An Uncertainty Based Framework for Quantifying the Effects of Climate Change on Extreme Event Flooding in the United States

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- Provided detailed RAS analysis for Howard County Maryland

FEMA Study Background

- Analyze impact of climate change on the National Flood Insurance Program
  - Recommended by the GAO
  - Rely on recent published findings (IPCC, CCSP, etc.)
  - Work will be reviewed by an expert panel
  - Objectives:
    - Location and extent of U.S. floodplains
    - Relationship between BFEs and insured properties
    - Economic structure of the NFIP
- This presentation represents preliminary work and is for illustrative purposes only – anticipated completion date: March 2010
- This work will not be used by FEMA to revise flood maps – it is purely for long term anticipation of effects on the NFIP
- This is not a study of Howard County or of Maryland specifically – only an illustration of the methodology

Outline

- Introduction
  - Climate Modeling and Extreme Climate Indicators
- Methodology
  - Regression Analysis
  - Observed and Projections
  - Monte Carlo Sampling for Uncertainty
- Results
  - Projections of Change
  - Impacts on Flooding
- Conclusions and Further Work

Climate Change

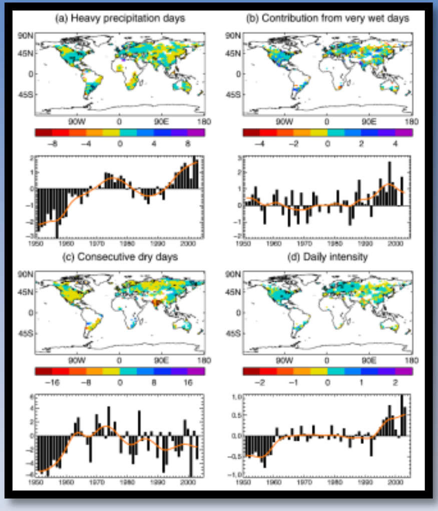
- IPCC AR4 (2007) – Climate Change Report
- Many climate models comprise the results in this report
- In General:
  - Temperature is increasing and will continue to increase
    - ➢ How much is the question…
  - Precipitation patterns are becoming more intense and this trend will very likely continue

Climate Indicators

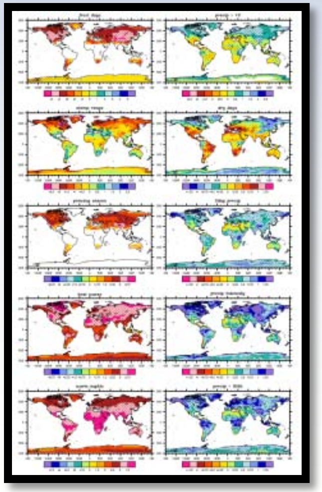
- Extreme Climate Indicators:
  - Focus on extremes in climate
  - Can these provide us with information on how extreme event flooding may change?
- Examples: (these are the important ones)
  - FD – Number of frost days per year
  - CDD – Maximum number of consecutive dry days per year
  - R5D – Maximum 5 day rainfall during a given year
  - There are numerous other temperature and precipitation related indices

Extreme Climate Indicators

From Alexander et al. (2006)



- Observations:
  - *Alexander et al. (2006)* used extreme climate indicators to examine trends in climate from 1951-2003
  - 2223 Temperature gages
  - 5948 Precipitation gages
  - Developed gridded global data set
- Projections:
  - *Tebaldi et al. (2006)* reported on climate model projections of extreme climate indicators
  - A suite of IPCC AR4 model runs provide extreme indices projections
    - 43 runs from 10 models across 3 scenarios
  - We identified 8 modeled indices that were analogous to the observed indices
  - 3 of the indices are important in this work



From Tebaldi et al. (2006)

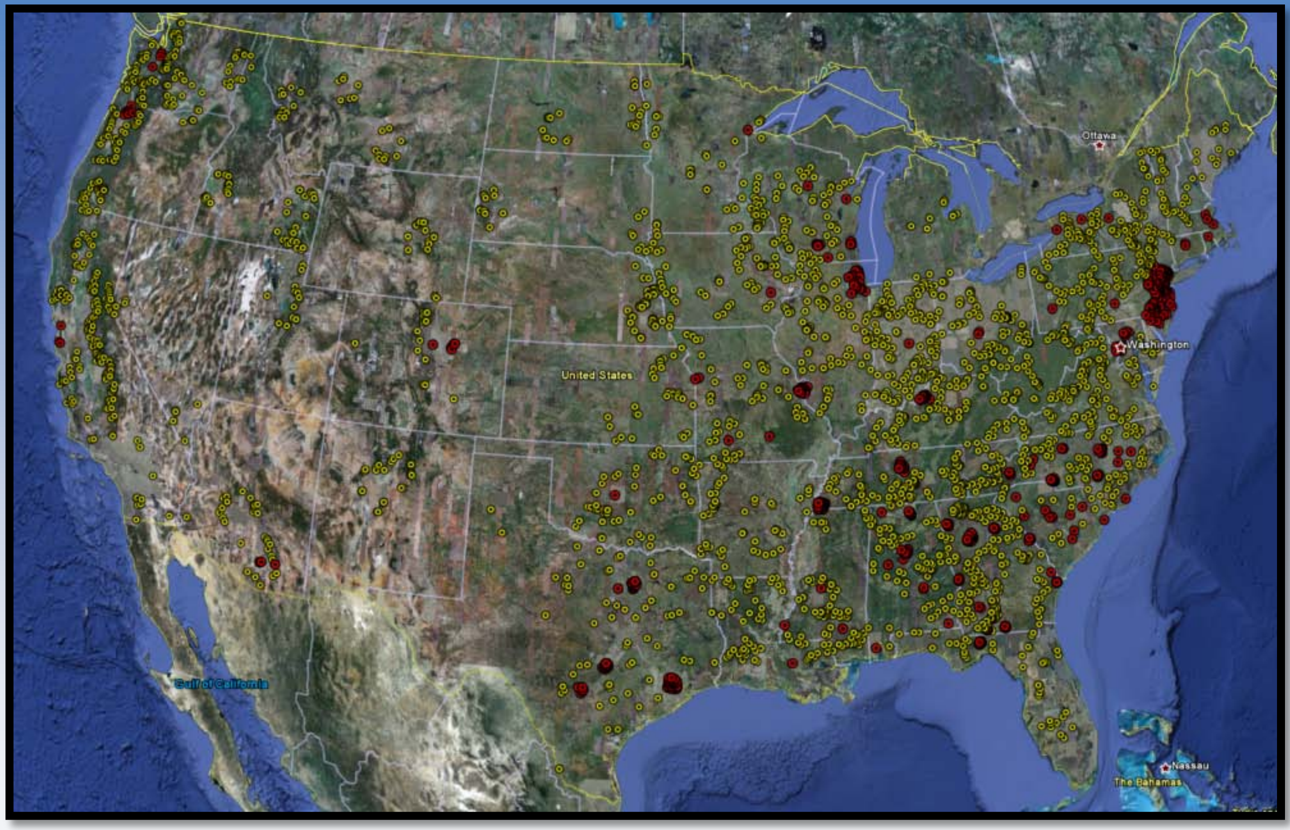
Methodology

1. Perform regression analysis to relate observed extreme indices to observed 1% chance flood
   - Get data to do this from existing gages
2. Use this relationship to project changes to the 1% chance flood using projections of extreme indices
   - Use Monte Carlo sampling to quantify uncertainty
3. Apply these projections to hydraulic modeling studies
   - Accounting for uncertainty
   - Determine new top widths, W.S. elevations, etc.

Regression Analysis

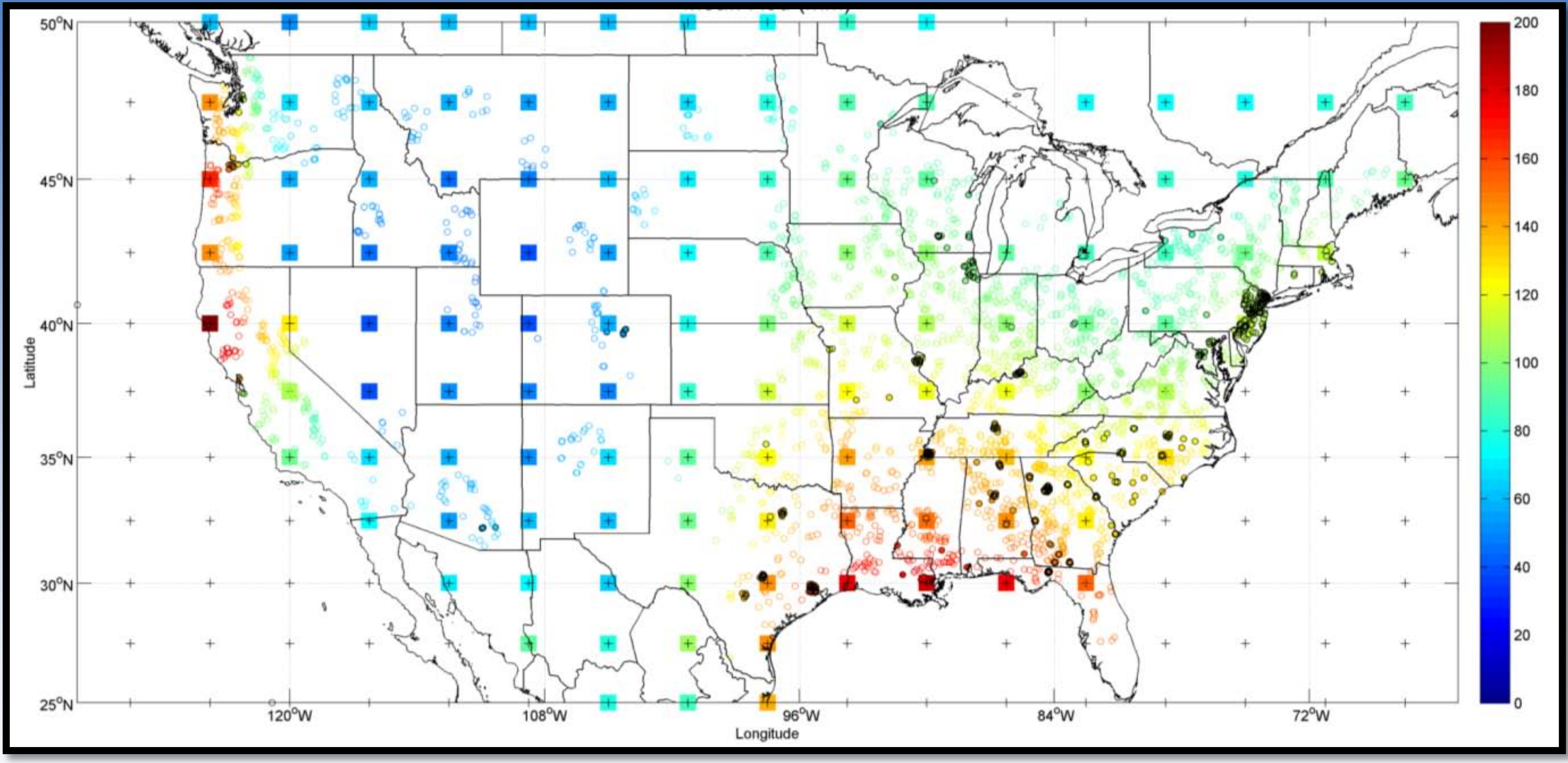
- Determine $Q_{1\%}$ as a function of a variety of other watershed and climate characteristics
- Outcome variable:
  - $Q_{1\%}$ - 100-yr, 1% chance discharge
- Predictor variables:
  - DA - Drainage area
  - SL - Average slope
  - ST - Storage
  - IA - Impervious area (related to population)
  - Extreme Indices: FD, CDD, and R5D

Gage Identification



- Identified 2,370 Urban and Rural Stations – from published USGS reports
- This data provided DA, SL, ST, IA, and Existing $Q_{1\%}$

Extreme Indices at Gages



Average Maximum 5 Day Rainfall Per Year from 1951-2003

- Extreme indices at gages were estimated using inverse distance weighting of the observed gridded extreme indices data set

Maryland Regression Equations

- Developed equations for whole U.S. then adjusted for regional bias in Maryland:

$Q_{1\%}$: (in $\log_{10}$ form):

$$Q_{1\%} = 0.29227 + 0.711\,(DA) + 0.169\,(SL) - 0.329\,(ST{+}1) + 0.180\,(IA{+}1) - 0.205\,(FD{+}1) - 0.176\,(CDD{+}1) + 1.444\,(R5D{+}1)$$

- Standard Error: 0.1725 log units or 41.3%
- $R^2 = 0.764$

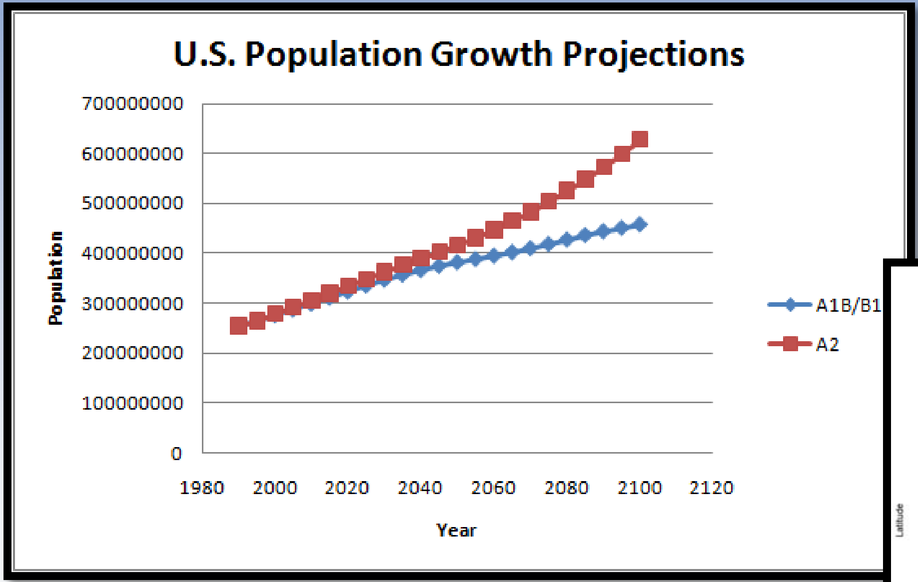
Note: This and other findings presented here are provisional and are shown for illustrative purposes only.

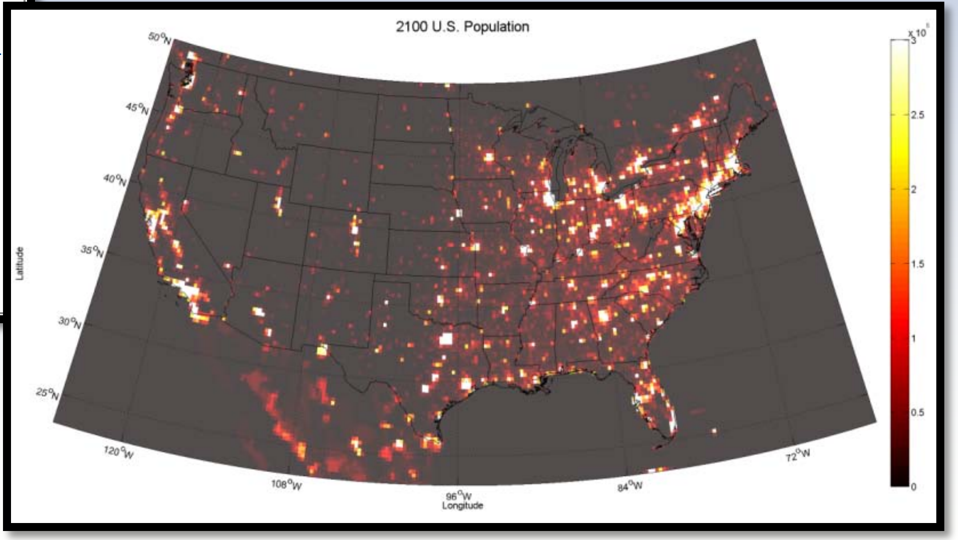
Projecting Change

- What will likely change?
- Impervious area due to changes in population density
  - Population projections related back to impervious area
  - Population projections consistent with IPCC report
- Extreme indices due to climate change
  - Suite of climate model projections

Population Projections

- **Bengtsson et al. (2006)** – *A SRES-based gridded population dataset for 1990-2100*
- Assumes a uniform rate of change spatially for the whole U.S.



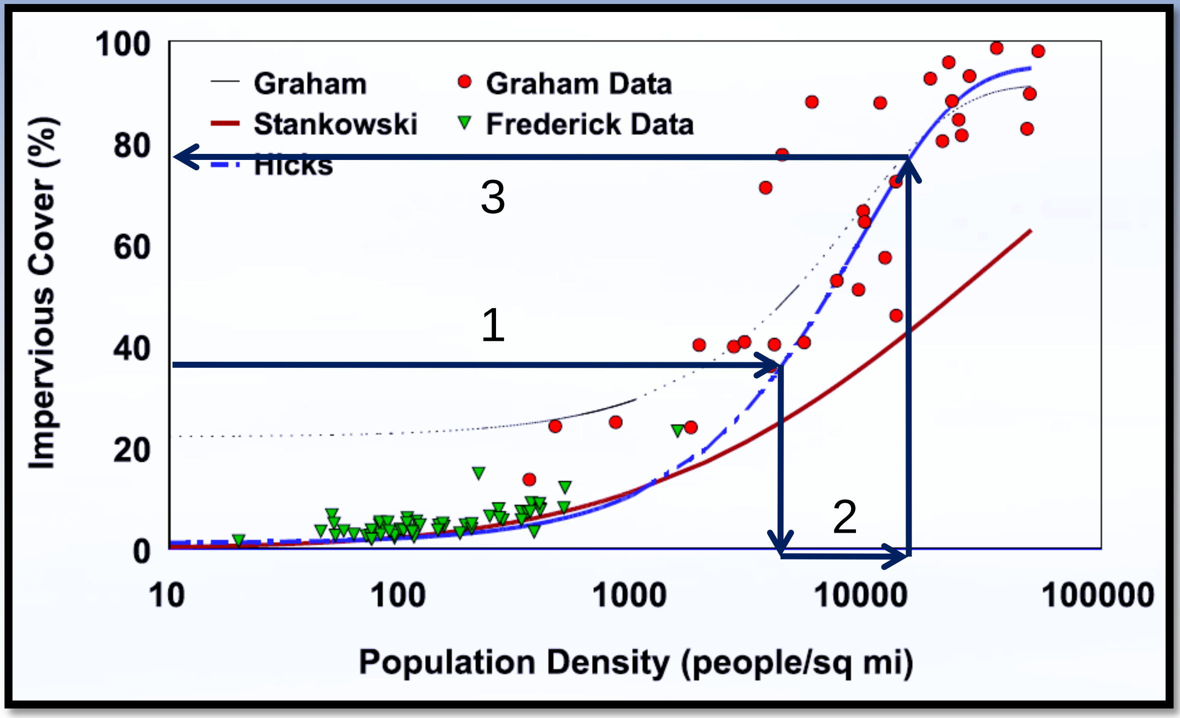


Impervious Area (Related to Population)

- Population projections available
  - Need to be able to relate these back to impervious area

- Used the Hicks curve (blue) since it is based on a wide range of data

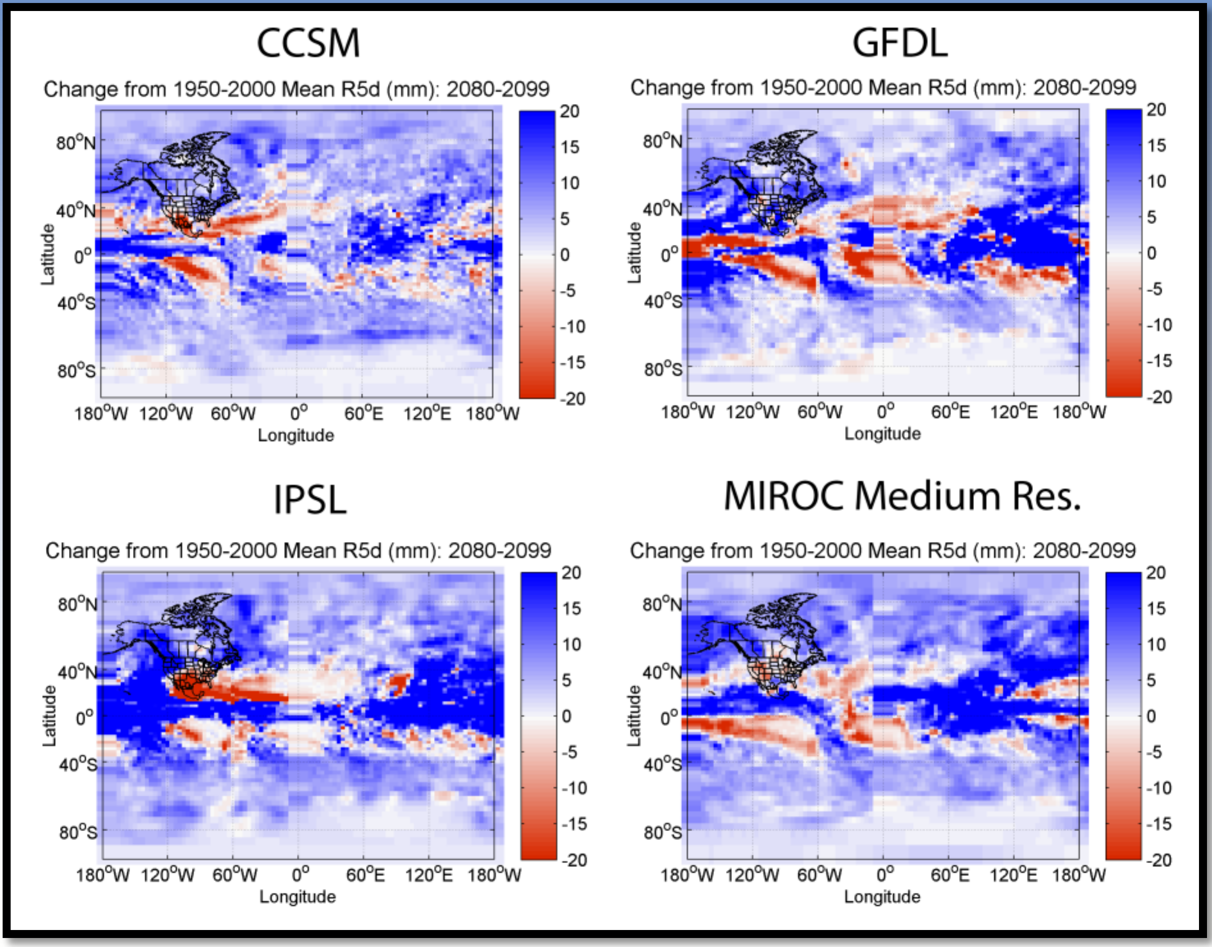
1. Determine population based on gage IA
2. Project population to some point in time
3. Determine IA projection from curve



From Bird et al. (2006) – Estimating Imperious Cover from Regionally Available Data

Climate Projections

- Multiple models and multiple runs provide different pictures of change…
- Model extreme indices outputs re-gridded and 20-yr means calculated
- 20-yr Means for 5 Epochs:
  - 2000-2019
  - 2020-2039
  - 2040-2059
  - 2060-2079
  - 2080-2099

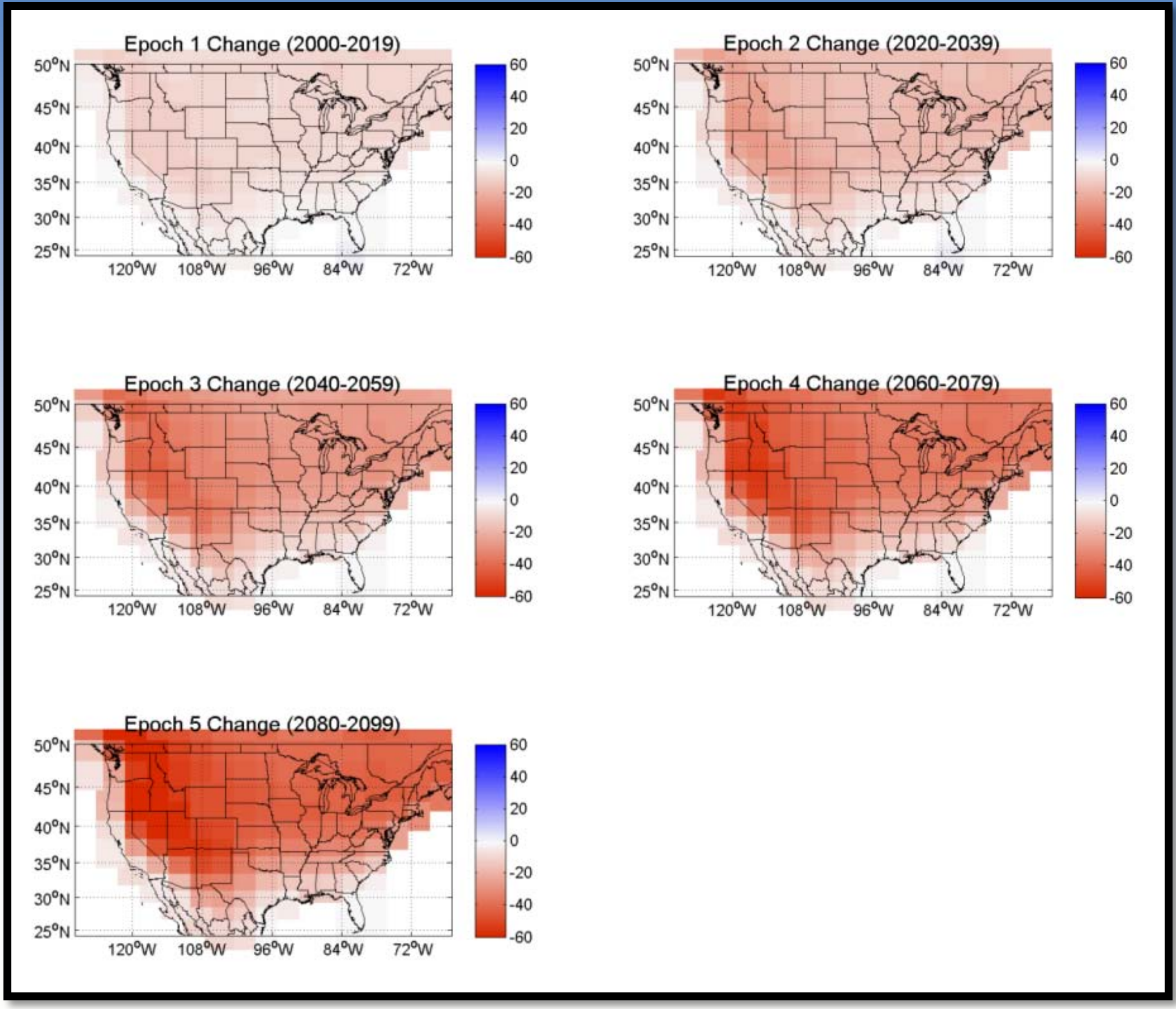


Extreme Indices Projections - Changes

- Multiple-model mean projected changes in:

  FD – Number of frost days per year

  over modeled existing conditions

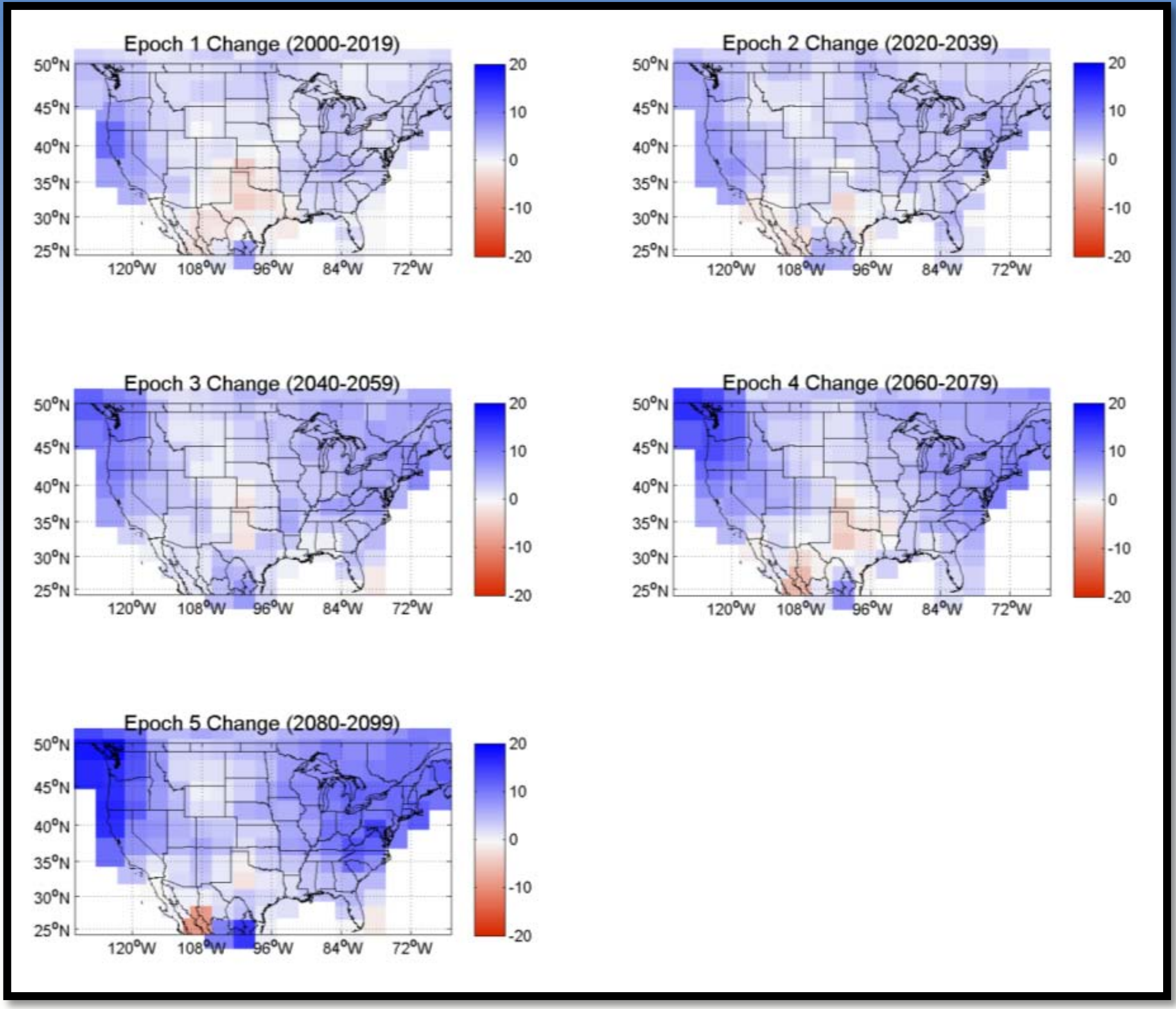


Extreme Indices Projections - Changes

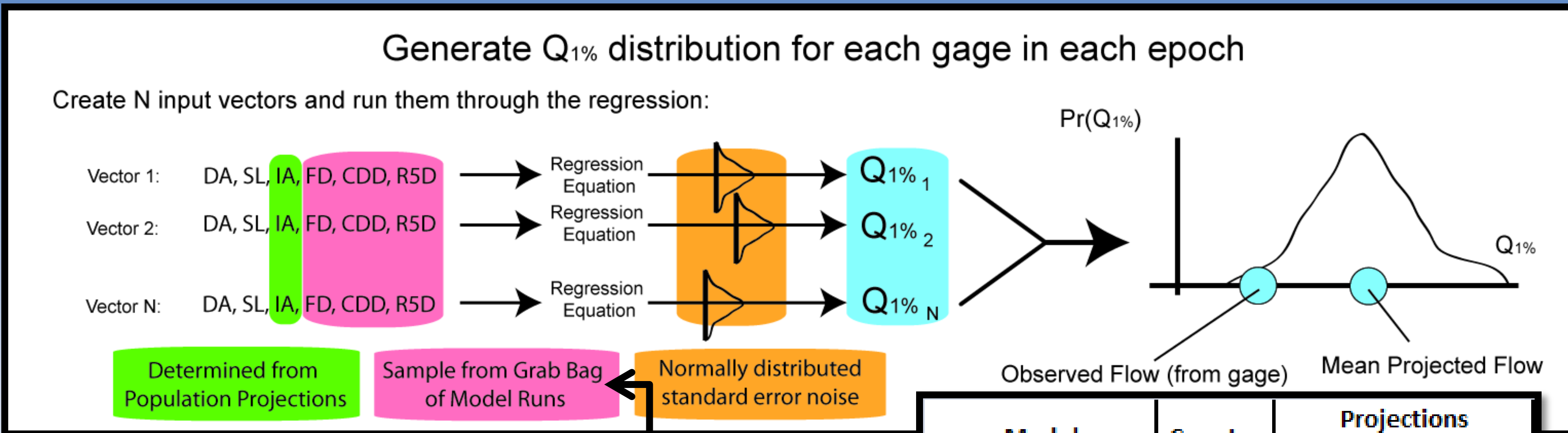
- Multiple-model mean projected changes in:

  R5D – Maximum 5 day rainfall per year (mm)

  over modeled existing conditions



Monte Carlo Analysis Procedure

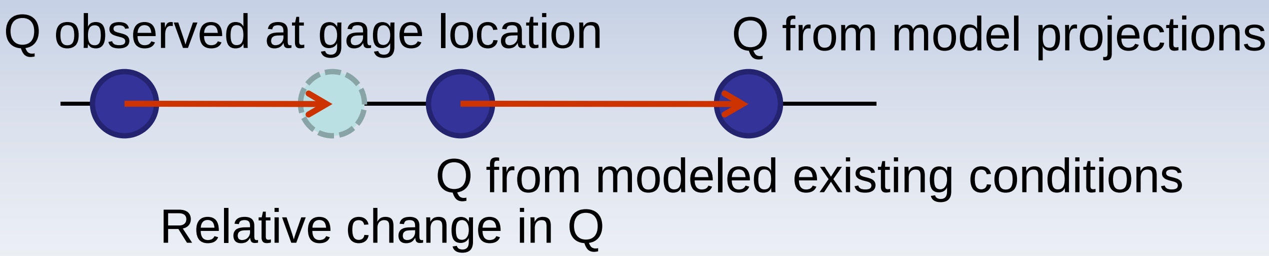


- Uncertainty accounted for by sampling from:
  - Multiple models, runs, and scenarios
  - Standard error from the regression equation

Model	Country	Projections		
		B1	A1B	A2
CCSM3	USA	X	X	
CNRM-CM3	France	X	X	X
GFDL-CM2.0	USA		X	X
GFDL-CM2.1	USA		X	X
INM-CM3.0	Russia	X	X	X
IPSL-CM4	France	X	X	X
MIROC3.2 Hi Res	Japan	X	X	
MIROC3.2 Med Res	Japan	XX	XXX	XXX
MRI-CGCM2.3.2	Japan		XXXXX	X
PCM	USA	XXXX	XXXX	XXXX
Total		**43**		

Monte Carlo Analysis Procedure

1. Determine the Q resulting from modeled existing conditions
2. Determine the projected Q for an epoch
3. Apply this modeled change in Q as a relative change in the existing observed Q

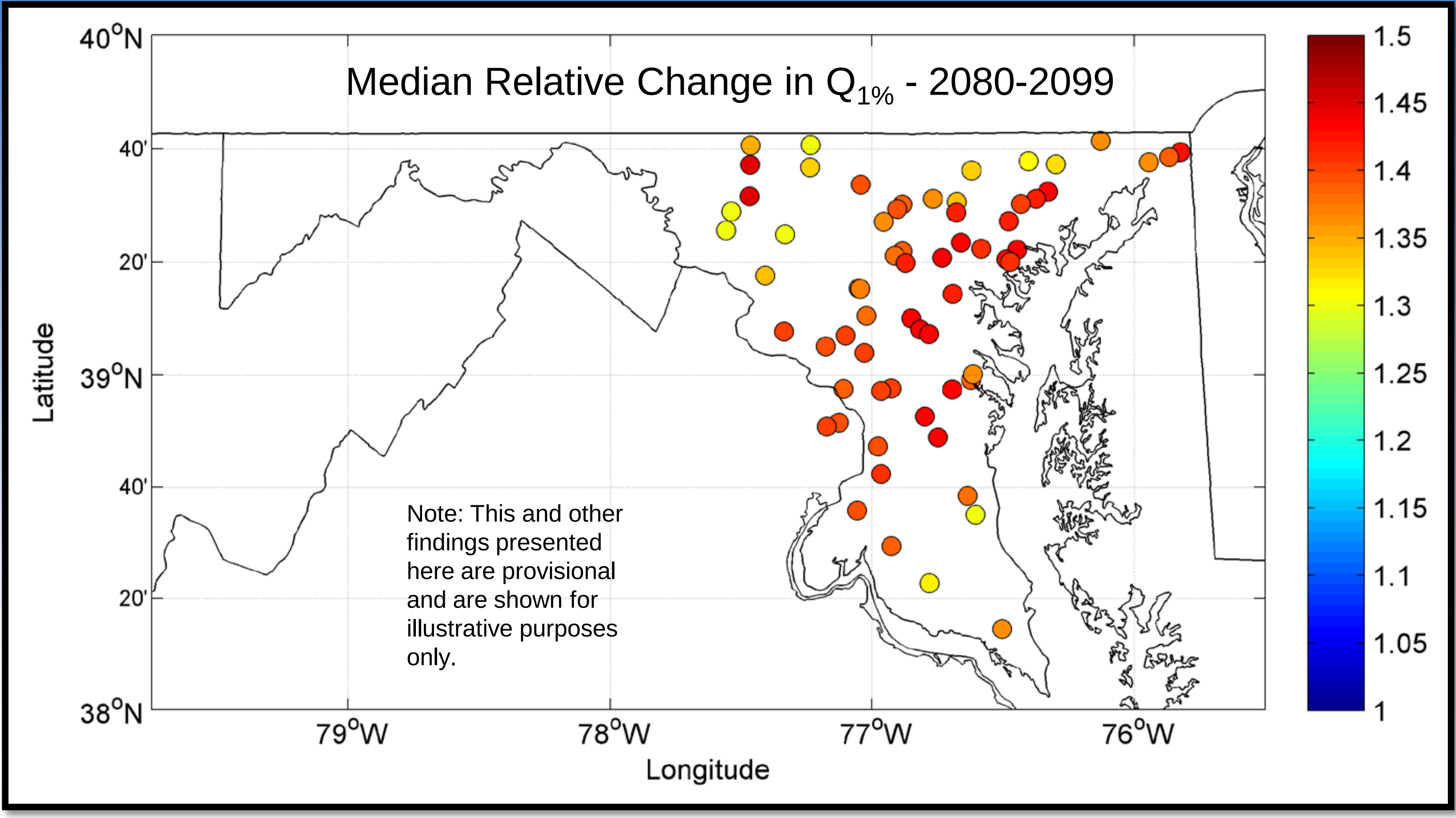


- This helps correct for model bias

Ultimately, we would like to say:

We estimate that $Q_{1\%}$ will change an average of n% from its present value over the next century.

Results: Projected Changes



Based on 1-million Monte Carlo simulations at each of the 65 gages in Maryland

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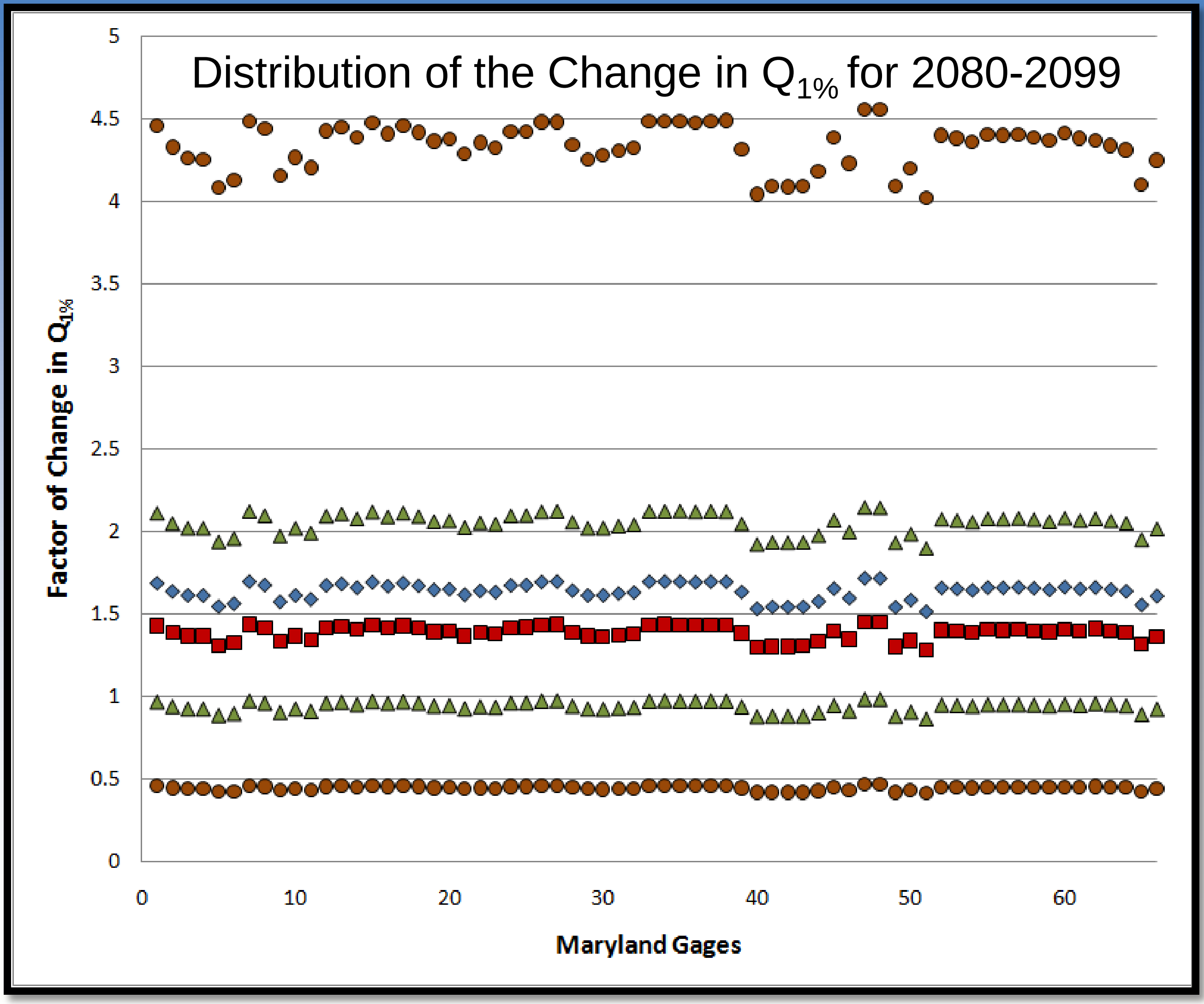
Distribution of Projected Changes



Upper 95th percentile

Upper quartile

Mean

Median

Lower quartile

Lower 95th percentile

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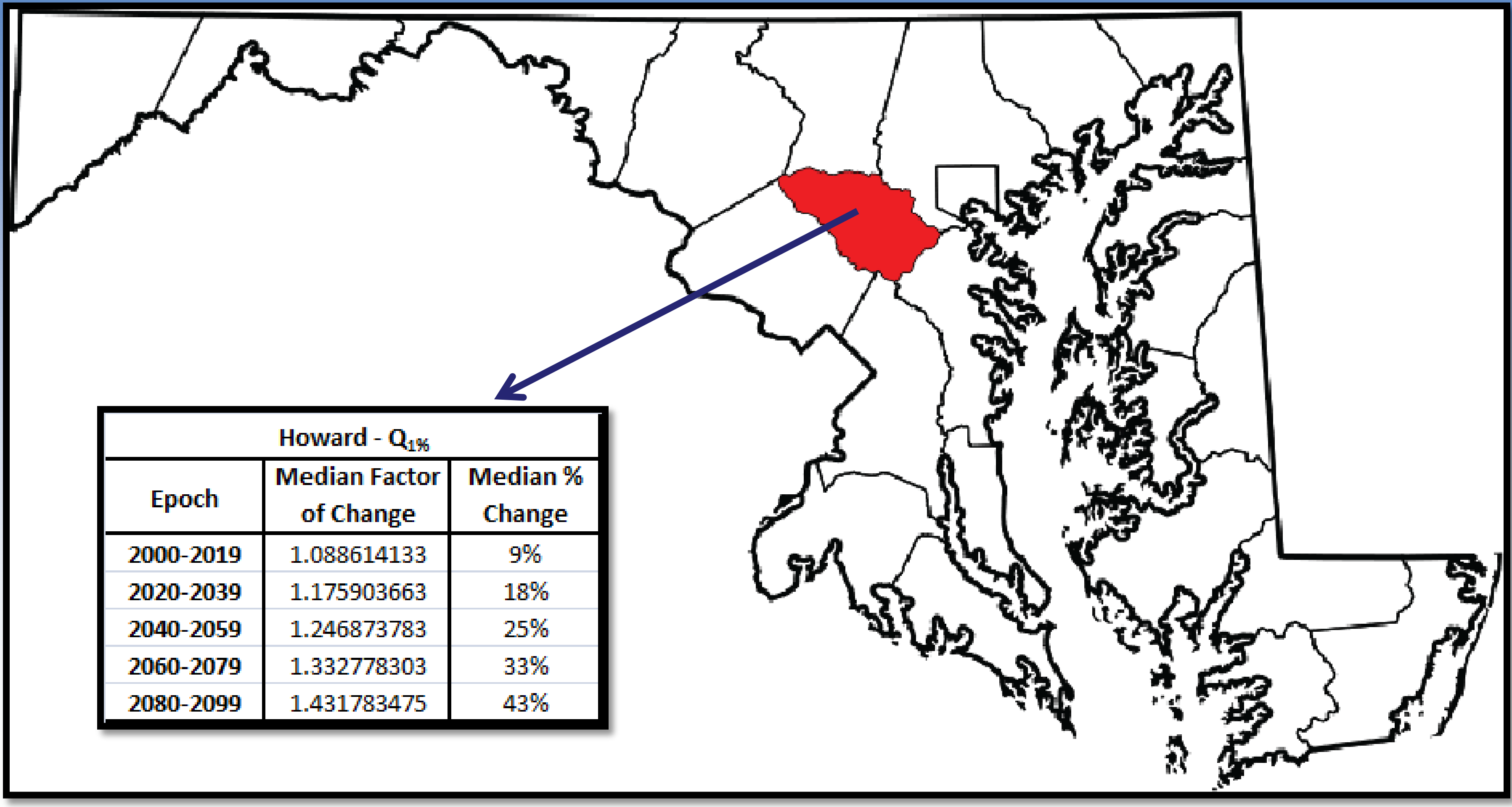
Analysis for Howard County Maryland



Howard - $Q_{1\%}$		
Epoch	Median Factor of Change	Median % Change
2000-2019	1.088614133	9%
2020-2039	1.175903663	18%
2040-2059	1.246873783	25%
2060-2079	1.332778303	33%
2080-2099	1.431783475	43%

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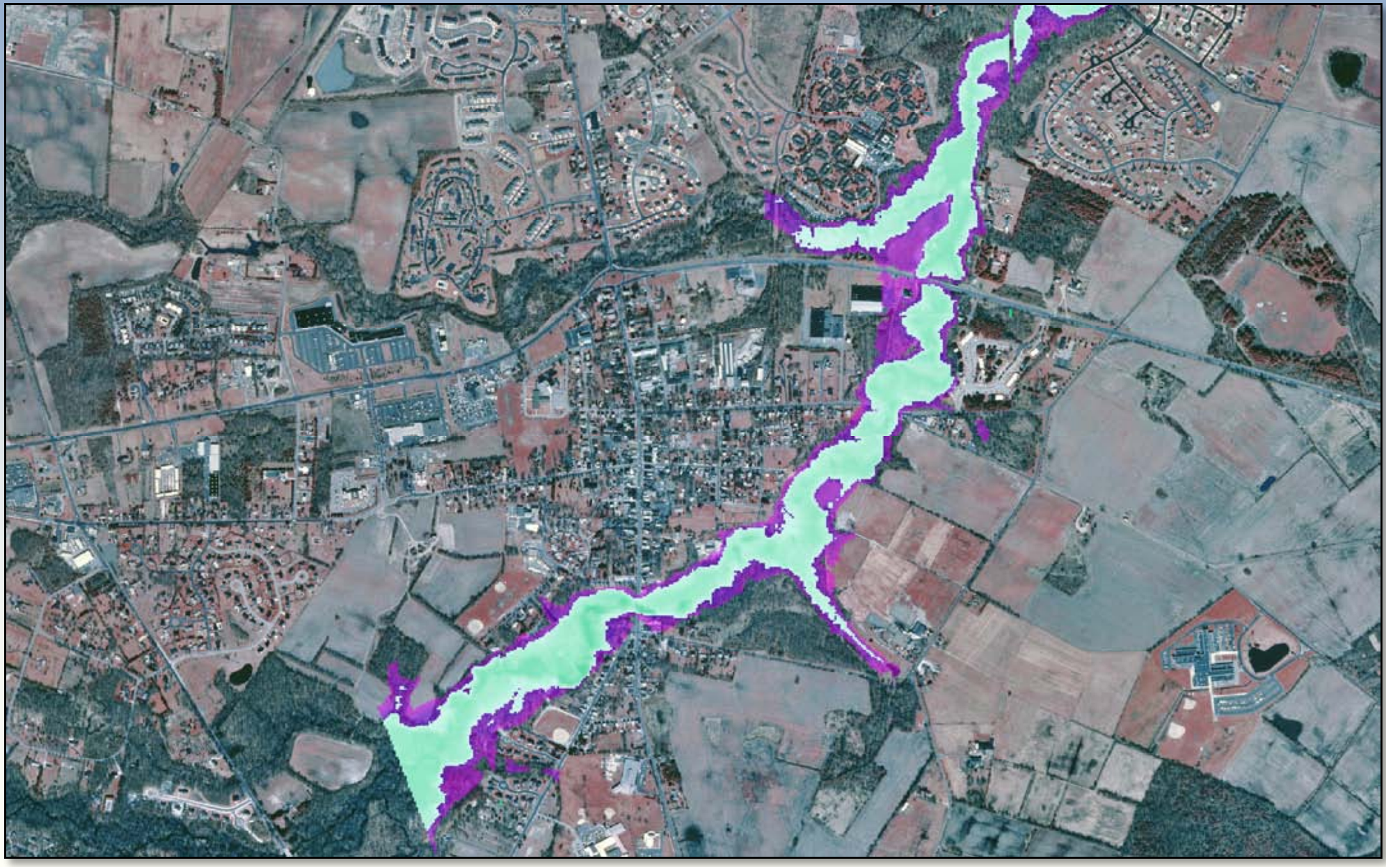
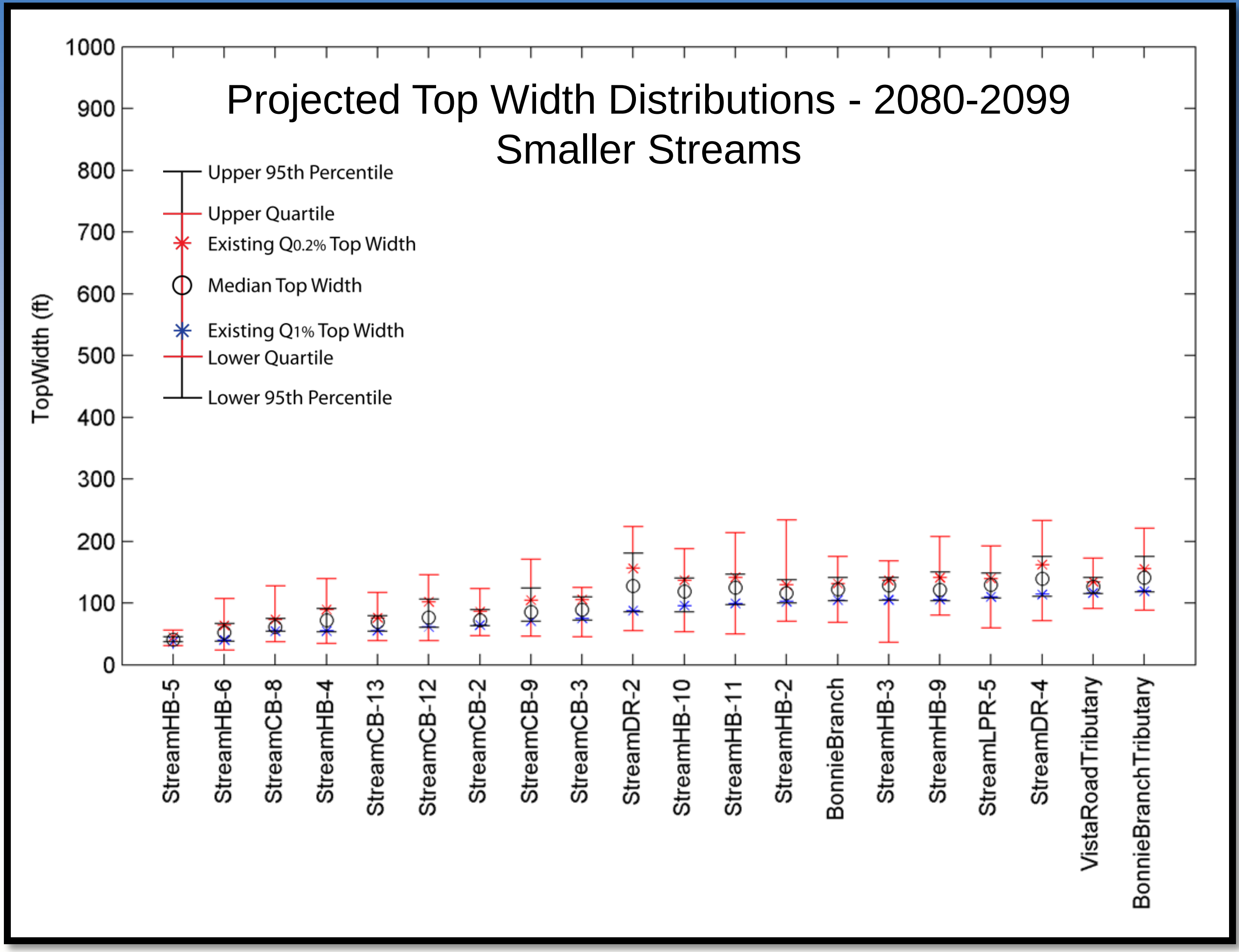
Projecting Flooding

Existing 1% (100-yr) Water Surface → New 1% (100-yr) Water Surface



Changes in Top Width for Howard County



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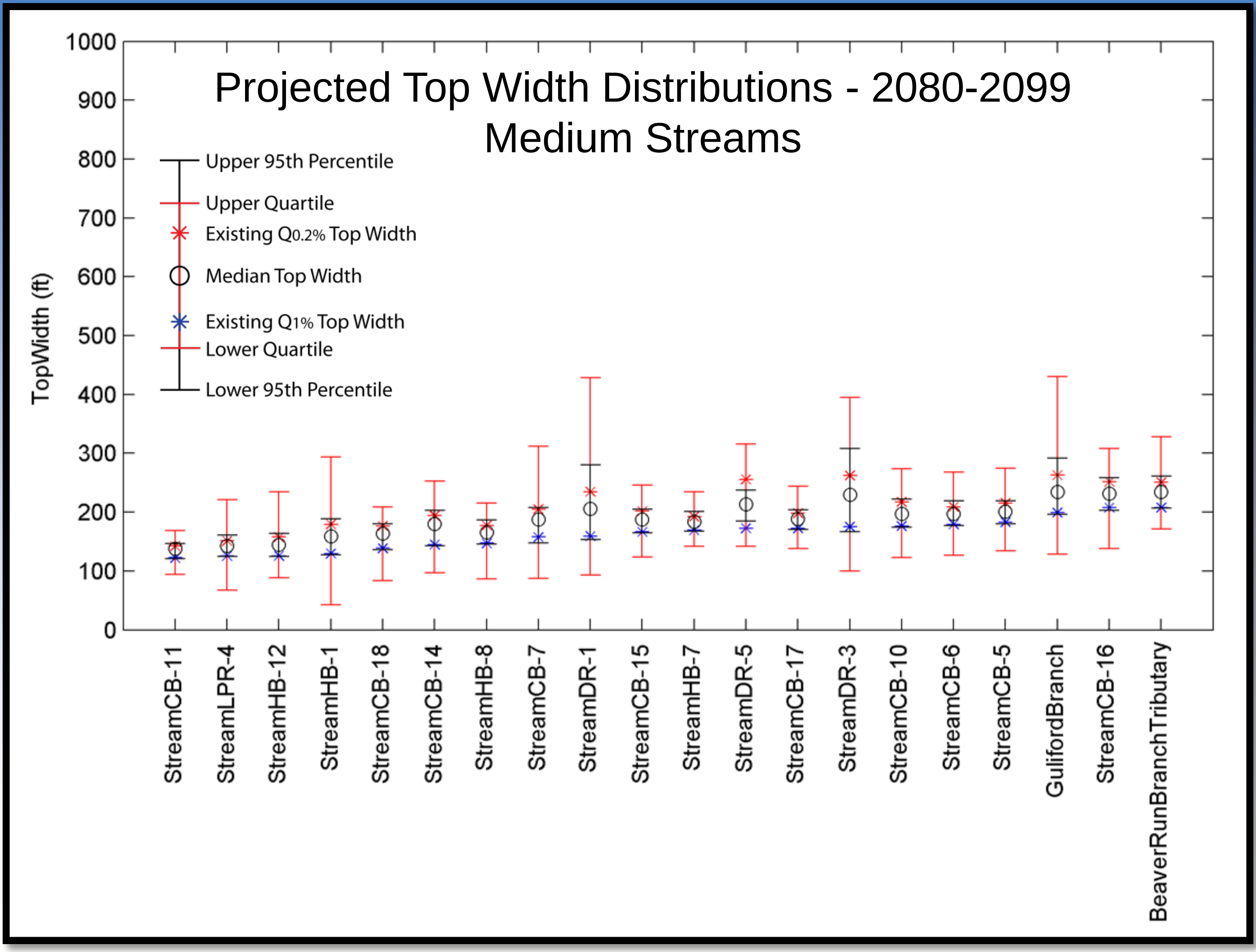

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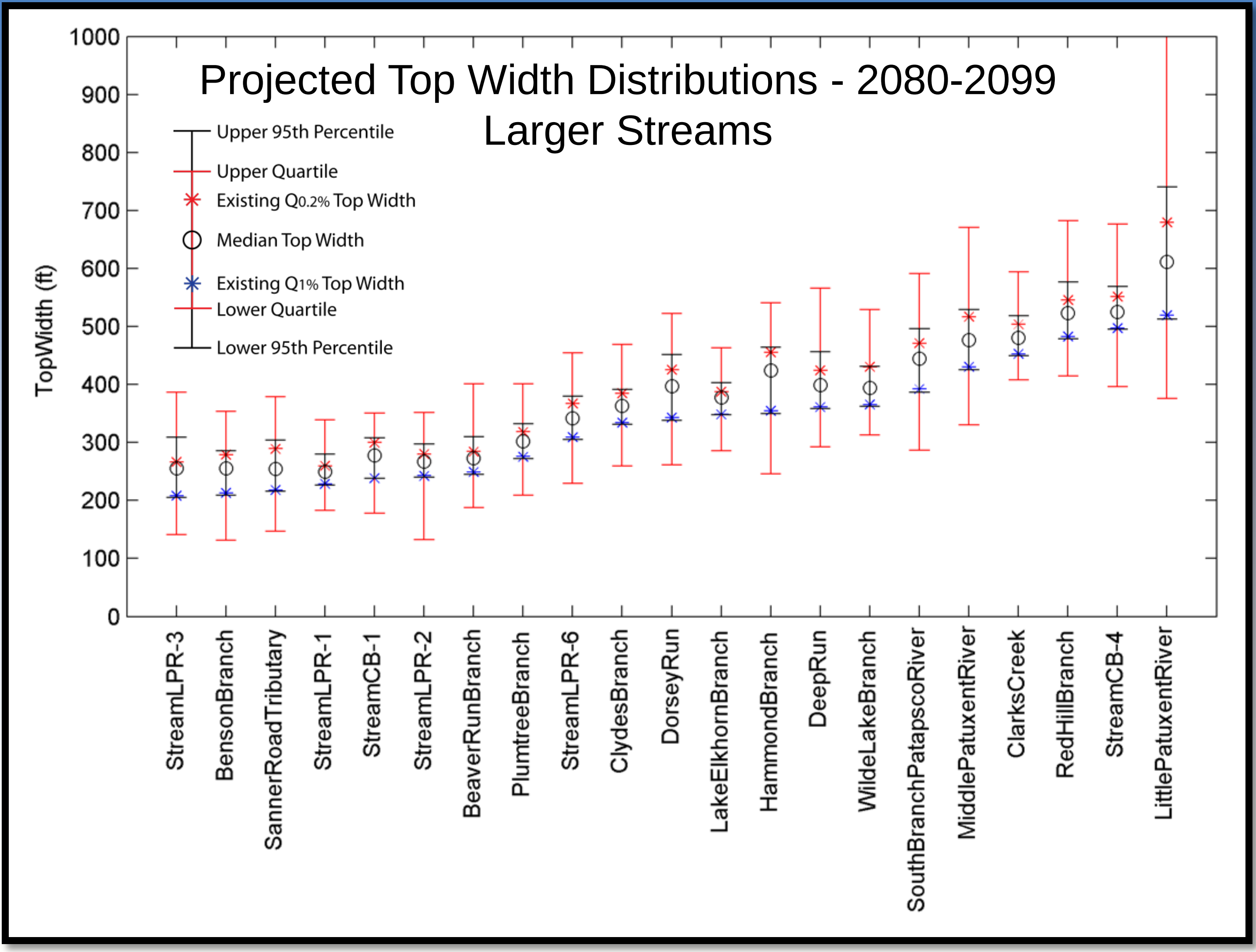

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Summary

- We used a set of 2,370 gages throughout the U.S. to relate watershed characteristics and extreme climate indices to the existing $Q_{1\%}$
- Using a suite of models, runs, and scenarios, we estimated the large uncertainty in climate and population projections and related this to projections of flooding
- Initial results suggest that future $Q_{1\%}$ flooding will become more severe throughout the next century

Future Directions

- More work must be done to further refine this approach
- Scale of study:
  - Although I showed illustrations for Maryland specifically, the scope of the overall study is such that it does not allow for this detailed scale of analysis
  - Future regional studies should focus on regional scale modeling and downscaling techniques
- Improved prediction accuracy of climate models and population models
- Methodologies must be developed within flexible frameworks to allow for the incorporation of new data, predictions, and modeling techniques

Questions - Thank You!

Additional Questions?
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