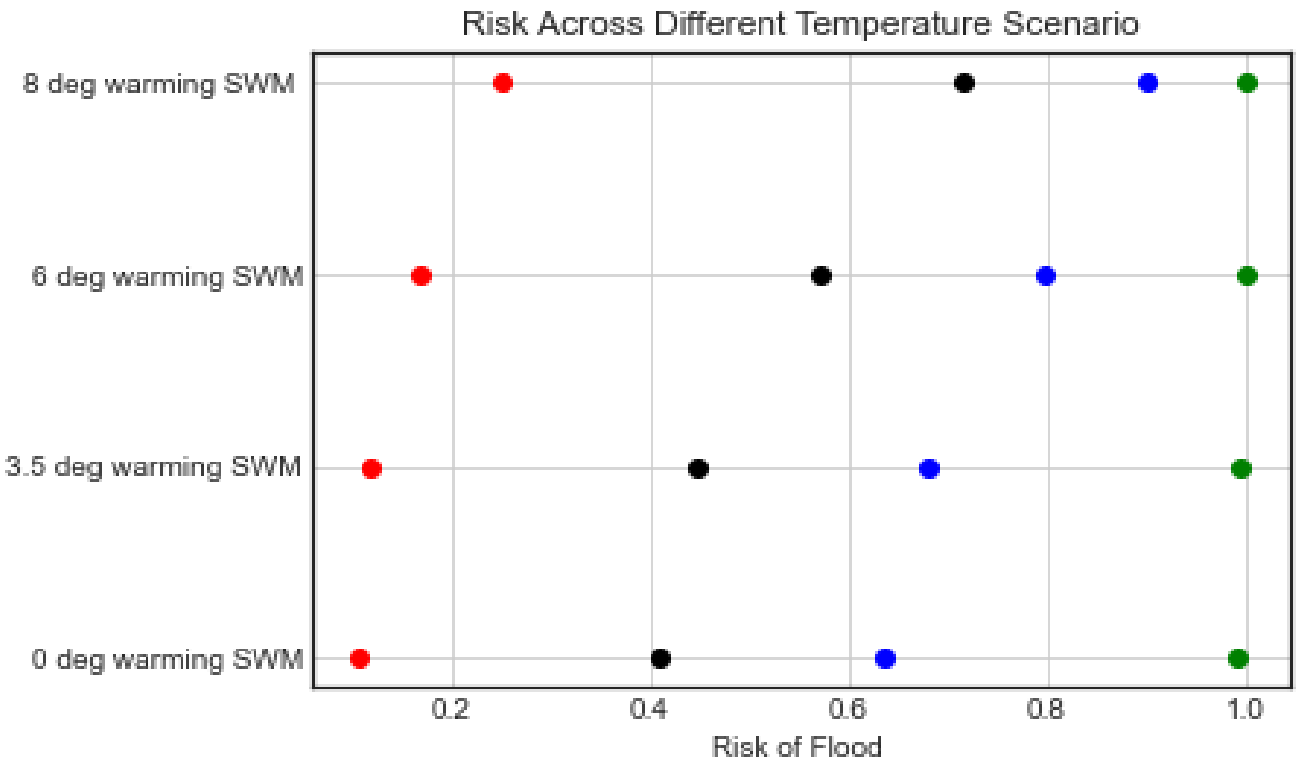
Warming creates greatest increase in risk for most extreme flows



Can track how increases in risk vary by flow extremity, design life, warming scenario.

Relative increase in risk is larger for more extreme flows

Historical
- 500-year flood
- 100-year flood
- 50-year flood
- 10-year flood

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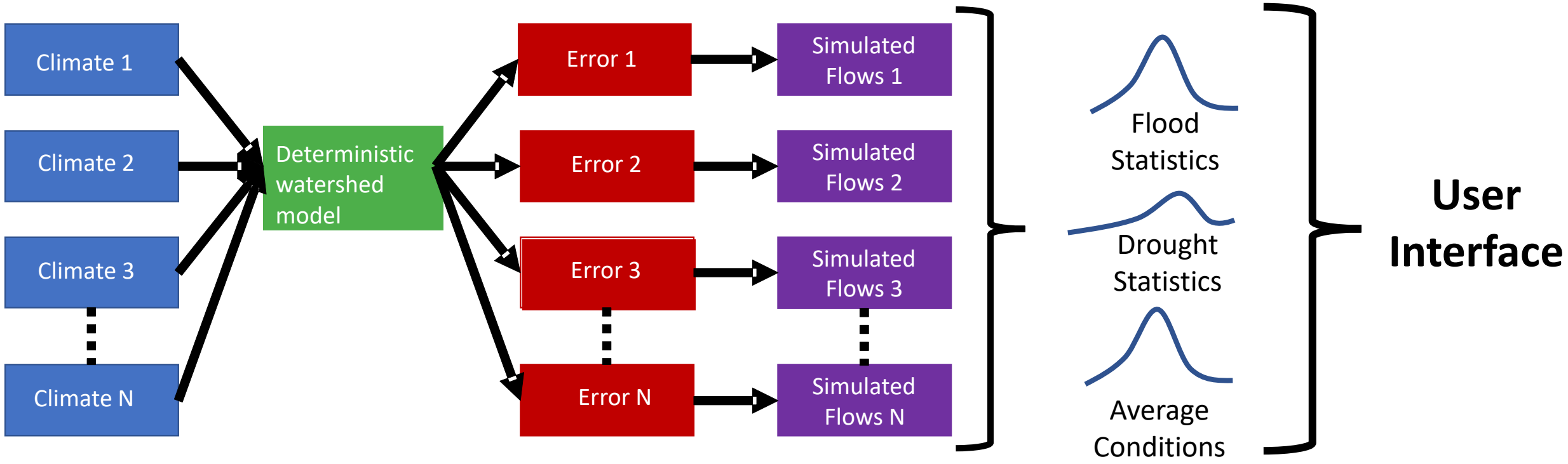
Summary: MA Climate-Hydrology Risk Approach



1. 1,700 climate projections created by the Stochastic Weather Generator
2. Climate projections run through the deterministic model
3. Error in modeled flows are used to create an “error model”
4. Combined deterministic model + error model = database of projected flows
5. Statistics are calculated from the database of flows

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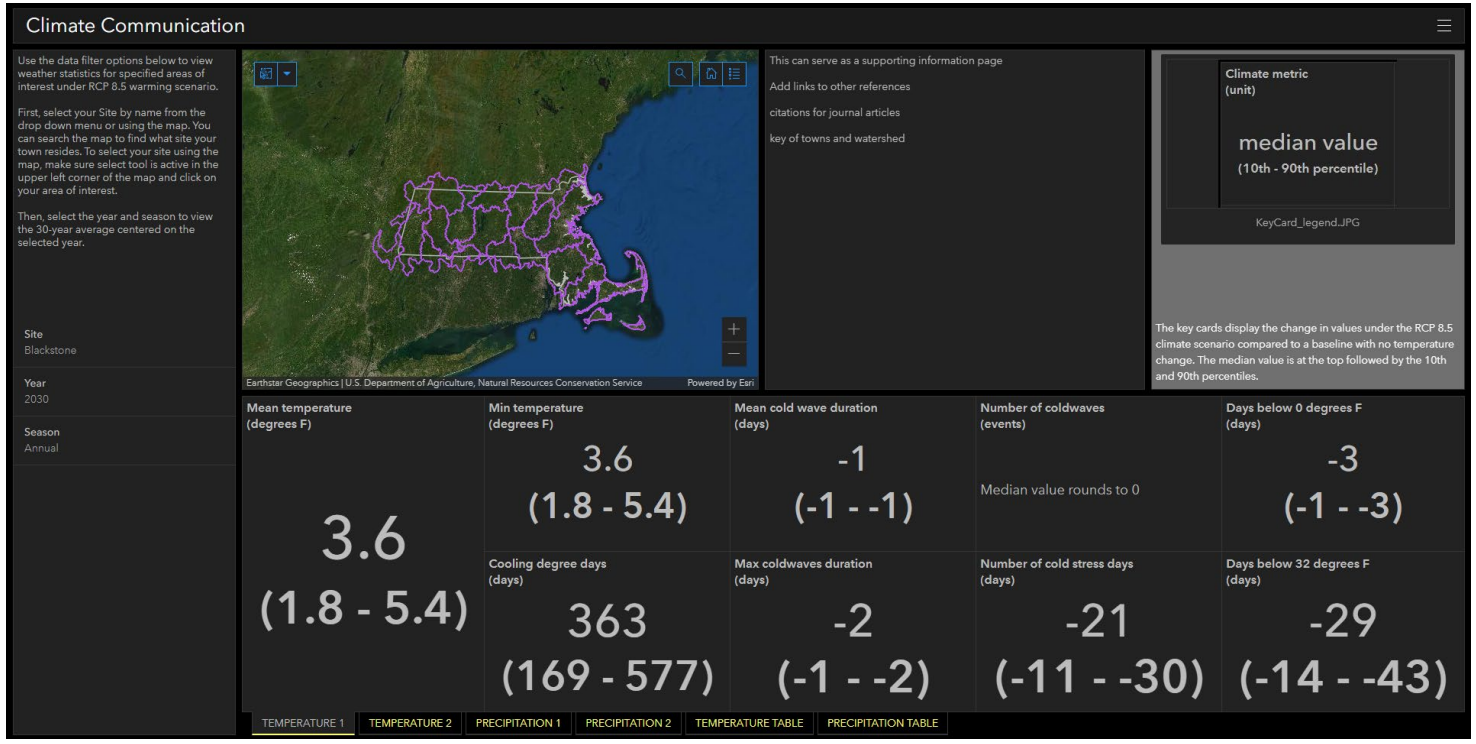
Climate Data Visualization

Stochastic Weather Generator results will be displayed on the redesigned MA Resilient page

- USGS, in collaboration with project team members, is in the process of developing an ArcGIS Dashboard to present SWG results
- Dashboard will reside on the MA Resilient page below the main MA Resilient map
- Dashboard presents the data in a numeric focused interface



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Climate Data Visualization

Climate Communication

Use the data filter options below to view weather statistics for specified areas of interest under RCP 8.5 warming scenario.

First, select your Site by name from the drop down menu or using the map. You can search the map to find what site your town resides. To select your site using the map, make sure select tool is active in the upper left corner of the map and click on your area of interest.

Then, select the year and season to view the 30-year average centered on the selected year.

Site
Blackstone

Year
2030

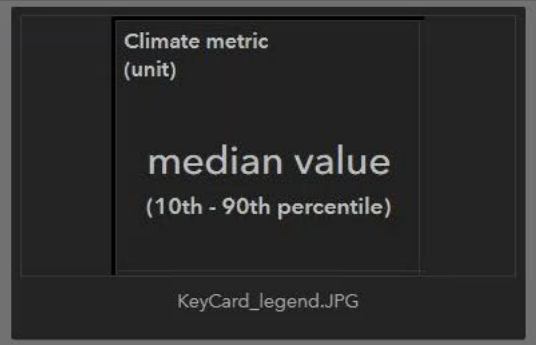
Season
Annual

This can serve as a supporting information page

Add links to other references

citations for journal articles

key of towns and watershed

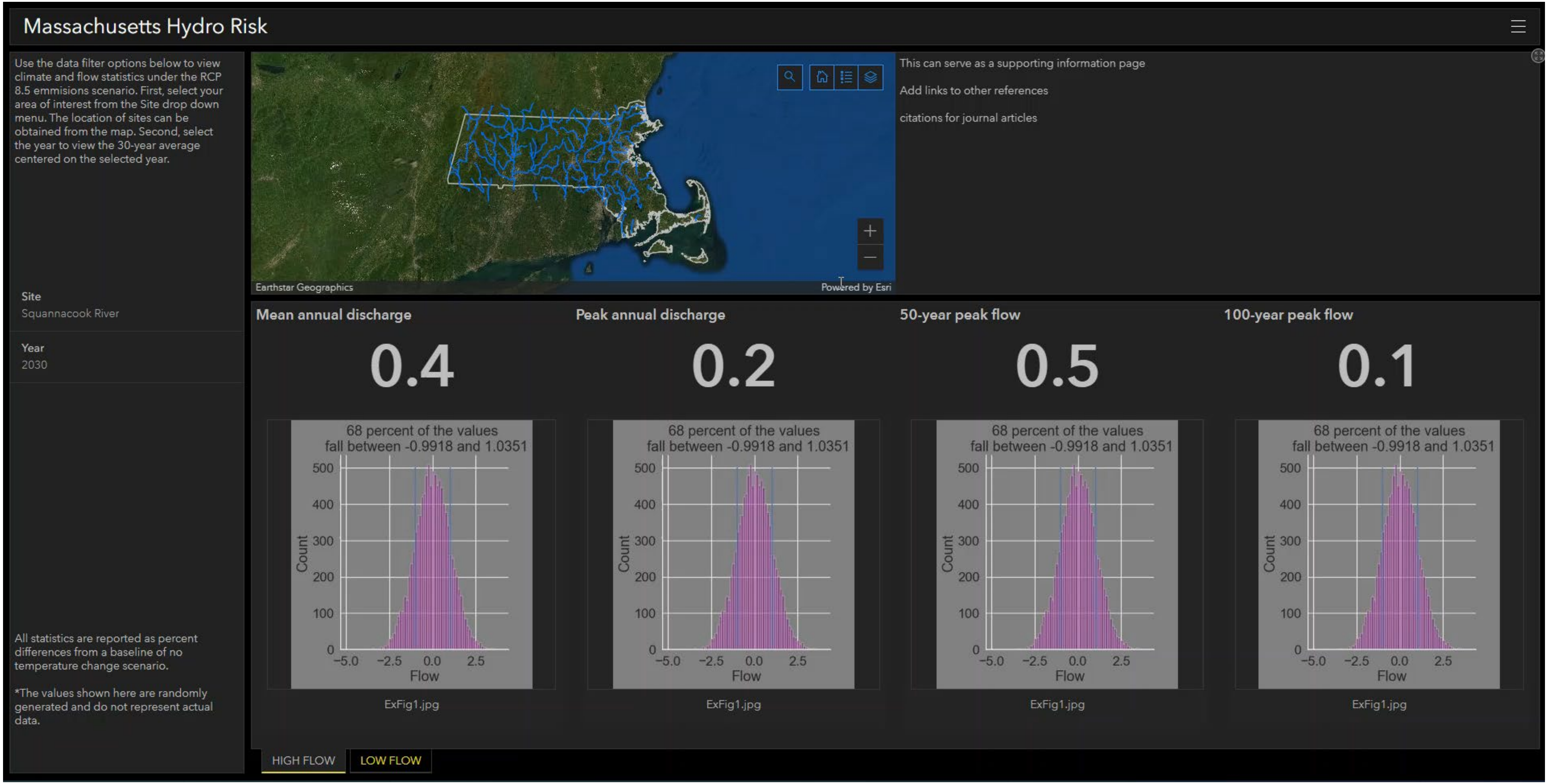


The key cards display the change in values under the RCP 8.5 climate scenario compared to a baseline with no temperature change. The median value is at the top followed by the 10th and 90th percentiles.

Mean temperature (degrees F) 3.6 (1.8 - 5.4)	**Min temperature (degrees F)** 3.6 (1.8 - 5.4)	**Mean cold wave duration (days)** -1 (-1 - -1)	**Number of coldwaves (events)** Median value rounds to 0	**Days below 0 degrees F (days)** -3 (-1 - -3)
	Cooling degree days (days) 363 (169 - 577)	**Max coldwaves duration (days)** -2 (-1 - -2)	**Number of cold stress days (days)** -21 (-11 - -30)	**Days below 32 degrees F (days)** -29 (-14 - -43)

TEMPERATURE 1 | TEMPERATURE 2 | PRECIPITATION 1 | PRECIPITATION 2 | TEMPERATURE TABLE | PRECIPITATION TABLE

Massachusetts Climate and Hydrologic Risk Project: Visualization



Questions?

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