Austin WATER | WATER FORWARD
INTEGRATED WATER RESOURCE PLAN

# "Hydrologic Modeling for Austin's Integrated Water Resource Plan"

Region K
August 29, 2018

# *Water Forward*
## Integrated Water Resource Plan (IWRP)

- Austin Water is leading interdepartmental effort in developing a 100 year water plan that reflects our community's values
- Council-appointed Task Force meets monthly
- Community outreach throughout the plan development process
- Plan to be completed in 2018 with updates on a five year cycle
- **Goal:** Ensure a diversified, sustainable, and resilient water future, with strong emphasis on water conservation

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# Drivers for Austin's IWRP

- 2007 - 2016 Extreme Drought
- Population Growth & Development
- Climate Change Impacts on Supply Reliability
- Alignment with Community Values

# Austin's Water Supply

- Colorado River and Highland Lakes
- Combination of state-granted water rights & long-term firm contract with Lower Colorado River Authority (325,000 acre-feet per year)
- Austin's municipal river diversions for 2017 were ~149k acre-feet

# IWRP Development Process

# Visit the Water Forward site for more info…

austintexas.gov/waterforward

## WATER FORWARD

Austin is one of the fastest growing cities in the country. With a rapidly growing city and a changing climate, Austin Water is working with other city departments, a Council-appointed citizen Task Force, and the community to develop a water plan for the next century.

The goal of the Water Forward plan is to ensure a diversified, sustainable, and resilient water future, with strong emphasis on water conservation. This plan will consider a range of strategies such as water conservation, water reuse, aquifer storage and recovery (ASR), and others.

## TOP CONTENT

- Water Restrictions
- Water Conservation
- Reclaimed Water Program
- Residential Customer Service
- Contact Information

## CONTACT INFO

Email

Sign up for E-Newsletter

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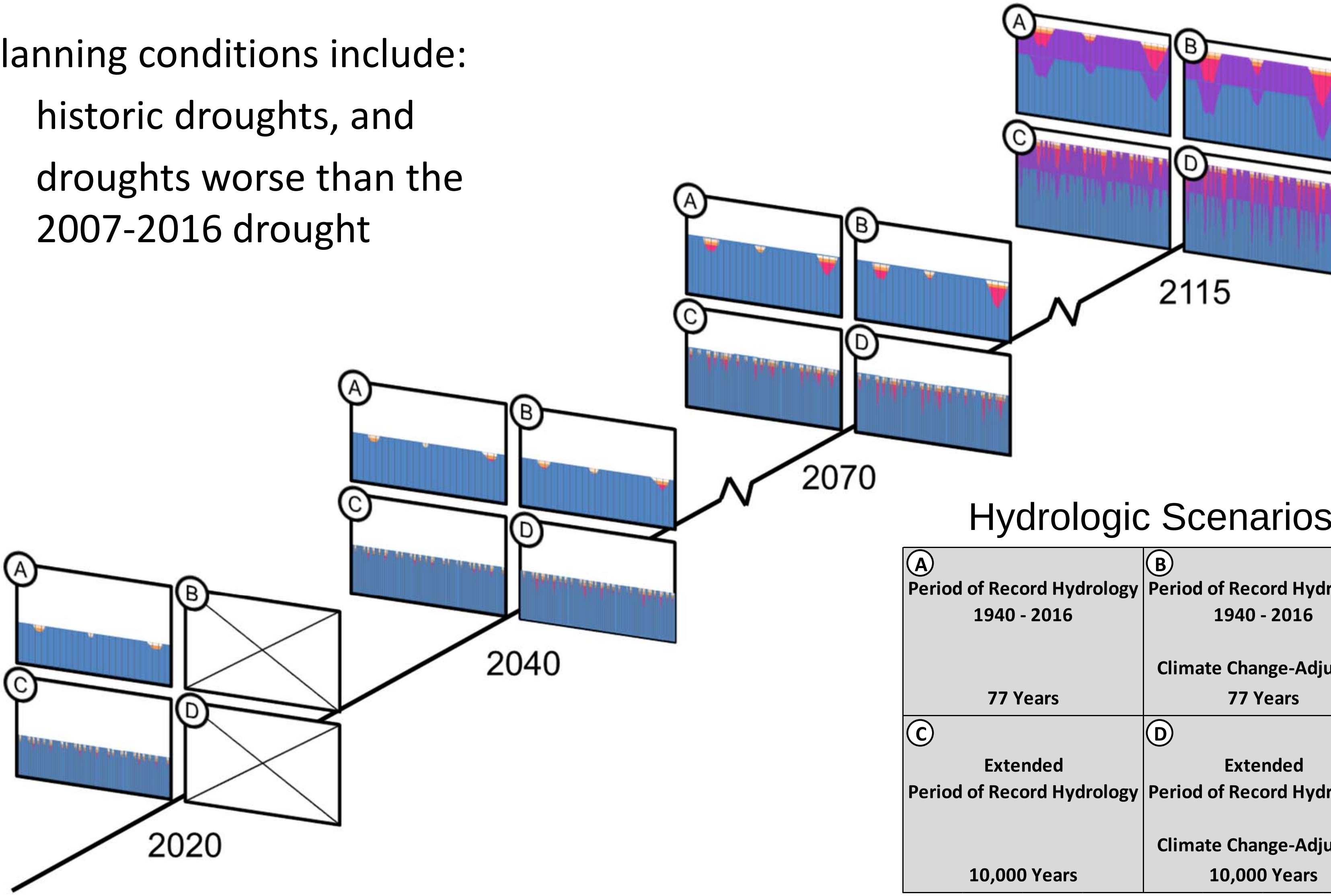
# Planning For Change and Uncertainties

Planning conditions include:

- historic droughts, and
- droughts worse than the 2007-2016 drought




## Hydrologic Scenarios

| | |
|---|---|
| (A) Period of Record Hydrology 1940 - 2016<br><br>77 Years | (B) Period of Record Hydrology 1940 - 2016<br><br>Climate Change-Adjusted<br>77 Years |
| (C) Extended Period of Record Hydrology<br><br>10,000 Years | (D) Extended Period of Record Hydrology<br><br>Climate Change-Adjusted<br>10,000 Years |

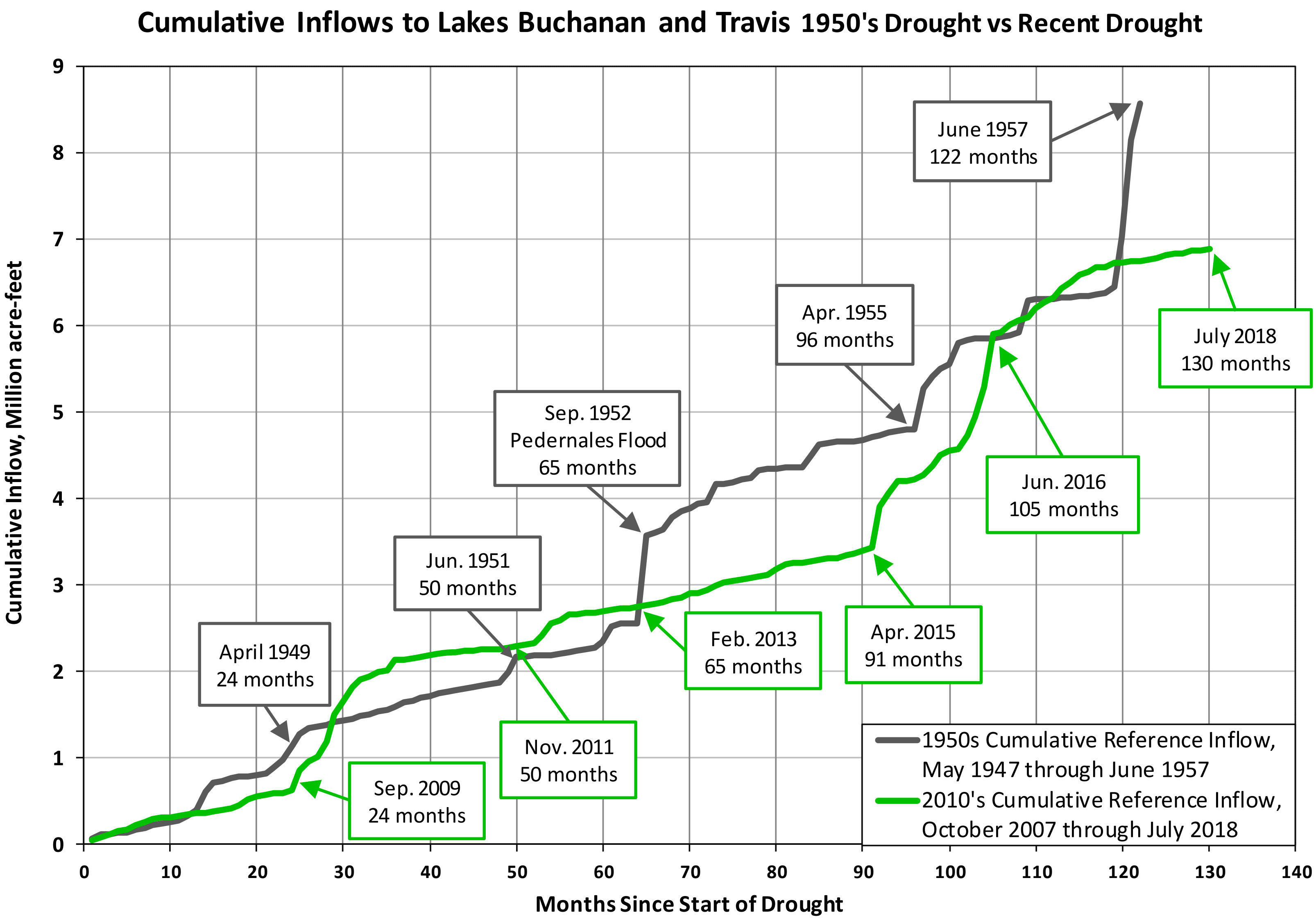

# CLIMATE IMPACTS ON WATER SUPPLY
# AN AUSTIN CASE STUDY

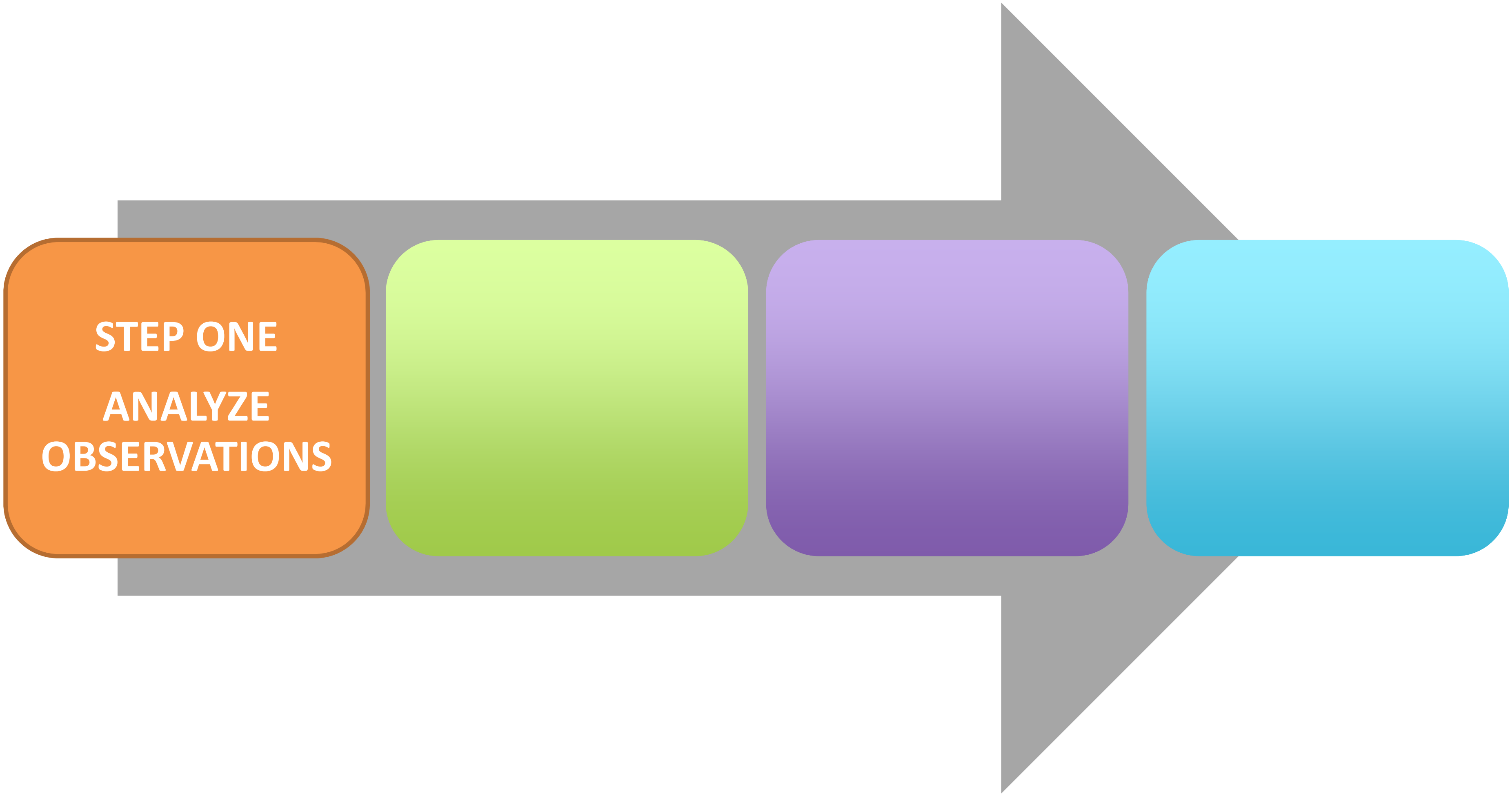
Marisa Flores-Gonzalez, Katharine Hayhoe, Richard Hoffpauir

# MOTIVATION

- Texas is already naturally at risk from regularly-occurring droughts and heavy rainfall events.
- The risks we face are not static: they are rising
- Every season in Texas has been warming since the 1950s
- Warmer temperatures accelerate evaporation and increase water vapor in the atmosphere
- **This exacerbates the duration & severity of droughts *and* increases the frequency of heavy rainfall events**

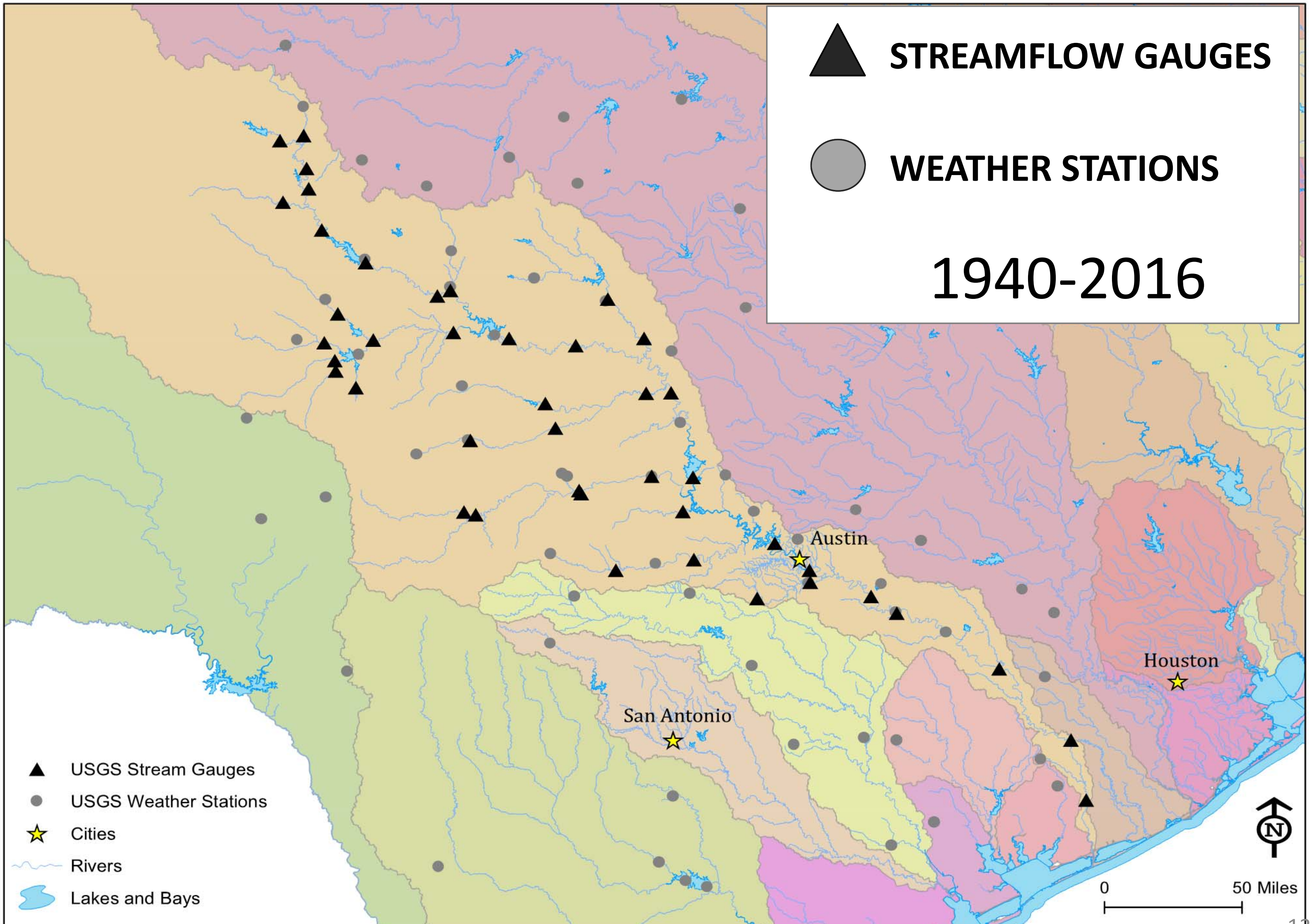
# Example: Recent Drought



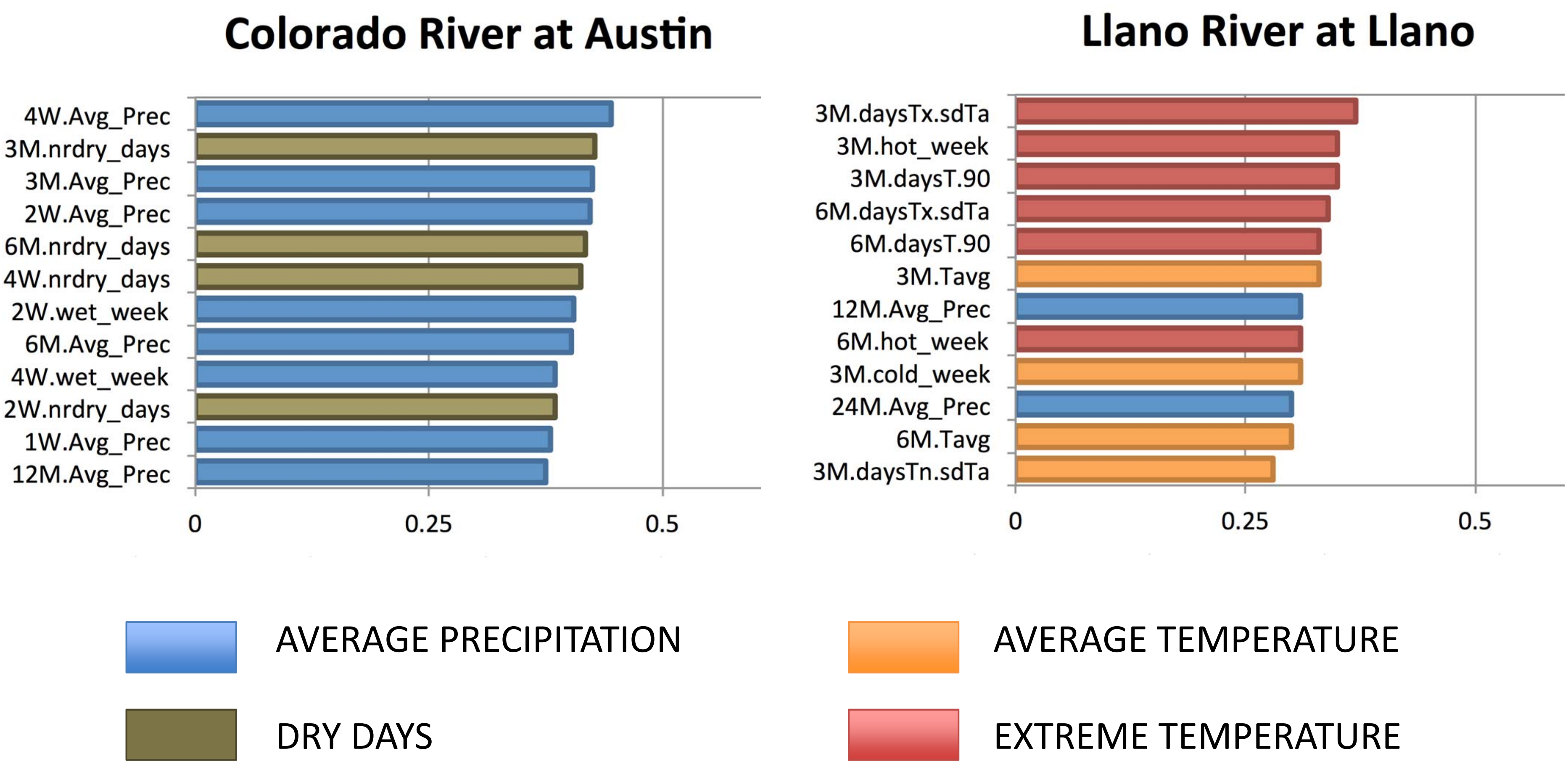

STEP ONE
ANALYZE OBSERVATIONS

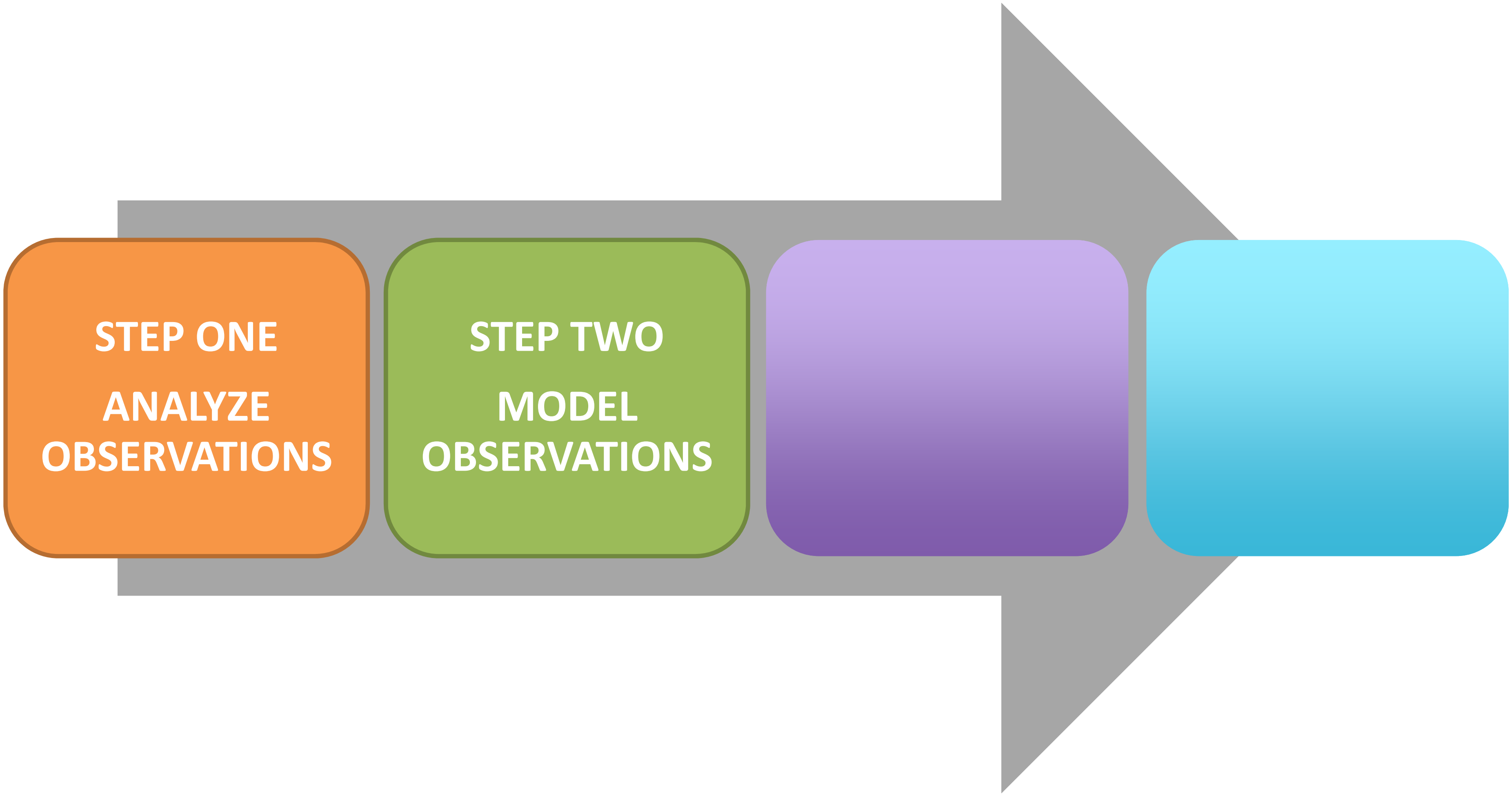
# HISTORICAL ANALYSIS

- Use daily temperature and precipitation to calculate **120 indicators** of average and extreme conditions over time scales ranging from 1 week to 24 months
- Quantify and evaluate **observed relationships** between climate predictors and hydrologic parameters at the selected gauges

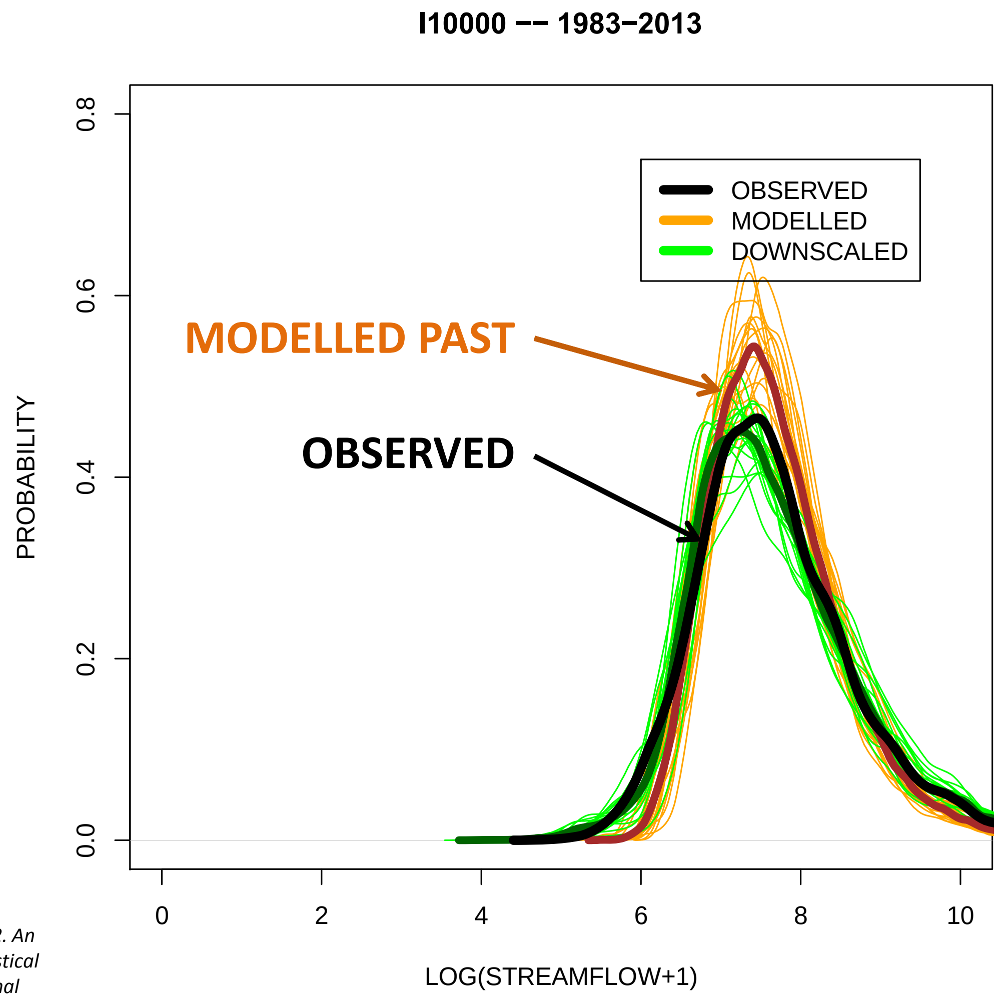

STREAMFLOW GAUGES
WEATHER STATIONS
1940-2016
Austin
Houston
San Antonio
USGS Stream Gauges
USGS Weather Stations
Cities
Rivers
Lakes and Bays
N
0
50 Miles

# TOP STREAMFLOW PREDICTORS

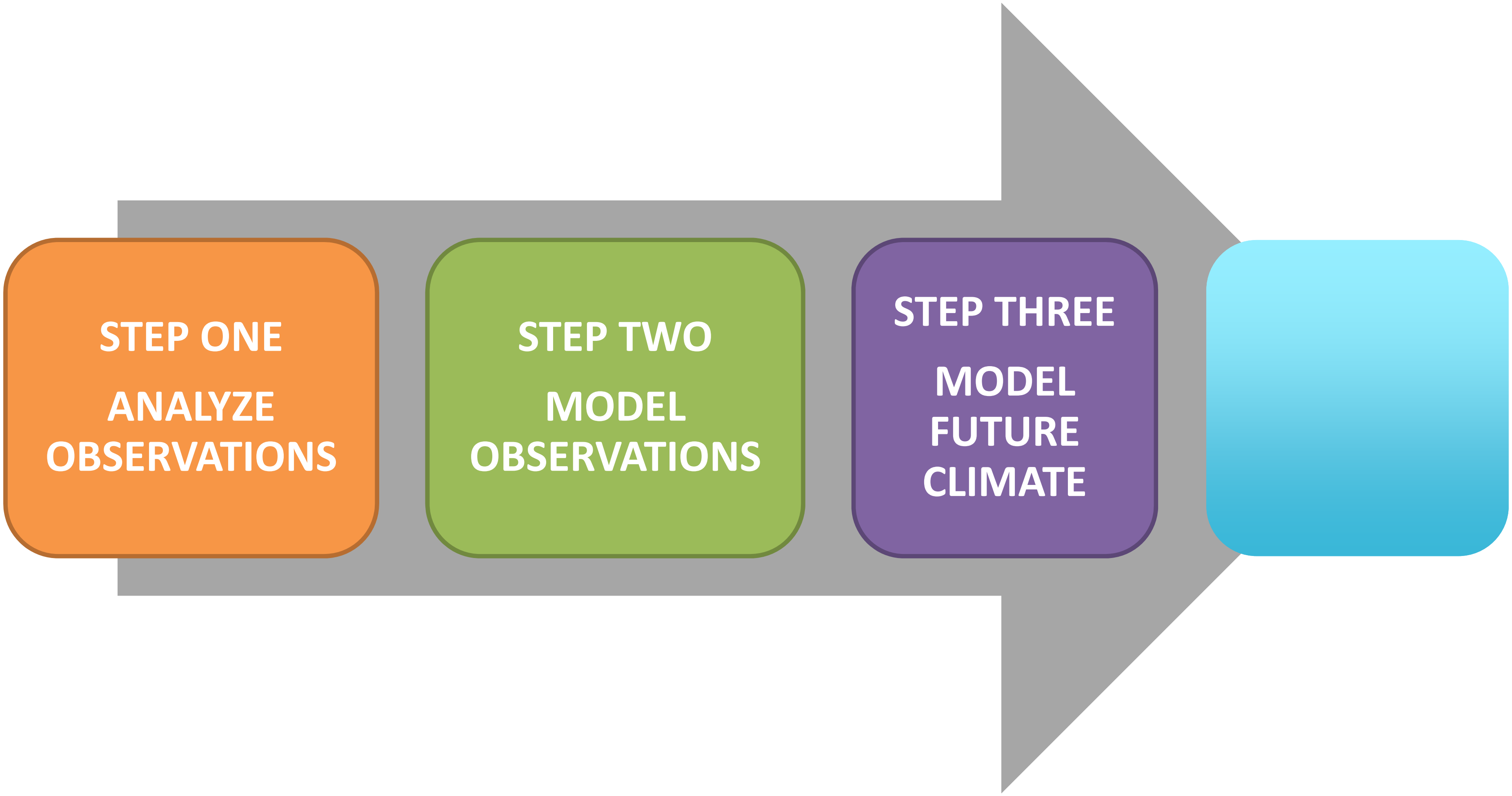



STEP ONE
ANALYZE OBSERVATIONS
STEP TWO
MODEL OBSERVATIONS

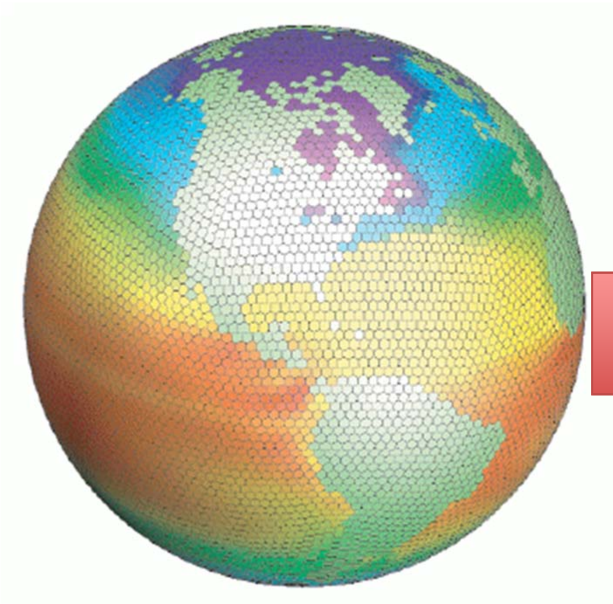
# COMPARING OBSERVED AND MODELED STREAMFLOW




*Regarding Downscaling Technique, See Also --*
*Stoner, A., Hayhoe, K., Yang, X., Wuebbles, D., 2012. An Asynchronous Regional Regression Model for Statistical Downscaling of Daily Climate Variables. International Journal of Climatology 33(11): 2473-2494.*


STEP ONE
ANALYZE OBSERVATIONS
STEP TWO
MODEL OBSERVATIONS
STEP THREE
MODEL FUTURE CLIMATE

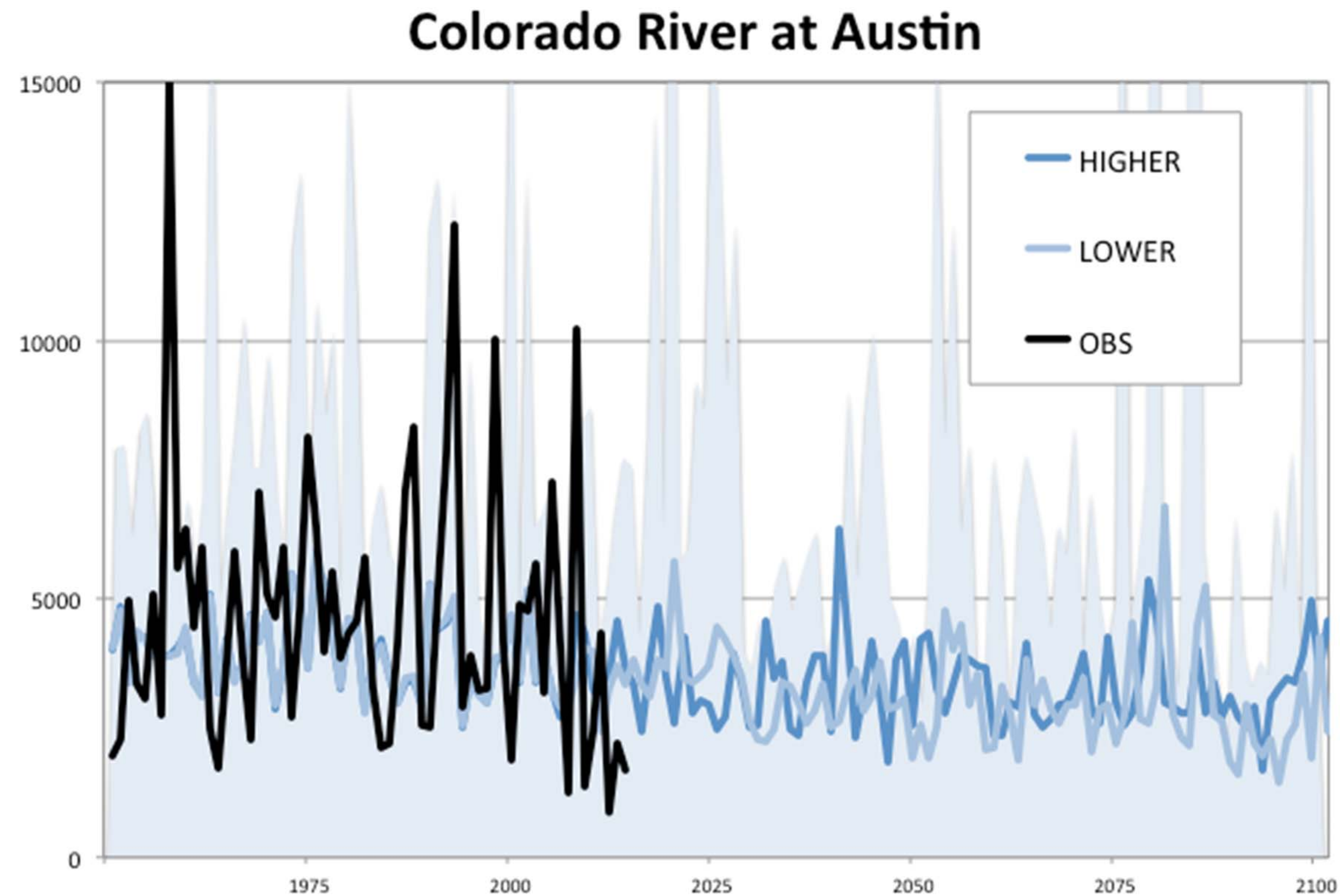
# GAUGE-SPECIFIC FUTURE PROJECTIONS



20 GLOBAL CLIMATE MODELS

OUR STREAMFLOW MODEL BASED ON HISTORICAL OBSERVATIONS


# ANNUAL AVERAGE STREAMFLOW



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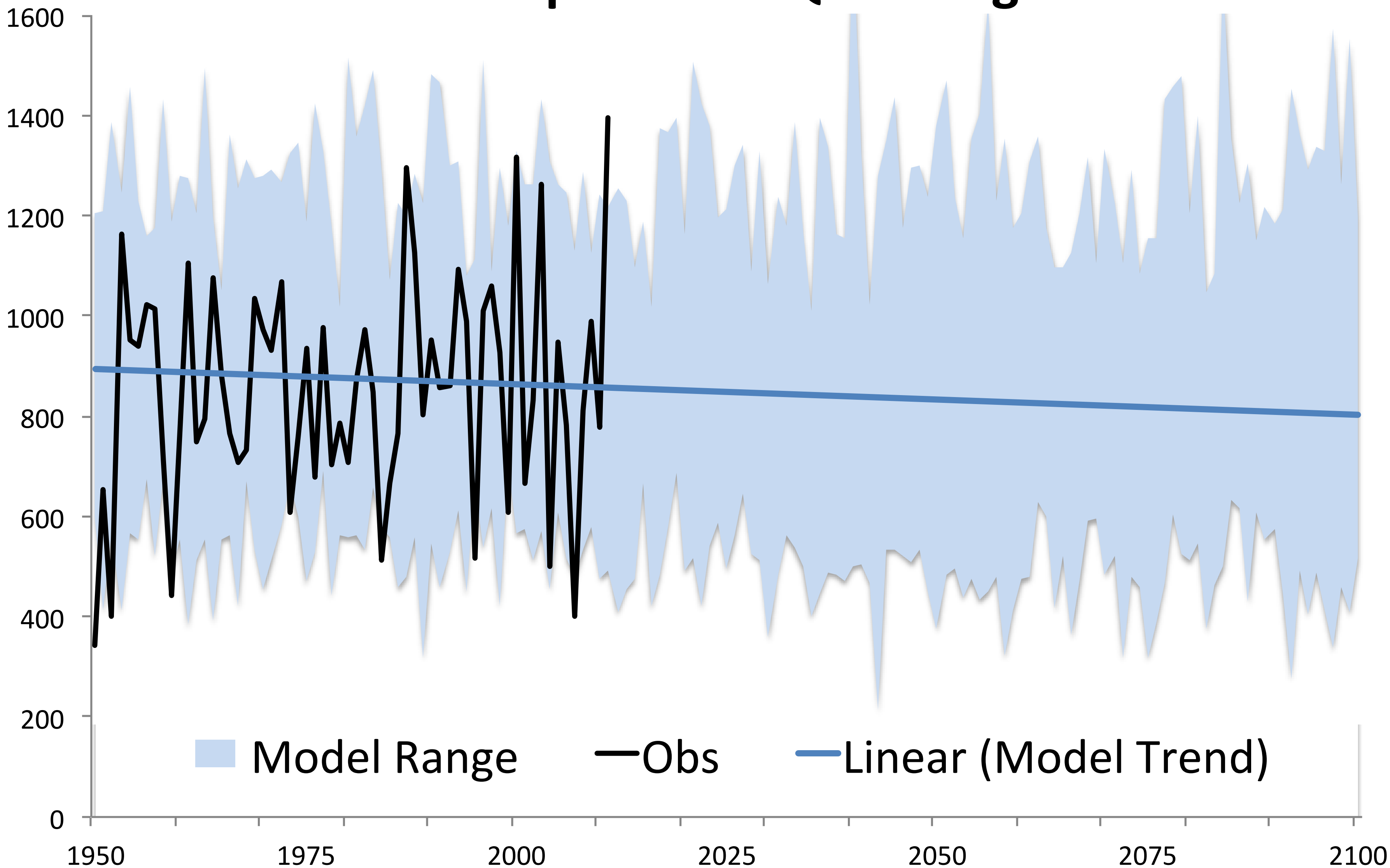
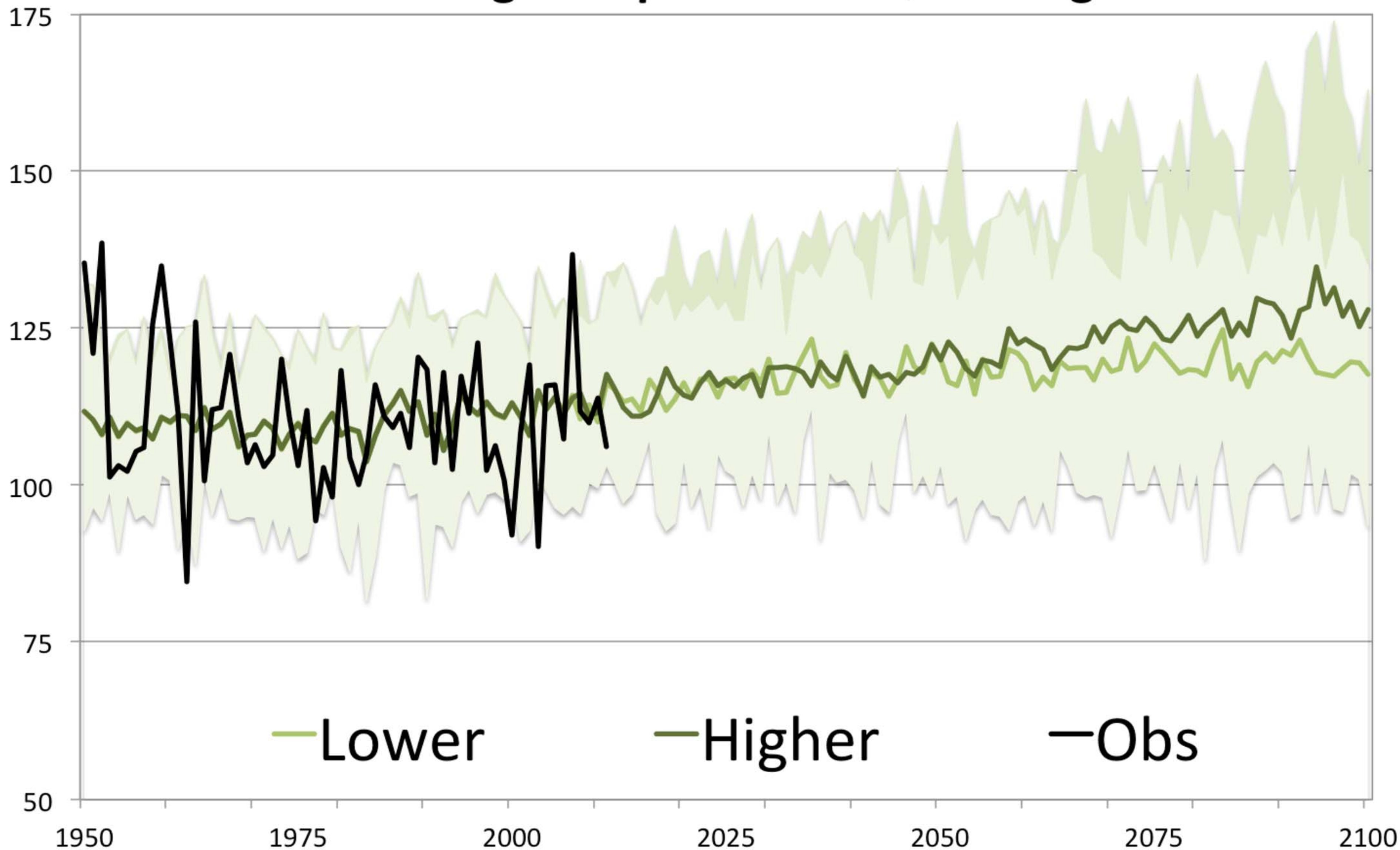
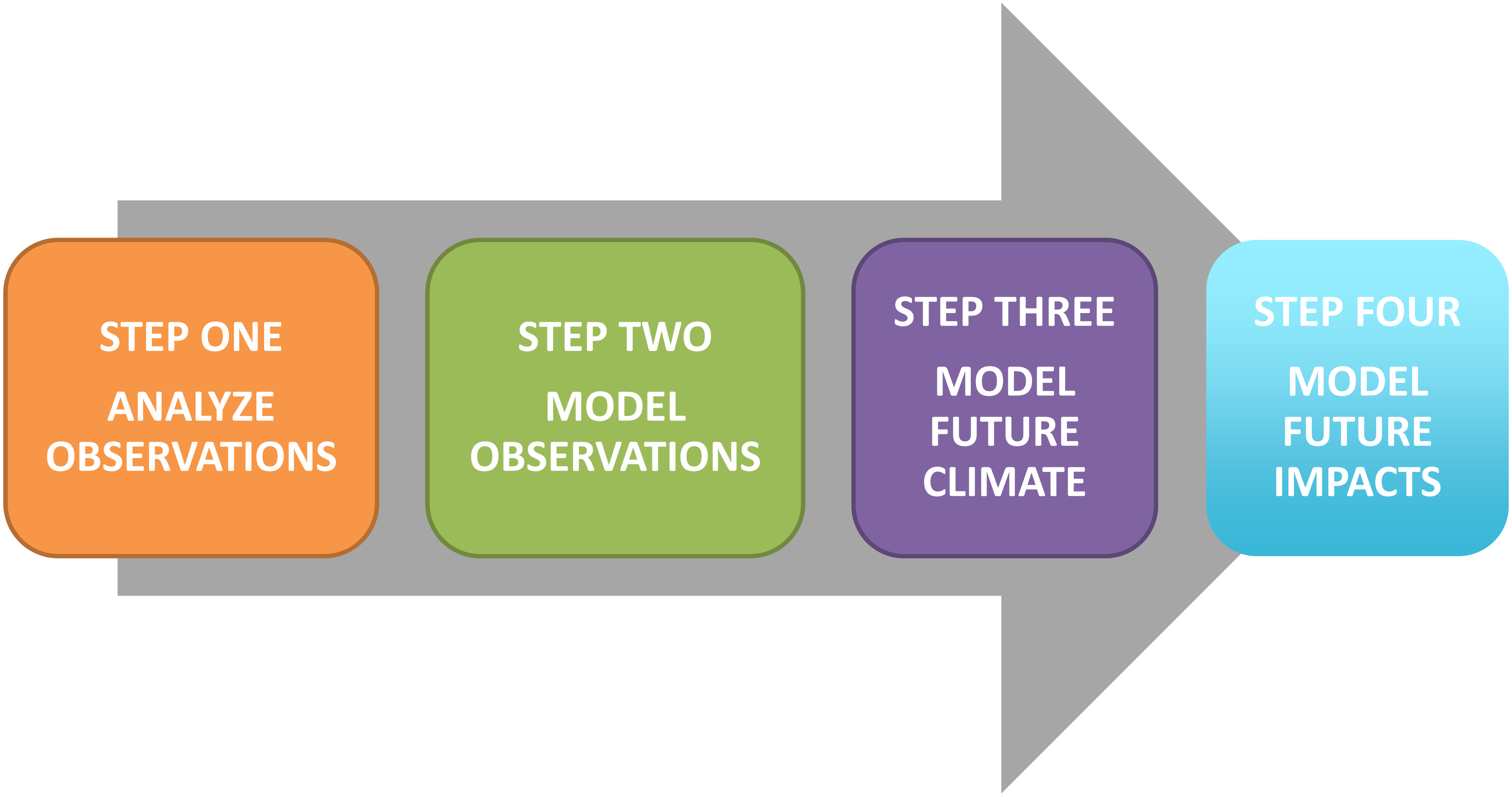
# Annual Precipitation - Quadrangle 710




Historical Texas precipitation and evaporation data available at:
http://www.twdb.texas.gov/surfacewater/conditions/evaporation/index.asp

# Annual Average Evaporation - Quadrangle 710




STEP ONE
ANALYZE OBSERVATIONS
STEP TWO
MODEL OBSERVATIONS
STEP THREE
MODEL FUTURE CLIMATE
STEP FOUR
MODEL FUTURE IMPACTS

# FROM SCIENCE TO APPLICATION

## GETTING FUTURE CLIMATE TRENDS INTO THE WAM

# What is a WAM?

A water availability model (WAM) is a computer modeling system that:

- Represents all existing water rights in the basin with a fixed set of management conditions,
- Simulates the water rights through a sequence of hydrologic conditions,
- Determines the amount of water that would be available to the rights under those hydrologic and management conditions.
- *https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html*

# Water Forward WAM Hydrologic Data

- Existing period of record naturalized flows and net evaporation-precipitation (77 years)

- Hydrology derived from 20 global climate models (GCMs) through year 2100 climate conditions.

- <u>**Goals**</u>: Generate WAM hydrologic inputs to reflect future climate trends and select candidate drought worse than the drought of record (DWDR) events.

# Water Forward WAM Modeling

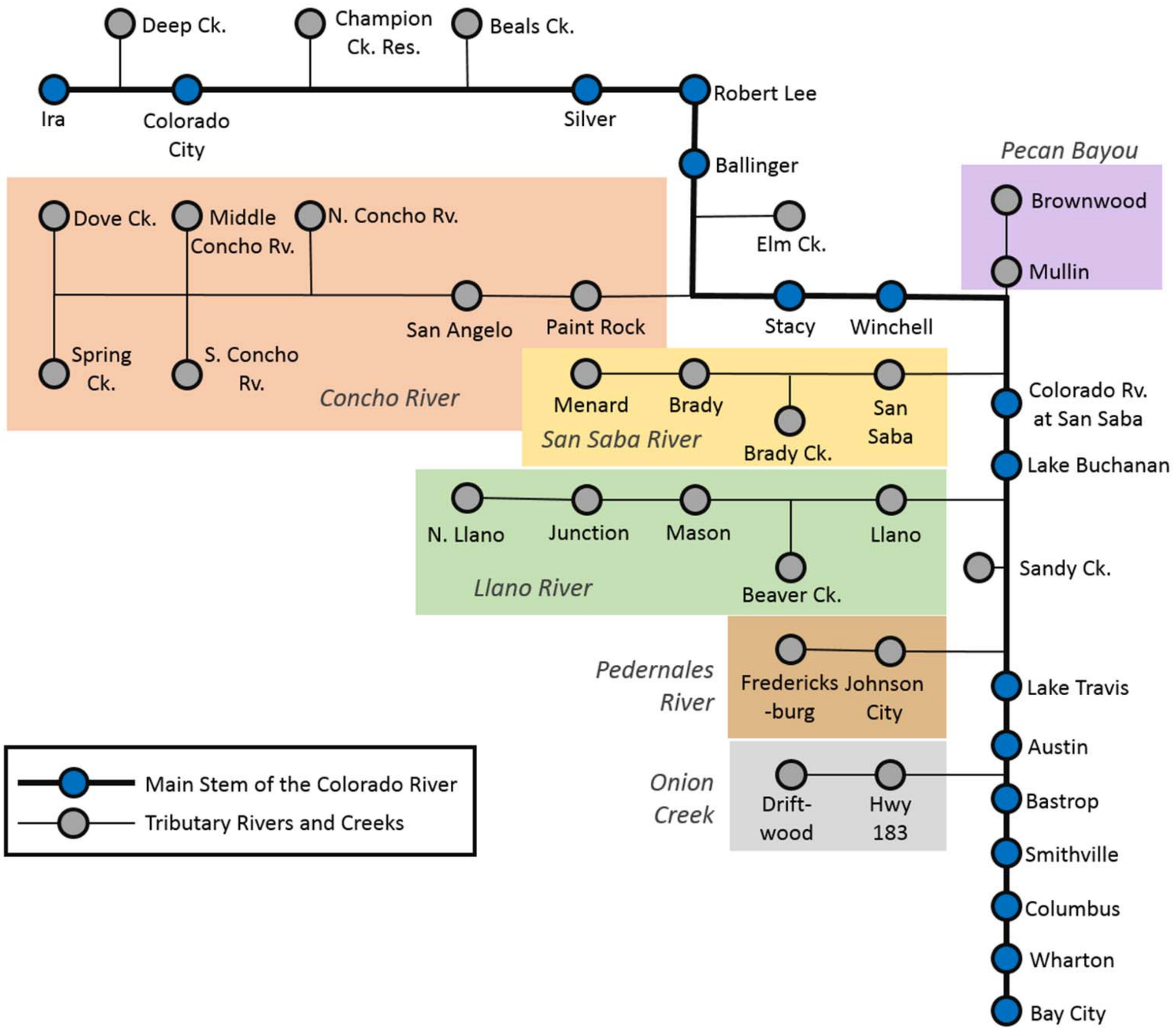
Perform water availability simulations for
4 different future demand projection horizons
with different hydrologic scenarios

| Demand Projection Years |
|---|
| 2020 |
| 2040 |
| 2070 |
| 2115 |

**X**

| | Observed Historical Hydrology, No Adjustment | Future Climate Adjusted Hydrology |
|---|---|---|
| **Results for Drought of Record** | 77 Years of Observed Historical Hydrology, 1940 – 2016 | 77 Years of Future Climate Adjusted Hydrology |
| **Results for Droughts Worse than the Drought of Record** | Stochastically Sampled Observed Historical Hydrology | Stochastically Sampled Future Climate Adjusted Hydrology |

# Colorado WAM Stream Gauges (primary CP's)



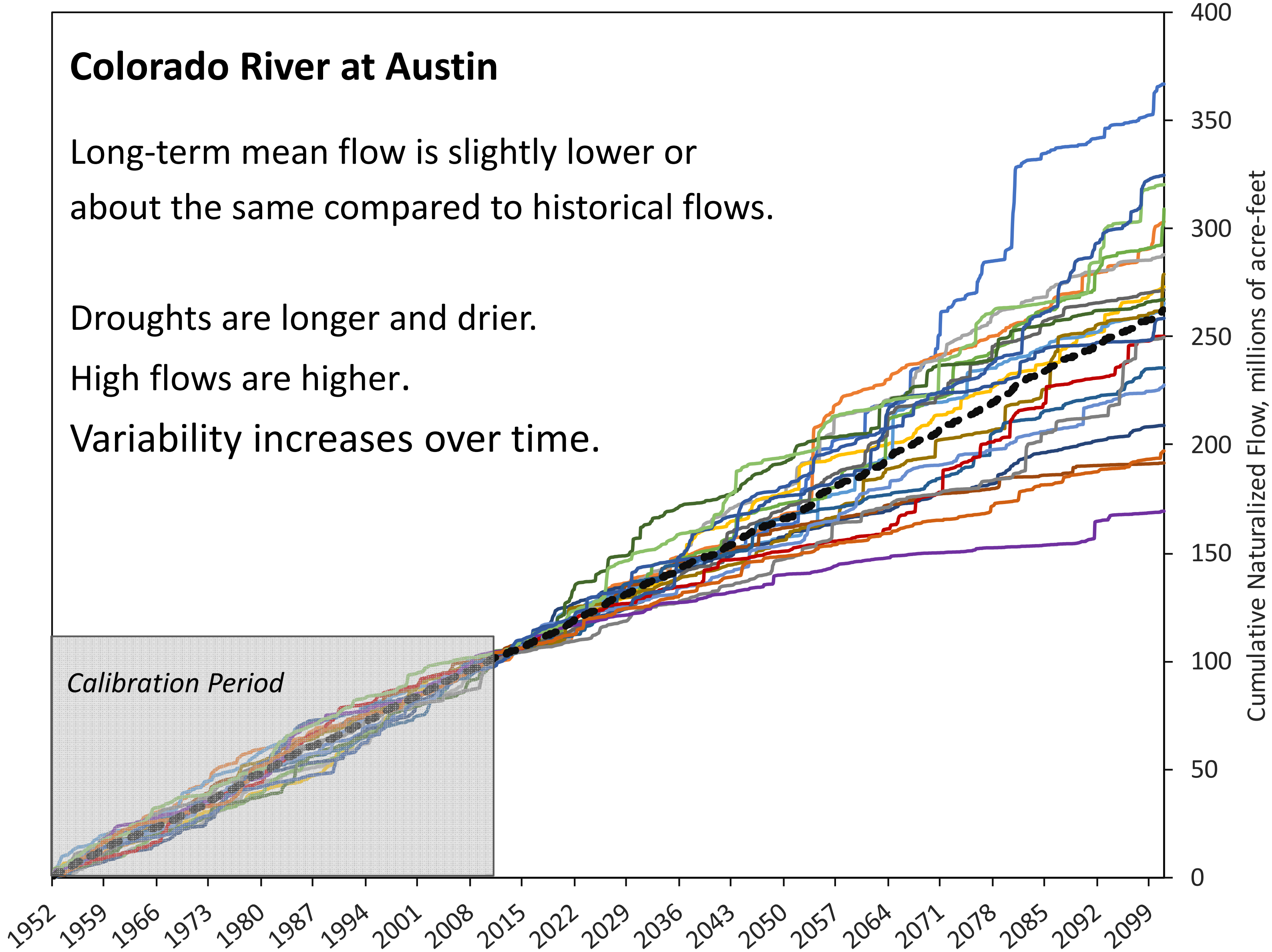

43 naturalized flow primary control points

48 net evap-precip (not shown here)

# Hydrology from Climate Models

- 20 climate models with climate trend on a current trajectory (RCP 8.5 scenario)
- Monthly time series from 1952 through 2100 derived from each of the 20 climate models.
  - 43 streamflow gauges
  - 20 quadrangles of precipitation and evaporation used to calculate net evap-precip at 48 locations
- Hydrology from climate models changes from 1952 through 2100 as the climate warms

# Naturalized Flow Results from 20 Climate Models



# Consolidating Hydrology Derived from Climate Models

- Demand projections represent future snapshots in time. The simulated hydrologic conditions should match the same snapshots in time.

- Create one additional hydrologic data set per demand horizon beyond 2020 with adjustment for future climate conditions.

- 2020 demand vs. Historical Hydrology
- 2040 demand vs. Historical & 2040 Climate Adjusted Hydrology
- 2070 demand vs. Historical & 2070 Climate Adjusted Hydrology
- 2115 demand vs. Historical & 2100 Climate Adjusted Hydrology

- *7 WAM simulations in total*

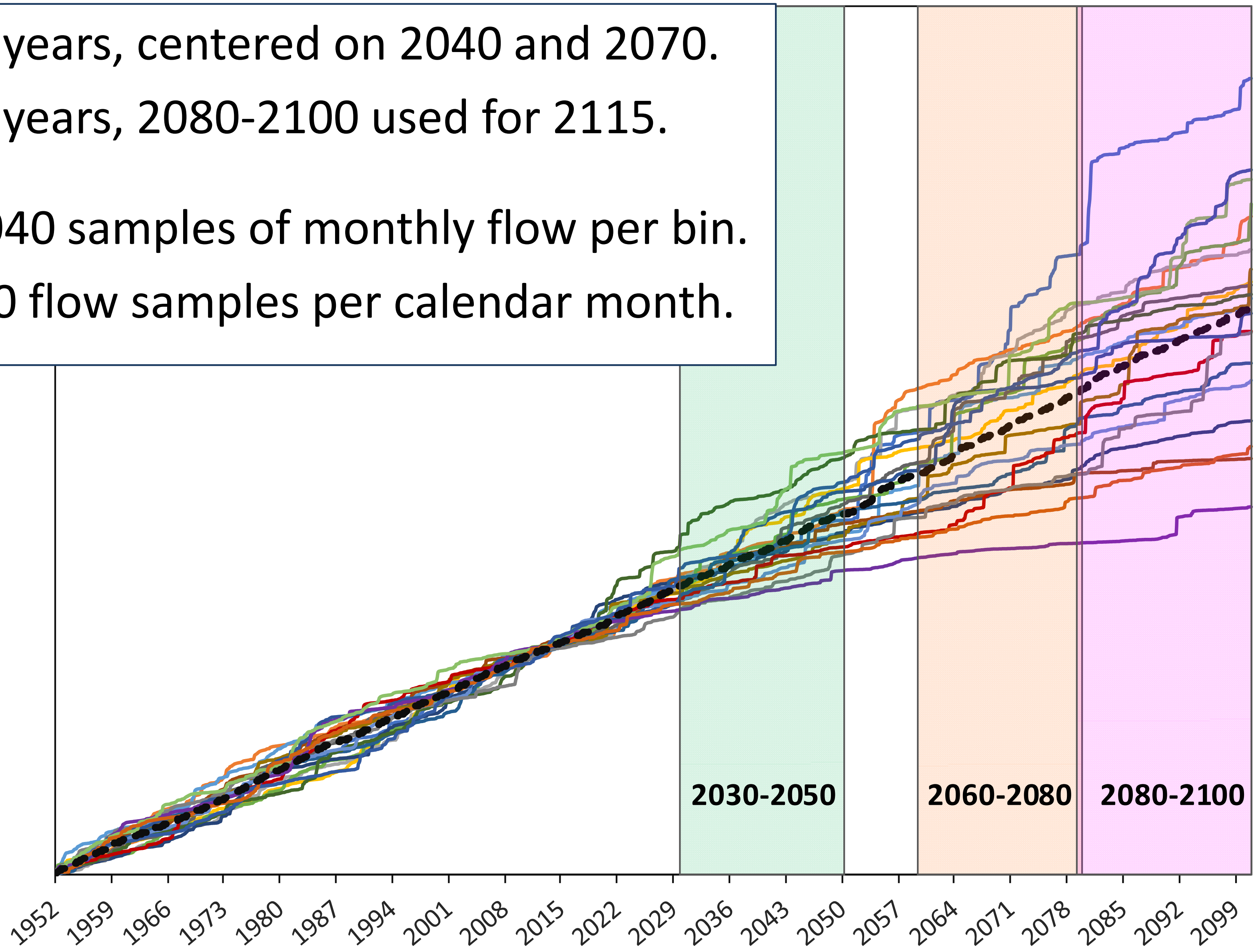
# Example of Bins for 20 Streamflow Models of Future Climate

21 years, centered on 2040 and 2070.

21 years, 2080-2100 used for 2115.

5,040 samples of monthly flow per bin.

420 flow samples per calendar month.



# Consolidation Process

- Use an **ensemble** of 20 climate model results to adjust the WAM's historical hydrologic data.
- Bin the 20 results around 2040, 2070, and **2100**.
- Adjust 1940-2016 WAM historical hydrology to reflect the range of hydrology in the ensemble/bins of 20 climate model results.
- Month-by-month adjustments of WAM historical hydrology at each control point.
- "Quantile Mapping"

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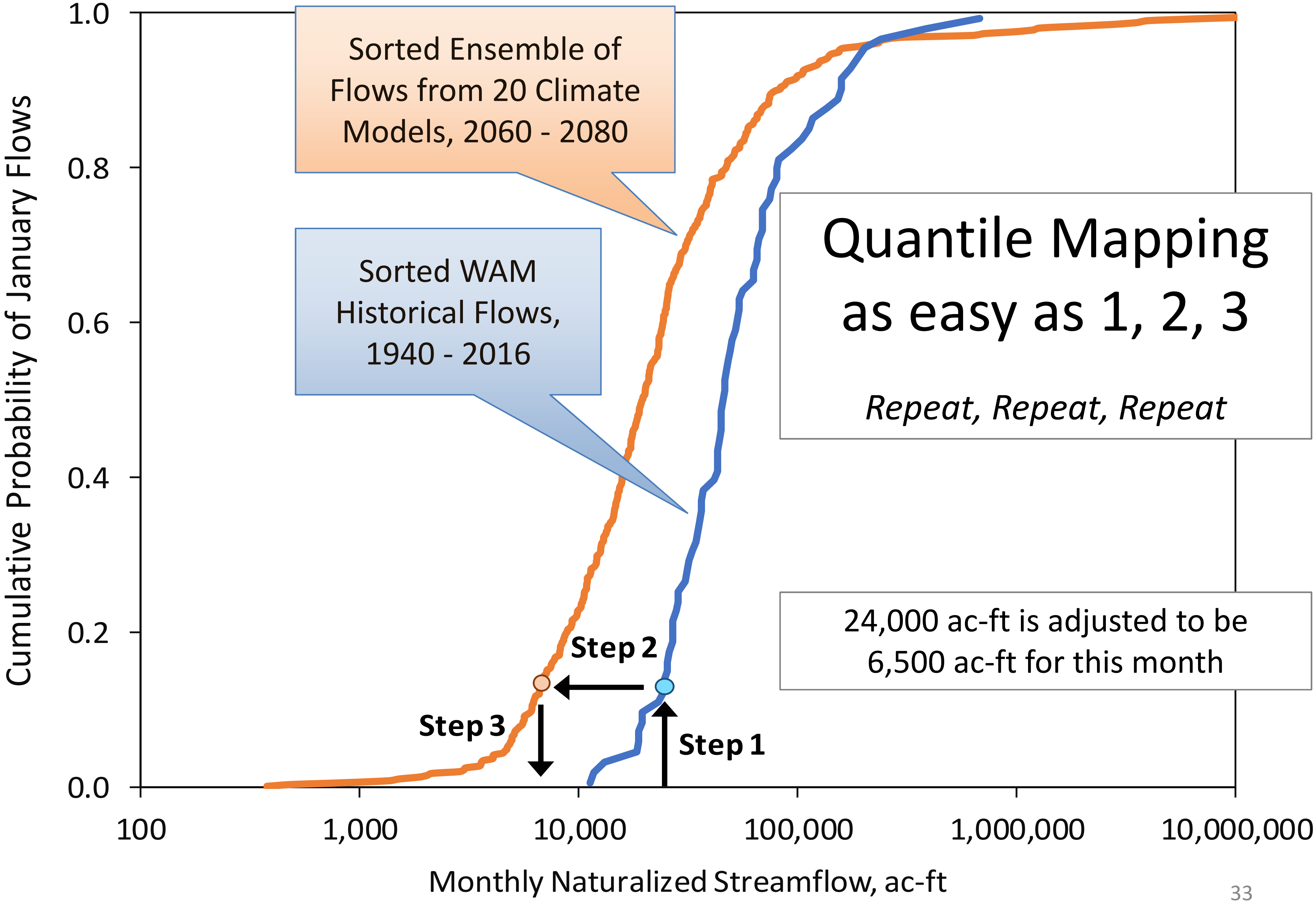
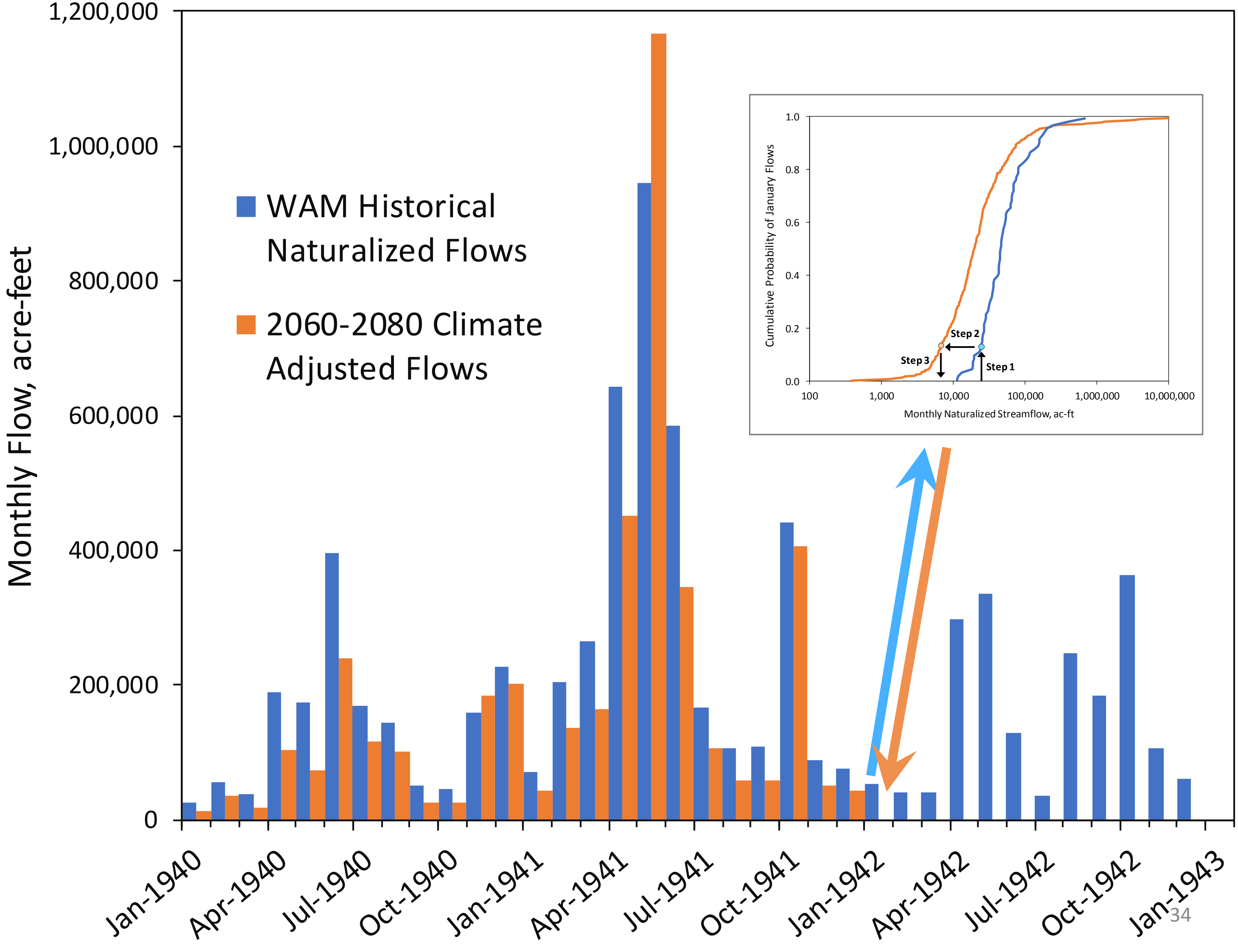





*For Another Application of Quantile Mapping, See also -- California Department of Water Resources. 2013. Bay Delta Conservation Plan. Appendix 5.A.2. November 2013.*


1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Monthly Flow, acre-feet
WAM Historical Naturalized Flows
2060-2080 Climate Adjusted Flows
Jan-1940
Apr-1940
Jul-1940
Oct-1940
Jan-1941
Apr-1941
Jul-1941
Oct-1941
Jan-1942
Apr-1942
Jul-1942
Oct-1942
Jan-1943
Cumulative Probability of January Flows
1.0
0.8
0.6
0.4
0.2
0.0
Step 1
Step 2
Step 3
100
1,000
10,000
100,000
1,000,000
10,000,000
Monthly Naturalized Streamflow, ac-ft

# Historical and Adjusted WAM Naturalized Flows for Austin's IWRP

## 77 Years, 1940 - 2016

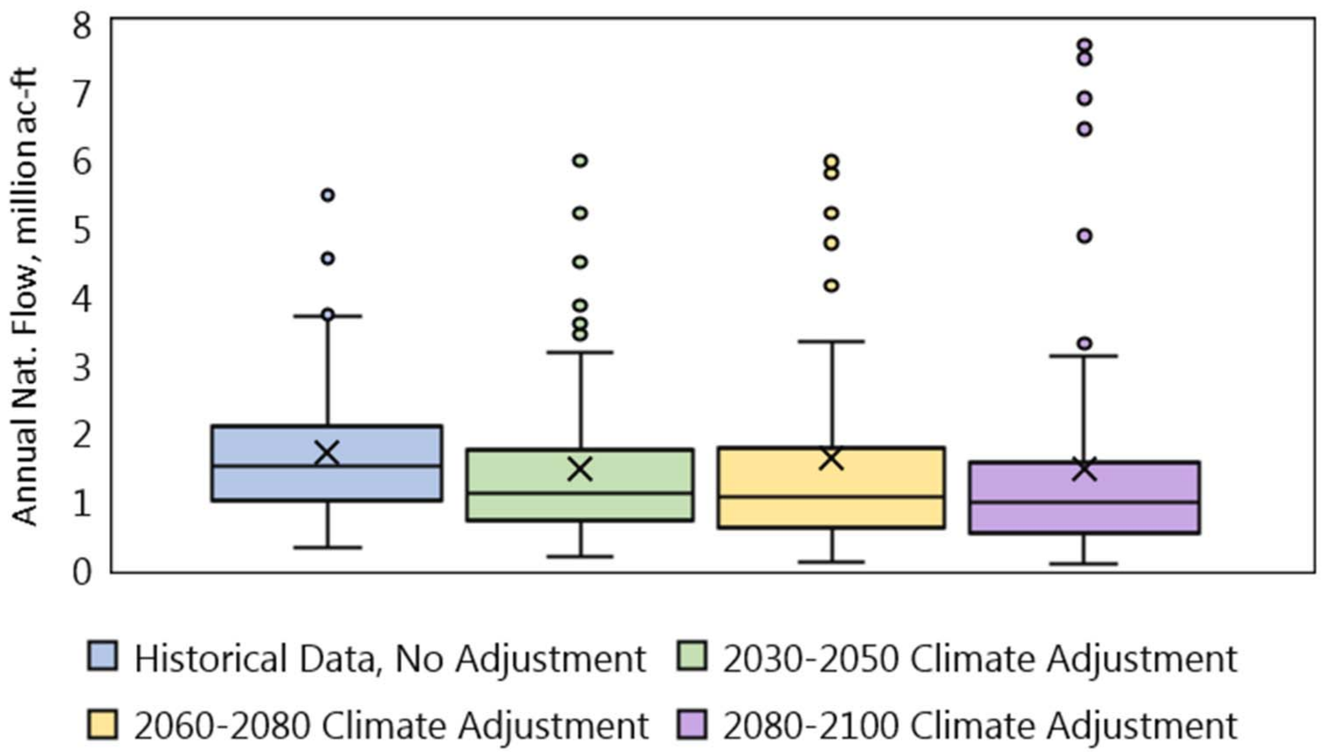
### Colorado River at Austin

Long-term mean flow is the same to slightly lower depending on the group of future conditions.

Droughts are longer and drier.

High flows are higher.

Variability increases with future conditions.



# Historical and Adjusted WAM Naturalized Flows for Austin's IWRP

## 77 Years, 1940 - 2016

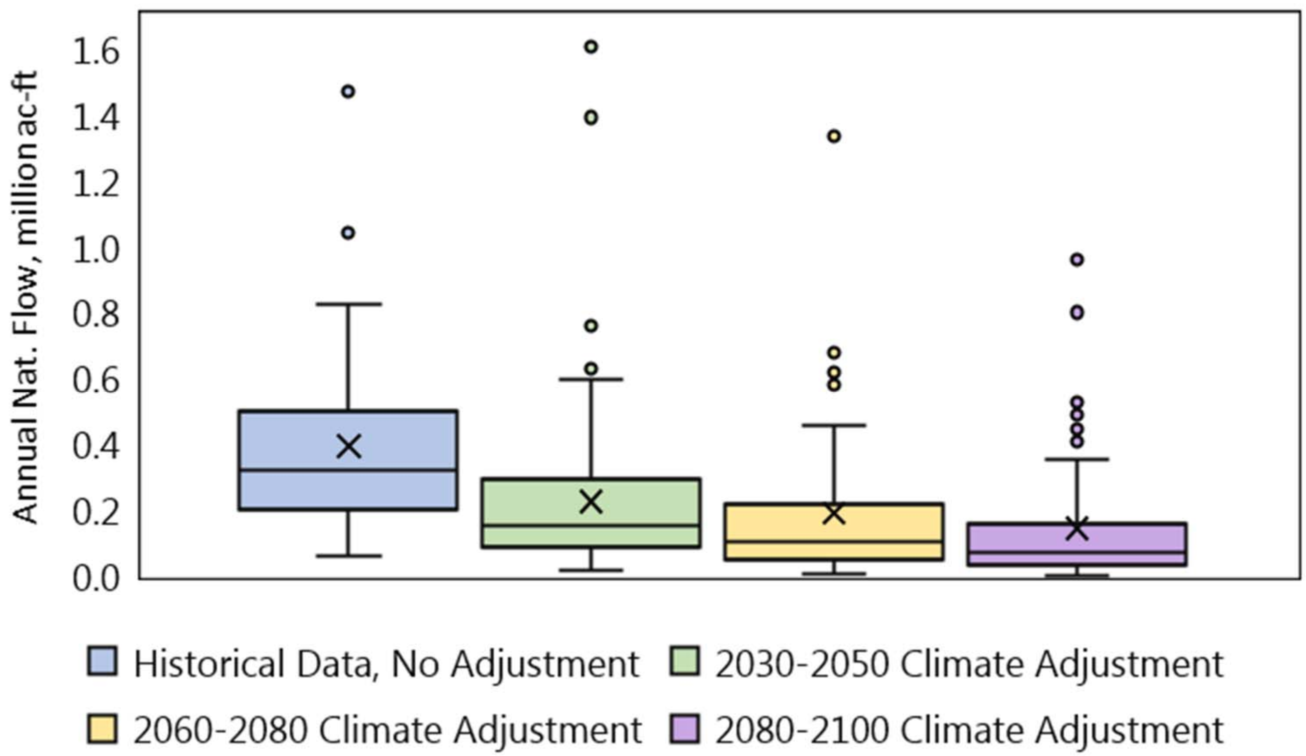
**Colorado River at Winchell**

Long-term mean flow decreases with future conditions.

Droughts are longer and drier.

High flows are about the same or lower.

Variability decreases with future conditions.



# Historical and Adjusted WAM Net Evap-Precip

| Reservoir | Historical WAM Net Evap-Precip | 2030-2050 Climate Adjustment | 2060-2080 Climate Adjustment | 2080-2100 Climate Adjustment |
|---|---|---|---|---|
| | *Average Annual Net Evap-Precip 1940-2016, feet* | | | |
| Lake O.H. Ivie | 3.5 | 3.8 | 4.3 | 4.6 |
| Lake Buchanan | 2.2 | 2.6 | 2.9 | 3.3 |
| Lake Travis | 1.9 | 2.3 | 2.6 | 2.9 |
| Bay City Dam | 1.5 | 1.4 | 1.6 | 1.8 |
| | *Average Annual Net Evap-Precip 2008-2015, feet* | | | |
| Lake O.H. Ivie | 4.2 | 4.5 | 5.1 | 5.4 |
| Lake Buchanan | 2.4 | 2.7 | 3.1 | 3.4 |
| Lake Travis | 2.1 | 2.4 | 2.7 | 3.1 |
| Bay City Dam | 1.5 | 1.4 | 1.6 | 1.8 |

# Planning For Uncertainties: Potential for Droughts Worse than the Drought of Record

# Water Forward WAM Modeling

Perform water availability simulations for
4 different future demand projection horizons
with different hydrologic scenarios

| Demand Projection Years |
|---|
| 2020 |
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# Beyond the 2010's Drought for Austin's IWRP

- The period of record contains 2 major droughts.
- For Austin's Water Forward IWRP, consideration of droughts worse than the drought of record (DWDR's) incorporated as prudent risk management for long-term planning.
- DWDR's by definition are not part of the historical record, and thus could "play out" in many different ways.
- **<u>Goal for DWDR Selection in Austin's IWRP</u>**: Select candidate DWDR events that represent a variety of drought duration and severity combinations. Water supply reliability metrics developed for candidate droughts.

# Steps for DWDR Development For Austin's IWRP

1. Create a long sequence of hydrology from sampling of the period of record.
2. Identify droughts in the long sequence.
3. Assign probability of occurrence to the droughts (return periods).
4. Based on return periods, select candidate DWDR events for planning analyses.

# Step 1. Markov Chain Monte Carlo Sampling

| |
|---|
| High, Upper 1/3 |
| Medium, Middle 1/3 |
| Low, Lower 1/3 |

**Step #1** Classify each year in period of record based on annual flow volumes

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1940 | 1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 |
| 1941 | 1951 | 1961 | 1971 | 1981 | 1991 | 2001 | 2011 |
| 1942 | 1952 | 1962 | 1972 | 1982 | 1992 | 2002 | 2012 |
| 1943 | 1953 | 1963 | 1973 | 1983 | 1993 | 2003 | 2013 |
| 1944 | 1954 | 1964 | 1974 | 1984 | 1994 | 2004 | 2014 |
| 1945 | 1955 | 1965 | 1975 | 1985 | 1995 | 2005 | 2015 |
| 1946 | 1956 | 1966 | 1976 | 1986 | 1996 | 2006 | 2016 |
| 1947 | 1957 | 1967 | 1977 | 1987 | 1997 | 2007 | |
| 1948 | 1958 | 1968 | 1978 | 1988 | 1998 | 2008 | |
| 1949 | 1959 | 1969 | 1979 | 1989 | 1999 | 2009 | |

**Step #2** Calculate transition probability between states based on the observed transitions

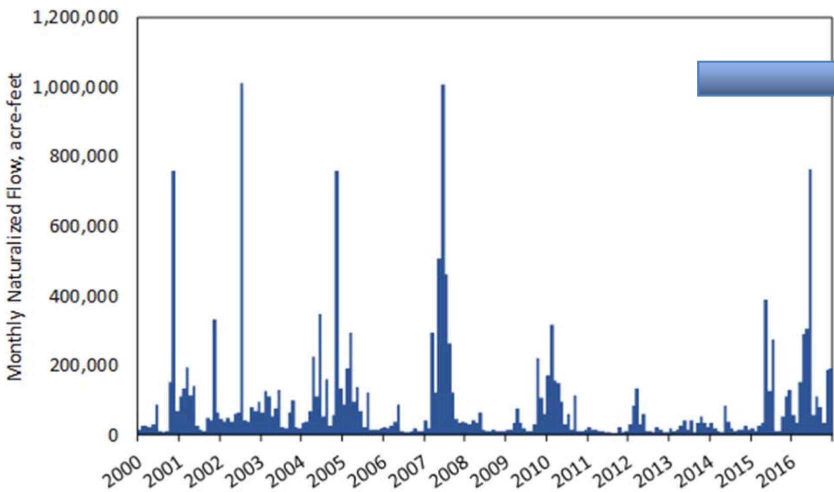
| | | Annual Transition State | | |
|---|---|---|---|---|
| | | Low | Med | High |
| Prior | Low | 42.3% | 38.5% | 19.2% |
| Annual | Med | 26.9% | 26.9% | 46.2% |
| State | High | 33.3% | 33.3% | 33.3% |

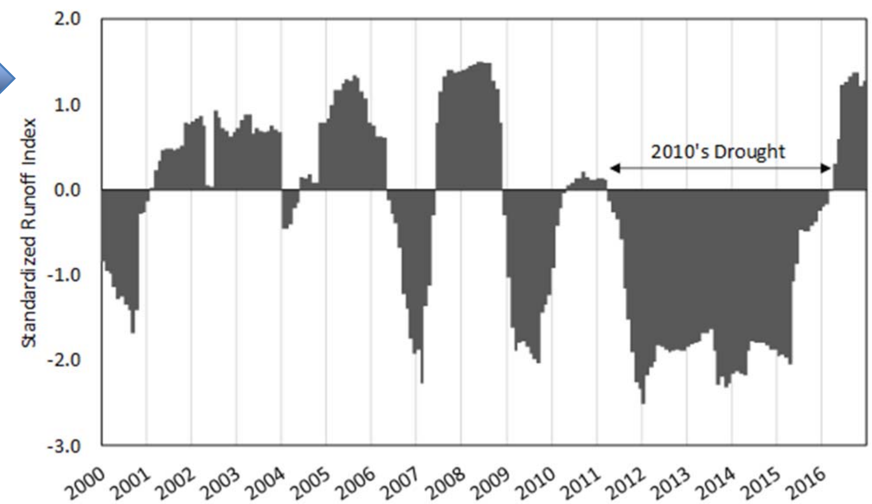
| **Step #3** Select sequence of states | **Step #4** Select specific year |
|---|---|
| High | 2007 |
| Med | 1985 |
| Med | 1966 |
| Low | 2012 |
| Low | 1947 |
| Med | 1995 |
| Low | 2006 |
| Low | 1972 |
| Low | 1993 |
| High | 1957 |
| High | 1965 |
| Med | 2000 |
| Med | 1994 |
| Low | 2011 |
| Med | 1978 |
| High | 1951 |
| High | 1989 |

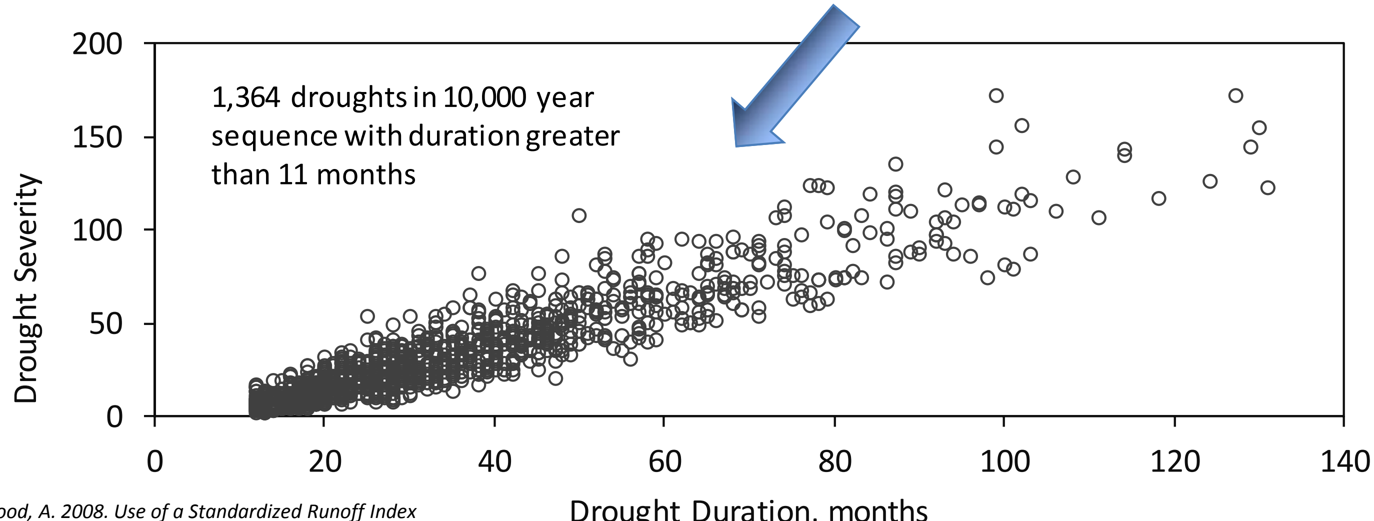
**Step #5** Build extended WAM hydrology input files according to the sequence of selected years

# Step 2. Identify Droughts

- Apply the Standardized Runoff Index (SRI) technique to obtain duration and severity of droughts over 10,000 year sequence.



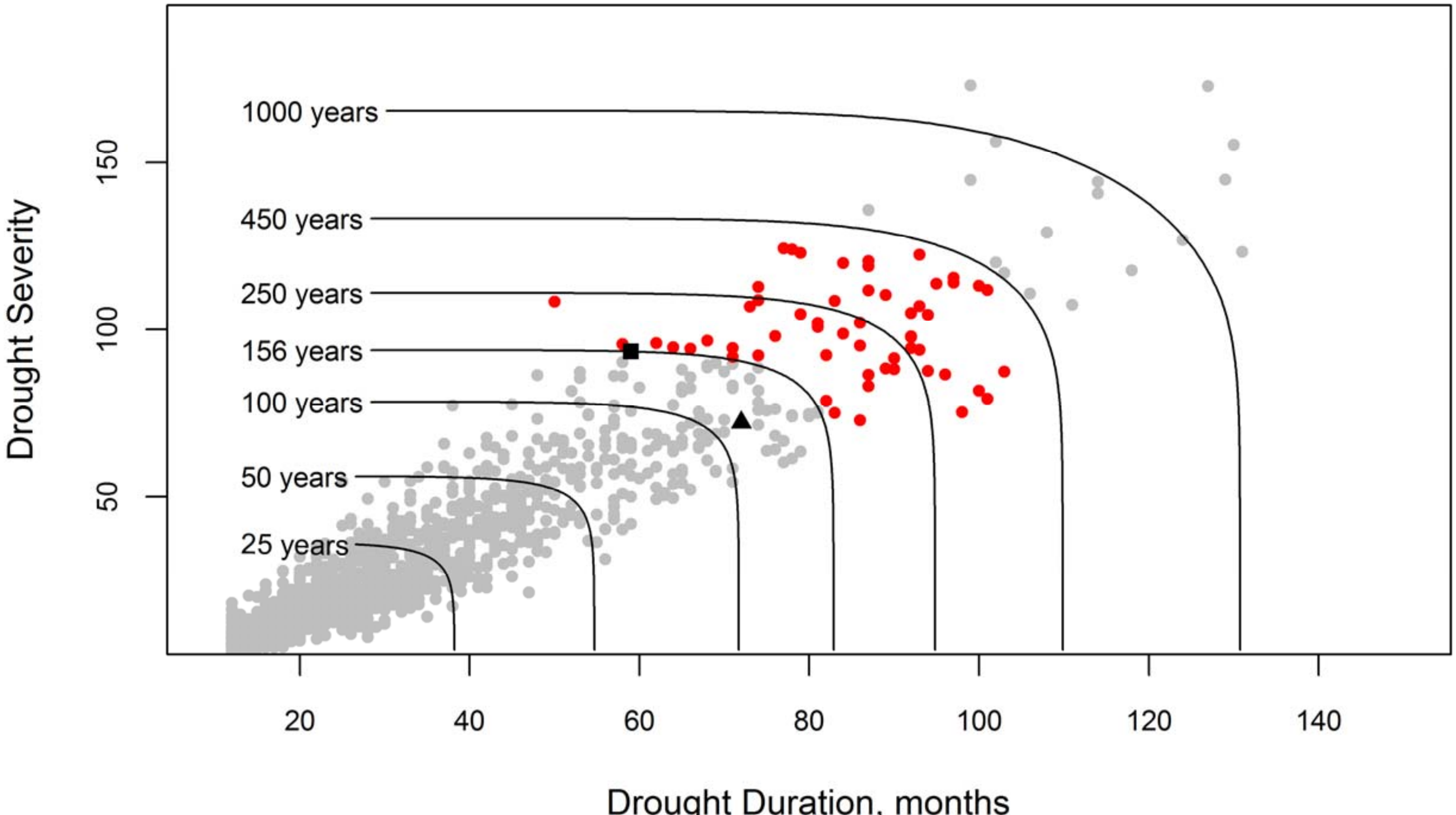




*Regarding SRI, See Also -- Shukla, S., Wood, A. 2008. Use of a Standardized Runoff Index for Characterizing Hydrologic Drought. Geophysical Research Letters, 35(2), 1-7.*

# Step 3. Drought Return Periods

- Assign probabilities to duration, severity, and joint probability of duration & severity. Return period calculated for the occurrence of duration and severity both exceeding the levels shown.

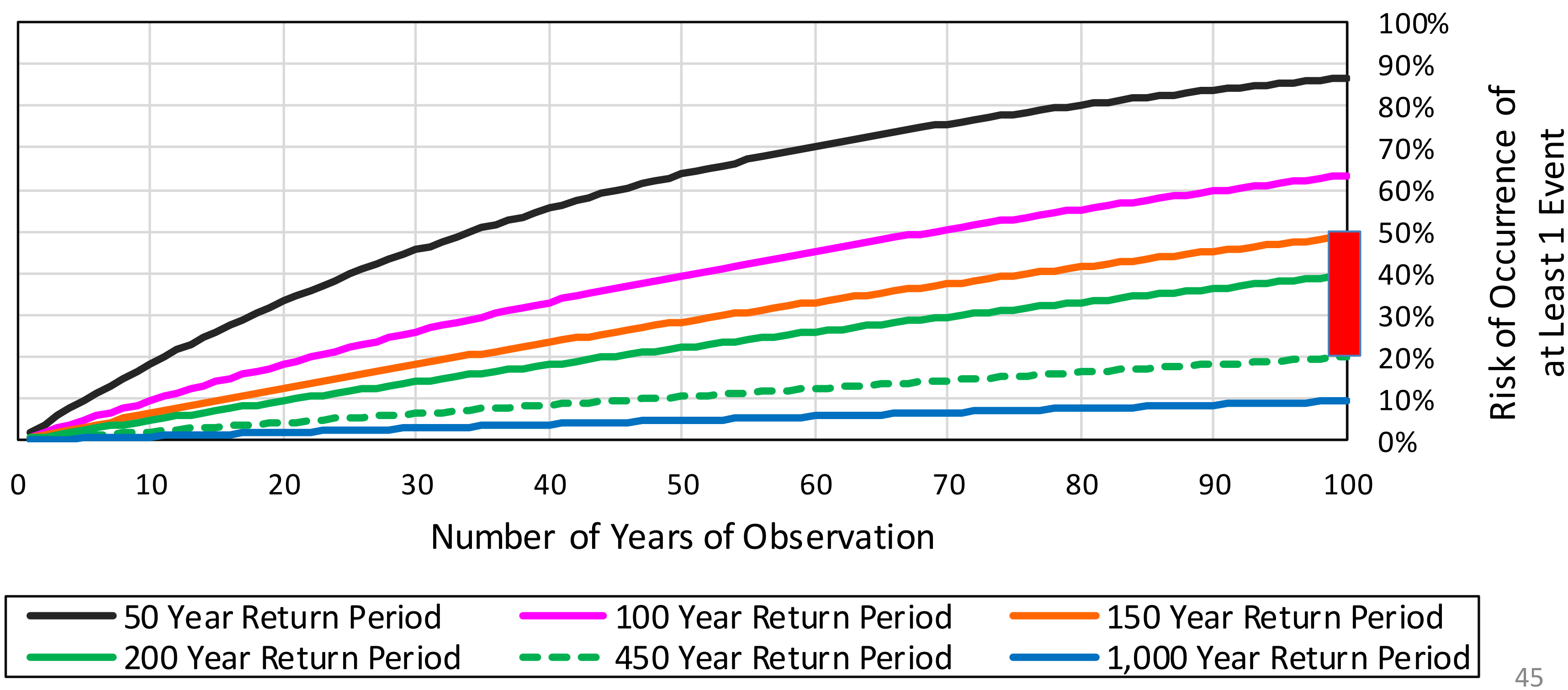



*Regarding steps from SPI/SRI to Drought Return Period, See Fig.2 in – Halwatura, D., Lechner, A., Arnold, S., 2015. Drought Severity-Duration-Frequency Curves: A Foundation for Risk Assessment and Planning Tools for Ecosystem Establishment in Post-Mining Landscapes. Hydrol. Earth Syst. Sci. 19(2): 1069-1091.*

*Regarding Drought Return Period, See Also -- Shiau, J. 2006. Fitting Drought Duration and Severity with Two-Dimensional Copulas. Water Resources Management, 20(5), 795-815.*

# Step 4. Candidate DWDR Selection

- Select droughts with lower chance of occurrence than 2010's drought, but greater than 20% chance in 100 years.



# Summary

- Austin's Water Forward IWRP is nearing completion.
- Regular IWRP updates will address new information.
- Historical hydrology is a key component of long-term planning, however for Austin's IWRP it was also important to consider planning for change and uncertainties.
- For Austin's IWRP, prudent risk management for long-term planning considers:
  - potential changes to hydrology based on the best available science, and
  - drought scenarios that differ from and are worse than the past.

# Thank You

You can follow the process and find more information at:

austintexas.gov/ waterforward