Advancing Climate Risk-Informed Flood Inundation Mapping: A Case Study of the Tuolumne River Watershed

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Presentation Overview

1. Project Background
2. Climate Change Science & Understanding
3. Overview of Climate Risk-Informed Approach
4. Summary of Results

Project Background

Pilot Project Objectives

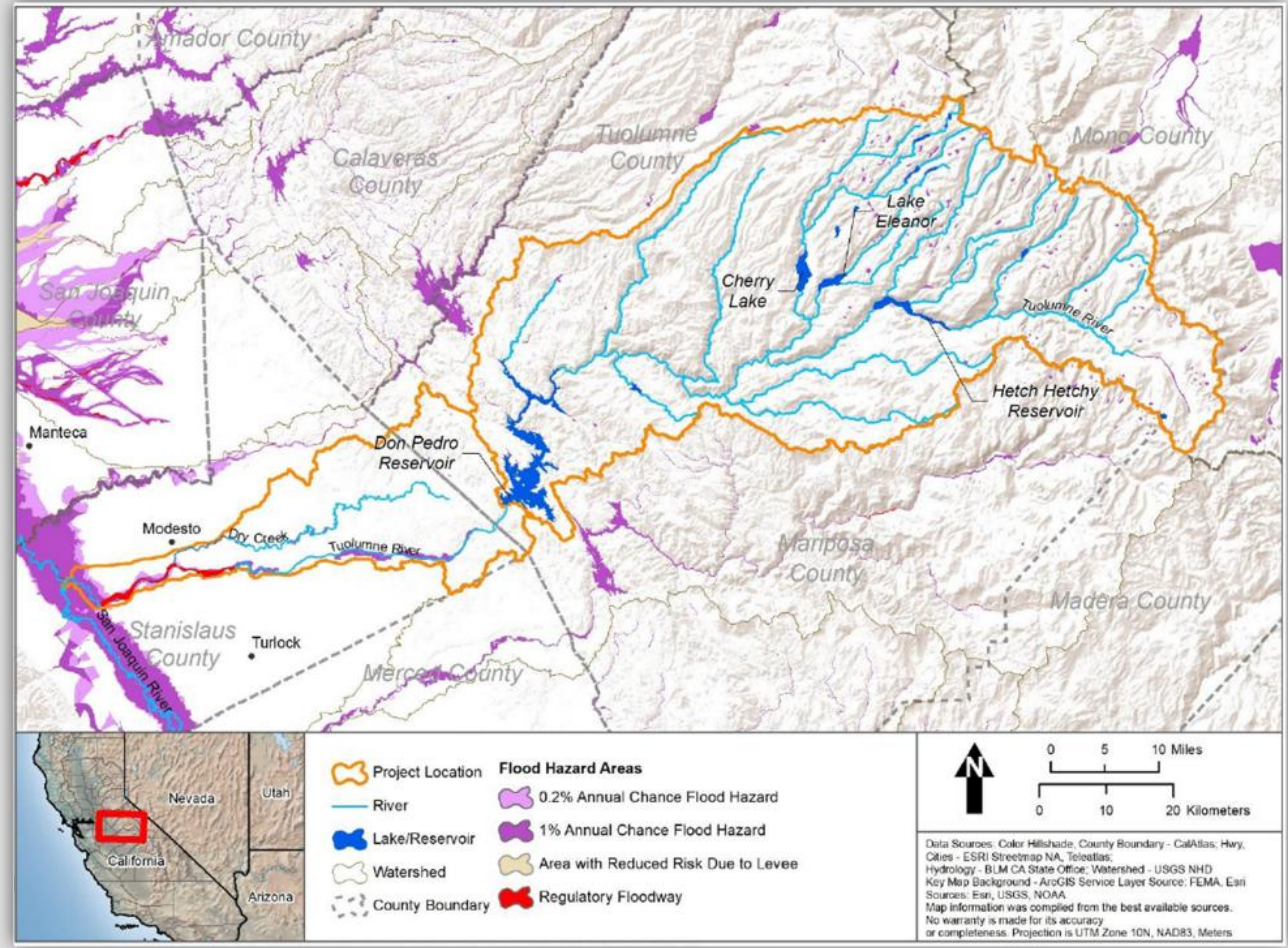
1. Develop a prototype floodplain inundation map following FEMA Risk MAP (Risk Mapping Assessment and Planning) guidelines with a climate risk-informed approach for decision-makers

2. Develop a communication tool (ArcGIS StoryMaps for flood risk) for decision-making

3. Enhance the tool development by communicating and engaging local communities

Pilot Study Area: Tuolumne Watershed

Tuolumne Watershed



Why the Tuolumne Watershed?

- Factors affected by climate change
  - **Elevation Range** (30 ft to 13,000 ft elev.)
  - **Snowpack** (60% of watershed upstream of Don Pedro Dam is above 5,000 ft elev.)
  - **Rain and Rain-on-Snow Events**
  - **Growing Flood Risks**
- On-going excellent relationship with local entities
  - Weather Generator Development
  - SJ Watershed Studies Collaboration

Current FEMA Mapping Standards

Category	Standard	FEMA Document
Inflow Hydrograph	Input hydrographs derived from rainfall-runoff models or other hydrologic methods	Hydrology: Rainfall-Runoff Analysis (Feb 2019)
Reservoir Storage	No storage capacity considered below Normal Pool Elevation for Multi-Purpose Reservoirs	Hydrology: Rainfall-Runoff Analysis (Feb 2019)
Channel Storage	Channel storage accounted using routing techniques	Hydrology: Rainfall-Runoff Analysis (Feb 2019)
Levees	Flood hazard reduction based on FEMA levee accreditation status	Levees (Dec 2020)
Future Conditions	Future development-based floodplain (Zone X) *No climate change impact on hydrology considered*	General Hydrologic Considerations (May 2016)

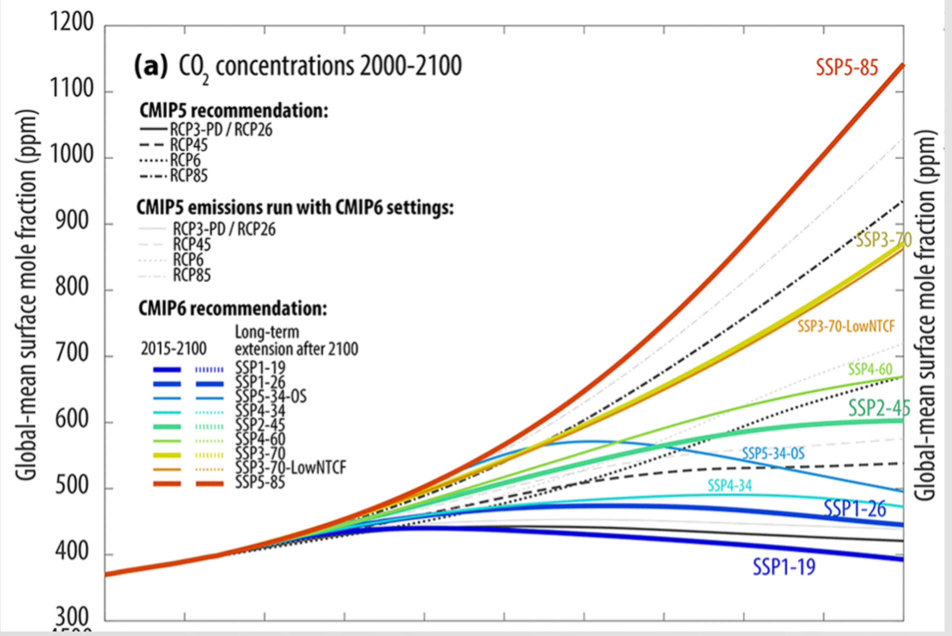
Climate Change Science & Understanding

Intergovernmental Panel on Climate Change (IPCC) and Coupled Model Intercomparison Project (CMIP)

IPCC Assessment Report (AR)	CMIP & Number of General Circulation Model (GCM)	Name and Number of Greenhouse Gas (GHG) Scenarios
1st (1990)		
2nd (1995)		
3rd (2001)	CMIP1/2 ~18 models (1997)	Special Report on Emissions Scenarios (SRES) – 6 Scenarios
4th (2007)	CMIP3 24 models (2006)	SRES – 6 Scenarios
5th (2014)	CMIP5 40 models (2014)	Representative Concentration Pathways (RCP) – 7 Scenarios, but only 4 are used in AR5
6th (2021/22)	CMIP6 50+ models (2020)	Shared Socioeconomic Pathways (SSP) – 5 Scenarios

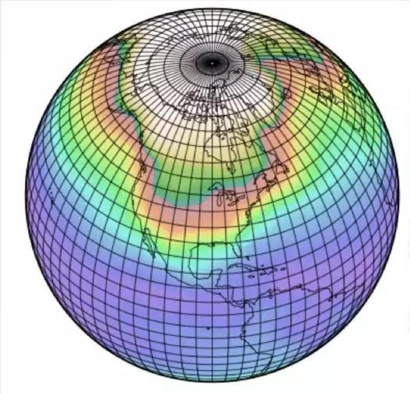
Using Climate Projections

Emission Scenarios



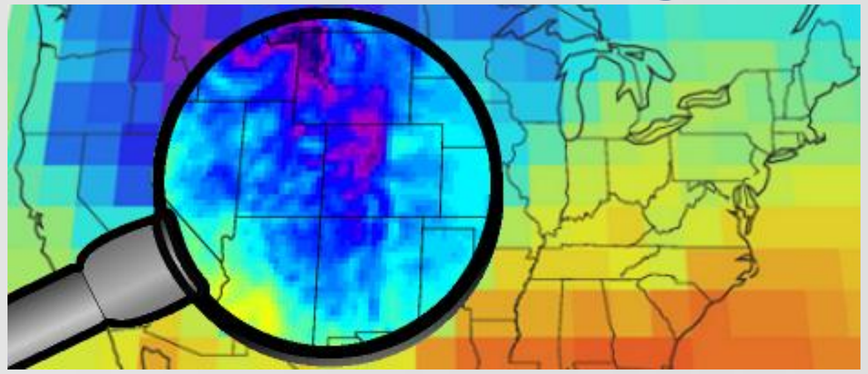
Shared Socioeconomic Pathways (SSP) with CO_2 concentrations:
4 "Benchmark" Scenarios
(SSPs 1-26, 2-45, 3-70, 5-85)

General Circulation Model (GCM)

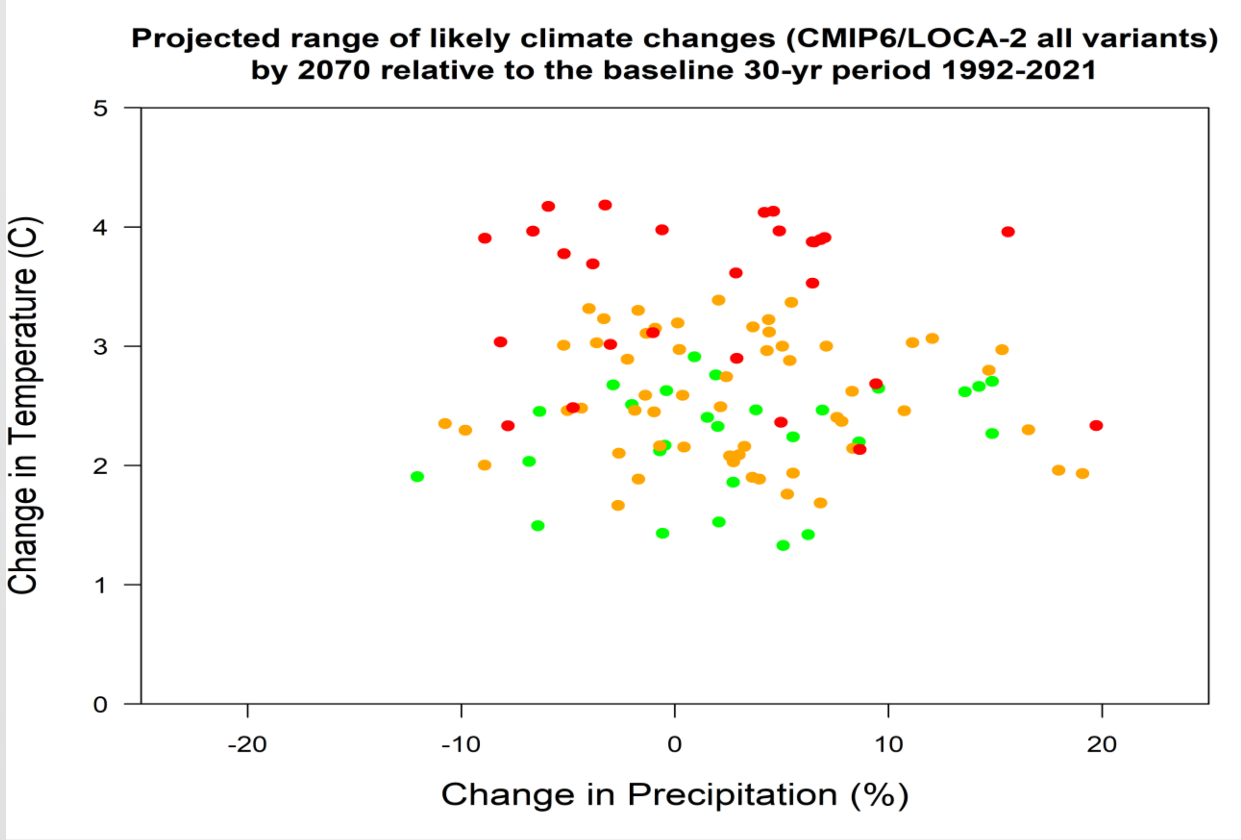


CMIP6: >130 models and multiple variants per model

Bias Correction + Downscaling



LOCA2: 200 individual projections from ~15 models covering 3 scenarios



- **Useful for establishing the plausible range** of climate change
- **Difficult, impractical, and problematic for using as direct inputs** to water resource system models

Challenges with Downscaled Climate Projections: *Climate Variability can Lead to Misleading Trends*

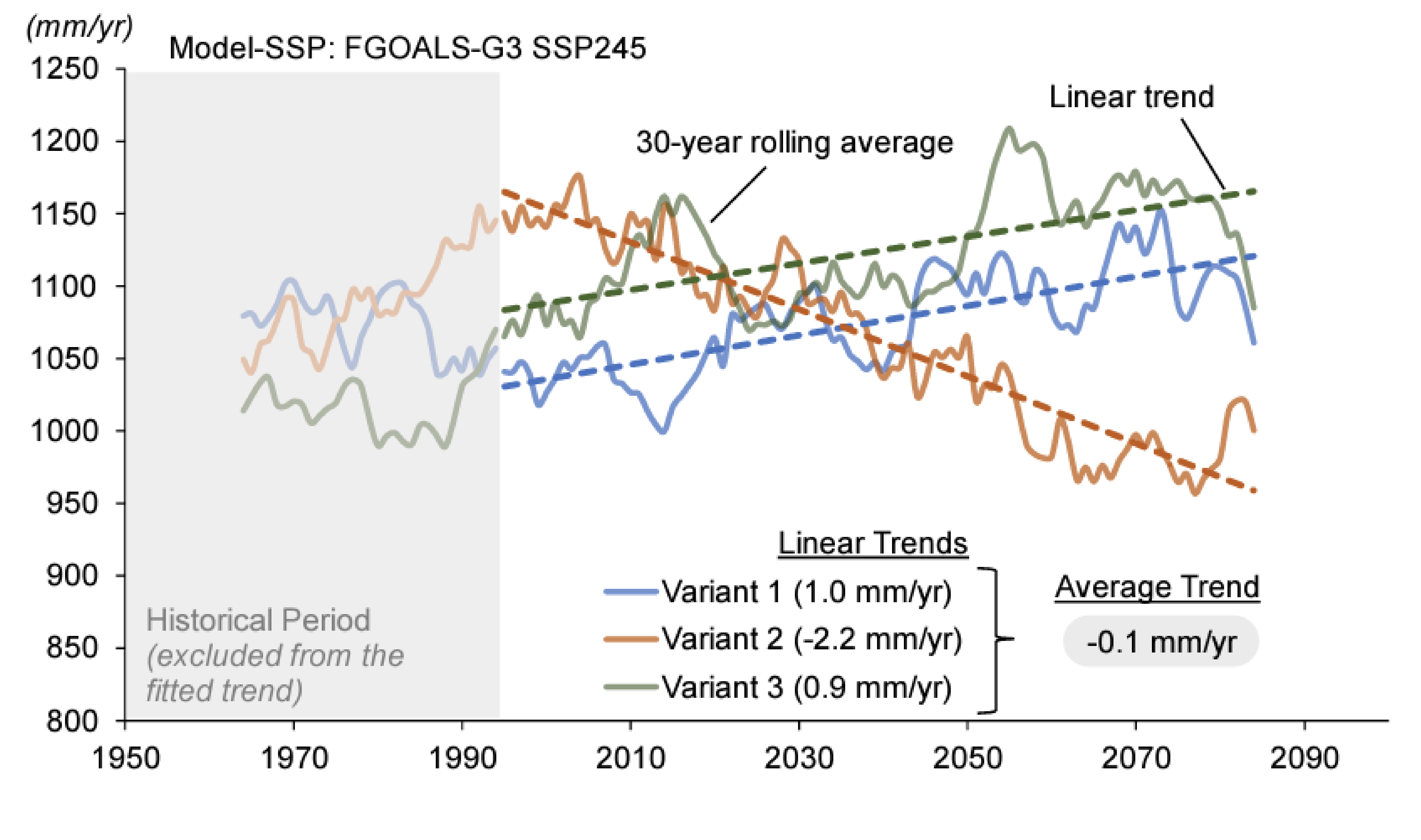


Figure taken from SWP Delivery Capability Report

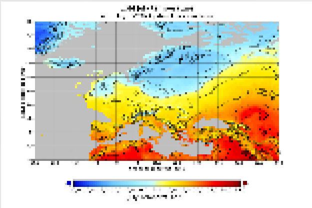
Using Climate Projections at DWR – Traditional Method

"Top Down" or Downscaling Approach

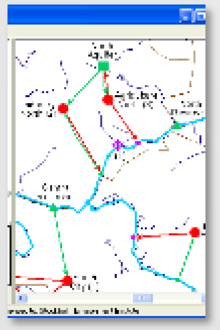
Select a Couple of General Circulation Model (GCM) Projections

Source: [*NOAA GFDL*]

Downscaling, Hydrologic Modeling

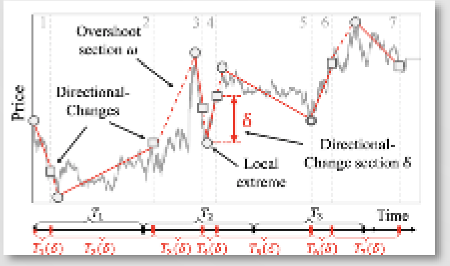


Operations and Planning Models



Source: [*SEI WEAP*]

Conditional System Performance Projections



There are 100's of Global Climate projections

→ Pick a scenario or set of scenarios to localize and use as the "future"

→ Predict future performance of your water system

→ Determine vulnerabilities and adapt as indicated

- Did we cover the full range of uncertainty to be prepared?
- Would the results be different if a different set of projections or method were used?
- How likely is this future, what is the risk?

Using Climate Projections at DWR – Current Approach

"Bottom Up" or **Decision Scaling** Approach

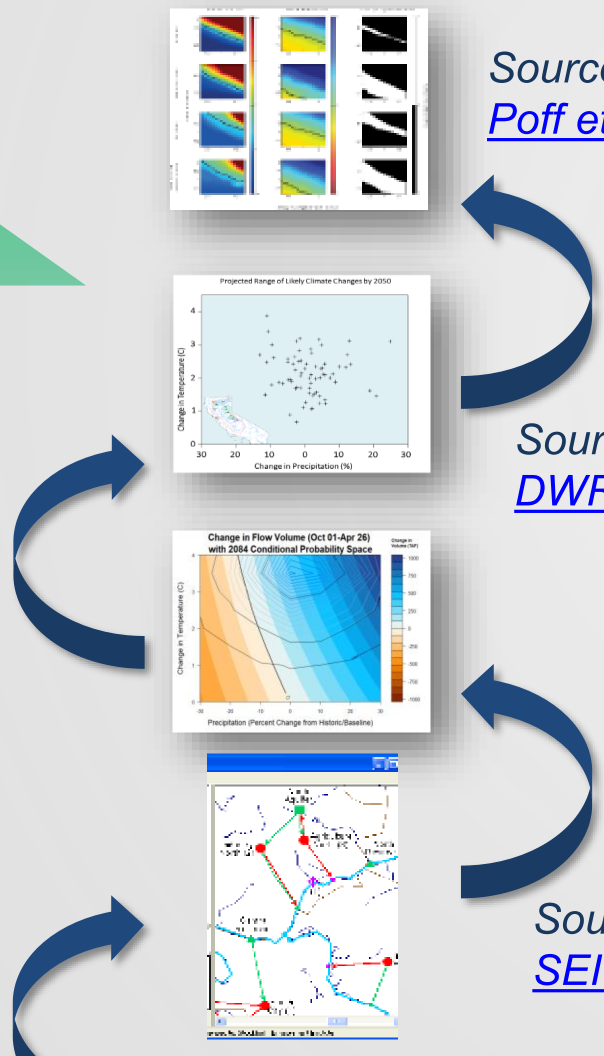
Adaptive Planning

Climate Model Ensemble

System Surface Response /Vulnerability Assessment

Operations and Planning Models

Climate/ Weather Generator or Paleoclimate Data



Source: Poff et al. (2016)

Source: DWR VA

Source: SEI WEAP

Systematic Climate Perturbations

Other images source: Wikimedia Commons

A way to prepare when you aren't sure what's coming (Stress Test)

→ Determine the sensitivity of a water system to a range of stress (weather or climate possibilities). **Where is our system vulnerable?**

→ Determine what threshold of performance is unacceptable or 'breaks' the system. **Find tipping points.**

→ Determine how likely that is to happen. **Incorporate original climate projections to assess the risk of these "unacceptable outcomes."**

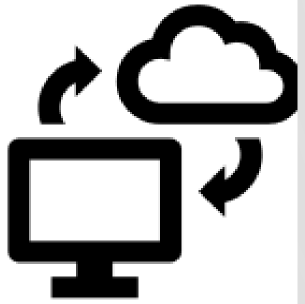
→ **ADAPT!** Take decision(s) toward what is "most" likely and/or "most" acceptable based on this risk assessment.

Climate Risk-Informed Analytical Approach

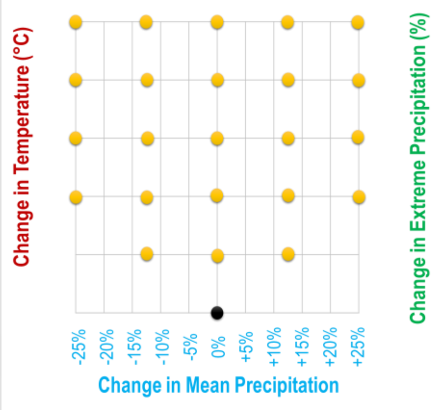
Analytical Framework

1. Climate Perturbations and Hydrologic Modeling

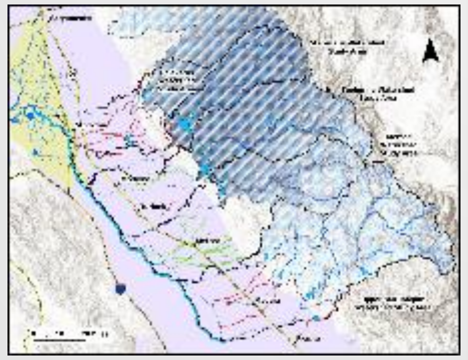
California's Historical Weather



Stochastic Weather Generator



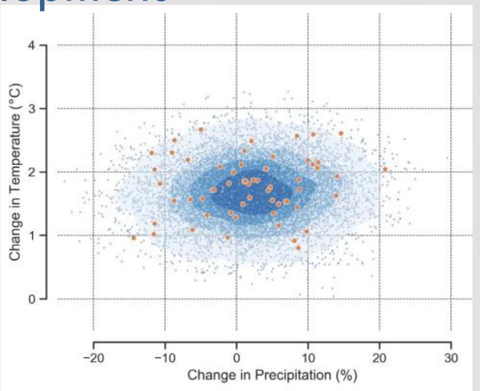
Climate Perturbations



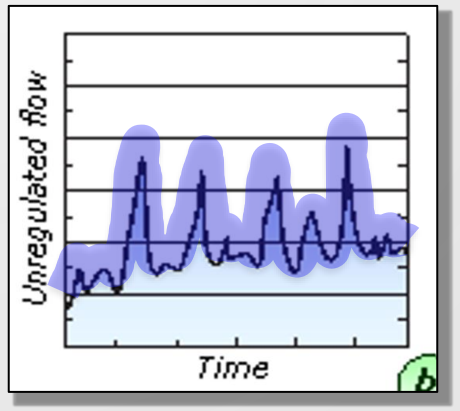
SAC-SMA Hydrologic Model

2. Climate Projections Analysis and Probability Distribution Function Development

GCM-based climate information (CMIP6 LOCA2 Downscaled)



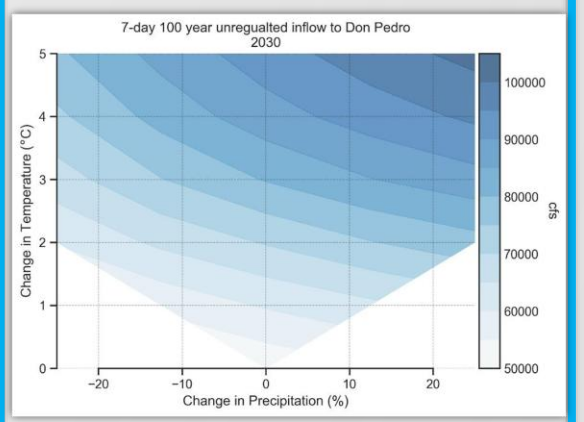
Plausible Range of Future Climate Change



Unregulated Flow Time Series

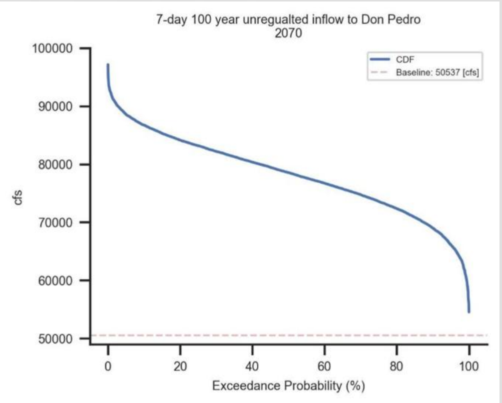
Unregulated Flow Frequency Analysis Using USGS Bulletin 17C Procedures

3. Unregulated Flow Frequency Analysis



System Stress-Test Response Surface

4. Stress-Test Surface Response Development



Likely Unregulated Flow under Climate Changes for a Planning Horizon

5. Unregulated Flow Cumulative Distribution Function

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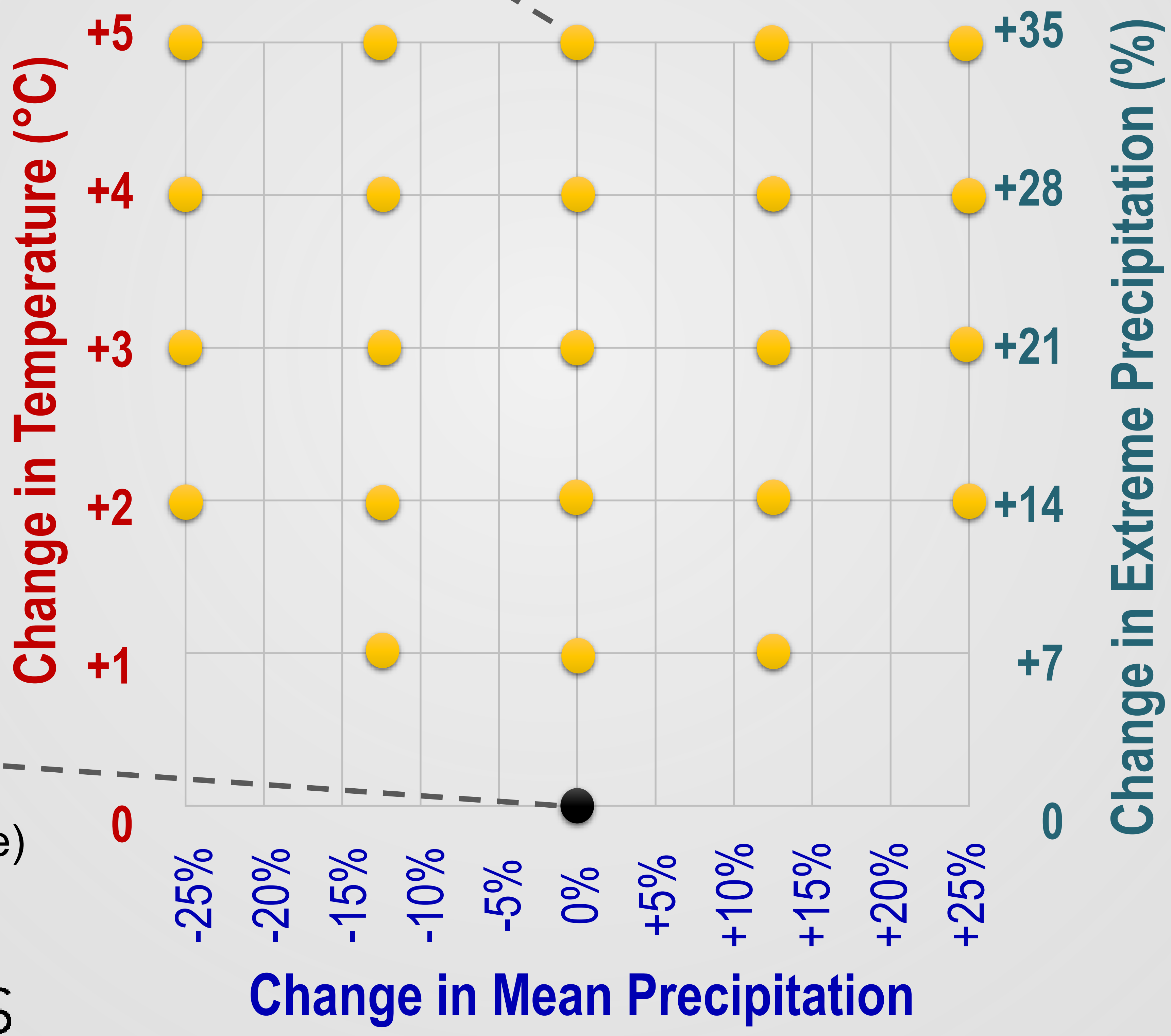
Climate and Perturbations

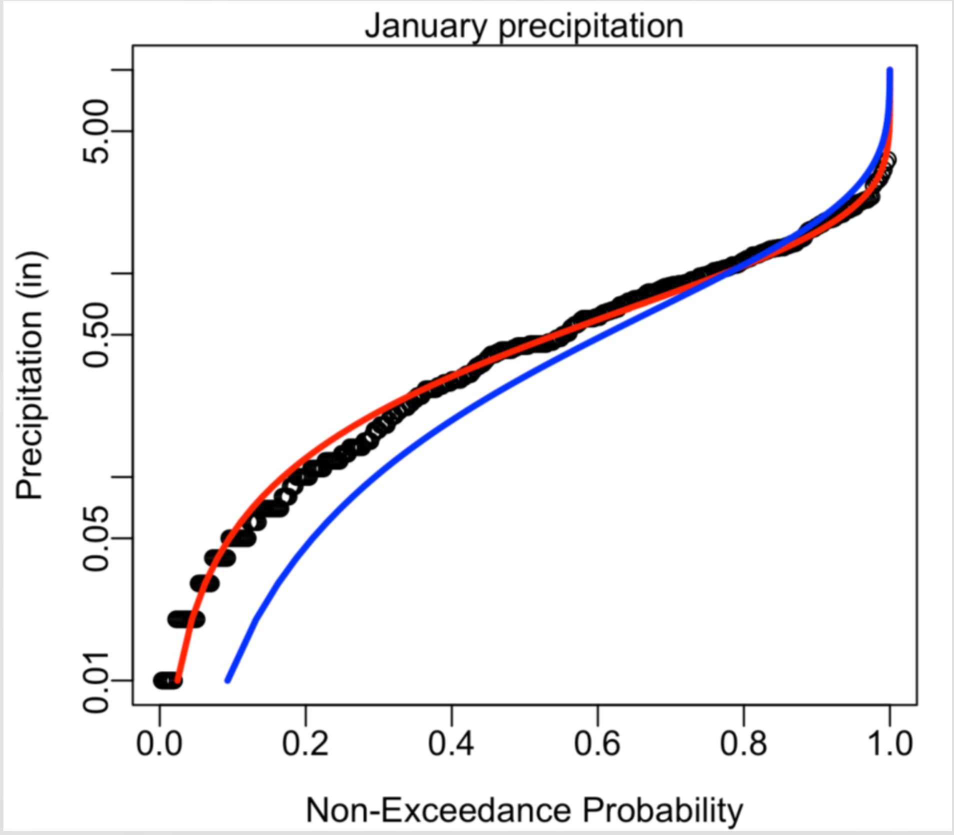
Perturbations:

- Baseline (1915-2018), temperature detrended
- 0°C to +5°C
- -25% to +25% total precipitation
- +7%/°C Clausius-Clapeyron scaling



Change in Extreme Precipitation:

+7% per °C



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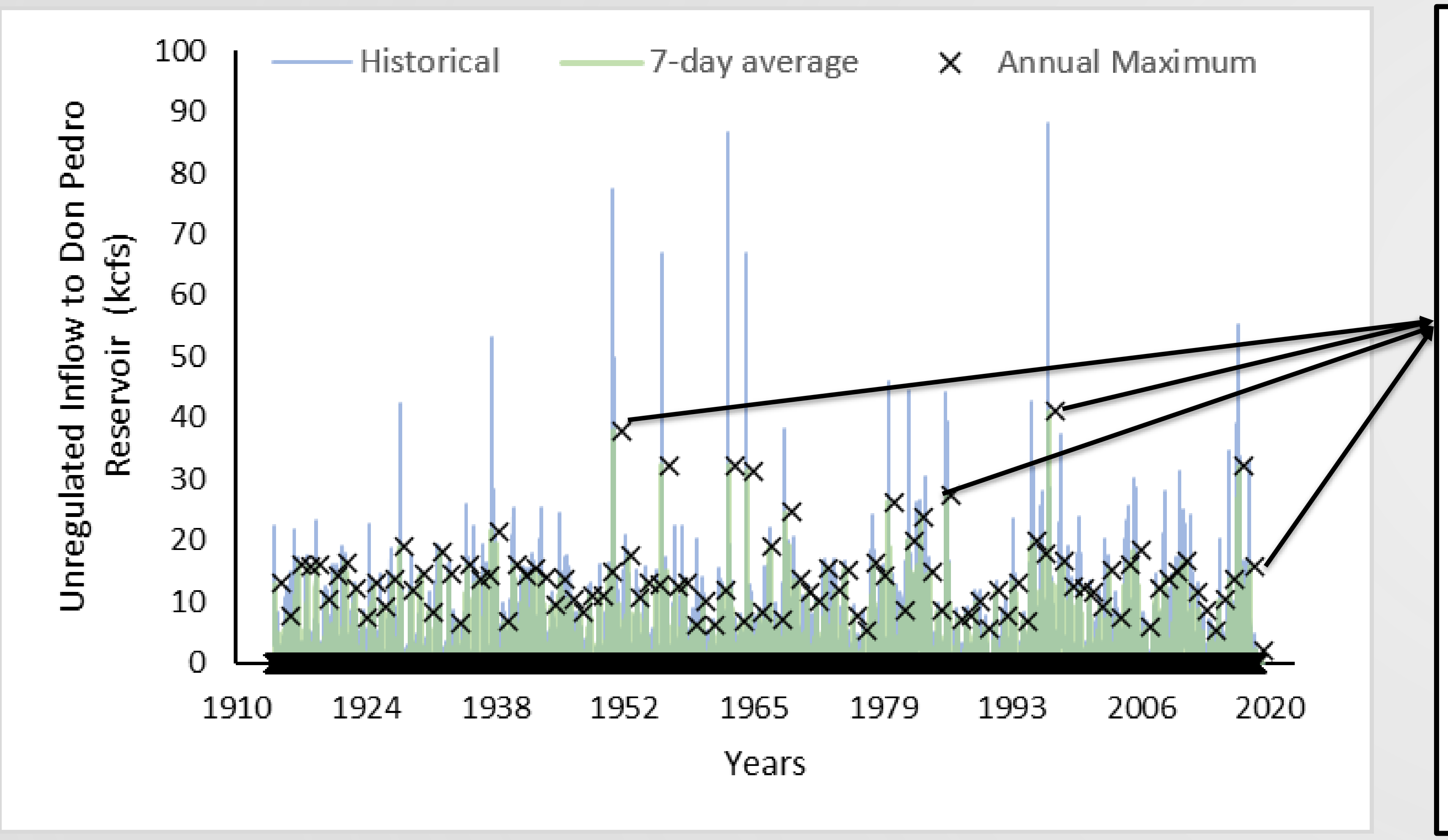
Unregulated Flow Frequency Analysis: Bulletin 17C

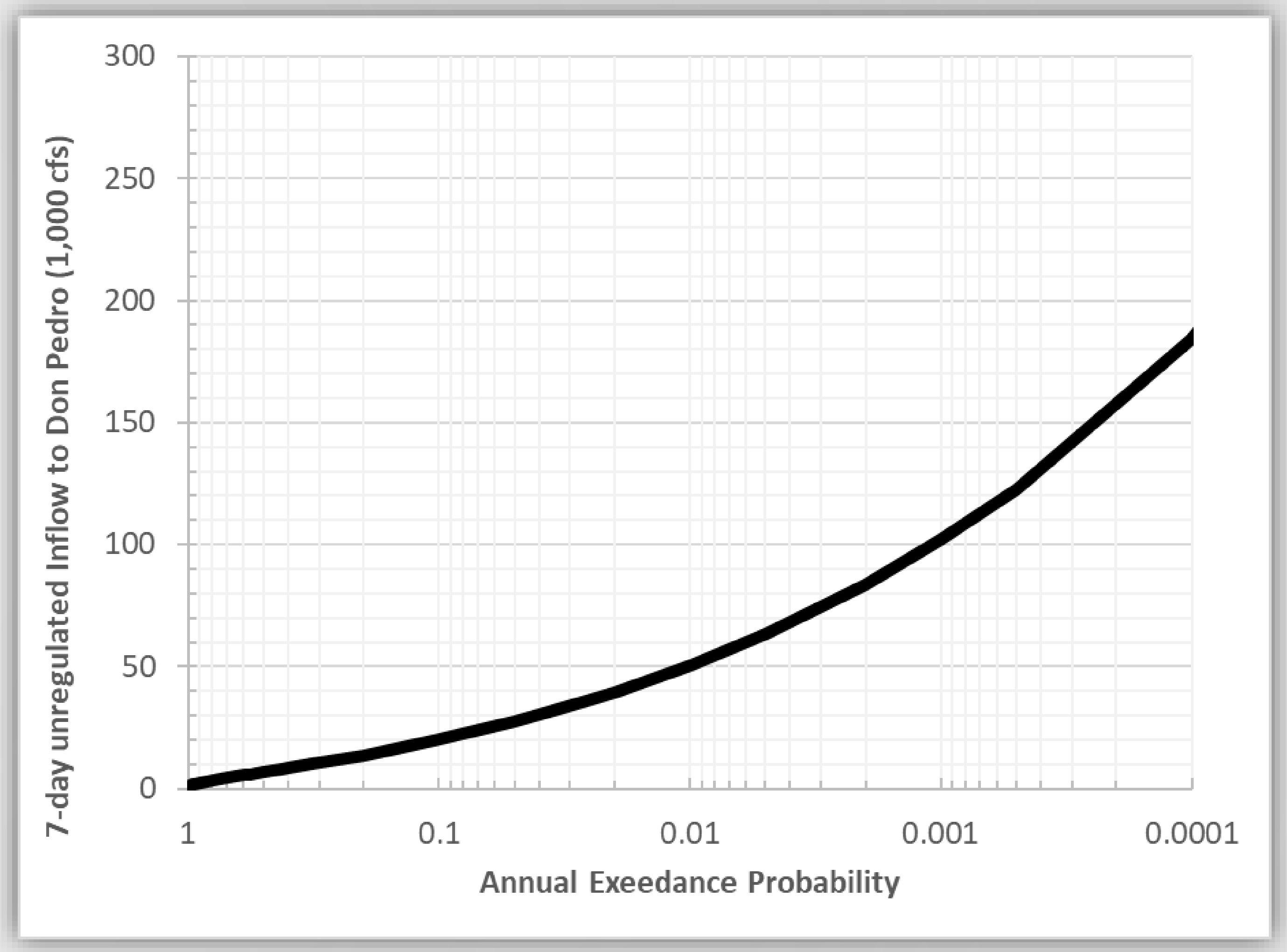
3. Unregulated Flow Frequency Analysis



IPAST

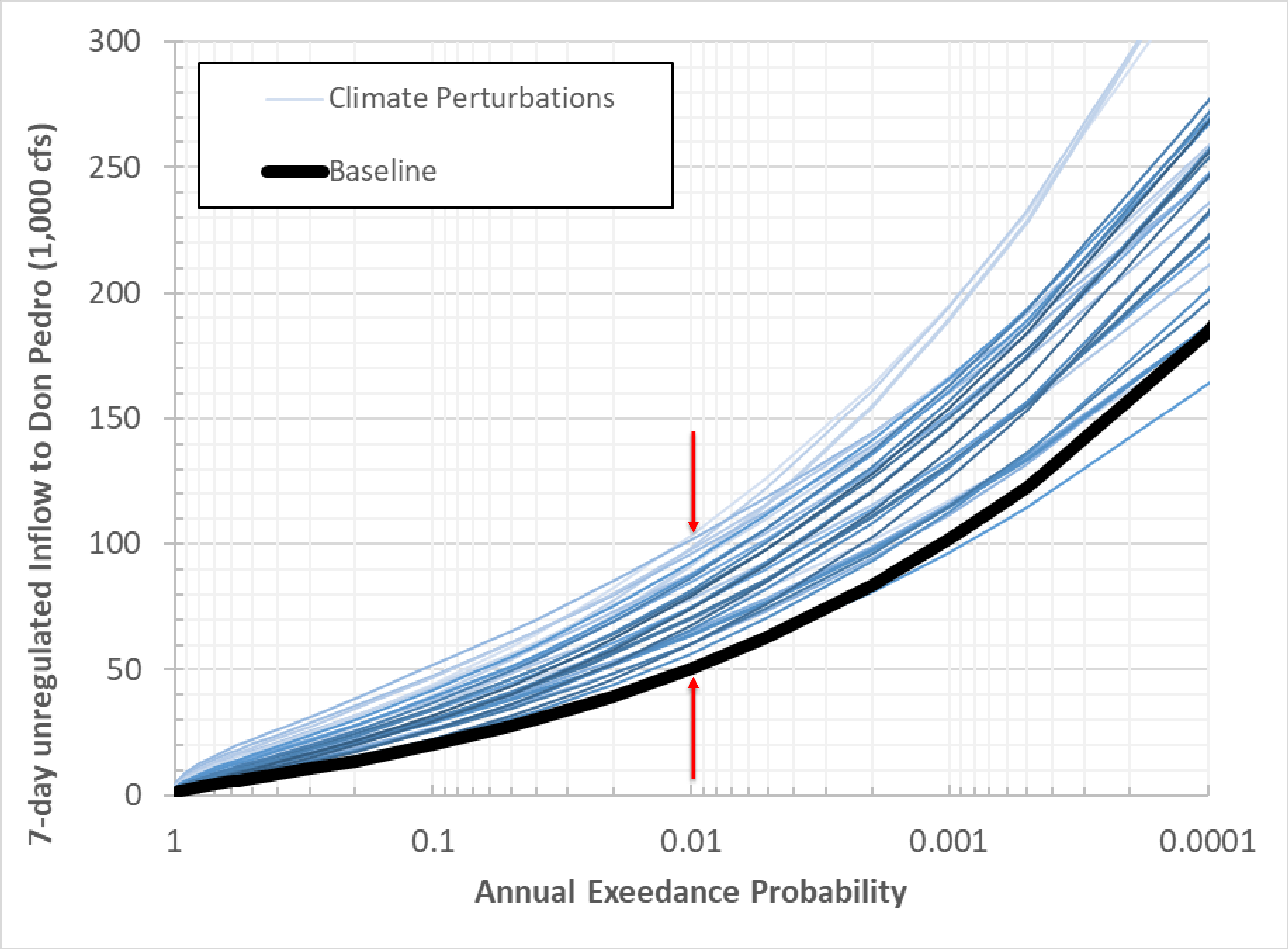
Log- Pearson Type III (LP3)

Bulletin 17C
EM 1110-2-1415

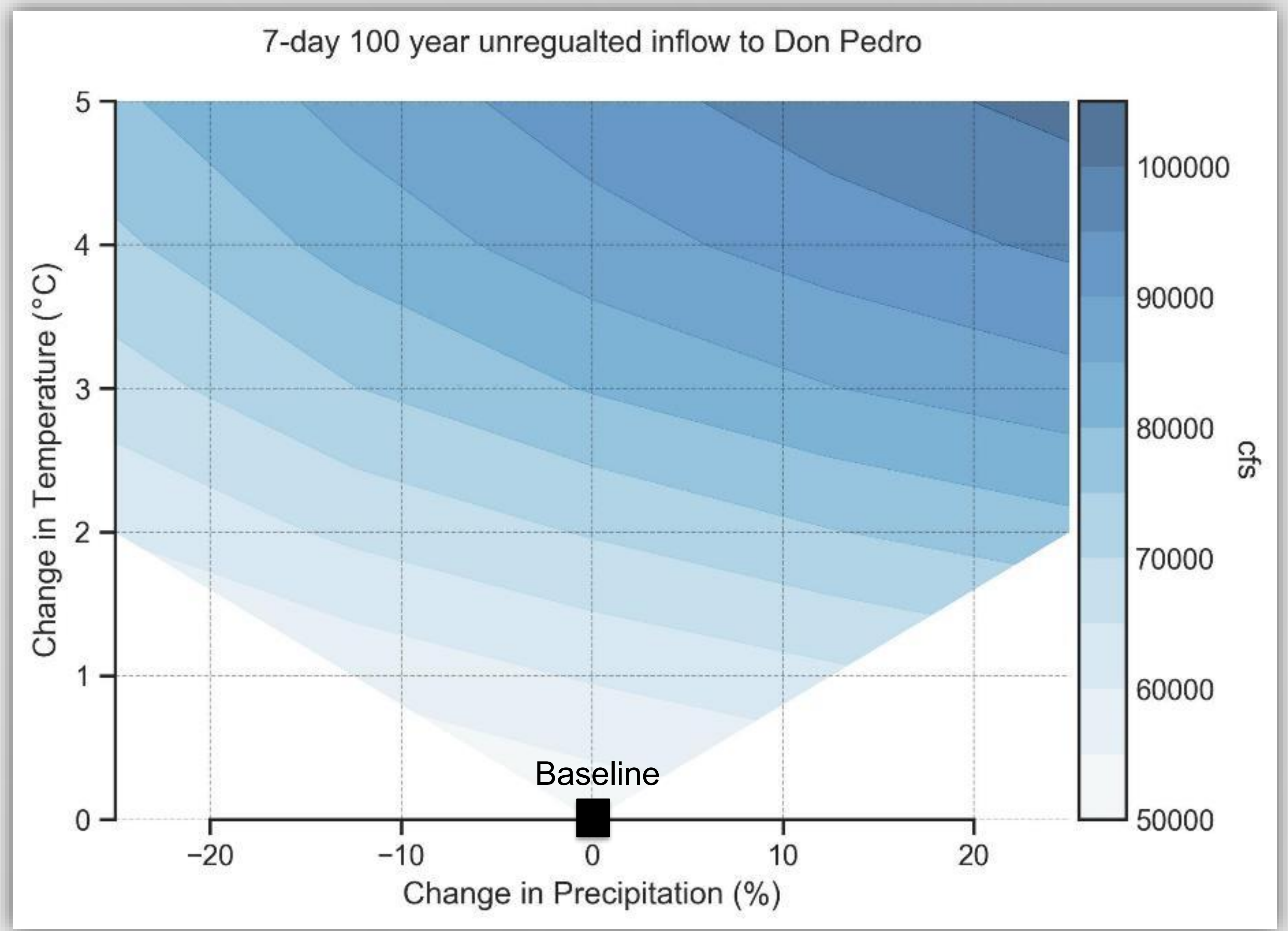


Bulletin 17C & Stress Test Response Surface

3. Unregulated Flow Frequency Analysis



4. Stress-Test Surface Response Development



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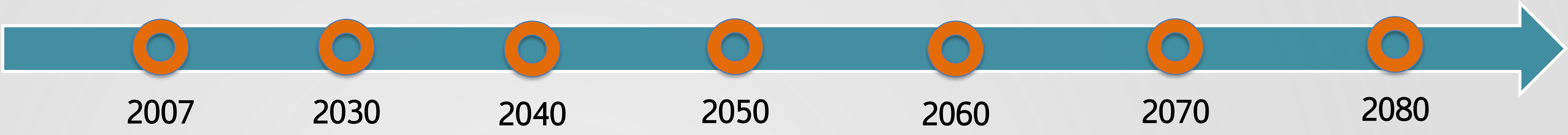
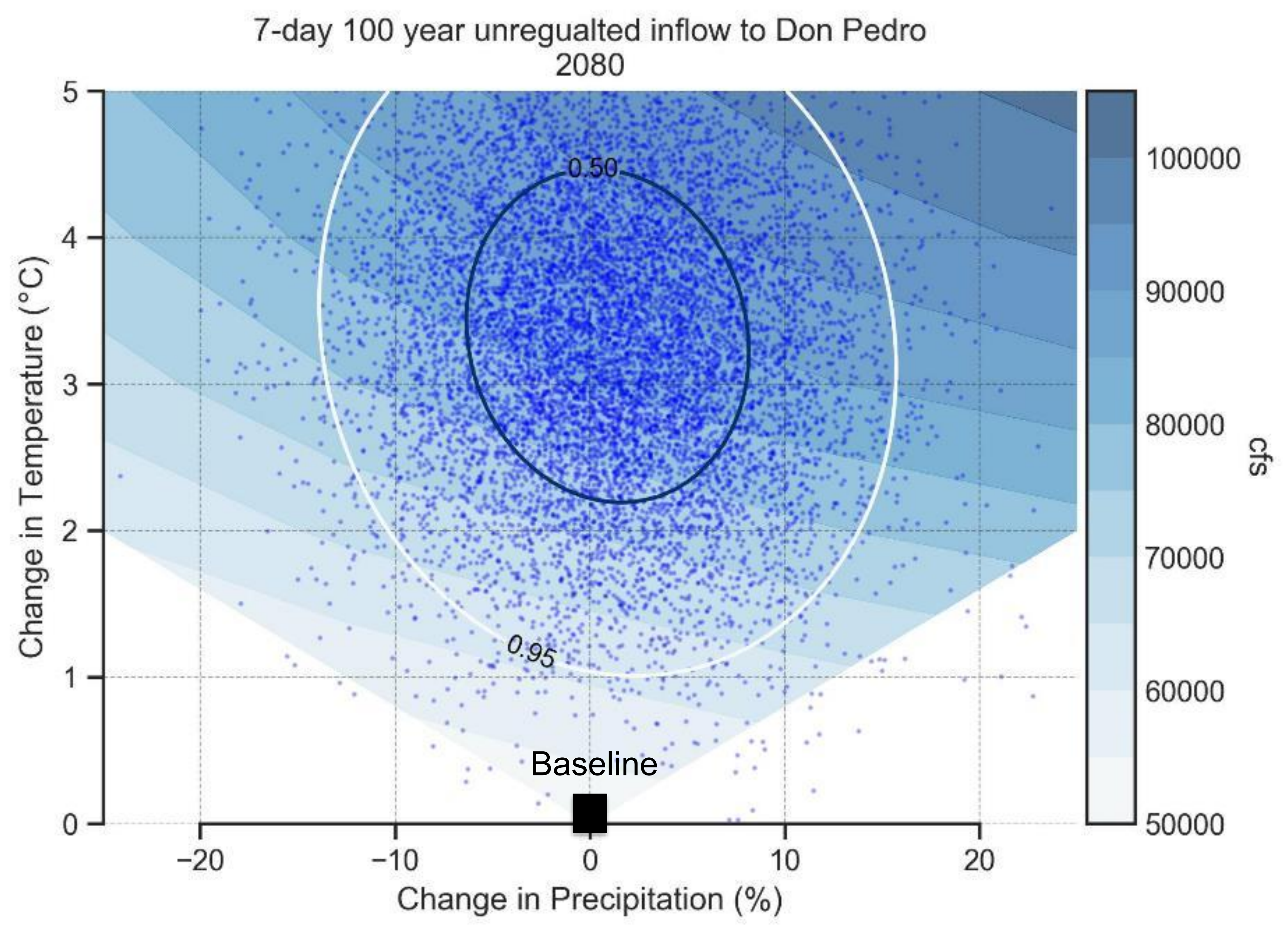
Climate Change Projections



2. Climate Projections Analysis and Probability Distribution Function Development

- Select a planning horizon
- Used CMIP6-LOCA2 downscaled GCM data with SSP variant averaging
- Developed bivariant Gaussian probability density function (PDF) of climate change signal
- Developed a 10,000-member random sample of changes in 30-year temperature and precipitation from the PDF



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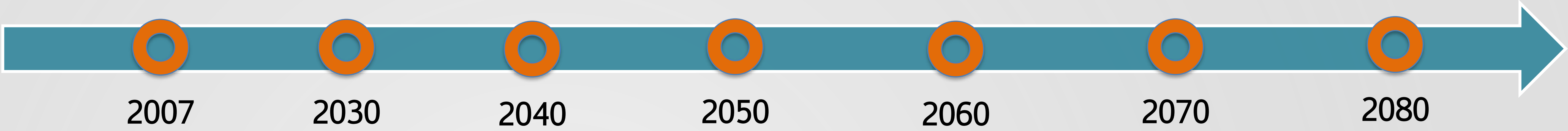
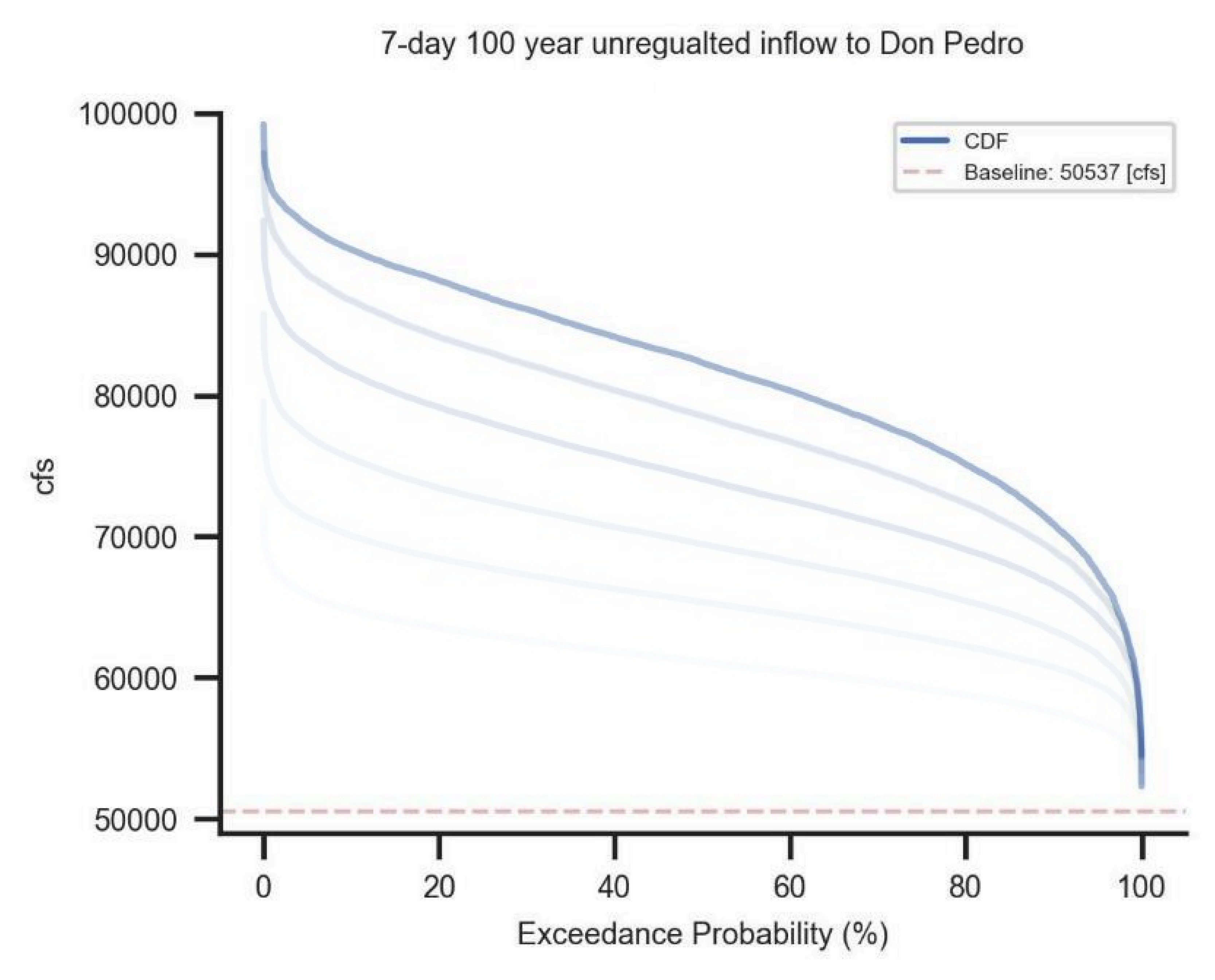
Cumulative Distribution Functions



5. Unregulated Flow Cumulative Distribution Function

- For each of 10,000-member random sample of changes in 30-year temperature and precipitation, corresponding 7-day 100-year inflow to Don Pedro was extracted.
- A cumulative distribution function for each planning horizon was developed from the extracted inflows.



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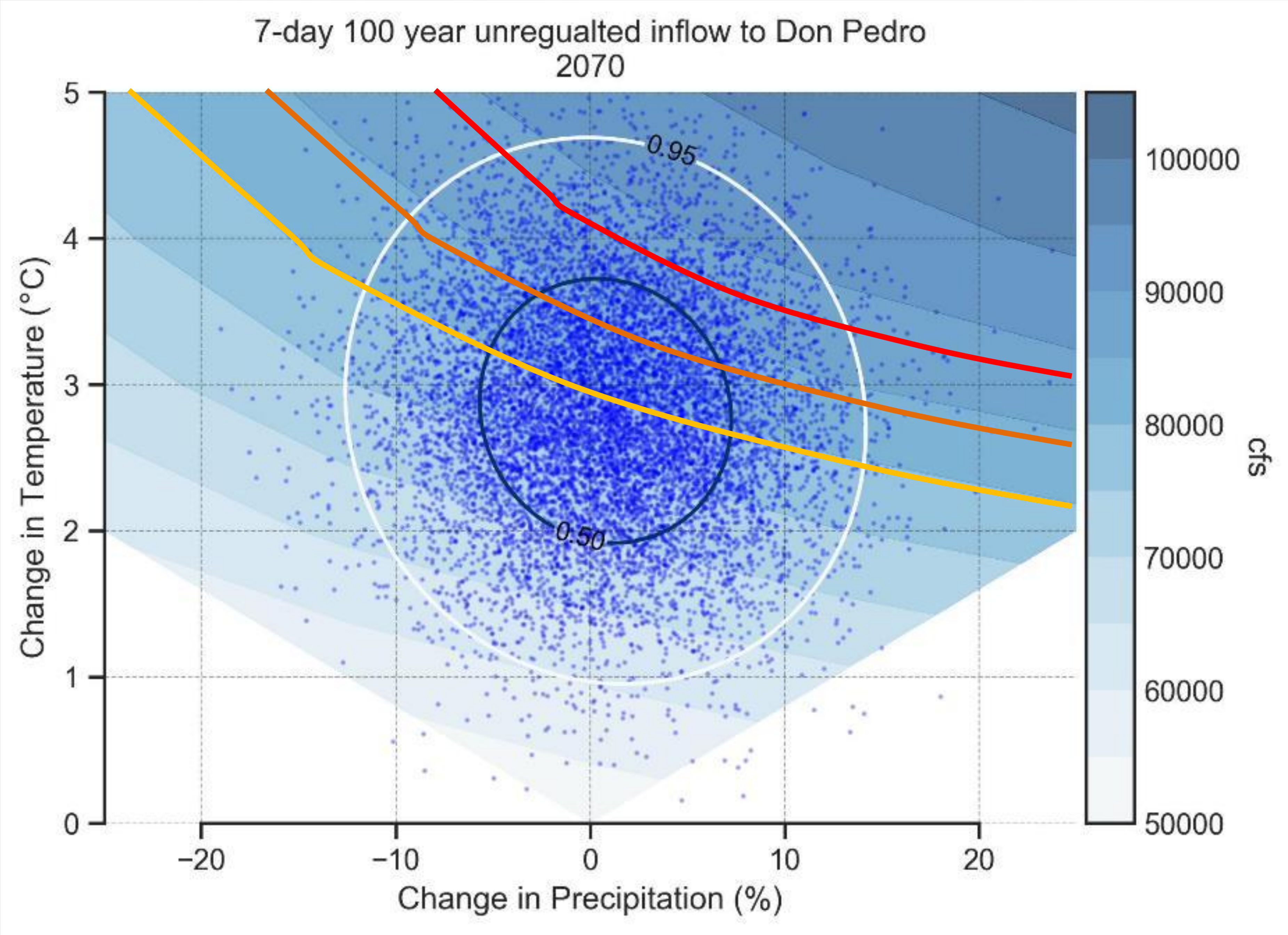
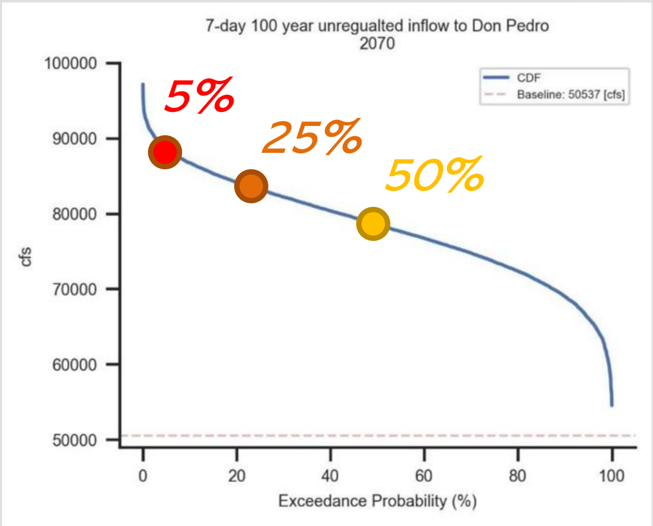
Identify Key Climate Change Scenarios

6. Identify Draft Key Climate Scenarios



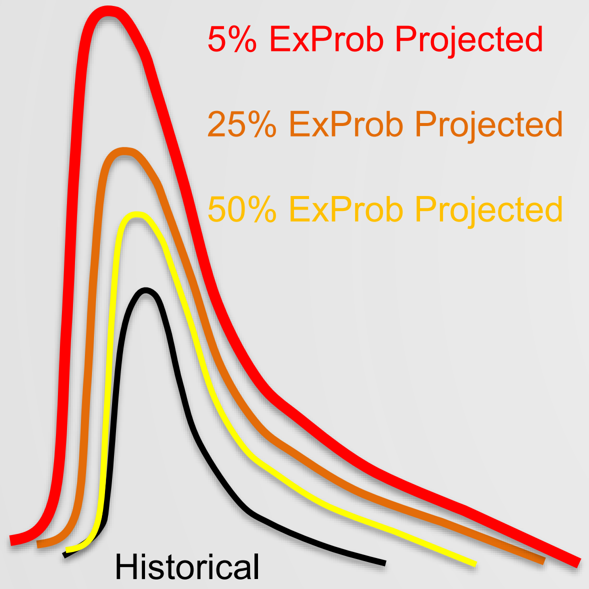
Floodplain Mapping Approach

6. Identify Draft Climate Scenarios



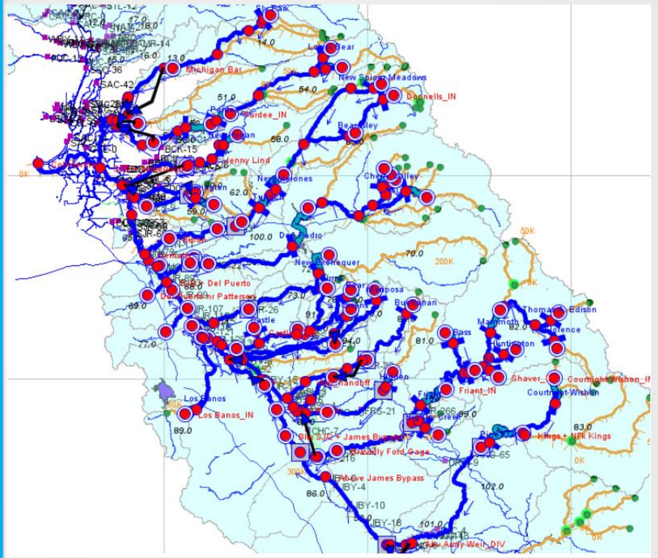
Likely Unregulated Flow under Climate Changes for a Planning Horizon

7. Select Representative Unregulated Flow Hydrographs



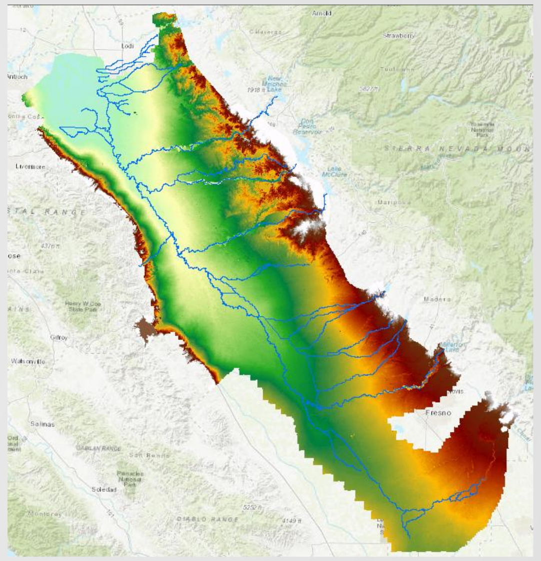
1% AEP Unregulated Hydrographs Selected from CVHS Scaled Events

8. Reservoir Operations Modeling



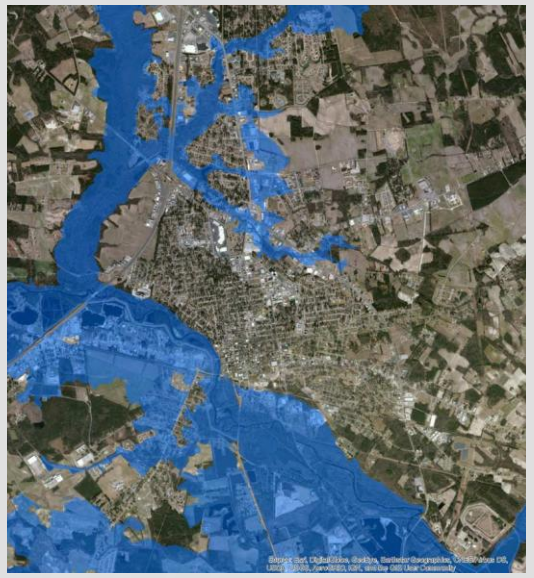
Reservoir Operations Simulation Model CVFPP 2022 HEC-ResSim

9. Hydraulic Modeling



San Joaquin River Hydraulic Model CVFED 2.0 HEC-RAS

10. Floodplain Mapping

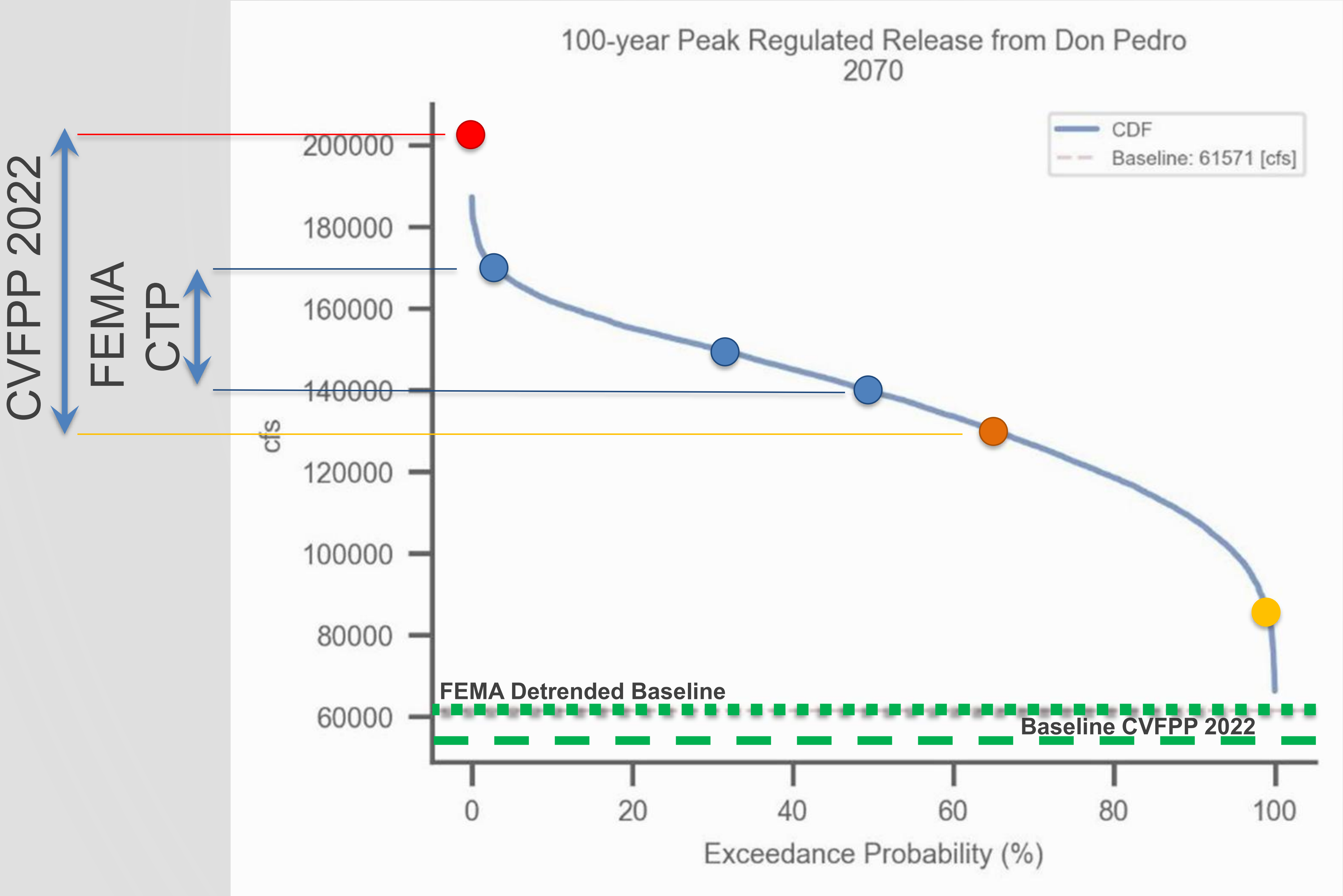


Floodplain Mapping

Summary of Results

Comparison with CVFPP 2022 Results

Annual Exceedance Probability (AEP)	Current (CFS)	2070 50% (CFS)	2070 25% (CFS)	2070 5% (CFS)
0.010	61,571	141,906	150,849	171,528



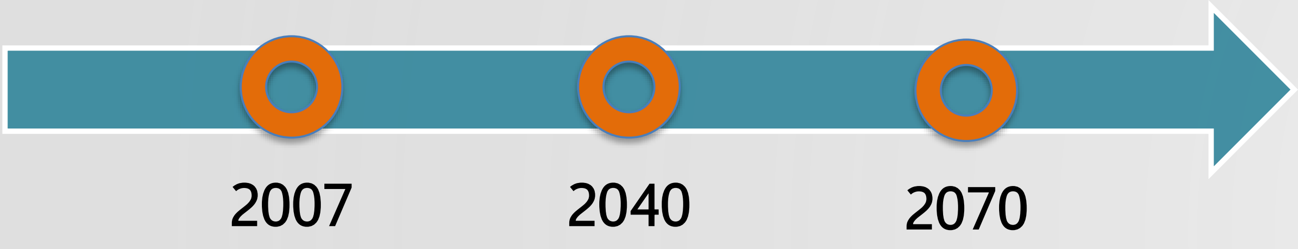
CVFPP 2022 Results				Flow (cfs)
AEP	2022 without-project	2072 without-project, low	2072 without-project, median	2072 without-project, high
0.100	10,600	10,700	11,000	14,200
0.040	13,400	18,400	34,000	69,500
0.020	32,600	49,600	75,100	132,100
0.010	55,200	84,400	130,700	208,300
0.005	83,000	126,900	192,500	315,600

A “small” difference in consideration of:

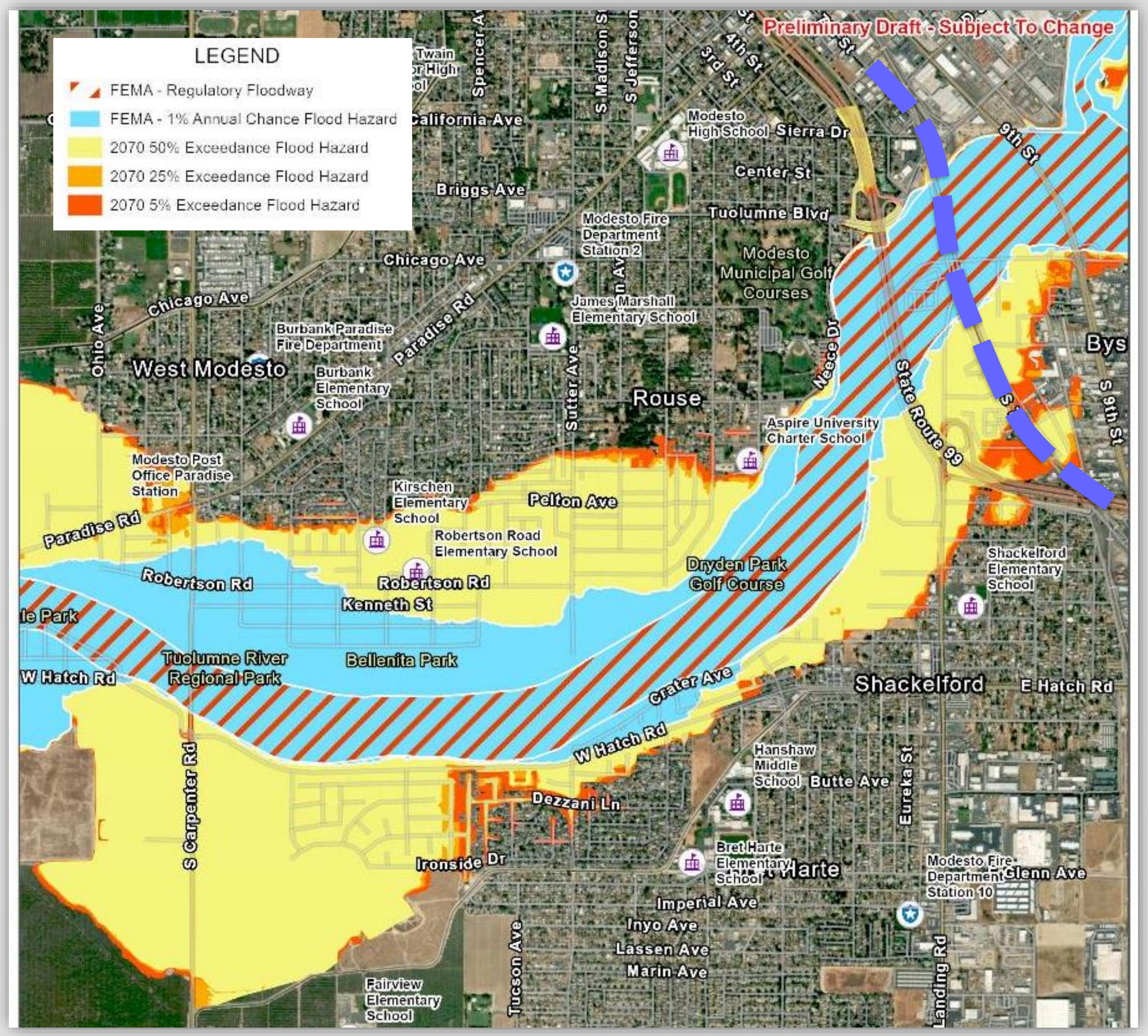
- Different sources of information (CVHS Vs. physical hydrological model run with observed temperature and precip) and period of record (1915-2011 Vs. 1915-2018)
- Very different climate change analytical approach (Top-down Vs. Bottom-up)

Flood Inundation Map

Developed Preliminary Inundation Maps for the Tuolumne River for Select Draft Climate Change Scenarios



Scenario	Planning Horizon	Levels of Concern
Current	2007	NA
Future Near-Term	2040	50%, 25%, 5%
Future Long-Term	2070	50%, 25%, 5%



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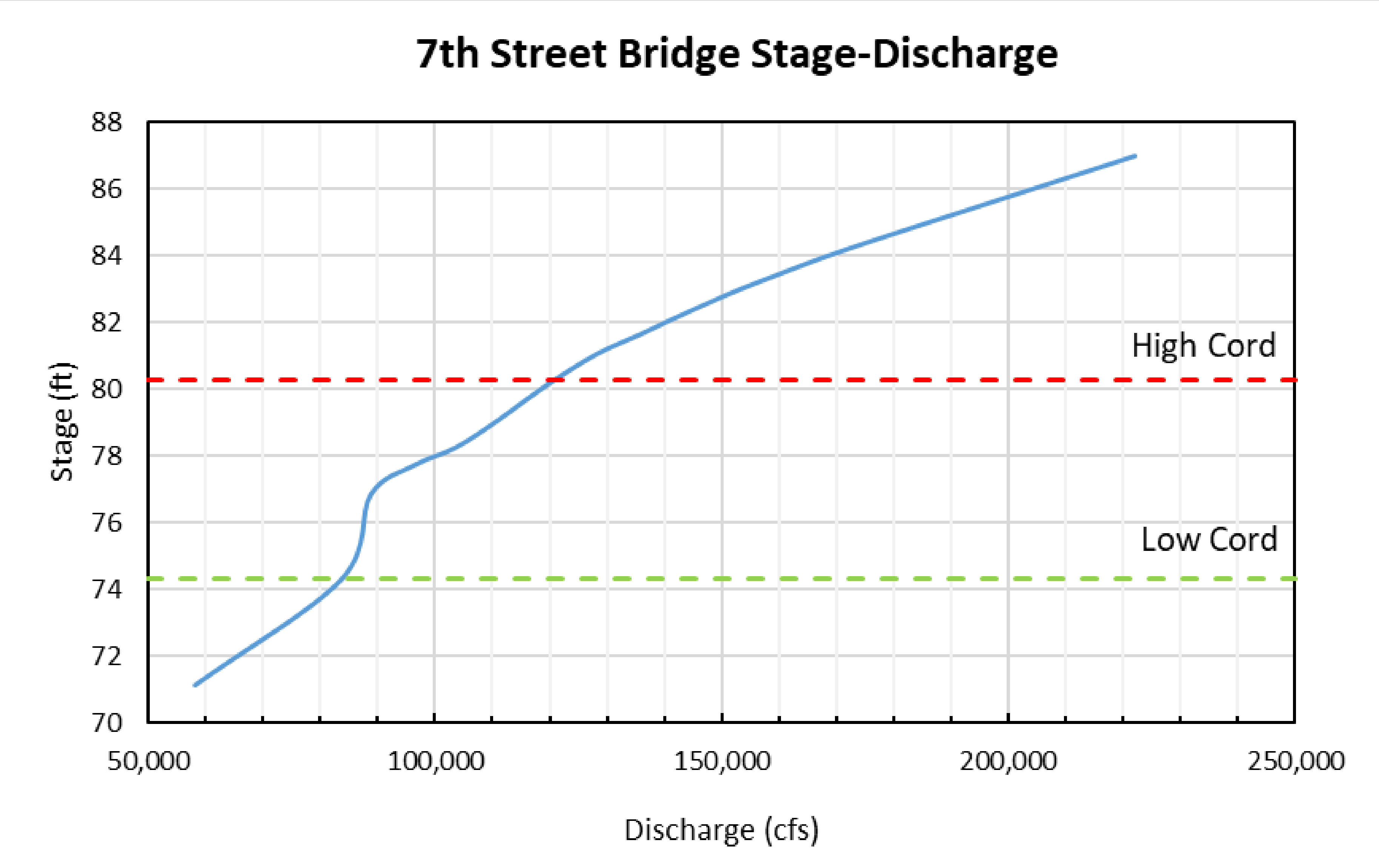
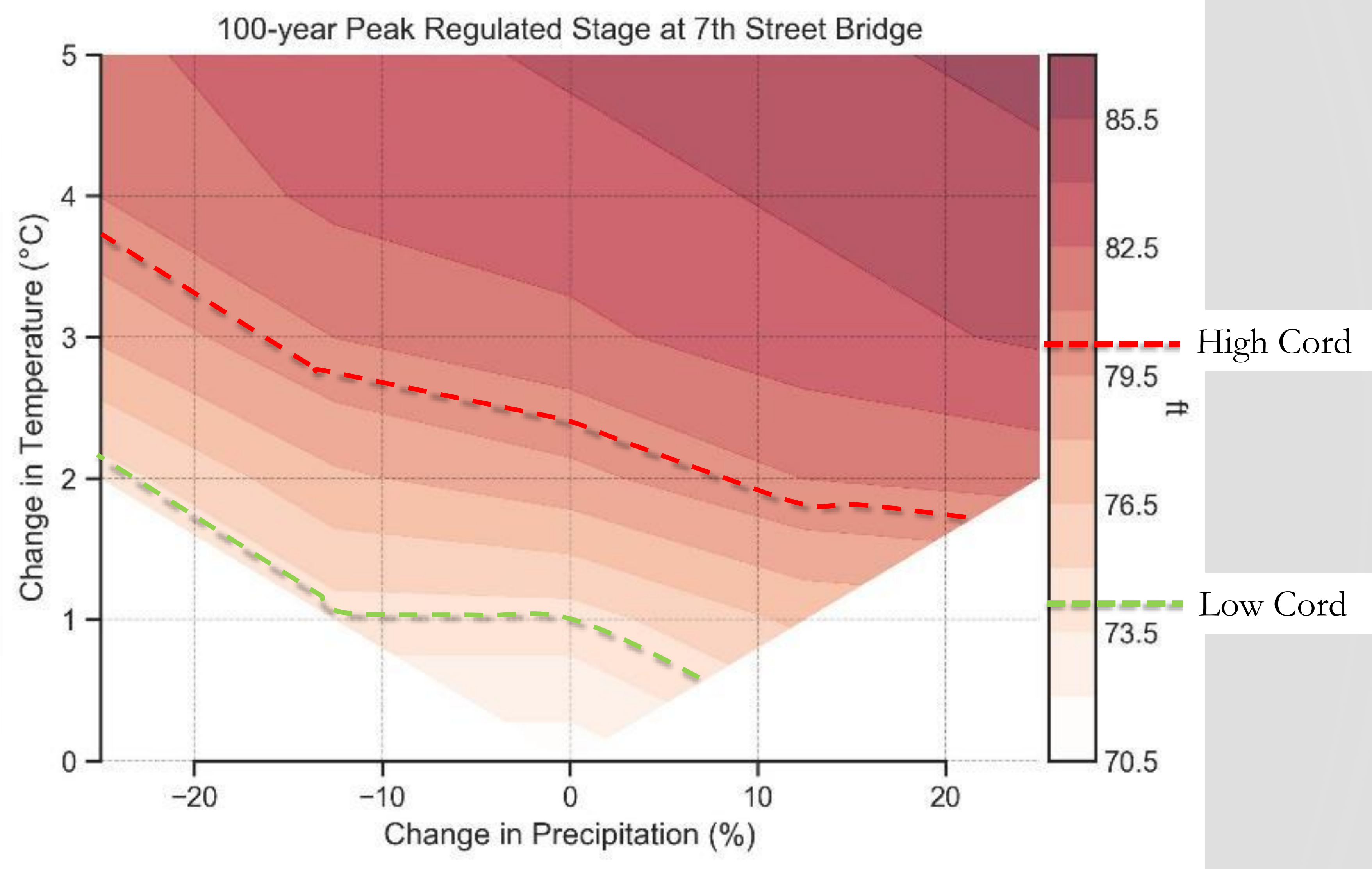
100-year Peak Regulated Stage at 7th Street Bridge





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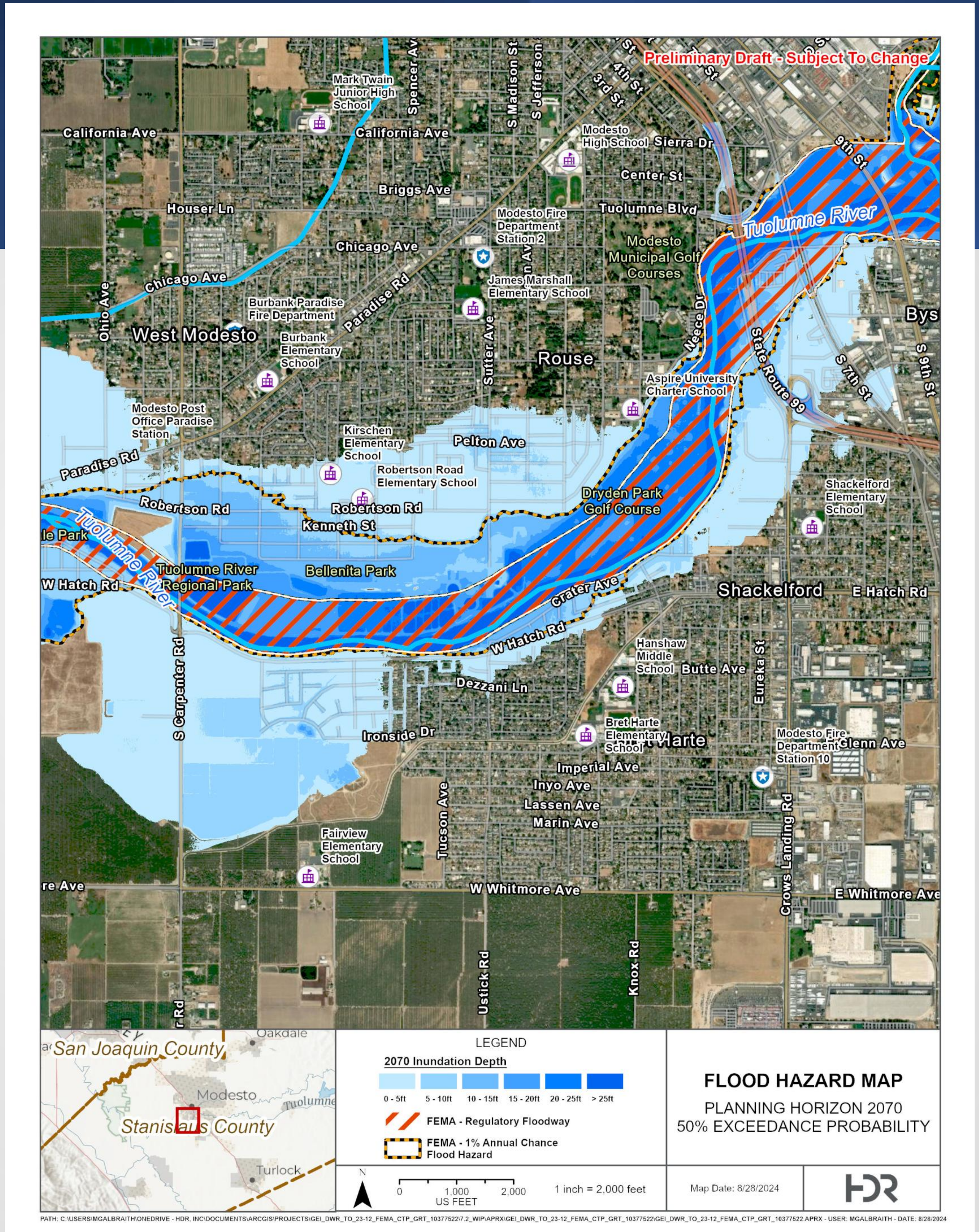
Flood Depth Map



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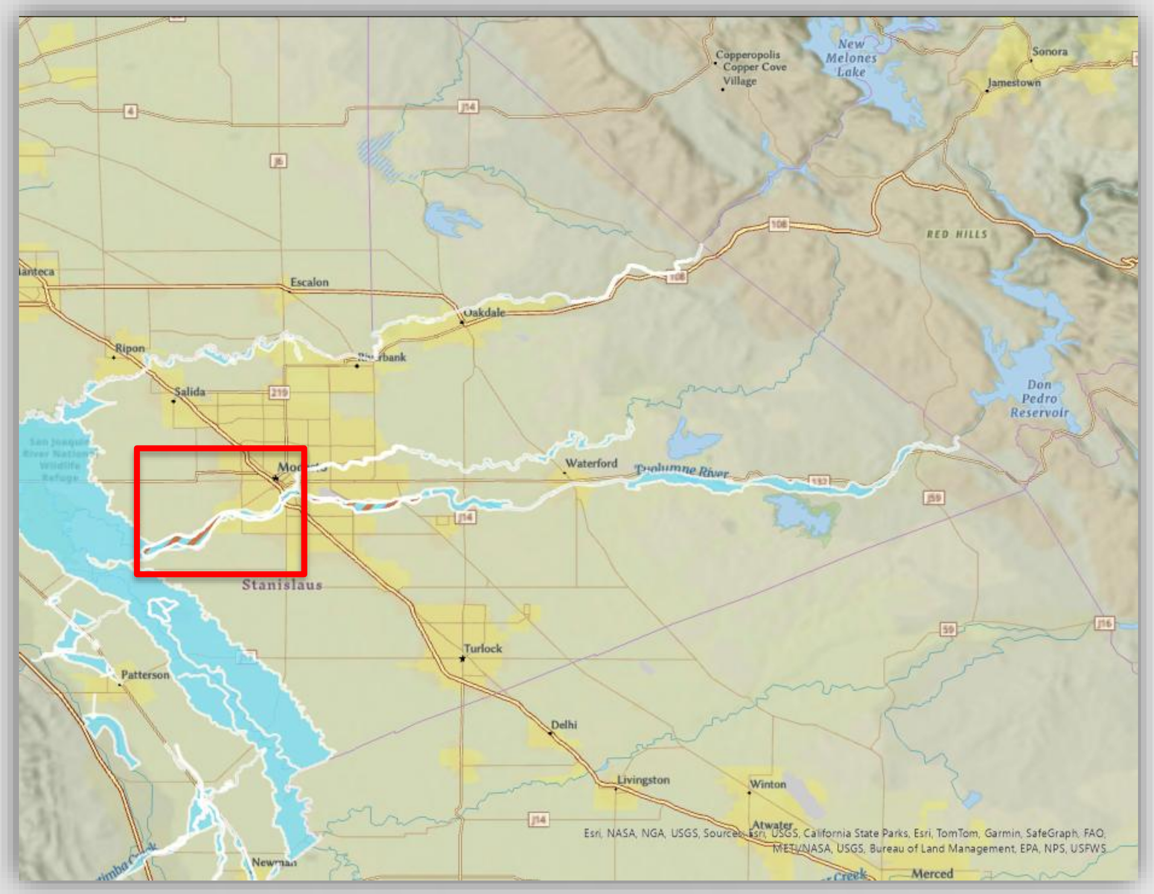
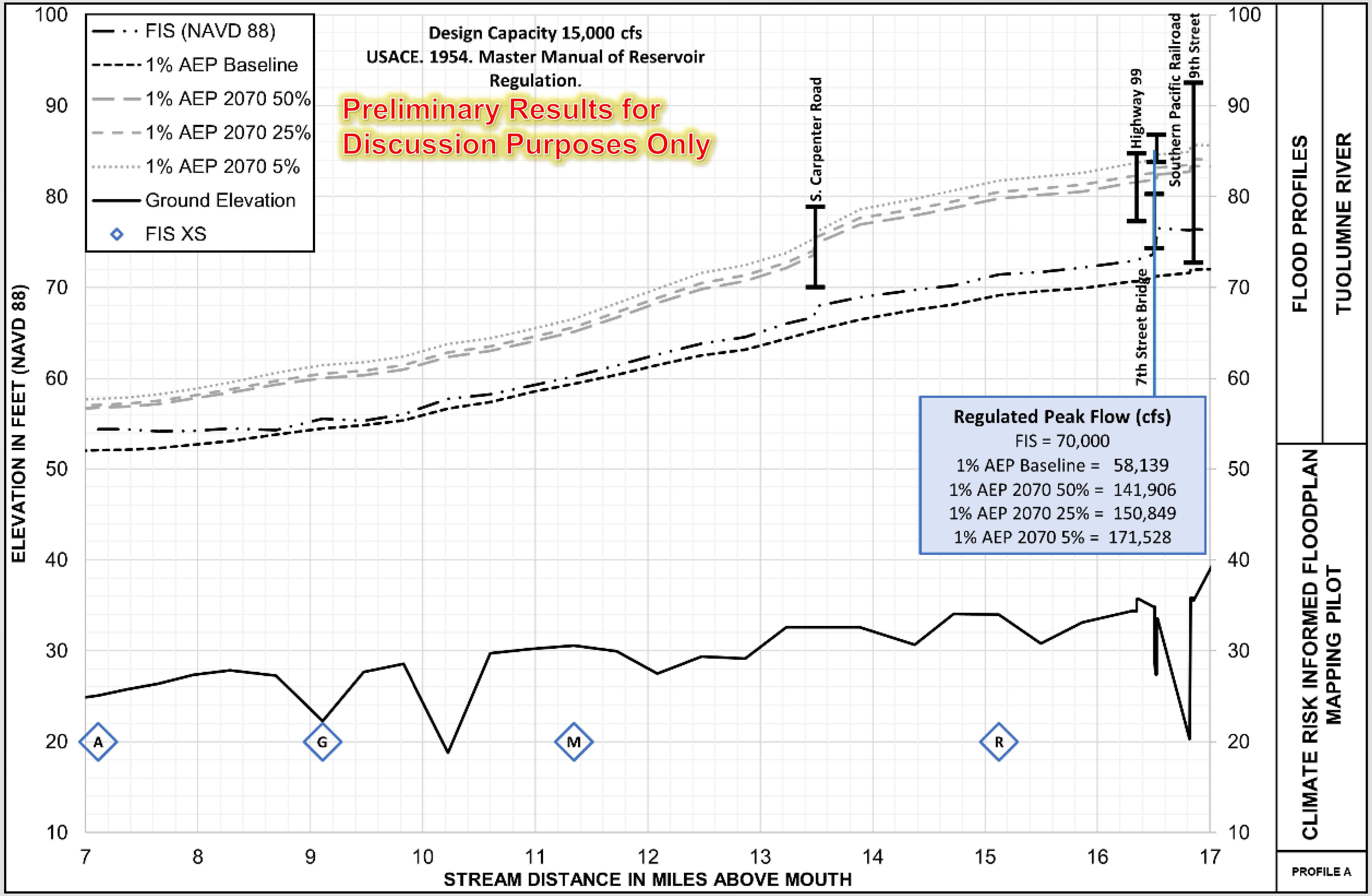
Flood Profiles





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Local Partners Engagement

Coordination Meetings

(with Community Partners)

Community Involvement

(with NGOs/RFMP)

FEMA Workshop

(with FEMA staff)

Community Partners

- City of Modesto
- Turlock Irrigation District
- Stanislaus County
- California Office of Emergency Services (OES)
- San Joaquin Area Flood Control (SJFCA)
- FEMA
- DWR
- USACE, Sacramento District

Questions?

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