PNWS-AWWA

# Incorporating Climate Change Impacts Into Water Demand Forecasting

## A framework for utility planning

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carollo

# Acknowledgments


**Project Advisory Committee | Inception, Direction, and Feedback**

- Michelle Maddaus (Maddaus Water Management), Tess Sprague (Brown and Caldwell), Maureen Hodgins (WRF), Alison Miner (The MDC), John Kij (American Water), Val Frenkel (TYLin)

**Project Contractor | Carollo Engineers | Guidebook Development**

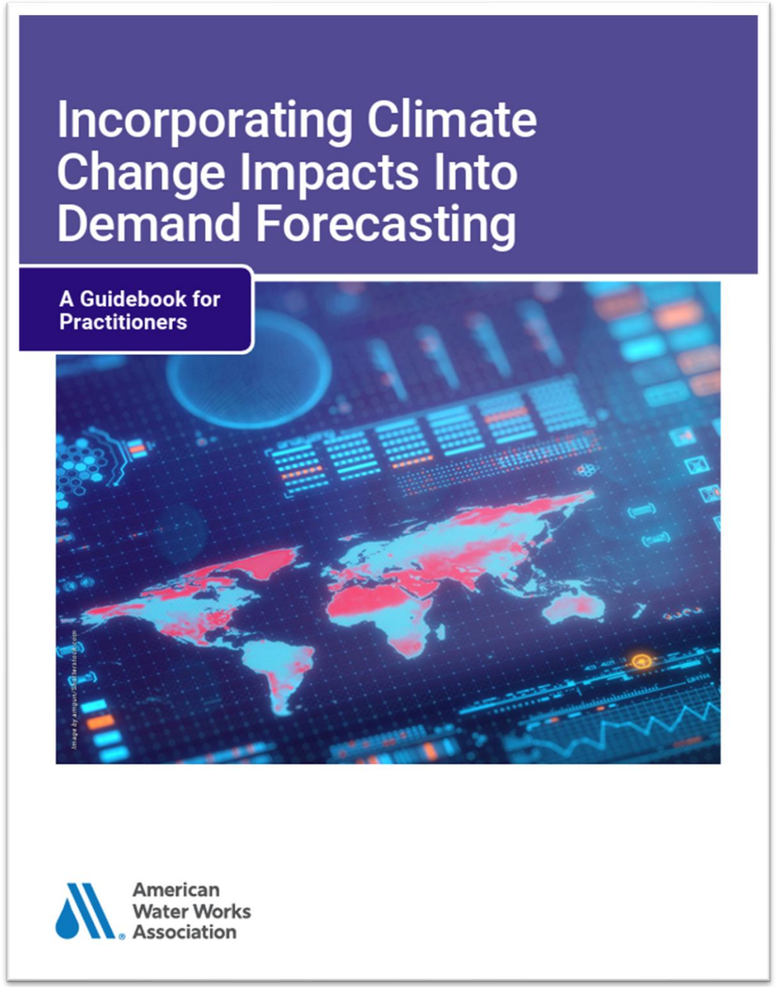
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**Case Studies Participants | Real-world Examples**

- Negin Ashoori and Tom Francis (BAWSCA); Nicole Rutigliano and Vinicius de Oliveria (TRWD); Darrin Geldert (Loudoun Water)

# How did it start?

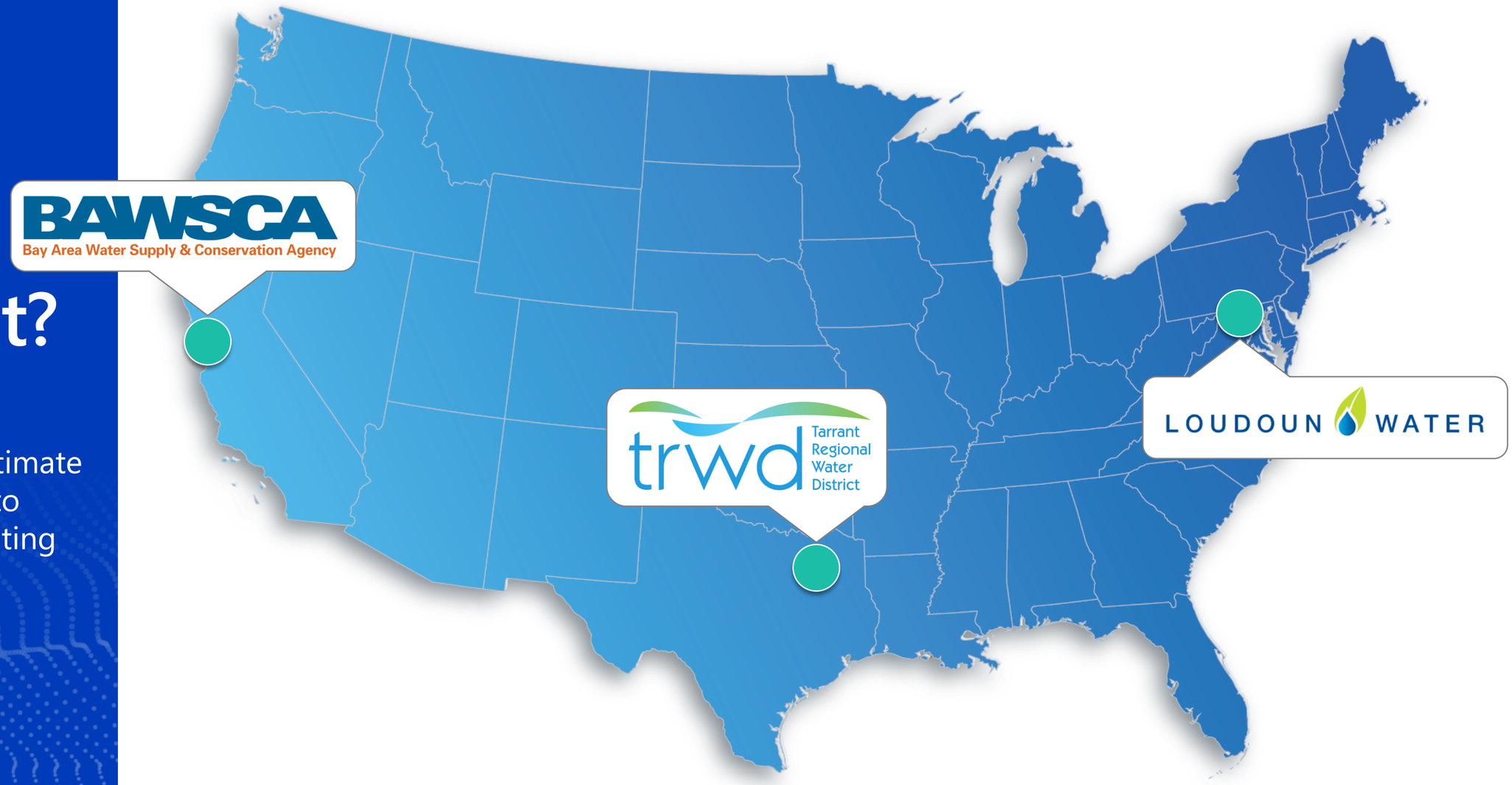
- AWWA Technical and Educational Council-sponsored project.
- Initiated by two AWWA Committees (Planning, Evaluation, and Research Committee; Climate Change Committee).
- Inspiration:
  - Climate change is exacerbating water demand issues, projected to increase
  - Relevant research from WUCA, WRF.



# What is it?

Methodologies to estimate impacts on demand to assist utilities in adapting to climate change.

## Three Case Studies



# Topics

- How Climate Impacts water demand
- Who Should Be Planning for Climate Change Impacts
- Understanding Climate Models
- Approaches to Demand Forecasting
- Case Studies
- Practical Steps for Your Utility

01

# Introduction and Framing

**Why this matters for water utilities everywhere**

# Climate Impacts on Water Demand

## Landscape Irrigation

Higher ET rates from rising temps; lower precipitation → higher net irrigation; longer growing seasons

## Cooling Demand

HVAC & cooling towers work harder longer; 5,389+ U.S. data centers highly temperature-sensitive

## Evaporation

Pools, fountains, and amenity ponds lose more water as atmospheric evaporative demand rises

## Peak Day Extremes

More frequent compound heat events (heatwave + drought) spike peak day demand and stress infrastructure

## Population Shifts

Climate-driven migration can accelerate or reverse service area growth trajectories unexpectedly

# Who Should Be Planning for Climate Change Impacts?

**67%**
of WUCA agencies already modeling climate change in demand forecasts

**RCW 43.20.310**
WSP initiated after June 30, 2025 must include a Climate Resilience Element

**50%+**
of water professionals have incorporated climate uncertainty into forecasting

**The short answer: utilities of all sizes, in all regions.**

- Western utilities have led due to high outdoor use, but the issue is not regional.
- Even where outdoor use is modest, climate intersects with population, efficiency, and supply planning.

**The main barriers reported by water professionals.**

- Technical know how to utilize climate data in demand models.
- Resources to advocate internally and communicate results externally.
- This guidebook directly addresses both barriers.

# The Urban Water Cycle

## Water demand sits at the center of utility operations

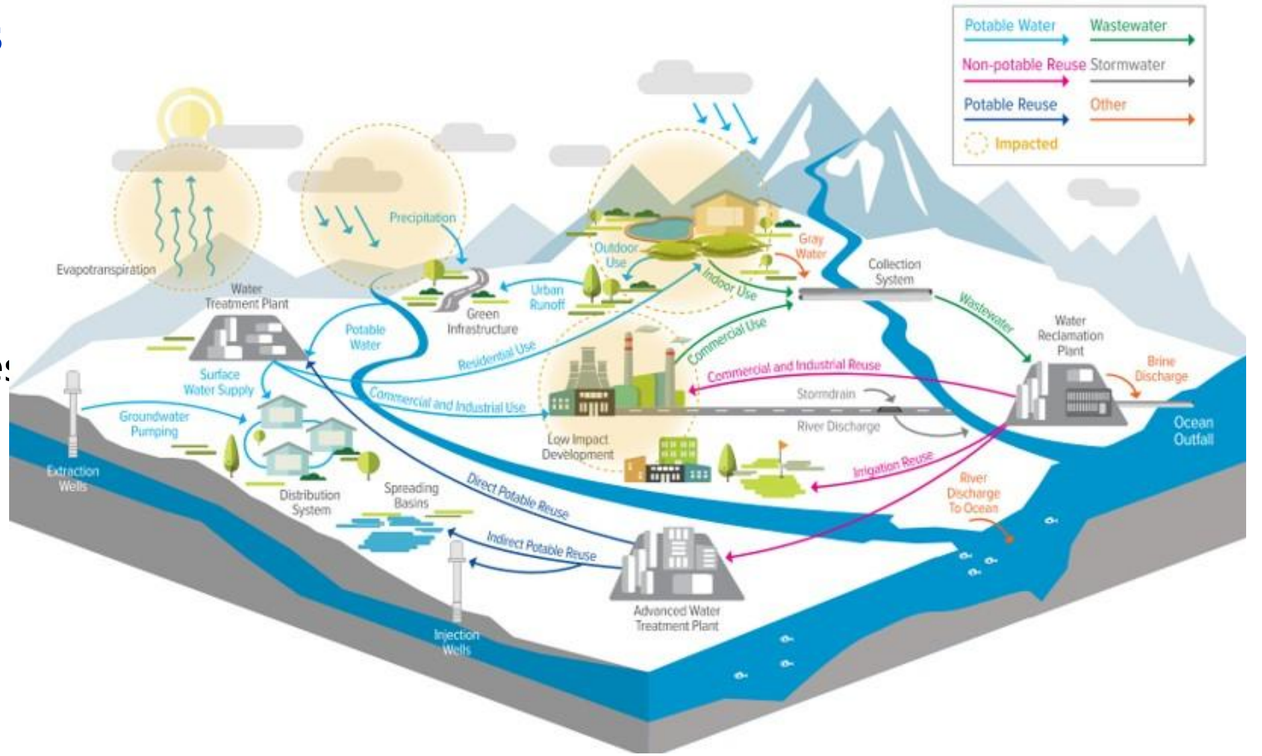
Peak seasonal demand drives infrastructure sizing, operations, and finances.

## Climate is reshaping both sides of the cycle

Hotter, drier conditions increase demand, while supply becomes less predictable.

## The implication: plan for change, not just growth

Forecast shifts in timing and peaks, not just total volume.




Source: Carollo Engineers, 2025

02

# Understanding Climate Models

**From global projections to local planning inputs**

# Future Climate

## What we are observing today

- Global temperatures already +1.1°C above pre-industrial levels.
- More frequent and intense heat waves and droughts.
- Precipitation events less frequent but more intense.

## What this means for water planning

- These trends are projected to continue and intensify under all future scenarios.
- Utilities that plan now will be better positioned than those that wait for impacts to materialize.

# From Global Models to Local Projections

## 01
### Emission Scenarios

Possible future climate trajectories.

Scenarios range from aggressive mitigation (~1.5°C) to business-as-usual (~4.5°C by 2100)

## 02
### General Circulation Models (GCM)

General Circulation Models simulate global atmosphere, ocean, land and sea/ice systems

~100–250 $km^2$ resolution, too coarse for local water planning

## 03
### Downscaling

Refines GCM outputs to ~6–12 km for regional and local use

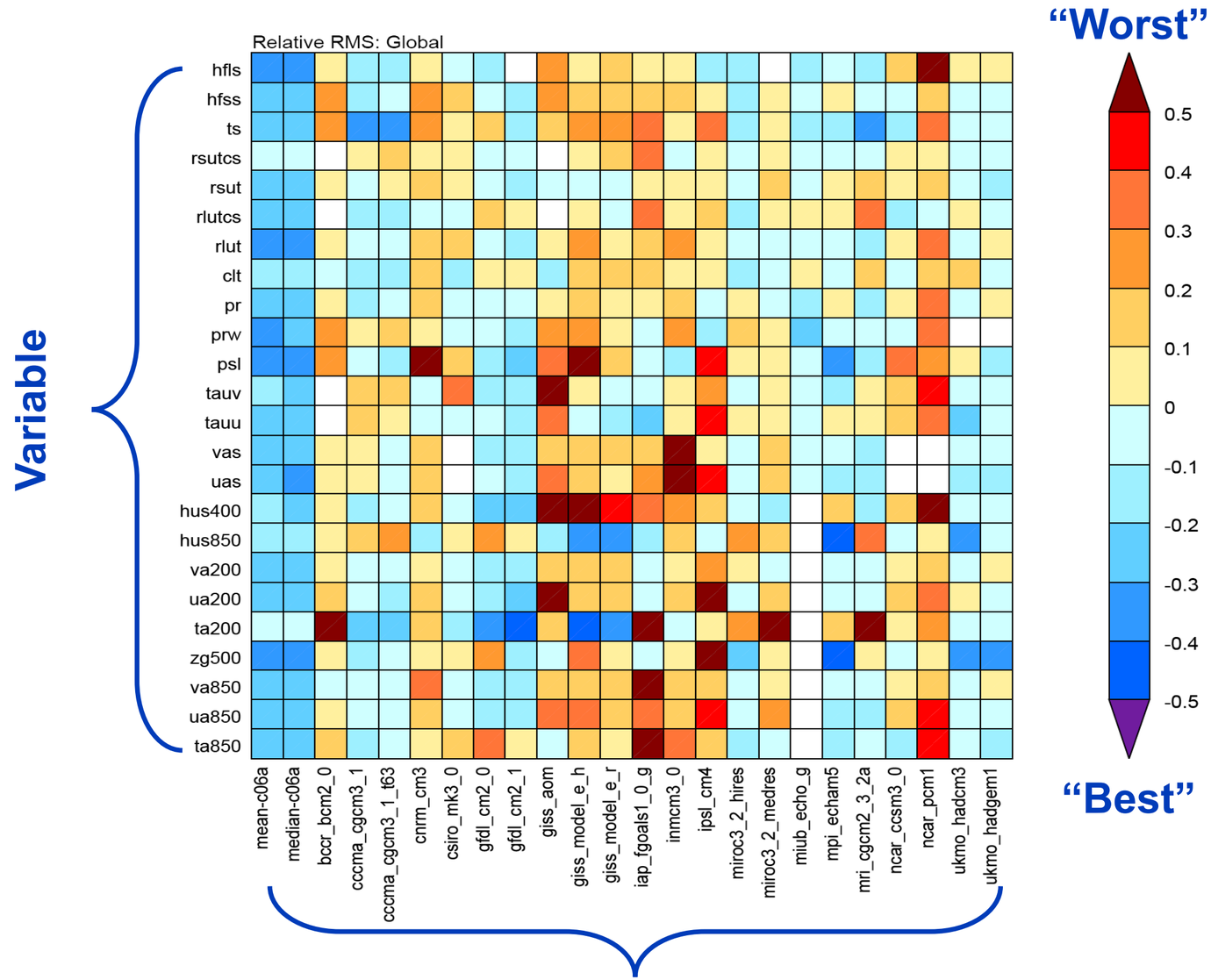
Statistical or Dynamical, bias correction applied to reduce systematic errors.

## 04
### Local Inputs

Monthly temperature, precipitation, ET projections at your service area

Key variables: surface air temp, precipitation, ET, humidity, wind

# General Circulation Models (GCM)

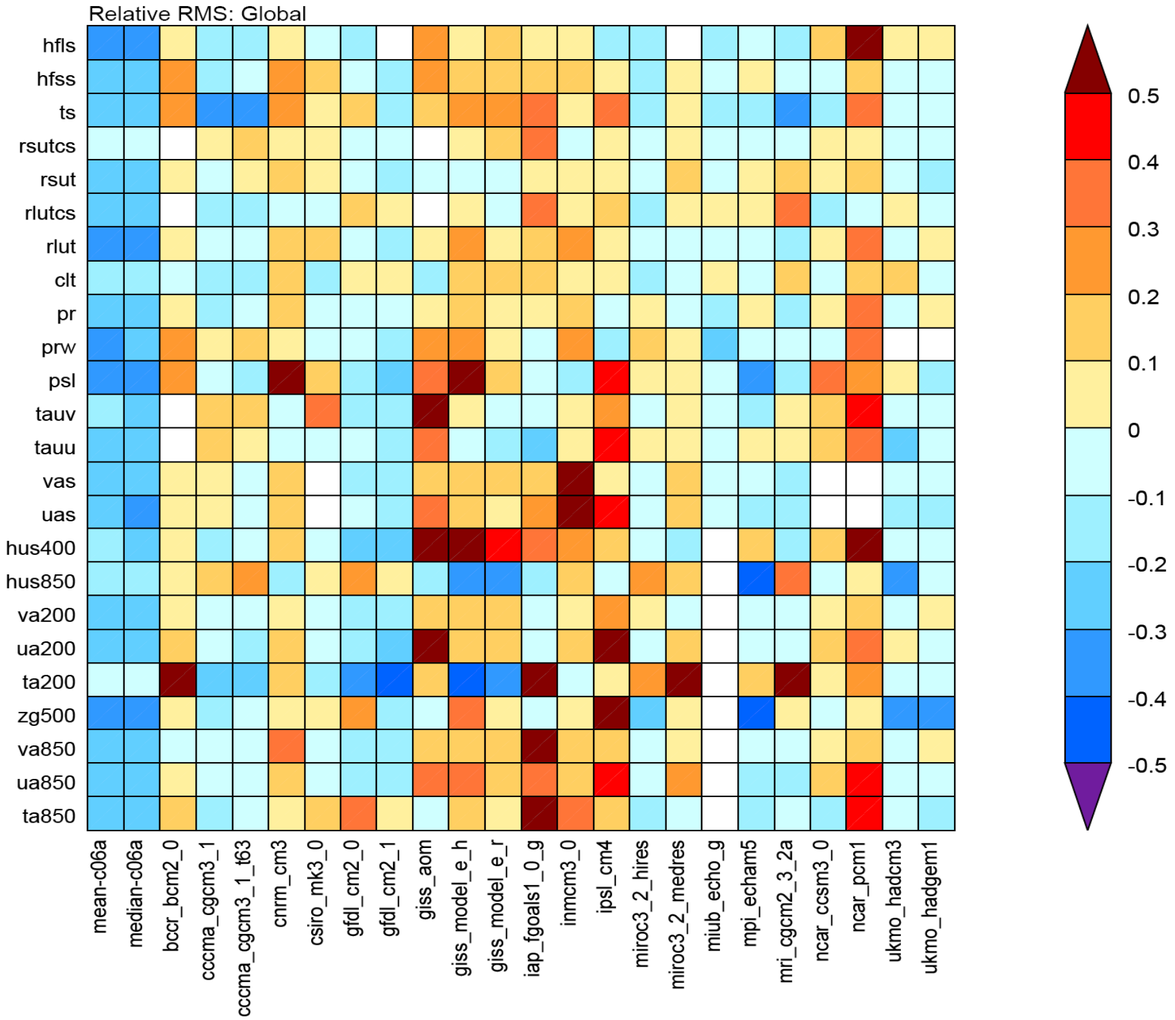



Source: Gleckler, Taylor, and Doutriaux, 2008

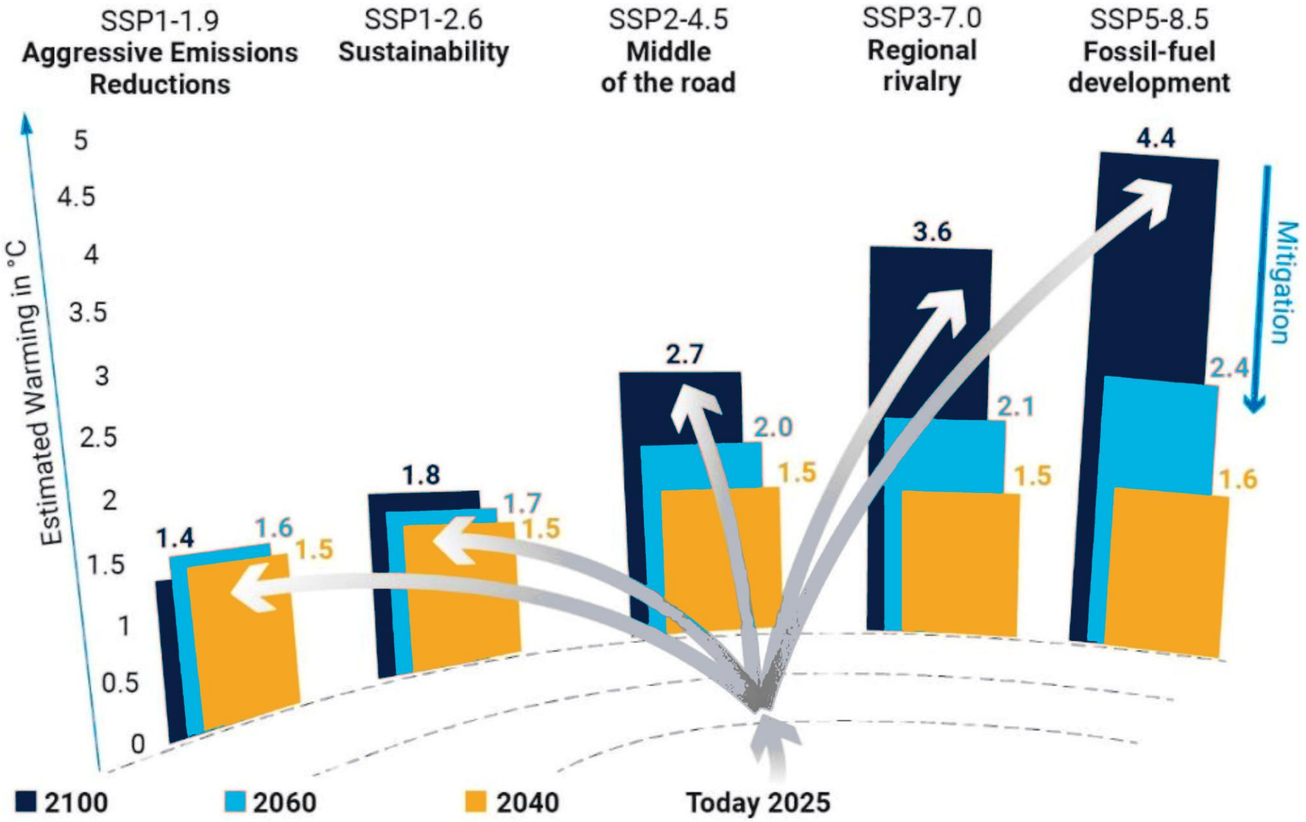
# GCM

**Variable**

- Latent heat flux at surface
- Sensible heat flux at surface
- Surface temperature
- Reflected SW radiation (clear sky)
- Reflected SW radiation
- Outgoing LW radiation (clear sky)
- Outgoing LW radiation
- Total cloud cover
- Precipitation
- Total column water vapor
- Sea-level pressure
- Meridional wind stress
- Zonal wind stress
- Meridional wind at surface
- Zonal wind at surface
- Specific humidity at 400 mb
- Specific humidity at 850 mb
- Meridional wind at 200 mb
- Zonal wind at 200 mb
- Temperature at 200 mb
- Geopotential height at 500 mb
- Meridional wind at 850 mb
- Zonal wind at 850 mb
- Temperature at 850 mb



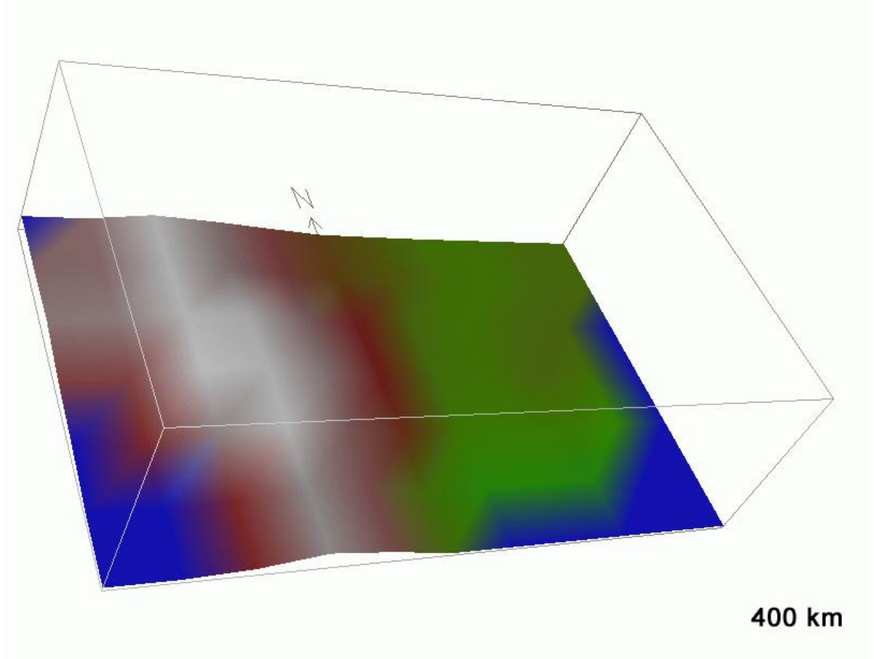
# Emission Scenarios



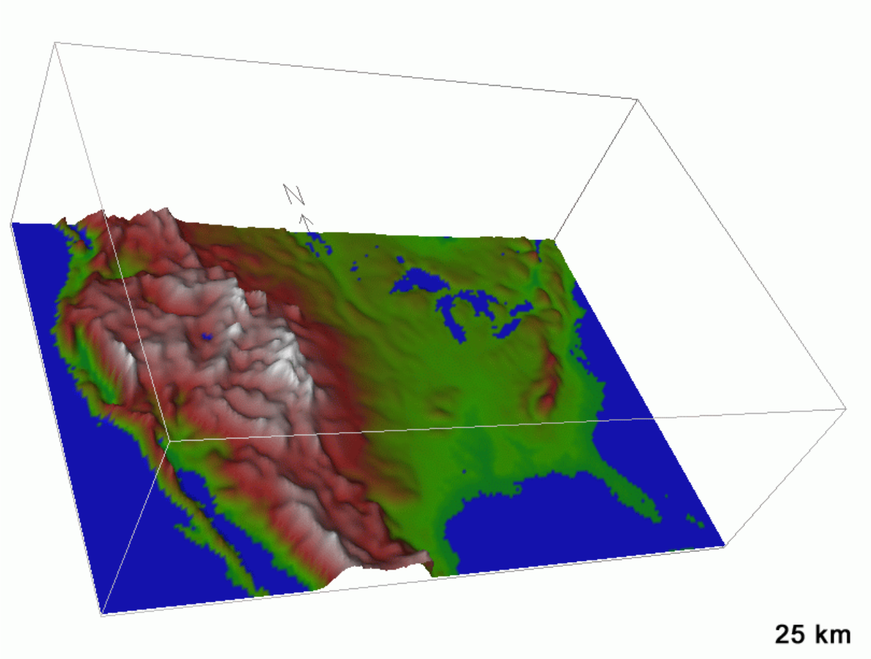

Source: Meinshausen, 2020

# Downscaling

## Climate Models




## Regional Models




## User Needs



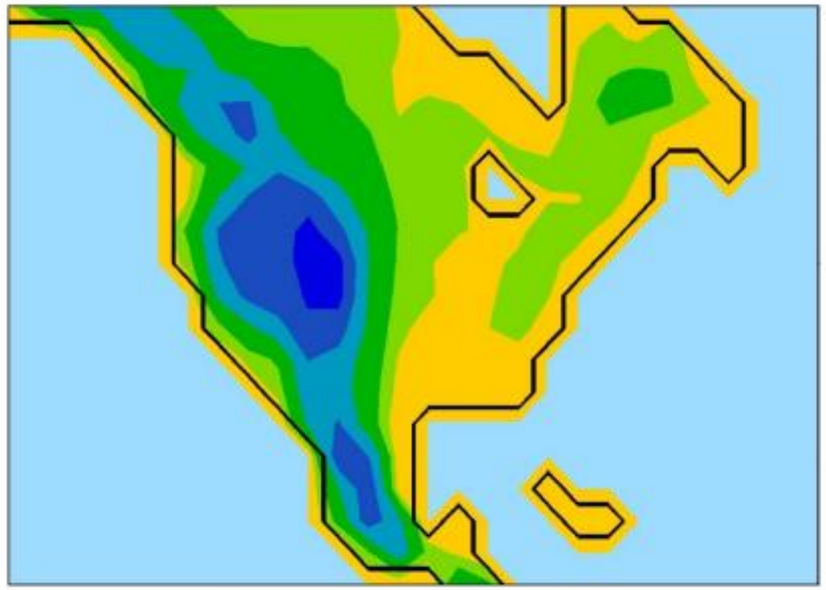
Source: National Center for Atmospheric Research (NCAR)

# Advantages of higher resolution

North America at typical global climate model resolution

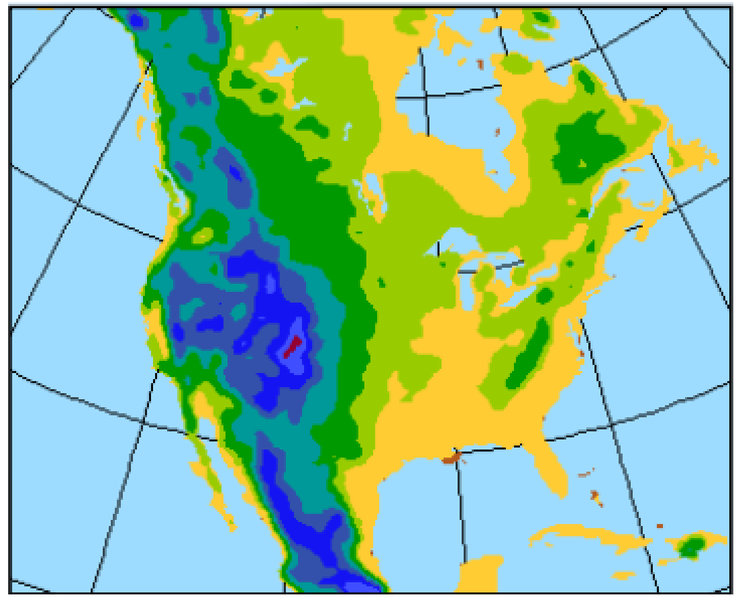
Model: Hadley Centre AOGCM (HadCM3)

Resolution: 2.5˚ (lat) x 3.75˚ (lon), ~ 280 km

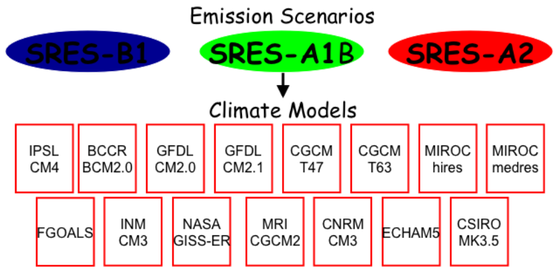


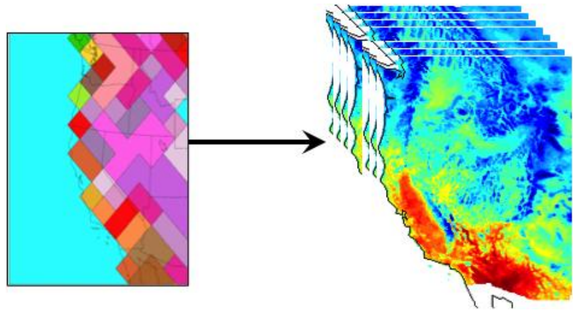
Source: Mearns, 2012

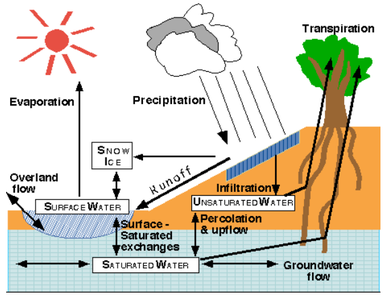
Downscaled to 50 km grid spacing



# Uncertainty Cascade of Achieving Local Climate Change Information






**Emission Scenarios**

- Socioeconomic
- Political

**GCMs**

- Carbon cycle
- Parameterization
- Resolution

**Downscaling**

- End-user Needs
- Statistical or Dynamical

**End User/Application**

# Managing Climate Model Uncertainty

## Model structural uncertainty

Each GCM simulates physical processes differently

## Scenario uncertainty

Different SSP/RCP assumptions yield different magnitudes

## Natural variability

Inherent short-term fluctuations at regional scales

### Free Data Resources

**USGS NCCV**
Temperature & precipitation for US

**NASA NEX-GDDP**
CMIP6, global, 25 km daily

**ClimateNA**
North America, 1 km resolution

**MACA CMIP5**
4–6 km, western US focus

**CA Climate Assessment**
California-specific, state-sponsored

# Approaches to Demand Forecasting

**Simple to advanced, matching method to your utility's needs**

# Getting Started

Before selecting a method, understand your weather–demand relationship

### Step A — Collect and visualize

- Monthly historical water production alongside temperature and precipitation.
- Correlations are often immediately obvious.

### Step B — Understand demand composition

- What share is outdoor?
- Who are your large customers? Any with significant cooling or irrigation needs?

### Step C — Choose temporal resolution

- Monthly data preferred — balances granularity with availability and reduces noise.
- Daily data possible with AMI, but more complex to model.

### Step D — Explore statistical correlations

- Max temperature vs. total production.
- This quantified relationship is the foundation every method below builds on.

# Method 1: Simple Adjustment Factor

**Best for:**

Small utilities, early-stage planning, or when you need a defensible first estimate without building a full model.

**What you need:**

Historical production data, a population forecast, and a published or estimated climate adjustment factor.

**Limitations:**

- The factor is often borrowed from other studies, may not reflect your specific service area
- Doesn't peak rates, only volume
- Hard to update as climate data improves

**Generalized Equation**

$$Q_{future} = Q_{base} \times (1 + f_{climate})$$

Where:

- $Q_{base}$ = Baseline demand (gcpd or total volume)
- $f_{climate}$ = Climate adjustment factor (e.g., +0.05 per °F of warming)

# Method 2: End-Use Modeling

**Best for:**

Utilities with significant outdoor demand, large industrial/commercial cooling accounts, or those planning targeted conservation programs.

**What you need:**

Billing data by customer category, ET data (ETo), landscape area estimates (remote sensing helps), large user inventory.

**Limitations:**

- Data intensive, landscape area, plant factors, and irrigation efficiency assumptions add up.
- Many underlying assumptions aren't based on locally collected data
- Accuracy depends heavily on quality of end-use audit

**Generalized Equation**

$$Q_{total} = \sum_{i=1}^{n} Q_i^{indoor} + \sum_{j=1}^{n} Q_j^{outdoor}$$

Example:

- $Q_{Outdoor} = Q_{irr} + Q_{pools} \cdots$

# Method 3: Adjusted Unit Use with Elasticities

**Best for:**

Utilities with solid historical monthly data and a reasonable number of years on record. This was the approach used by TRWD in the Texas case study.

**What you need:**

Monthly production data, historical weather, downscaled climate projections, and elasticities.

**Limitations:**

- Borrowed elasticities from other regions may not reflect your customers' behavior
- Assumes the historical weather-demand relationship holds in the future

**Generalized Equation**

$$CCAq^{s}_{m,y} = Bq^{s}_{m,y} \times \left(\frac{MXT^{cc}_{m,y}}{MXT^{b}_{m,y}}\right)^{e_t} \times \left(\frac{PRC^{cc}_{m,y}}{PRC^{b}_{m,y}}\right)^{e_p}$$

Where:

- $CCAq$ = climate change adjusted unit use (gpcd, gphd, or gped)
- $Bq$ = base period unit use for sector s in month m, year y
- $\frac{MXT^{CC}}{MXT^{b}}$ = future vs. base average maximum monthly temperature
- $\frac{PRC^{CC}}{PRC^{b}}$ = future vs. base monthly precipitation
- $e^{t}$ = temperature elasticity
- $e^{p}$ = precipitation elasticity

# Method 4: Advanced Mathematical / Econometric Models

**Best for:**

Large utilities with significant growth potential, complex customer mixes, or where multiple compounding drivers need to be modeled simultaneously.

**What you need:**

10–20+ years of monthly data across multiple variables, production, weather, population, income, water rates, drought restriction history, housing characteristics.

**Limitations:**

- Time-intensive and costly to build correctly
- Requires data that many utilities don't have readily available
- Reflects historical behavior, won't capture future behavioral shifts automatically

**Generalized Equation**

$$q^{s}_{m,y} = f\left(C_1, C_2, \ldots C_j, X_1, X_2, \ldots, X_k\right)$$

Where:

- $q$ = unit water use for sector s, month m, year y.
- $C$ = climate variables (precipitation, temperature, etc.)
- $X$ = additional explanatory variables (income, water price, housing density, drought restrictions, conservation adoption, etc.)

# Case Studies

# Three Agencies Across the Country

## Tarrant Regional Water District (TRWD)

Fort Worth, Texas · 2.4M served

*Method: Advanced Mathematical / Econometric Models*

**Key result:**

+19% annual demand under hot/dry scenario; June factor of 1.35

## Loudoun Water

Ashburn, Virginia · 330K residents + 137K employees

*Method: Adjusted unit use with elasticities*

**Key result:**

+5.7% July gpcd by midcentury; data centers amplify all climate impacts

## Bay Area Water Supply & Conservation Agency (BAWSCA)

San Mateo, California · 1.87M served, 26 member agencies

*Method: Advanced Mathematical / Econometric Models*

**Key result:**

1°F = 0.4–1.3% demand increase by season; 50 mgd scenario range by 2045

# TRWD: Background & Methodology

## Background

- Raw water supplier, 11-county North Texas region; 51 wholesale customers; 2.4M people served
- Surface water only — four owned lakes, 250+ miles of pipeline, firm yield ~550,000 acre-feet/year
- Needed to understand if and when growth would overtake conservation savings post-2011 drought

## Methodology

- Multiple linear regression: 1994–2018 monthly data.
- Variables: days w/o precip, days >99°F, avg max temp, monthly & prior-month precip
- CMIP5 GCMs (RCP 6.0 & 8.5) downloaded for DFW Airport grid cell
- Hot/Dry ensemble: upper 50th pct temperature, lower 50th pct precipitation
- Warm/Wet ensemble: lower 50th pct temperature, upper 50th pct precipitation

**At a glance**

People served
**2.4 million**

Historical firm yield
**~550K acre-ft/yr**

Climate model
**CMIP5 ensemble**

Scenarios
**Hot/Dry + Warm/Wet**

# TRWD: Key Results

**Hot/Dry scenario (2070 projection)**

- Annual water demand increases by a factor of 1.19 — 19% above historical average weather baseline
- June demand factor of 1.35 — a 35% increase in the peak month of irrigation demand

**Warm/Wet scenario (2070 projection)**

- Annual demand increases by factor of 1.10 — higher precipitation provides partial offset
- June and September still show significantly elevated demand factors

**Reality check: 2022 and 2023 set back-to-back all-time demand records**

- Demands surpassed the 2011 drought-of-record that climate factors were benchmarked against
- Under hot/dry trajectory: demands could reach 900,000+ acre-feet by 2070

> *"Before, the impacts were theoretical. Now we have a consistent, agreed-upon framework and portfolio of water demands from which we plan."*
>
> — Nicole Rutigliano, Water Supply Manager, TRWD

# Loudoun Water: Background & Methodology

## Background

- Eastern Loudoun County, VA; 330K residents, 137K employees; potable + reclaimed water
- Nonresidential consumption up 30% since 2015, driven almost entirely by data center growth
- 40+ million $ft^2$ of data centers operating; another 40M $ft^2$ under development

## Methodology

- AMI data as the modeling foundation, enabled sector-level and geospatial demand models
- Regression at multiple scales: system-wide, single-family, multifamily residential
- Temperature had the strongest t-statistic across all models; system $R^2$ = 0.904
- CMIP3 & CMIP5: 32 GCMs × 2 scenarios (RCP4.5 + RCP8.5) = 64 model outputs
- Ensembled into two scenarios: Hot-Normal Wet and Hot-Very Wet

**At a glance**

Service area pop.

**330K residents**

Data center floor area

**40M+ $ft^2$ (operating)**

System model $R^2$

**0.904**

GCM outputs used

**64 (32 × 2 scenarios)**

# Loudoun Water: Key Results

## Temperature projections

- Short term (2030–2050): +4.0–4.8°F in summer months
- Midcentury (2050–2070): +5.0–7.4°F in summer months
- End of century (2070–2099): +9.0–10.4°F in summer months

## Extreme heat events

- Days exceeding 95°F to increase by 8 (short term), 25 (midcentury), and 69 per year (end of century)

## Demand impacts — July peak

- 2023 actual: 105 gpcd at 91.2°F avg max temp
- Short term: 109 gpcd (+3.8%) · Midcentury: 111 gpcd (+5.7%)
- Data centers compound all climate impacts, warmer temps = more cooling water needed

> *"Developing a data-driven model to explore future demand scenarios is a concrete, practical step toward incorporating climate into demand forecasting."*
>
> — Darrin Geldert, Planning Manager, Loudoun Water

# BAWSCA: Background & Methodology

## Background

- 26 member agencies, Alameda/San Mateo/Santa Clara Counties; 1.87M residents, 40K+ businesses
- Supply: ~85% Hetch Hetchy (snowmelt-dependent), 10–15% local reservoirs, <5% groundwater
- Despite 34% population growth since 1987, total demand has fallen 32% — driven by conservation

## Methodology

- Customized econometric demand function for each of 26 member agencies
- Up to 24 years of monthly data per agency; variables include rates, weather, population, drought restrictions
- Layered into end-use DSS Model (Demand Side Management Least Cost Planning)
- Climate inputs: California 4th Climate Change Assessment — a published expert regional synthesis
- Projected warming: 1.6°F (RCP4.5) to 2.2°F (RCP8.5) by 2045

**At a glance**

Member agencies
**26**

People served
**1.87 million**

Historical data per agency
**Up to 24 years**

Projected 2045 warming
**1.6–2.2°F**

# BAWSCA: Key Results

## Climate sensitivity findings

- A 1.0°F temperature rise increases demand by:
  - 1.3% in spring
  - 0.4% in summer
  - 1.1% in late fall/winter
- Bay Area coastal microclimates moderate summer warming compared to inland service areas

## Scenario results (5 scenarios tested)

- Population growth is the dominant demand driver, Scenario A (high growth) → ~255 mgd by 2045
- Slowing growth rate alone (Scenario B vs A) lowers 2045 demand by 34 mgd
- Climate change (Scenarios C/D) elevates demand even with active conservation underway
- Total range across all scenarios: up to 50 mgd difference by 2045

> *"Our sensitivity analysis will enable more informed decision making on regional water efficiency programs and future investments in water supply projects."*
>
> — Negin Ashoori, Senior Water Resources Engineer, BAWSCA

# Case Study Comparison at a Glance

| | TRWD · Texas | Loudoun Water · Virginia | BAWSCA · California |
|---|---|---|---|
| **Method** | Advanced demand function (regression) | AMI regression + adjusted unit use | Hybrid econometric + end-use DSS |
| **Climate data** | CMIP5 ensemble, 2 scenarios | 64 GCM outputs, 2 scenarios | Published regional assessment, 5 scenarios |
| **Key result** | +19% annual demand (hot/dry); June factor 1.35 | +5.7% July gpcd by midcentury; data centers amplify | 50 mgd scenario range by 2045 |
| **Next steps** | Annual demand tracking dashboard; IWSP update | Recycled water expansion; 1B gal quarry storage | Strategy 2050 — demand vs. supply resilience |

# Practical Steps for Your Utility

# Steps 1–3: Build Your Foundation

**1**

## Assess Historical Weather & Demand

Collect and plot monthly production (gpcd) with temperature and precipitation
Identify visual correlations; explore statistical relationships

**2**

## Explore Climate Change Impacts

Collect downscaled climate data covering range of potential futures
Focus on variables driving water use: temperature, precipitation, ET
Summarize projected monthly changes across your planning horizon

**3**

## Assess Major Water Uses

Identify demand categories most responsive to weather changes
Isolate outdoor demand (minimum month method in cooler climates)
Map the portion of total demand climate change is most likely to affect

# Steps 4–6: Model, Apply, and Monitor

**4**

## Determine Best Approach to Model Impacts

Consider data availability, staff capacity, and whether consultant support is needed
Match sophistication to expected magnitude of impacts; simple is often sufficient
Choose from: adjustment factor, end-use model, elasticities , demand function

**5**

## Apply Approach and Summarize Results

Develop scenarios pairing climate change with population, conservation, and other drivers
Create a demand envelope graphic, the single most powerful stakeholder communication tool
Document all assumptions, inputs, and results for future updating

**6**

## Monitor, Refine, and Mitigate

Track actual demands vs. projected scenarios annually
Monitor how climate outcomes are trending relative to modeled scenarios
If impacts are materializing: launch turf replacement, cooling tower efficiency, or recycled water programs

# Key Takeaways

1. Climate change is already affecting water demand. In 2022 and 2023 TRWD records prove theoretical impacts are real.
2. There is a method for every utility, from a simple 1°F adjustment factor to a full econometric demand function.
3. Start with the weather–demand relationship. Each case study began here, before applying any climate projection.
4. Use scenarios, not single forecasts. A demand envelope that brackets uncertainty is more defensible and more useful.
5. Combine climate with other drivers, population, conservation, and densification all interact with climate.
6. The guidebook is free at AWWA.org, methods, formulas, case studies, and a full climate data resource table.

# Thank You

## Questions?

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