

Assessment of Population and Municipal Water Demand Projections in Texas Water Supply Plans

Prepared by
Fitsume Wolkeba, Tewodros Tesfamichael,
Jon Paul Pierre, Robert C Reedy,
Kelley Keese, Bridget Scanlon

Prepared for
Texas Water Development Board
Under Contract Number 2500012881

Bureau of Economic Geology,
Jackson School of Geosciences,
University of Texas at Austin
September 2026

This page is intentionally left blank

Executive Summary

Developing reliable municipal population and water demand projections is foundational to Texas water resources planning. This project evaluates the accuracy of prior Texas Water Development Board (TWDB) population and water demand projections, characterizes their uncertainties, and recommends methodological and administrative refinements where appropriate. The overall goal is to make the projection process more accurate, transparent, flexible, and efficient for TWDB, Regional Water Planning Groups (RWPGs), and other stakeholders.

TWDB develops population and water demand projections by Water User Group (WUG) every five years under 31 Texas Administrative Code (TAC) Sections 357.31 and 358.4. After six regional water planning cycles from 2002 through 2022, the transition toward utility-based planning, and the addition of hundreds of municipal WUGs, a detailed review of current population and municipal water demand projection methods is timely. Improving these methods should strengthen the reliability of the projections while simplifying the process used to evaluate, negotiate, and finalize values for inclusion in regional water plans.

Municipal water demand projections are intended to represent drought-of-record conditions and therefore should generally exceed observed water use during average or wetter periods. The TWDB develops draft projections using TDC projections and historical water use data, incorporates feedback from RWPGs, and produces final projections for the SWP based on the feedback. In this context, underestimation is typically more consequential than overestimation because underestimated water use can lead to insufficient identification of potential water supply needs during severe drought. Excessive overestimations can also become critical, as it may lead to unnecessary infrastructure expansion. A more robust projection approach should support more reliable and actionable estimates of long-term municipal water supply needs, which is a core function of TWDB water planning.

The study reviewed population and water demand projection practices used by other western states and summarized relevant literature. It also compared the Texas State Water Plan (SWP) population projections from planning cycles between 2002 and 2022 with US Census Bureau population counts at the RWPG, county, and WUG levels. Municipal water demand projections were compared with reported actual water uses at the same geographic scales, including comparisons with 2011 (extreme drought year) water use and with maximum observed water use during the planning time period (2002 – 2022).

The review of other state water plans indicates that few states develop projections as regularly, systematically, or comprehensively as Texas. Several states rely more heavily on utility-scale summaries that are aggregated to the state level or on less formal planning cycles. This comparison highlights the strength of the Texas planning framework.

Key findings

- The State Water Plan projections compared favorably with US Census Bureau population estimates across State, RWPG, county, and WUG scales.
- Projection reliability decreases as the projection horizon increases, reflecting the compounding uncertainty inherent in long-term demographic and water demand forecasts.

- Uncertainties in absolute population projection generally increase with population size, whereas percentage error tends to decrease for larger population units.
- The draft and final population and water demand projections were identical for a large percentage of counties and WUGs, limiting required revisions to a small percentage of counties and WUGs. In these revised instances, the adjustments yielded a demonstrable reduction in underestimation errors in both population and water demand projections in the final vs draft projections. Although the final plans successfully reduced underestimation critical concern for drought years—they resulted in increased overestimation. This excessive overestimation presents a different risk: a potential surge in capital costs driven by over-built infrastructure.
- State Water Plan population projections generally followed expected uncertainty patterns. Underestimation appears to have decreased in more recent planning cycles at the RWPG, county, and WUG scales, whereas overestimations have increased.
- Performance of municipal water demand projections improved across planning cycles, with reduced underestimation at State, RWPG, county, and WUG scales.
- Comparisons of municipal water demand projections with 2011 drought use and maximum observed water use indicates that, while projected and actual water use generally align, extreme-use conditions may warrant larger buffer capacities in major urban centers to improve resilience to future climate and population pressures.
- Error attribution indicates that gallons per capita per day (GPCD) estimates rather than population projections are the main contributor to differences between projected water demand and actual municipal water use.

Recommendations

Population projections generally perform well but become increasingly uncertain over longer planning horizons. Future State Water Plans should incorporate low-, medium-, and high-growth scenarios linked to municipal water demand estimates providing a range of water demand estimates associated with TDC benchmark projections to better communicate uncertainty and assess risk. Greater flexibility for RWPGs to adjust growth allocations based on local knowledge would further improve projection accuracy, particularly in rapidly growing metropolitan areas.

Gallons Per Capita Per Day (GPCD) assumptions contribute more to municipal water demand projection errors than population projections. Improving GPCD estimation through a transparent and standardized framework, combined with routine evaluation of projected and observed values, would enhance projection reliability. Particular attention should be given to large urban utilities, where GPCD errors can significantly affect drought preparedness.

Future water demand projections should provide a buffer above actual use and be evaluated against drought-of-record conditions, maximum historical use, and extreme events such as the 2011 drought. Incorporating system leakage into GPCD and water demand projections, improving utility-level planning data, and establishing a continuous monitoring program to compare projected and observed outcomes after each planning cycle by comparing with available water use data would help identify systematic biases and support ongoing methodological improvements.

Texas has one of the most comprehensive municipal population and water demand projection programs in the United States. While TWDB's methodologies are generally sound and have improved over time, rapid population growth, drought risk, and climate variability warrant refinements to better support long-term water planning.

Table of Contents

Executive Summary.....	i
List of Figures	1
List of Tables.....	3
List of Acronyms and Abbreviations	4
1. Introduction.....	5
2. Methodology.....	7
2.1. Literature Review and Bibliography	7
2.2. Assessing Reliability of Population and Water Demand Projections	7
2.2.1. Assessing Reliability of Population Projections.....	8
2.2.2. Assessing Reliability of Water Demand Projections.....	9
2.2.3. Gallons per Capita per Day (GPCD) Comparison.....	10
2.2.4. Uncertainty Analysis.....	10
2.2.5. Cumulative Distribution Function (CDF)	11
2.3. Drivers of Errors in Water Demand	11
2.3.1. Qualitative Error Attribution	11
2.3.2. Refined Laspeyres Decomposition Error Attribution.....	11
2.3.3. Logarithmic Mean Divisia Index (LMDI) Decomposition Analysis	12
3. Results and Discussions	13
3.1. Population Projections	13
3.1.1. Accuracy of Texas Demographic Center (TDC) County Population Projections relative to US Census	14
3.1.2. Population Projections at the State Level relative to US Census	16
3.1.3. Population Projections at Regional Water Planning Group (RWPG) Level relative to US Census	17
3.1.4. Population Projections at the County Level relative to US Census	19
3.1.5. Population Projections at Water User Group (WUG) Level relative to US Census.....	25
3.2. Water Demand Projections	33
3.2.1. Water Demand Projections at the State Level relative to Actual Water Uses	34
3.2.2. Water Demand Projections at the Regional Water Planning Group (RWPG) Level relative to Actual Water Uses	34
3.2.3. Water Demand Projections at the County Level relative to Actual, 2011 and Maximum Water Uses.....	35

3.2.4.	Water Demand Projections at the Water User Group (WUG) Level relative to Actual, 2011 and Maximum Water Uses	44
3.2.5.	Accuracy of Gallons Per Capita per Day (GPCD) Estimates at the Water User Group (WUG) Level	53
3.2.6.	Evaluation of urbanization and impacts on GPCD on USGS land use change data	54
3.2.7.	Water User Group (WUG) Level Population and Gallons Per Capita per Day (GPCD) Error Attribution in Water Demand Across Plans	58
4.	Summary	60
5.	Recommendations.....	62
5.1.	Consider Modifications to the Population Projection Framework while Explicitly Addressing Uncertainty	62
5.2.	Provide Greater Regional Flexibility in Allocating Future Growth.....	62
5.3.	Strengthen GPCD Methodology and Review Procedures.....	63
5.4.	Better Account for Drought Demand and System Leakage	63
5.5.	Improve Utility-Level Data Integration	64
5.6.	Establish a Continuous Projection Performance Monitoring Program.....	64
5.7.	Overall Recommendation	64
6.	References	65
7.	Appendix	66
7.1.	Bibliography — with Abstracts and Planning Implications	67
7.2.	Projections of Population Growth and Water Demand in Western States of the United States.....	109
7.3.	Select Texas Regional Water Plans	155

List of Figures

Figure 1: Workflow illustrating the methods used in the study.	7
Figure 2: Census population (for 2020) in regional water planning groups (RWPGs), counties and Water User Groups (WUGs).	8
Figure 3: Difference between TDC population and US Census, under the different migration scenarios.	15
Figure 4: TDC comparison with census a) differences and b) percent differences	16
Figure 5: Comparison of final population projection to census at RWPG.....	18
Figure 6: Regional Water Planning Group (RWPG) level final projections from all planning years	19
Figure 7: County level quadrant plots of percentage differences between a) 2017 and b) 2022 draft and final population projections for 2020 with census	21
Figure 8: Spatial distribution of differences between draft and final population projections with census at county	22
Figure 9: County level Cumulative Distribution Function (CDF) of magnitude and percentage differences between draft and final population projections a.	22
Figure 10: County level draft and final projections from all planning years a) Mean Absolute error (MAE) and b) Mean Percent Error (MPE).	24
Figure 11: Water User Group (WUG) level quadrant plots of percentage differences between a) 2017 and b) 2022 draft and final population projections for 2020 with census.	26
Figure 12: Spatial distribution of differences between draft and final population projections with census at Water User Group (WUG) level	27
Figure 13: Water User Group (WUG) level Cumulative Distribution Function (CDF)	28
Figure 14: Water User Group (WUG) level draft and final population projections from all planning years a) Mean Absolute Error (MAE) and b) Mean Percent Error (MPE) .	30
Figure 15: Cumulative Distribution Function (CDF) of a) magnitude b) percent differences between rural and urban SWP draft and final populations.....	32
Figure 16: Draft and final population projection differences with census in select cities across the different planning and projection years.....	33
Figure 17: Comparison of final water demand projection to actual water use at Regional Water Planning Group (RWPG).....	35
Figure 18: County level Cumulative Distribution Function (CDF) of draft and final water demand projections	37
Figure 19: Spatial distribution of differences between final water demand projections with actual water use at county level	39
Figure 20: Spatial distribution of differences between final water demand projections with 2011 water use at county level	40

Figure 21: Spatial distribution of differences between final water demand projections with maximum (2000-2020) water use at county level	41
Figure 22: Comparison of 2017 and 2022 population projections difference with census with final water demand difference	43
Figure 23: Margin Error (MOE) for Mean Absolute Error (MAE) of water demand projection compared to actual water use at county level.....	44
Figure 24: Water User Group (WUG) level quadrant plots of percentage differences between a) 2017 and b) 2022 draft and final water demand projections	45
Figure 25: Spatial distribution of differences between draft and final water demand projections with actual water use at Water User Group (WUG) level.	47
Figure 26: Spatial distribution of differences between draft and final water demand projections with drought year 2011 water use at Water User Group (WUG) level.	48
Figure 27: Spatial distribution of differences between draft and final water demand projections with maximum water use at Water User Group (WUG) level.	49
Figure 28: Water User Group (WUG) level Cumulative Distribution Function (CDF) of draft and final water demand projections.....	50
Figure 29: Margin Error (MOE) and 95% Confidence Interval (CI) for Mean Absolute Error (MAE) water demand projection.	51
Figure 30: Water User Group (WUG) level Cumulative Distribution Function (CDF) of 2017 and 2022 SWP urban and rural	52
Figure 31: Difference between projected and actual Gallons Per Capita per Day (GPCD) across plans at Water User Group (WUG) level	55
Figure 32: Spatial distribution of differences between projected and actual Gallons Per Capita per Day (GPCD) across plans at Water User Group (WUG) level.....	56
Figure 33: Major Cities a) Trend of population, Gallons Per Capita per Day (GPCD), and reported water use b) City GPCD comparisons.....	57
Figure 34: Population and Gallons Per Capita per Day (GPCD) error attribution across plans using refined Laspeyres decomposition error attribution.	58
Figure 35: Population and Gallons Per Capita per Day (GPCD) error attribution: Logarithmic Mean Divisia Index (LMDI) Decomposition Analysis.....	59
Figure 36. Planning horizon frequency and update goals for the 22 states west of the Mississippi River.....	147

List of Tables

Table 1: Percentage difference between state level TDC projection vintages and Census data ... 14

Table 2: Percentage difference between state level population projection and census 16

Table 3: Percentage of counties with better fit to census in draft and final projections. 20

Table 4: Percentage of underestimating counties compared to census. 20

Table 5: Percentage of WUGs with better fit to census in draft and final projections. 26

Table 6: Percentage of underestimating WUGs compared to census. 26

Table 7: Draft and final State Water Plan (SWP) population projections percentage differences
with census of select cities. 31

Table 8: Discrepancies between draft and final water demand projections against actual water
use in major cities for 2022 SWP 52

List of Acronyms and Abbreviations

af	Acre Feet
CDF	Cumulative distribution function
CI	Confidence Intervals
D	Demand
GPCD	Gallons per capita per day
LMDI	Logarithmic Mean Divisia Index
MAE	Mean Absolute Error
MOE	Margin of Error
MPE	Mean Percent Error
P or Pop.	Population
RWPG	Regional Water Planning Group
SD	Standard Deviation
SE	Standard Error of the mean
SWP	State Water Plan
TDA	Texas Department of Agriculture
TDC	Texas Demographic Center
TCEQ	Texas Commission on Environmental Quality
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
WUG	Water User Group

1. Introduction

State water planning is an integral part of the Texas Water Development Board's (TWDB) mission. Although the first State Water Plan (SWP) was published in 1961, the passage of Senate Bill 1 in 1997 established the current regional water planning process, requiring the state plan to be updated every five years. Under 31 Texas Administrative Code (TAC) § 357.31 and § 358.4, the TWDB is tasked with developing population and water demand projections for each Water User Group (WUG). Since 1997, this five-year cycle has produced six iterations of regional water plan projections. The SWP represents the long-term plan that is designed to ensure adequate water supplies for Texas during a recurrence of the drought of record. Among the many objectives of the SWP is the support of reliable water supplies for all major water-use sectors, including municipal, irrigation, manufacturing, mining, livestock and steam electric power generation. A new 2027 SWP will be adopted in July. This most recent SWP (2027) projects Texas' population to increase from 34.2 million to 52.3 million by 2080. Texas has experienced the most rapid population growth of any state within the US over the past 5 years. Water demand for irrigation is projected to decrease whereas water demand for the municipal sector is projected to rise continuously and represent the sector with the highest water demand in 2060 (TWDB, 2027) .

TWDB develops municipal population and water demand projections as part of the regional and state water planning process. The initial step in the process includes the county level population projections developed by the Texas Demographic Center, which are disaggregated into individual, stand-alone Water User Groups (WUGs), typically larger cities and utilities, and County-Other WUGs, which aggregate rural areas outside utility service areas along with smaller utilities that do not independently qualify as stand-alone WUGs. Because County-Other historical water use is derived by reaggregating raw utility- and county-level data rather than compiled from direct utility reporting, it is best understood as an estimate rather than as directly observed Census or metered water use. Baseline water use (gallons per capita per day, GPCD) is estimated for each municipal WUG using historical water-use data from TWDB Water Use Surveys, utility reports, service area populations, and water sales information. Long-term projections (50 yr) account for conservation from plumbing code savings.

Future water use is calculated from population times GPCD. Texas Water Development Board (TWDB) develops draft state water plans providing population and water demand decadal projections every 5 years for 16 regional water planning groups (RWPGs) based on a uniform methodology. To formulate its draft water-use projections, the TWDB combines draft demographic projections with a dry-year GPCD baseline and factors in projected conservation resulting from plumbing code savings. This underlying dry-year GPCD is derived by taking a municipality's net water use, calculated as total intake volumes minus sales to municipal wholesale and industrial entities, and dividing it by the empirical census population recorded during that designated drought year. The draft population and water uses are converted into final projections using data and information from the Texas Commission on Environmental Quality (TCEQ), Texas Dept. of Agriculture (TDA), Texas Parks and Wildlife Department (TPWD), planning groups, and the public.

TWDB transitioned from a city-based municipal water user group (WUG) framework to a utility-based framework during the 5th regional water planning cycle, which culminated in the 2021

Regional Water Plans and was incorporated into the 2022 State Water Plan. Prior state water plans generally defined municipal WUGs based on cities and towns, whereas the utility-based approach reflects actual water service providers. Utility-based planning allows a more efficient planning process by planning directly for the entities in charge of providing water. These changes resulted in a slight increase in the number of WUGs.

The objective of this study was to review TWDBs population and municipal water demand projection methodologies to improve the reliability and quality of the projections and to simplify the process from draft to final projections into the regional water plans.

To address this objective, a number of tasks were conducted:

1. A literature review of population and municipal water demand projections developed by other state agencies responsible for water supply planning, and review other agencies and organizations population projections methodologies
2. Assessment of the accuracy of the county-level population projections generated by the State Demographer over the past planning cycles when compared to decennial Census count populations by the US Census Bureau
3. Evaluation of the accuracy of the Texas regional and state water plan population projections over the past planning cycles when compared to historical populations by the US Census Bureau at RWPG, county and WUG levels
4. Determination of the accuracy of the Texas regional water plans' municipal water demand projections over the past planning cycles when compared to reported / estimated use at RWPG, county and WUG levels
5. Exploration of ways to address uncertainty in projections as a means of providing flexibility in selecting the magnitude of and/or shifting geographic locations of some portion of projected populations (these would also translate into equivalent water demand shifts) and determine the right geographic scale(s) at which to allow various degrees of flexibility. This work would result in a reasonable allowance for flexibility for RWPGs to revise TWDB's draft population and municipal water demand projections.

2. Methodology

The methodology was developed and implemented following the framework described in sections 2.1 to 2.3 and Figure 1. All associated data are available in supplementary information (Table SI). The following sections provide a brief description of the methods used for comparing projected population, water demand, and GPCD estimates with available observation-based estimates.

2.1. Literature Review and Bibliography

We conducted a literature review of how other states in the Western US develop population projections and municipal water demand projections to support their water supply planning efforts, and the length of the state’s planning horizon for which they are projecting (Appendix 7.2). We also reviewed other agencies in Texas, including the Harris-Galveston and Fort Bend Subsidence Districts Joint Regulatory Plan Review, North Texas Municipal Water District, North Central Texas Council of Governments, Capital Area Council of Governments, and Texas Department of Transportation (Appendix 7.3).

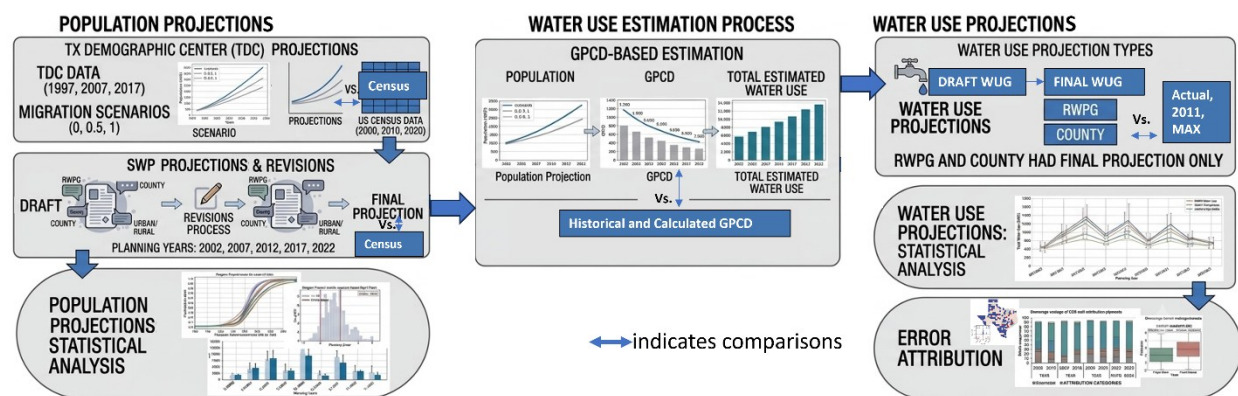


Figure 1: Workflow illustrating the methods used in the study. We compared the Texas Demographic Center (TDC) county population projection against US census data. Furthermore, both draft and final State Water Plan (SWP) population projections were benchmarked against census data at various spatial levels (Regional Water Planning Groups (RWPG), County, and Water User Groups (WUGs)). Key to acronyms inside the figure: TCEQ = Texas Commission on Environmental Quality; TDA = Texas Department of Agriculture; TPWD = Texas Parks and Wildlife Department.

2.2. Assessing Reliability of Population and Water Demand Projections

The study area comprises 16 RWPGs that collectively divide the state’s 254 counties, with Water User Groups (WUGs) serving as the highest-resolution spatial unit (Figure 2). Reflecting evolving demographic boundaries, the WUG sample size scales from 974 in 2002 to 1,334 in 2007 and 2012, 1,363 in 2017, and 1,618 in 2022. Population size is highly heterogeneous across these scales, with the highest values concentrated within major urban corridors, including Houston, Dallas-Fort Worth, El Paso, Austin, and San Antonio.

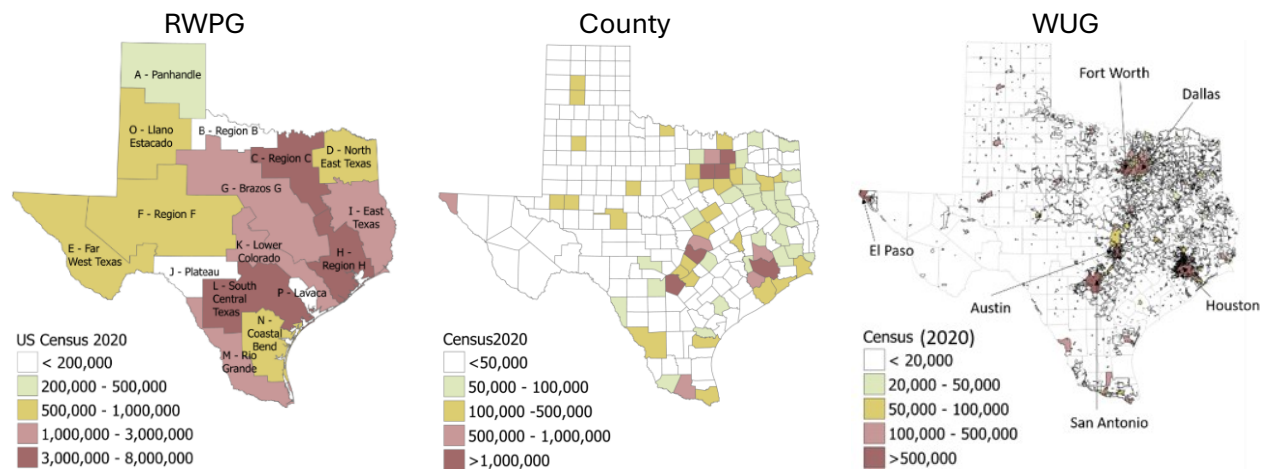


Figure 2: Census population (for 2020) in regional water planning groups (RWPGs), counties and Water User Groups (WUGs).

2.2.1. Assessing Reliability of Population Projections

TWDB initiates its population projection process by developing draft estimates using a uniform, top-down methodology applied statewide. For initial county-level projections, the TWDB relies on the TDC data, draft SWP projections were developed using the most recent TDC vintage, which utilizes the standard cohort-component method. This procedure estimates future populations by analyzing separate cohorts based on age, sex, and race/ethnicity, tracking changes through defined rates of births, deaths, and migration. Subsequently, the TWDB sub-allocates these county populations down to individual municipal Water User Groups (WUGs) by applying historical growth data, thereby generating the initial, granular draft estimates. Central to this methodology is the assumption of net migration rate, as birth and survival rates tend to align more closely with historical trends. TDC generates projections using multiple migration scenarios to model potential future population movements:

1. Natural Increase (0.0) Scenario: Assumes zero net migration, meaning all projected population change is solely attributable to the natural difference between births and deaths.
2. Half-Migration (0.5) Scenario: Assumes that migration rates for each population cohort occur at half the rate estimated during the reference decade (e.g., 2000–2010 or 2010–2020).
3. Full Migration (1.0) Scenario: Assumes that migration rates for each population cohort maintain the same rate observed during the reference decade.

to evaluate the accuracy of county-level population projections from the Texas Demographic Center (TDC), we benchmarked historical projections against U.S. Census Bureau counts for 2000, 2010, and 2020. This validation assessed three distinct projections from TDC, specifically those used in 1997, 2007, and 2017 draft SWPs. Each projection was evaluated against subsequent Census benchmark data: the 1997 projection against 2000, 2010, and 2020 Census data; the 2007 projection against 2010 and 2020 data; and the 2017 projection against 2020 data.

Although the full or a composite migration scenario may be applied in specific counties with locally observed rapid growth, the TWDB applies the Half-Migration Scenario for the majority of counties for long-term planning. The reasons for selecting this baseline is the recommendation by the Texas State Demographer for long-term projections.

The draft population projections serve as the starting point for a critical review period that ultimately leads to the final, TWDB-adopted numbers. This involves RWPGs and their consultants reviewing the draft WUG-level population projections and consulting with local utilities, municipalities, and economic development corporations to pinpoint local factors, such as new major employers or residential developments, that the uniform statewide model may have overlooked. Following this review, the RWPGs formally submit revision requests to the TWDB, which must be supported by detailed documentation justifying the change; these revisions frequently focus on refining the spatial distribution of population growth. Any requested increase in population projections for a county or WUG must be accompanied by a matching decrease in projections for another – minimal increases in regional population projection totals are considered. Finally, TWDB staff evaluates these justifications, consulting with other state agencies as necessary, before proposing the final set of projections for TWDB adoption, which are then mandatory for use in the State Water Plan. This iterative process, which combines sophisticated statewide modeling with essential local knowledge, is designed specifically to enhance the accuracy and credibility of the population projections for local water supply planning.

In this report, the draft and final projected populations in the SWP were compared with US decennial census population at different spatial levels: RWPG, county, WUGs (including urban and rural WUGS), County Other Water User groups (i.e. small, rural water systems that are aggregated utilities that provide less than an average of 100 acre-feet per year (af/yr), as well as rural areas not served by a water utility in a given county).

Projected population from 2002, 2007, 2012, 2017 and 2022 planning years were compared with census on projected years of 2000, 2010, and 2020. We used City IDs for 2000, 2010 and water utility Entity IDs for the 2017 and 2022 planning period for 2020. TWDB developed a bridge to connect City IDs and entity IDs in 2017 accounting for both IDs. The excel files provide the bridge used for connecting the two IDs (Table S13).

We computed the error magnitude and the percentage of error compared to the total census population to assess how the projections diverged from census values. We used Cumulative Distributions Functions (CDFs) to show over and under estimations, identifying where over estimations or underestimations were most pronounced across the population distribution.

2.2.2. Assessing Reliability of Water Demand Projections

Water demand is estimated from population times per capita water use (GPCD). TWDB develops draft water use projections using draft population projections, representative dry year GPCD (e.g., 2011 or 2022), and any plumbing code savings (equation 1). Dry year GPCD is calculated as net use (sum of intake volumes minus sum of sales volumes to municipality wholesale & industrial) divided by the residential population. TWDB develops draft water demand projections for 16 Regional Water Planning Groups (RWPGs) for municipal water use (single/multi family, commercial and institutional water use) and five non-municipal water uses (irrigation, livestock, manufacturing, mining, and steam-electric power).

Draft Water demand Projection = Draft Population Projections *

$$\text{Dry Year GPCD} - \text{Any Efficiency Savings} \quad (1)$$

The final projections are based on revisions on the draft projections using feedback from RWPGs. The revision is based on evidence of data errors in calculation of dry year water use, evidence that dry year water use was abnormal due to temporary physical infrastructure constraints, evidence of select instances where rapid growth and commercial/institutional development may increase per-person use or evidence of a different fixture installation schedule (note: these criteria represent examples and are not limited to those listed). RWPGs rely on data from WUGs to request adjustments on water demand projections.

Similar to population projection evaluation we compared municipal water demand projections from 2002, 2007, 2012, 2017, and 2022 SWP with actual water use (net use) for 2000, 2010 and 2020. 2002 projections for 2000, 2010 and 2020, 2007 projections for 2010 and 2020, 2012 projections for 2010 and 2020 and 2017 and 2022 projections for 2020 were compared with actual water use at the state, RWPG, county, WUG, and select county other levels where robust data was available.

We calculated the CDFs of the differences and percentage difference between water demand projections (draft and final) and actual water use for projections from each planning period to assess if there are any systematic over /under estimations across plans and projections.

In addition, we benchmarked the projected water demand against observed water use from 2011—historically one of the driest years on record in Texas—as well as the maximum recorded water use spanning the 2000–2020 period. This comparative evaluation serves to assess the structural validity and performance of the projection models under extreme hydrological conditions.

2.2.3. Gallons per Capita per Day (GPCD) Comparison

We compared the “Base Dry-Year GPCD,” with 2012, 2017, and 2022 GPCDs and also with the GPCD we calculated using equation 2 to check consistency of the draft GPCD estimates.

$$\text{GPCD} = \frac{\text{Net Water USe}}{\text{Census Population}} \quad (2)$$

2.2.4. Uncertainty Analysis

We calculated the Mean Absolute Error (MAE), Mean Percentage Error (MPE), the Standard Deviation (SD), and the 95th percentile Confidence Intervals (CI) of the MAE. These metrics were used to quantify the difference between draft and final population projections relative to census data, and the draft and final water demand projections relative to actual water use, using the following equations. Furthermore, errors in underestimation and over estimation were evaluated by separately calculating the margin of error for under and over estimations.

$$\text{Mean Absolute Error (MAE)} = \frac{\sum_0^n \text{Projection} - \text{Census}}{n} \quad (3)$$

$$\text{Mean Percentage Error (MPE)} = \frac{\sum_0^n (\text{Projection} - \text{Census}) / \text{Census}}{n} \quad (4)$$

$$\text{Standard Error (SE) of the mean} = \frac{SD}{\sqrt{n}} \quad (5)$$

$$\text{Margin of Error (MOE)} = t_{\alpha/2, df} \times SE \quad (6)$$

$$95\% \text{ Confidence Interval Upper Bound} = \text{MAE} + \text{MOE}$$

$$95\% \text{ Confidence Interval Lower Bound} = \text{MAE} - \text{MOE}$$

where n is number of observations, SD is standard deviation based on samples, $t_{\alpha/2, df}$ = critical t-value at significance level α and degrees of freedom $df=n-1$

2.2.5. Cumulative Distribution Function (CDF)

The Cumulative Distribution Function (CDF), $F_X(x)$, is a fundamental concept in probability theory that describes the probability that a continuous random variable X will take a value less than or equal to a specific value x. Mathematically, the CDF is defined as:

$$F_X(x) = P(X \leq x) \quad (7)$$

The Cumulative Distribution Function (CDF) is used to quantify percentage of values with in a given interval [a, b]. We used it to quantify the percentage of under and overestimations in population projections (when compared with census) and water demand projections (when compared with actual, 2011 and maximum water uses). A CDF interpretation example using random population data is given in the supplementary (Figure S6). In the CDF plots presented in this report, the horizontal axis shows the error or percentage difference (e.g., over- or underestimation of population or water use), and the vertical axis shows the cumulative percentage of counties or WUGs at or below that error value. A curve that rises steeply near zero indicates that most counties or WUGs had small errors, while a curve that is shifted right or left indicates a systematic over- or underestimation, respectively. Where the curve crosses the 50th percentile identifies the median error for that group, and comparing the horizontal position of two curves at the same percentile shows the relative difference in typical error magnitude between the groups being compared (e.g., urban versus rural, or draft versus final plans).

2.3. Drivers of Errors in Water Demand

Error analysis was conducted to determine whether the water demand projections deviate from the actual water use as a result of population projection errors or GPCD errors.

2.3.1. Qualitative Error Attribution

We conducted a qualitative analysis to determine whether overestimations in water use aligned with overestimations in population. For each county, we assessed whether water use discrepancies tracked population trends. If a water use overestimation coincided with a population overestimation, the error was primarily attributed to population projections. Conversely, if water demand and population trends diverged, it indicated that population was not the primary driver of the errors in the water use projections.

2.3.2. Refined Laspeyres Decomposition Error Attribution

Errors in population and GPCD projections were quantified, and their relative attribution to the total water demand error across plans was estimated using the following refined Laspeyres decomposition error attribution (Sun, 1998) equations:

$$\text{Total error } E = E_{\text{Pop}} + E_{\text{GPCD}} + E_{\text{Pop_GPCD}} \quad (8)$$

$$\text{Population Attribution: } E_{\text{Pop}} = (\text{Pop}_{\text{proj}} - \text{Pop}_{\text{act}}) \times \text{GPCD}_{\text{act}} \quad (9)$$

$$\text{GPCD Attribution: } E_{\text{GPCD}} = \text{Pop}_{\text{act}} \times (\text{GPCD}_{\text{proj}} - \text{GPCD}_{\text{act}}) \quad (10)$$

$$\text{Residual (Interaction) Attribution: } E_{\text{Pop_GPCD}} = (\text{Pop}_{\text{proj}} - \text{Pop}_{\text{act}}) \times (\text{GPCD}_{\text{proj}} - \text{GPCD}_{\text{act}}) \quad (11)$$

$$\text{Total Error in Water Demand} = (\text{Pop}_{\text{proj}} \times \text{GPCD}_{\text{proj}}) - (\text{Pop}_{\text{act}} \times \text{GPCD}_{\text{act}}) \quad (12)$$

where: E = estimated, and subscript Pop = population, subscript GPCD = gallons per capita per day, subscript act is actual and subscript proj is projected.

The decomposition was applied across planning cycles using paired projected and observed values for each WUG (We have provided a separate linked excel file as Table S20).

2.3.3. Logarithmic Mean Divisia Index (LMDI) Decomposition Analysis

Logarithmic Mean Divisia Index (LMDI) can break down changes in an aggregate indicator like water demand into contributing factors, such as population and GPCD (Ang, 2005). It can handle error attribution or rather the lack thereof. It has been widely used in environmental economics.

LMDI is a perfect decomposition method i.e. there is no residual term (Total Error = Effect of population + Effect of GPCD): In many models, such as the conventional or Refined Laspeyres index method, there is a "leftover" gap between the actual change and the sum of the explained factors:

$$\Delta D = \underbrace{\Delta P \cdot \text{GPCD}_{\text{act}}}_{\text{Population Effect}} + \underbrace{\Delta \text{GPCD} \cdot P_{\text{act}}}_{\text{GPCD Effect}} + \underbrace{\Delta P \cdot \Delta \text{GPCD}}_{\text{Interaction Residual (R)}}$$

Where $\Delta P = P_{\text{proj}} - P_{\text{act}}$, $\Delta \text{GPCD} = \text{GPCD}_{\text{proj}} - \text{GPCD}_{\text{act}}$, and $R = \Delta P \cdot \Delta \text{GPCD}$ represents an unallocated structural interaction term ($R \neq 0$).

However, LMDI eliminates this residual ($R = 0$). LMDI is also symmetrical: it satisfies the factor-reversal test, meaning the results are consistent whether you look at the change from Year A to Year B or vice versa.

$$E_{\text{pop}} + E_{\text{GPCD}} = D_{\text{proj}} - D_{\text{act}} \quad (13)$$

$$D = P \times \text{GPCD} \text{ where } \text{GPCD} = D/P;$$

Total water demand is defined as $D = P \times \text{GPCD}$, where $\text{GPCD} = \frac{D}{P}$. LMDI solves errors using a

$$\text{specific weight: } w = \text{weight} = \frac{D_{\text{proj}} - D_{\text{act}}}{\ln(D_{\text{proj}}) - \ln(D_{\text{act}})} \quad (14)$$

$$\text{Population Contribution (E}_{\text{pop}}\text{): } w \times \ln\left(\frac{P_{\text{proj}}}{P_{\text{act}}}\right) \quad (15)$$

$$\text{GPCD Contribution (E}_{\text{GPCD}}\text{): } w \times \ln\left(\frac{\text{GPCD}_{\text{proj}}}{\text{GPCD}_{\text{act}}}\right) \quad (16)$$

Where: D_{proj} = Projected aggregate water demand, D_{act} = Actual observed aggregate water demand, P_{proj} = Projected population size, P_{act} = Actual population size, $\text{GPCD}_{\text{proj}}$ = Projected per capita water use rate, GPCD_{act} = Actual per capita water use rate, E_{pop} = Estimated error contribution attributed to population projections, E_{GPCD} = Estimated error contribution attributed to GPCD projections

By using this specific weight, the sum of the log-changes of the population and GPCD perfectly equals the log-change of the total water use. This ensures that 100% of the variation is attributed to population and GPCD, leaving no unexplained portion. This makes this method useful for analyzing whether the water demand projections deviate from the actual water use as a result of population projection errors or GPCD errors supplementing the Refined Laspeyres Decomposition error attribution.

3. Results and Discussions

To provide context for regional practices, a comparative literature review was conducted to evaluate the population and municipal water demand projection methodologies used by other U.S. states for long-term water supply planning (Appendix 7.2). The review examined differences in planning horizons, projection methods, and forecasting assumptions. A parallel review of the forecasting frameworks used by selected Texas agencies—including the Harris-Galveston and Fort Bend Subsidence Districts Joint Regulatory Plan, the North Texas Municipal Water District, the North Central Texas Council of Governments, the Capital Area Council of Governments, and the Texas Department of Transportation—is presented in Appendix 7.3. The following sections present results from analyses of population, municipal water demand, and GPCD projections.

Overall, the other states reviewed share some elements with the Texas framework but differ in granularity and structure. Most peer states examined, including Missouri, North Dakota, and South Dakota, derive per-capita water use estimates directly from utility or supplier reporting tied to local population estimates, without a single standardized statewide baseline. Several states, such as Oklahoma (Water for 2060) and Washington (Water Use Efficiency rules, which cap system leakage at 10%), explicitly incorporate conservation or efficiency assumptions into their demand projections, similar to use of plumbing-code-driven savings in Texas.

The Texas approach is comparatively more formalized and granular, relying on a statewide network of utility-service-area-based Water User Groups, a standardized Water Use Survey baseline, and a mandated five-year planning cycle. However, as with most of the states reviewed, The Texas baseline water-use data ultimately depends on self-reported utility data rather than independently verified measurements, a limitation shared broadly across the states surveyed.

3.1. Population Projections

One of the primary concerns when evaluating population projections is the potential for underestimating population because that could result in underestimation in water demand projections. However, there are also concerns about overestimating the magnitude of projected populations to remain consistent with state population. TWDB evaluates population projections at the Water User Group (WUG), county, Regional Water Planning Group (RWPG), and state level, hierarchically constraining these estimates using the next largest spatial resolution (specifically, WUGs roll up to county, counties roll up to RWPG, and RWPGs roll up to the state level) (Figure 2). Population underestimations and overestimations were explicitly accounted for during the population-level evaluation of the projections.

Population evaluations generally show that as the projection horizon extends in time, the reliability of the projections degrades and discrepancies between population projections and census data tend to increase. In general, the magnitude of discrepancies between projections and census data increases with population size, whereas the percentage discrepancies generally decrease with population size because percentages are normalized by population size, thereby reducing the influence of population size (Figures S1, S2 and S4, and Tables S19a and S19b).

3.1.1. Accuracy of Texas Demographic Center (TDC) County Population Projections relative to US Census

For all three TDC migration scenarios (0.0, 0.5, and 1.0), discrepancies between county-level population projections used in the 1997, 2007, and 2017 draft SWP and actual Decennial Census data (2000, 2010, and 2020) increased for projection years further into the future. (Table 1, Figure 3a and 3f). Recent projections (2007 and 2017) demonstrated considerably less population underestimation across all migration scenarios compared to earlier projections (1997), evidenced by the step increase in the median magnitude differences relative to the census (Figure 3a).

The optimal migration scenario required to minimize the magnitude and percent discrepancies between TDC, and census projections varies depending on the specific projection period.

Discrepancies between TDC and census were slightly lower for migration scenario of 0.5 for the 2007 and 2017 plans based on both magnitude and percent discrepancies (Table 1, Figures 3c–3f).

In terms of magnitude, discrepancies between the TDC and the census correlated positively with county population (Figure 4a); that is, small discrepancies were observed in counties with relatively smaller populations, and vice versa (as shown by lines close to 0 in the cumulative plots for census counties with a population less than 24,000) (Figure S1). The percentage differences were smaller for populated counties compared to less populated counties (Figure 4b).

Counties with population increase from 2000-2020 show more overestimation than counties that shrank in population (Figure 4c and 4d).

Table 1: Percentage difference between state level TDC projection and actual Decennial Census data (county aggregate)

Population Plan year	Migration Scenario	% Difference Projection year		
		2000	2010	2020
1997	0	-10	-21	-28
1997	0.5	-7	-13	-16
1997	1	-2	-4	-2
2007	0		-10	-17
2007	0.5		-4	-5
2007	1		3	11
2017	0			-6
2017	0.5			-1
2017	1			5

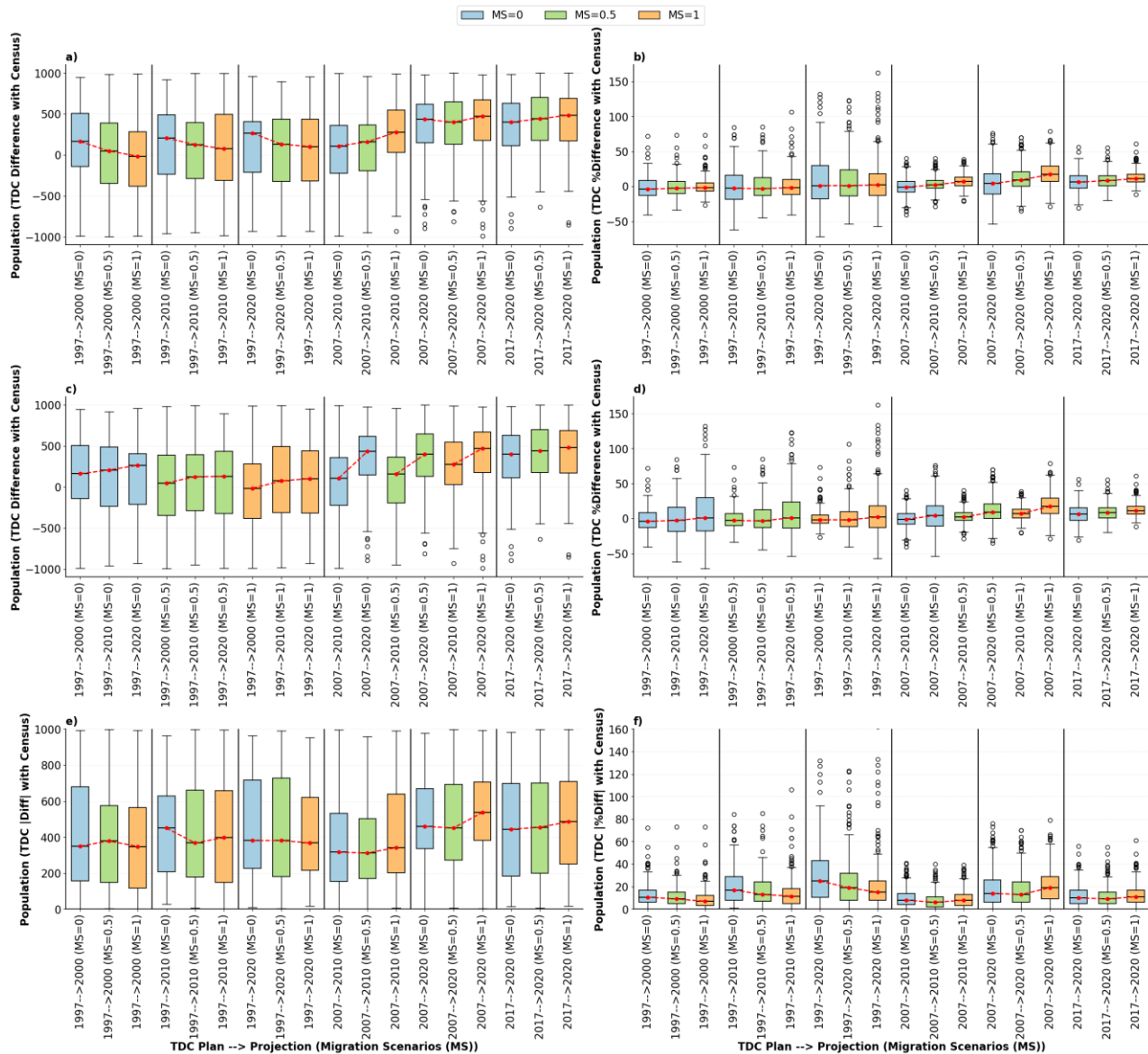


Figure 3: Difference between TDC population and US Census, under the different migration scenarios (M is million) a) difference with census arranged based on migration scenario b) %difference with census arranged based on migration scenario c) difference with census arranged based planning and projection year d) % difference with census arranged based on arranged with planning à projection year e) absolute difference with census arranged based on arranged with planning à projection year f) absolute % difference with census arranged based on arranged with planning à projection year (Data provided in Table S1).

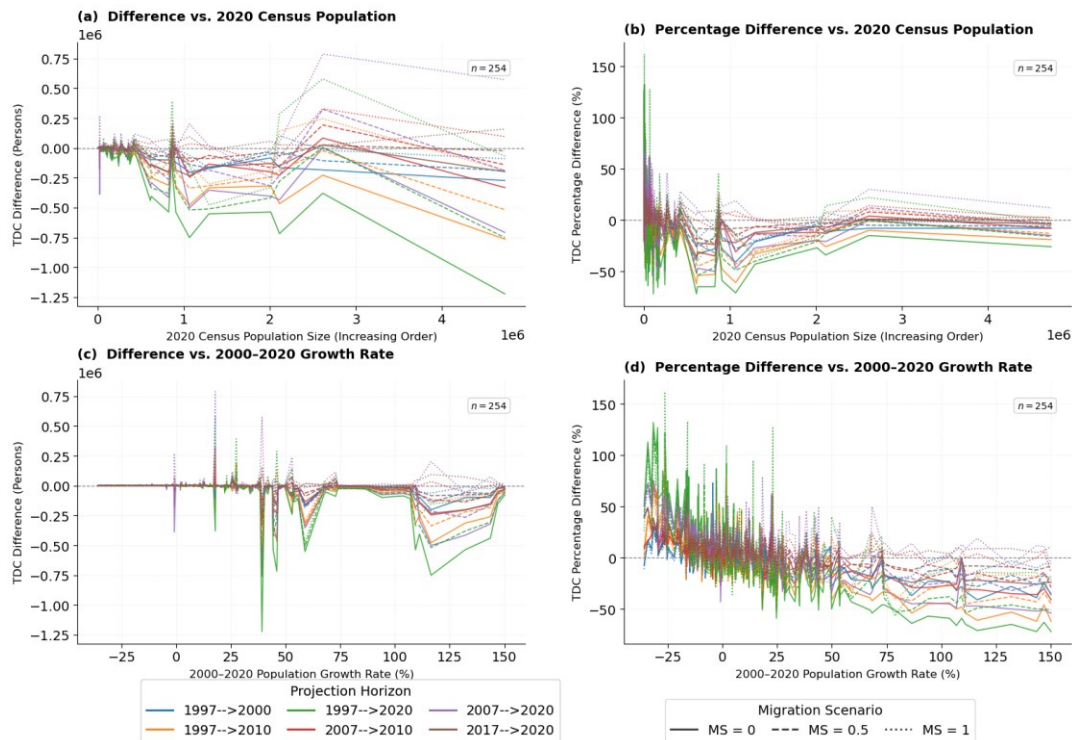


Figure 4: TDC comparison with census a) differences and b) percent differences plotted against increasing 2020 census population. c) differences and d) percent differences plotted against population changes from 2000 to 2020

3.1.2. Population Projections at the State Level relative to US Census

At the state level, aggregating the county population to the state level, underestimations were generally more common in draft projections (Table 2). Final projections reduced these underestimations compared to the census in all plans and projections, with the sole exception of the 2007 projection for 2010. Looking at the most recent planning cycles, the 2022 plan did not show underestimations compared to the census. Instead, both the draft and final projections overestimated compared to the census; the draft overestimated by 364,679 (1%) and the final by 549,840 (2%). In contrast, the 2017 planning cycle shows a marginal draft underestimation of -25,267 (-0.1%), but its final projection ultimately resulted in an overestimation of 364,679 (1.3%).

Table 2: Percentage difference between state level population projection and census Final (draft)

Population	% difference		
	Projection year		
Plan year	2000	2010	2020
2002	0.1 (-3)	-2 (-7)	-1 (-6)
2007		-1 (-0.1)	0.1 (-0.1)
2012		1 (-1)	2 (-0.1)
2017			1.3 (-0.1)
2022			2 (1)

3.1.3. Population Projections at Regional Water Planning Group (RWPG) Level relative to US Census

The difference between draft and final projections at the RWPG level was negligible. According to the 2020 census data, the RWPG populations range from 51,000 to 7.7 million (Figure 2a). The more recent planning periods in the State Water Plan (SWP) (2017 and 2022) show slightly reduced underestimation of the projected population relative to the census in comparison with earlier planning periods (2002, 2007, 2012) for most RWPGs (Figures 6a-6e). Highly populated RWPGs show projections from earlier planning periods (2002, 2007, and 2012) consistently underestimating populations when compared to census values, with discrepancies increasing for longer planning horizons.

In terms of population magnitude, the most significant absolute discrepancies are concentrated within the most densely populated RWPGs, specifically Region C (encompassing the Dallas-Fort Worth metroplex), Region H (encompassing Houston), and Region M (encompassing Laredo) (Figures 5a-5e). Error patterns in Region C varied over time: significant underestimation occurred in the 2002, 2017, and 2022 planning periods, while overestimation was noted in the 2007 and 2012 planning periods. Region H exhibited a persistent underestimation bias across earlier planning periods (2002, 2007, and 2012), although recent plans (2017 and 2022) showed slight overestimation. Conversely, Region M consistently overestimated the census population across all plans, with the most notable overestimation occurring in the 2012 plan's projection for 2020.

Consistent with general findings, percentage differences between SWP and census population projections increased with the projection period, rising from 3% (2002 projection for 2000) to 4% (for 2010), and reaching 8% in the 2020 projection (Figures 5a). This escalating percentage error was consistent across all planning cycles evaluated against target Census years. Specifically, multi-decade retrospectives comparing projections against both 2010 and 2020 Census figures apply to the 2002, 2007, and 2012 plans, while the 2017 and 2022 plans were evaluated against the 2020 Census target). Similarly, discrepancies in population percentages were negatively correlated with population size with exceptions of high-population Regions H and K which show larger underestimation percentage in the earlier plans, a discrepancy that was largely mitigated in the recent plans (2017, 2022). These regional trends collectively indicate a general reduction in underestimation severity in the most recent planning cycles.

Low populated RWPGs (E, J, and N) consistently exhibited the largest percentage overestimation compared to census data across all plans (spikes in the dotted percentage lines in Figures 5a-5e). The percentage difference compared to census in these regions decreased to less than 15% in recent plans (2017, 2022), down from more than 20% in the 2002 plan.

Analysis of the recent 2017 and 2022 planning cycles demonstrate notable advancements in projection accuracy, yielding the lowest overall median errors and tightly constrained confidence intervals across both underestimating and overestimating cohorts (Figures 6). Underestimation errors and their associated variances were consistently lower than those observed for overestimation. This suppressed volatility among underestimating cohorts may be a statistical artifact of a smaller sample size, as evidenced by the occasionally wide margins of error relative to the absolute error magnitudes. Consistent with these general findings, an evaluation of summary error metrics confirms a systematic pattern of compounding uncertainty across longer-term projection horizons. As shown in Figure 6, both the Mean Absolute Error (MAE; Figure 6a)

and Mean Percentage Error (MPE; Figure 6b) expand alongside their 95% confidence interval widths as the forecasting horizon extends.

Magnitude and percentage differences between final population projections against census (RWPG)

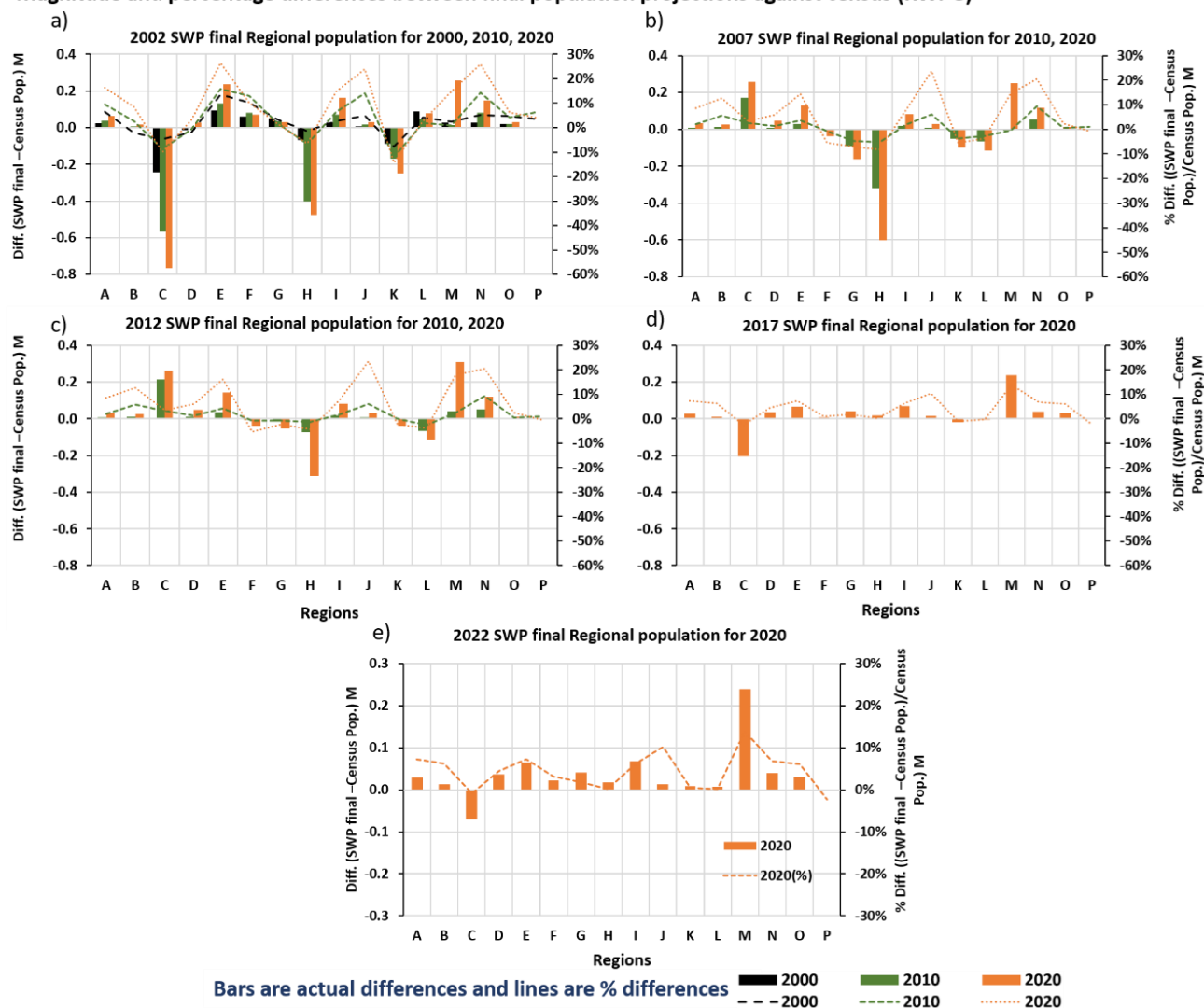


Figure 5: Comparison of final population projection to census at RWPG. Bars: absolute difference; dashed line, percentage difference (Data provided in Table S2).

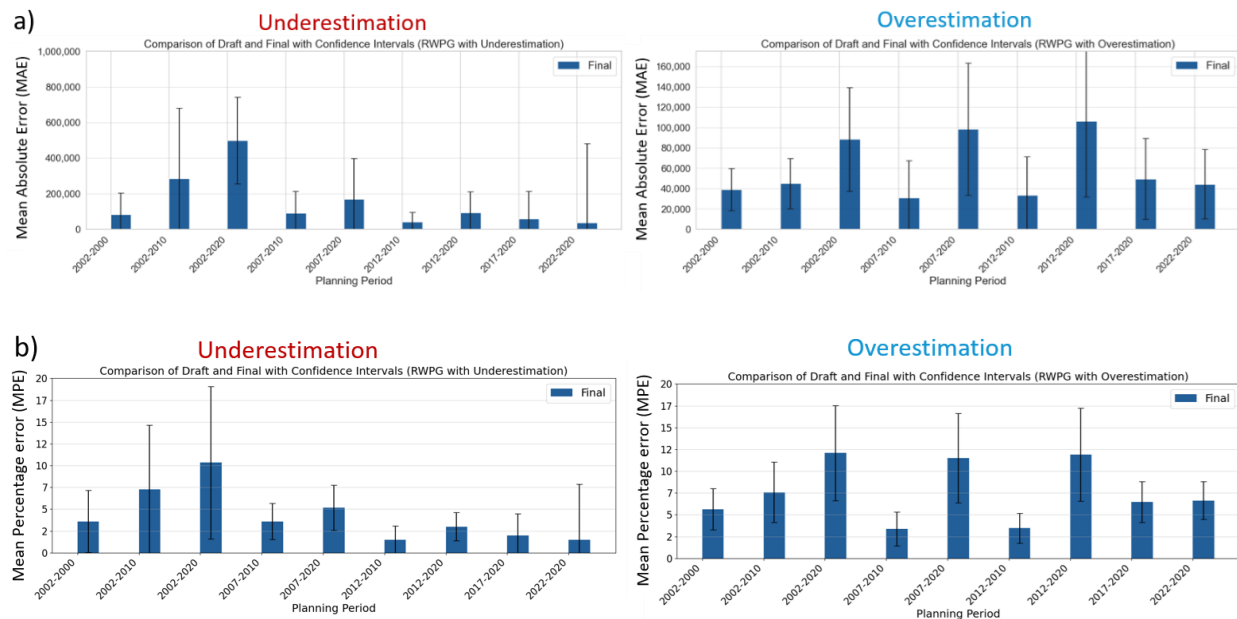


Figure 6: Regional Water Planning Group (RWPG) level final projections from all planning years a) Mean Absolute error (MAE) and b) Mean Percent Error (MPE) with 95% confidence interval when compared with census (Data provided in Table S2, S14 and S15). The bars show mean percentage and the lines show uncertainty ranges expressed as 95% confidence intervals.

3.1.4. Population Projections at the County Level relative to US Census

The final and draft projections were identical in the majority of counties (e.g., 84% of counties in 2017 and 91% in 2022) (Figure 7). Only a limited number of counties showed revisions that resulted in changes to the draft projections. Overall, these revisions yielded relatively closer estimates to the census data than the draft projections, with six of the nine final projections closer to the census (Table 3). Specifically, in the recent plans (2017 and 2022), the final projections consistently resulted in smaller errors (more percentage of counties close to census, (Table 3) and smaller underestimation (Figure 7)) compared to the draft, indicating that the revision process successfully reduced county-level underestimation errors.

This pattern of final projections less prone to underestimation than draft projections is evident in several instances (Table 4). Although underestimations were consistent in both the draft and final projections in the most recent 2022 plan (both affecting under 15% of counties), the 2017 plan showed less underestimation in the final plan (5% fewer counties than draft) for the 2020 projections than the draft plan. Similar reductions in underestimations in final plans were observed in 2007 (~6% fewer counties than draft for 2010 and 8% fewer for 2020) and 2012 (1.6% fewer counties than draft for 2010 and 0.4% fewer for 2020). Furthermore, for the 2002 plan, final projections underestimated population in 15% fewer counties for the 2000, 2010, and 2020 projections than the draft projections.

Generally, recent plans tended to show reduced underestimation, which is reflected by an decrease in counties colored red (Figure 8) and across the CDF lines (Figure 9), for both draft and final projections. Quantitatively, the percentage of counties underestimating compared to the census based on the draft projection reduced steadily (Table 4), beginning with the 2002 plan

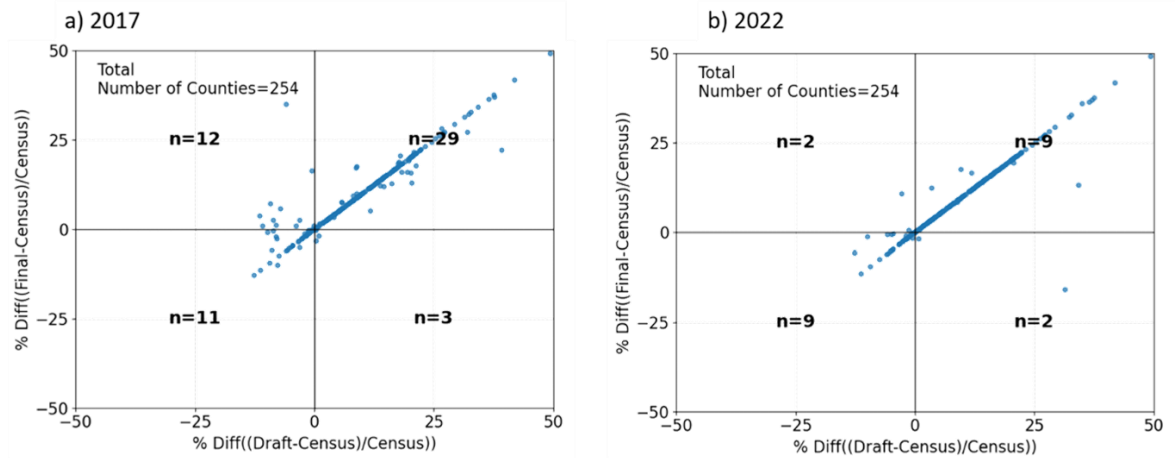
(53% for the 2000 projection), and subsequently plateauing around 15% in both the 2017 and 2022 plans (Table 4). In contrast, the percentage of counties underestimating final projections compared to the census population decreased from the earliest 2002 projection for 2000 (37% of counties) to the 2022 projection for 2020 (15% of counties). The 2002 draft population projections showed substantial inaccuracies, representing a greater degree of underestimation compared to other historical periods.

Table 3: Percentage of counties with better fit to census in draft and final projections. Bold values indicate improved final projections. The percentage of draft and final projections that are identical increased over time.

Planning year	Projection year	Draft (%)	Final (%)	Same (%)
2002	2000	19.7	30.7	49.6
2002	2010	25.6	27.2	47.2
2002	2020	31.1	22.1	46.9
2007	2010	8.6	9.8	81.6
2007	2020	11.8	9.0	79.2
2012	2010	7.1	7.9	85.0
2012	2020	8.3	6.7	85.0
2017	2020	9.1	14.2	76.8
2022	2020	3.6	5.9	90.6

Table 4: Percentage of underestimating counties compared to census.

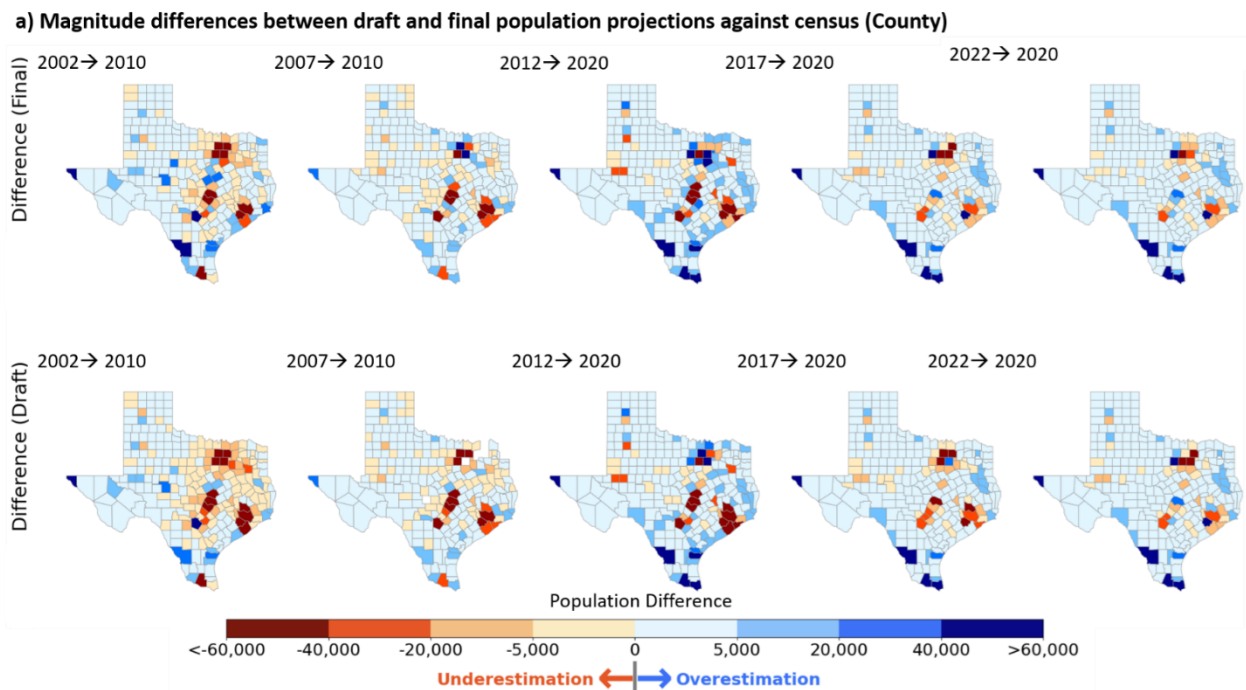
Plan type	Projection year	Percentage of underestimating counties (%)				
		Planning year				
		2002	2007	2012	2017	2022
Draft	2000	53				
Final	2000	37				
Draft	2010	47	31	26		
Final	2010	32	26	25		
Draft	2020	38	17	15	19	15
Final	2020	24	15	15	15	15



Draft = Final : 197 (78%)

Draft = Final : 230 (91%)

Figure 7: County level quadrant plots of percentage differences between a) 2017 and b) 2022 draft and final population projections for 2020 with census 2020 (Data provided in Table S3). n is the number of counties where draft is different from final.



b) Percent differences between draft and final population projections against census (County)

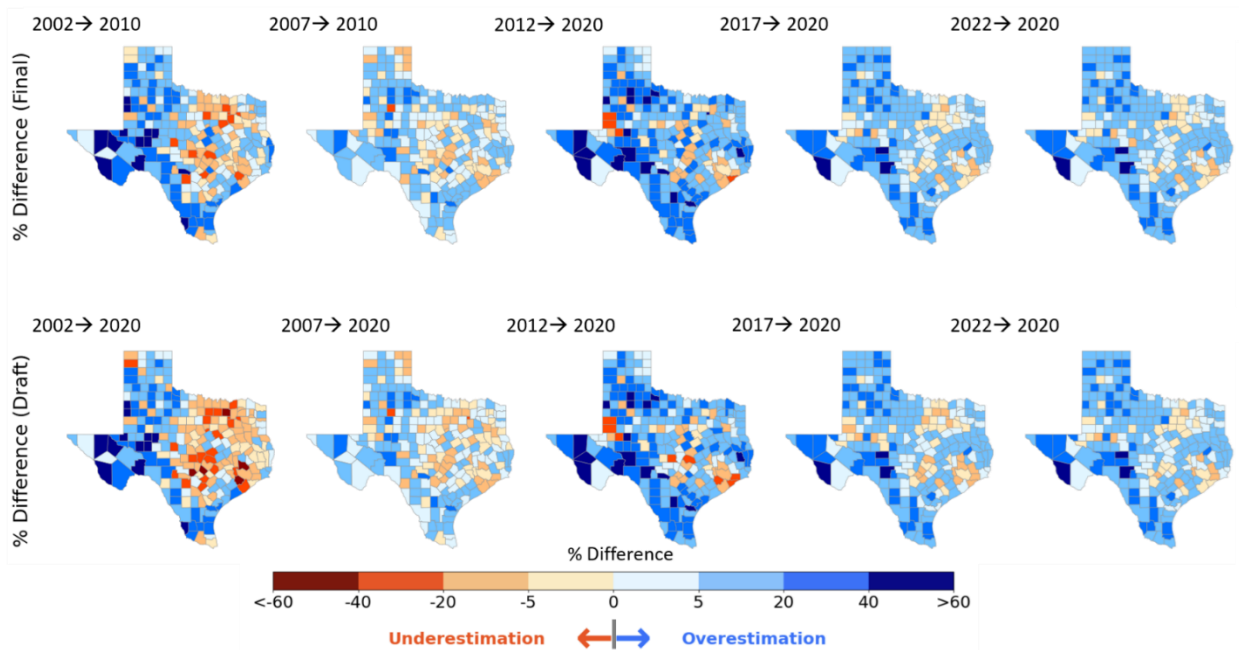


Figure 8: Spatial distribution of differences between draft and final population projections with census at county level a) magnitude of differences b) percentage differences (Data provided in Table S3).

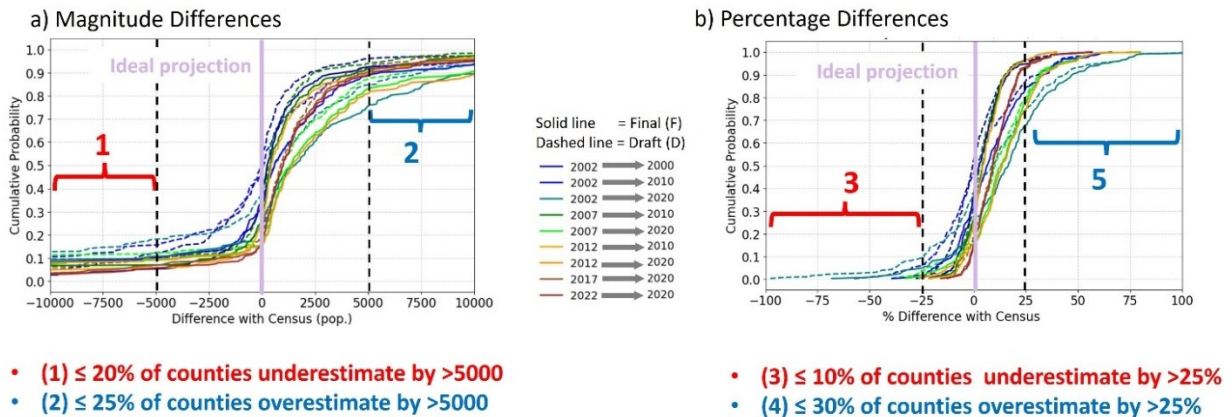


Figure 9: County level Cumulative Distribution Function (CDF) of magnitude and percentage differences between draft (dashed line) and final (solid line) population projections against census a) magnitude of differences b) percentage differences (Data provided in Table S3).

a) Magnitude Discrepancies in Population Projections at County Level

Substantial variations are observed between projections and census data across certain highly populated counties, demonstrating both large-magnitude underestimations and overestimations depending on the planning cycle. Most underestimations at the county level were less than 5,000 people, with less than 20% of counties being underestimated by more than 5,000 people (Figures

8a and 9a). In recent plans underestimation by more than 5,000 people decreased to less than 5%. The magnitude of underestimation, relative to the census data, shows a clear correlation with county population, irrespective of whether the plan was draft or final (Figures 8a and 9a): larger populations correlated with larger observed underestimations. For instance, large population counties, such as Tarrant (including Fort Worth) were underestimated across all plans (draft and final) and projection years by more than 40,000 people. Harris County (includes Houston) was underestimated in earlier plans (2002, 2007, 2012) by more than 40,000 people (draft and final). This value subsequently reduced to 22,226(23,275) underestimations in recent plans (2017, (2022)). Similarly, Travis County (including Austin) generally maintained an underestimation in earlier plans exceeding 40,000 (draft and final). However, this trend lessened significantly in the 2017 and 2022 plans, where the underestimation was reduced to 16,928, culminating in a slight overestimation of the census in the 2022 final plan (8,436) (Supplementary data).

While underestimation is critical for water demand projections, large magnitude overestimations are also important for identifying where plans significantly overestimate population magnitudes. In recent plans (2017 and 2022), population projections (both draft and final) in 18%–22% of counties (~ 50±5 counties out of 254 counties) were overestimated by more than 5,000 people (Figure 9a). A consistent, relatively larger magnitude overestimation ($\geq 40,000$ people) was observed in both draft and final projections within large population counties, such as El Paso (2020 census: 865,657), Webb (267,114), Nueces (353,178), Cameron (421,017), Fort Bend (822,779), and Jefferson (256,526) (Figure 8a).

Bexar County (including San Antonio) showed significant shifts (in both final and draft projections), initially displaying overestimation magnitudes exceeding 40,000 in the 2002 plan, subsequently shifting to underestimation by more than 40,000 in the 2007 and 2012 plans, and finally reducing this underestimation to 35,283 in recent plans (2017 and 2022). Furthermore, large population counties, such as Dallas, exhibited high variability, displaying periods of significant magnitude underestimation in some plans and overestimation in others (in both draft and final projections).

b) Percentage Discrepancies in Population Projections at County Level

A consistent finding was the underestimation percentage across most large population counties, including Bexar, Travis, Harris, and Dallas, which consistently showed a smaller percentage difference of ~-5% compared to the census (in both draft and final), particularly in the recent plans (2017, 2022) (Figure 8b). Over time, a trend of reduced percentage underestimation was observed from 2002 to 2022. In the most recent plans (2017 and 2022), underestimation decreased, with no counties underestimating by more than 25% relative to corresponding census population (Figure 9b). Only a relatively small number of counties experienced a large percentage of underestimation; fewer than 10% of counties were underestimated by more than 25% relative to corresponding census population (in both draft and final for the 2002, 2007, and 2012 plans). Underestimation by more than 25% (relative to corresponding census population) was generally more prevalent during the earlier planning periods (2002 and 2007). Specifically, the 2002 projections displayed a greater magnitude of underestimation than other planning periods (Table 4).

Relatively less populated counties, such as Culberson, Presidio, and Edwards, exhibited a significantly higher percentage of overestimation ($\geq 60\%$ in both draft and final) relative to census

population. However, such substantial overestimation was limited to a few counties, as fewer than 30% of all counties were overestimated by more than 25% relative to corresponding census population. This pattern has remained consistent across plans, projections and draft and final versions (Figure 8b): While overestimation was notably greater in the 2012 plan for 2020 across most counties (both draft and final projections (85%), the more recent projections for 2020 (2017 and 2022) showed that the majority (75% to 80%) of counties were overestimated by less than 25% relative to corresponding census population (Figures 9b).

c) Population Projections Margin of Error and Uncertainty Analysis at County Level

Overall longer-term projection horizons magnified both error metrics and expanded the 95% confidence intervals across all plans, reflecting the structural uncertainty of long-range projections. Across both magnitude (MAE) (Figure 10a) and percentage errors (MPE) (Figure 10b), draft water projections consistently exhibited higher median errors than final projections in counties prone to underestimation, whereas final revisions resulted in large overestimation errors. When evaluating recent performance, the 2017 and 2022 planning cycles demonstrate the most reliable results. For underestimating counties, their absolute and percentage errors stabilized at historic lows with significantly tightened confidence intervals, pointing to improvements in recent plans (2017 and 2022) (Figure 10). In contrast, earlier planning cycles, particularly the 2002 and 2007 plans, were highly variable, marked by massive error margins when projecting for 2020. However, the overestimating cohorts from these earlier plans reveal that final plans increased projections.

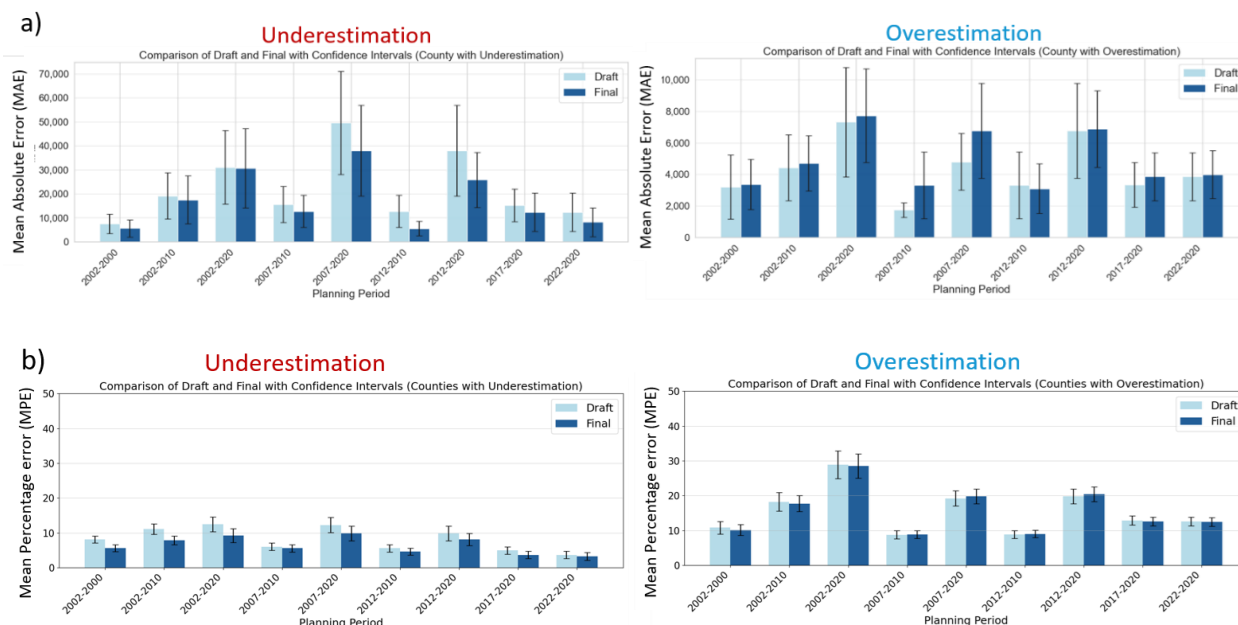


Figure 10: County level draft and final projections from all planning years a) Mean Absolute error (MAE) and b) Mean Percent Error (MPE) with 95% confidence interval when compared with census (Data provided in Table S3, S14 and S15).

3.1.5. Population Projections at Water User Group (WUG) Level relative to US Census

The total number of Water User Groups (WUGs) expanded over the planning periods studied, scaling from 974 in the 2002 plan to 1,618 in the 2022 plan. This shifting baseline introduces inherent difficulties when conducting direct cross-plan longitudinal comparisons. The steady growth in individual entries—progressing from 974 (2002) to 1,334 (2007 and 2012), 1,363 (2017), and finally 1,618 (2022)—is primarily driven by the TWDB systematically lowering the minimum population and volumetric service thresholds required for an entity to be designated as an independent WUG and the structural transition from a city-based to a utility-based framework after 2017. This administrative shift officially designated hundreds of smaller municipal utilities, water supply corporations, and special districts as standalone planning groups. Additionally, rapid population growth and advanced geographic mapping over those 20 years allowed the state to identify and establish these highly specific, separate water planning boundaries.

For the majority of WUGs, draft and final projections were identical (e.g., 63% of WUGs in 2017 and 86% of WUGs in 2022) (Figure 11, Table 5). Projections in WUGs with differing draft and final projections were revised. Comparison of draft versus final in the revised WUGs show that final projections generally tended to reduce underestimation across all plans (Table 6). Consequently, final projections were generally less prone to underestimation than draft. Overall, the final projections yielded relatively closer estimates to the census than the draft projections across all plans and periods, indicating that the revision process successfully assisted in mitigating WUG-level errors in more recent periods.

Generally, the number of underestimations remained relatively smaller than the number of overestimations at the WUG level. Recent plans demonstrate a general tendency toward reduced underestimation in both draft and final projections. This trend is evidenced by the reduced proportion of red-colored WUGs in Figure 12 and is further reflected by the corresponding cumulative distribution function (CDF) lines in Figure 13 and Table 6, for both draft and final projections. Although the percentage of WUGs exhibiting underestimation decreased from the 2002 plan to the 2022 plan, the most substantial reductions in underestimation were consistently recorded in the 2007, 2012, and 2017 plans. Specifically, the 2012 plan consistently demonstrated the highest percentages of WUG-level reduced underestimation for both the 2010 and 2020 projections relative to earlier plans (Table 6). However, the reduced prevalence of underestimation is not directly correlated with the absolute number of WUGs, as these plans contained different total counts (e.g., the 2012 plan encompassed 1003 WUGs).

Table 5: Percentage of WUGs with better fit to census in draft and final projections. Bold values indicate improved final projections. Draft and final are same in increasing percentage with recent projections.

Planning year	Projection year	Draft (%)	Final (%)	Same (%)
2002	2000	25.18	23.5	51.32
2002	2010	26.98	22.96	50.06
2002	2020	28.88	21.06	50.06
2007	2010	8.8	8.49	82.71
2007	2020	10.5	7.9	81.6
2012	2010	9.3	13.6	77.1
2012	2020	11.3	11.5	77.2
2017	2020	5.8	6.7	87.5
2022	2020	4.1	5.7	90.2

Table 6: Percentage of underestimating WUGs compared to census.

Plan type	Projection year	Percentage of underestimating WUGs (%)				
		Planning year				
		2002	2007	2012	2017	2022
Draft	2000	40				
Final	2000	29				
Draft	2010	40	35	32		
Final	2010	29	32	25		
Draft	2020	34	28	25	28	30
Final	2020	25	25	22	27	28

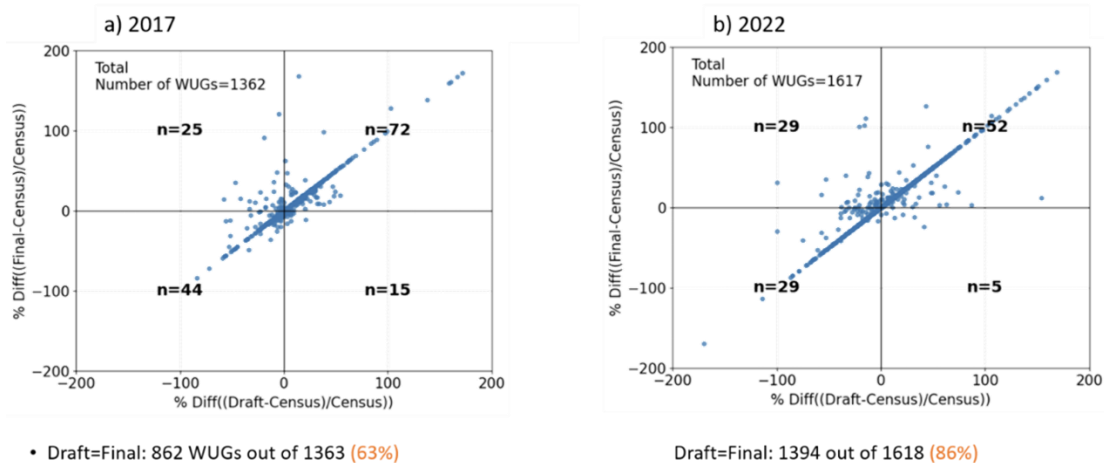
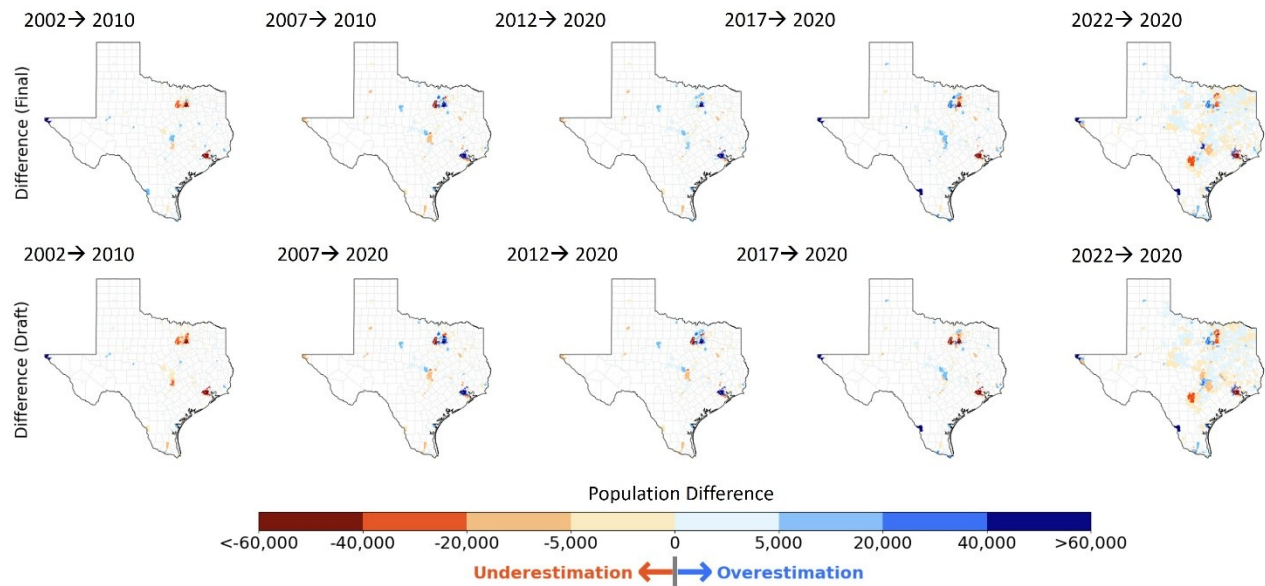


Figure 11: Water User Group (WUG) level quadrant plots of percentage differences between a) 2017 and b) 2022 draft and final population projections for 2020 with census 2020 (Data provided in Table S4). n is the number of WUGs where draft is different from final.

a) Magnitude differences between draft and final population projections against census (WUGs)



b) Percent differences between draft and final population projections against census (WUGs)

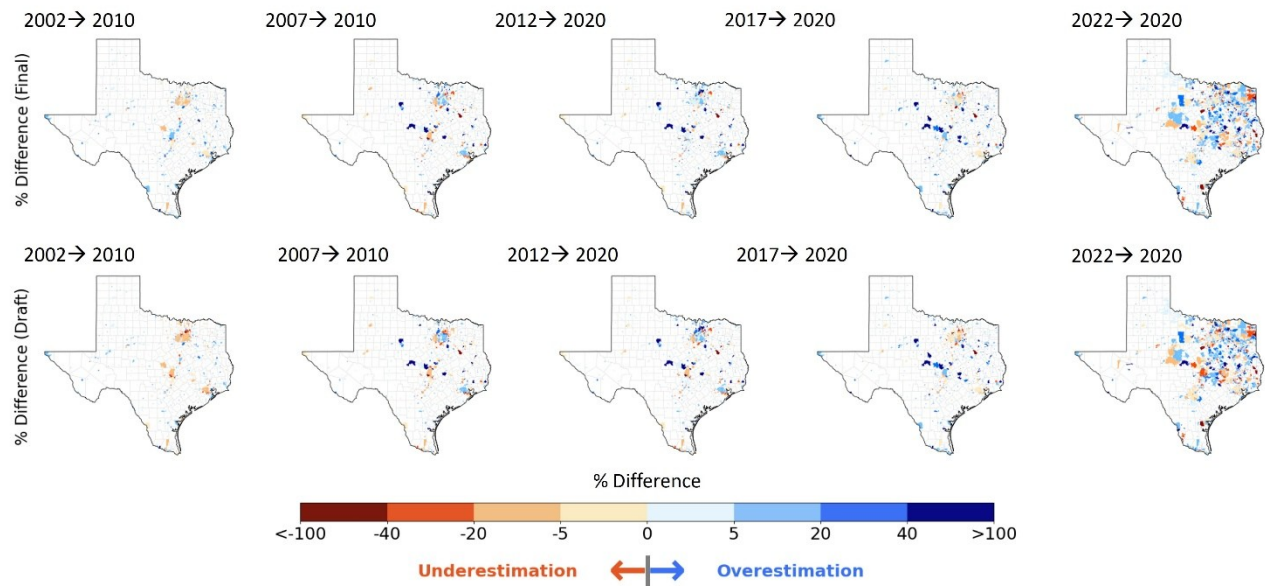


Figure 12: Spatial distribution of differences between draft and final population projections with census at Water User Group (WUG) level a) magnitude of differences b) percentage differences (Data provided in Table S4).

a) CDF of magnitude and percentage differences between draft and final population projections against census (WUGs)

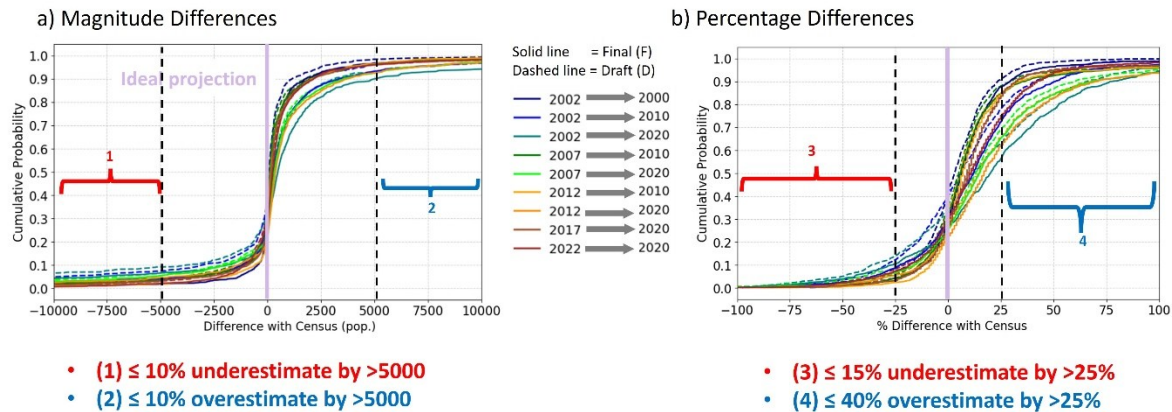


Figure 13: Water User Group (WUG) level Cumulative Distribution Function (CDF) of a) magnitude and b) percentage differences between draft and final population projections against census (Data provided in Table S4).

a) **Magnitude Discrepancies in Population Projections at Water User Group (WUG) Level**

Most underestimations at WUG level were less than 5,000 people, with less than 10% of WUGs being underestimated by more than 5,000 people (Figures 12a and 13a), and underestimation reduced to less than 5% of WUGs in recent plans (2017, 2022) (Figure 13a). The magnitude of underestimation demonstrated a clear correlation with the population of the WUGs (Figure 12a). Projections in large population WUGs, such as Houston (population = 2,248,414) (Final:125,444(56,166) and Dallas (Final: 35,528(62,243)), underestimated census population across recent (2022 (2017)) plans (Figure 12a). Underestimation at such highly populated WUGs in recent plans is concerning as it may result in underestimation in projected water demand. Similarly, Fort Worth (2020 census population = 918,915) showed one of the largest underestimations in 2007 in both the draft (108,266) and final (132,609) plans, and also in the 2012 and 2017 final plans by 31,672. Austin (2020 census population = 982,619) showed underestimation by 4,857 people in the 2017 draft projection for 2020.

WUG-level population overestimations were predominantly below 5,000 people, fewer than 10% of WUGs overestimated by more than 5,000 (Figure 13a). A consistent relatively larger magnitude overestimation was observed in draft and final projections within highly populated WUGs. For instance, in recent projections (2022 (and 2017)), WUGs such as El Paso (2020 census population = 678,815), Fort Worth (2020 census population = 918,915), and Laredo (2020 census population = 255,205) demonstrated overestimations exceeding 20,000 (45,769 (55,216), 22,194 (35,056), 45,759 (44,764) respectively). Houston (2020 census population = 2,248,414) and Dallas (2020 census population = 1,242,136) also showed overestimation in final plans by large numbers (216,346(141,523), 110621(147,499)) in the 2007 (and 2012) plans.

b) **Percentage Discrepancies in Population Projections at Water User Group (WUG) Level**

At the WUG level, 15%–45% of WUGs were underestimated (i.e., their projections fell below the corresponding census population) across all plans and both draft and final projections (Figures

12b and 13b). Overall, only a relatively small number of WUGs experienced a large percentage of underestimation (in both draft and final projections); specifically, less than 15% of WUGs were underestimated by more than 25% relative to corresponding census population. However, larger underestimation percentage was found across most small population WUGs, including Cut and Shoot, and Eustace in both draft and final projections. These WUGs showed a difference of more than 100% compared to the census, particularly in the recent 2022 plans.

There were notable outliers from the general trend of decreasing percentage underestimation with increasing population of WUGs: larger percentage differences were observed within highly populated WUGs, such as Fort Worth (37%) and Dallas (14%). These larger discrepancies were consistently present in both the draft and final earlier plans (2002 and 2007) projections for 2020 (Figure 12b). Because these specific WUGs exhibit both large percentage differences and significant magnitude variation, they require attention. A detailed discussion of these more populated WUGs is provided in the urban-rural section.

Depending on the specific planning cycle, an overestimation margin exceeding 25% (relative to corresponding census population) was observed in 10%–40% of all evaluated WUGs as illustrated across all individual plans (Figures 13b). Specifically, overestimations greater than 25% (relative to corresponding census population) were observed in 15% and 25% of WUGs for the 2017 and 2022 plan respectively. New London (2020 population=958) resulted in the highest overestimation in the recent 2022 plan with overestimation by ~200% followed by Coahoma (2020 population=945) ~150%.

c) Population Projections Margin of Error and Uncertainty Analysis at Water User Group (WUG) Level

An examination of the draft-to-final revision process at the WUG level reveals diverging behaviors between underestimating and overestimating cohorts even though most WUGs have similar draft and final population (e.g. 90% of WUGs in 2022 plan had similar draft and final values). For WUGs prone to underestimation, final revisions successfully decreased Mean Absolute Errors (MAEs) (Figure 14a) and Mean Percentage Errors (MPEs) in almost all cohorts (Figure 14b). Conversely, in overestimating cohorts, final revisions frequently introduced larger errors or failed to notably improve draft accuracy, pointing to an asymmetric correction process. Across both groups, longer projections horizons systematically elevated error magnitudes and widened the 95% confidence intervals, illustrating the compounding uncertainty of longer projections.

The recent 2017 and 2022 plans established the lowest median errors for underestimating WUGs, accompanied by highly constrained confidence intervals. While the older 2002 plan projections for the year 2000 superficially present lower raw errors and tighter margins than some intermediate plans, this performance must be interpreted alongside its structural data constraints. The 2002 plan had a smaller number of WUGs compared to subsequent cycles. This restricted sample size artificially narrowed the variance and absolute error bounds, masking the true historical model volatility that becomes visible when projecting over longer horizons, such as the expansive error intervals seen in the 2002-2020 and 2007-2010 overestimations.

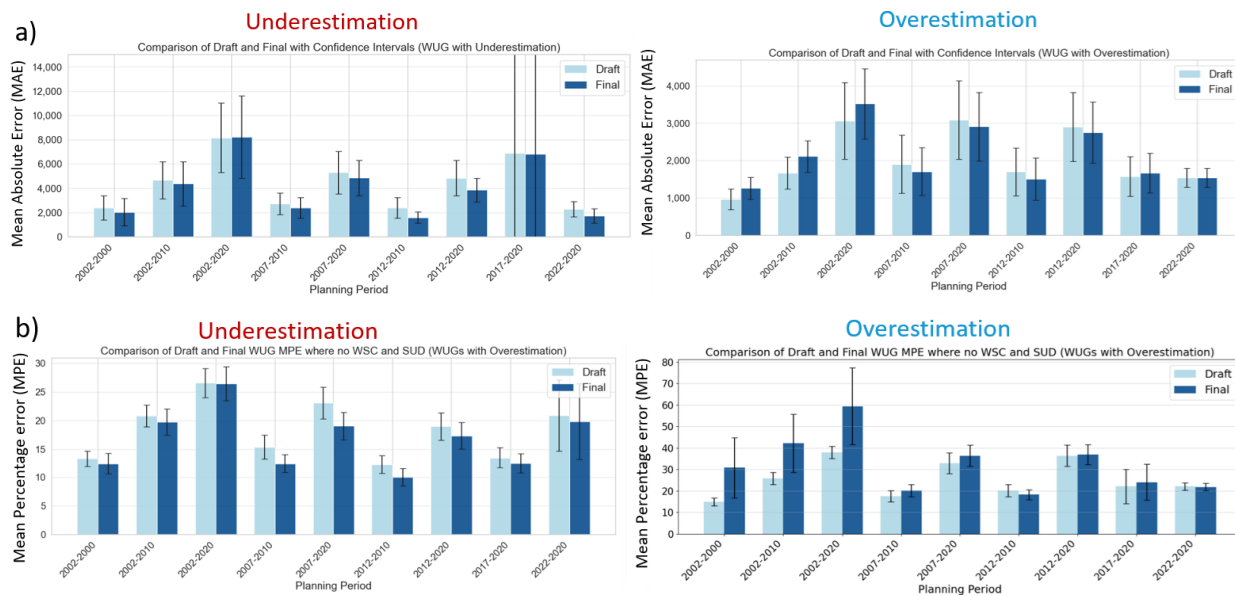


Figure 14: Water User Group (WUG) level draft and final population projections from all planning years a) Mean Absolute Error (MAE) and b) Mean Percent Error (MPE) with 95% confidence interval when compared with census (Data provided in Table S4, S14 and S15).

d) Accuracy of Urban and Rural Water User Group (WUG) Population Projections

Urban and rural Water User Group (WUG) classifications were defined in accordance with the statutory criteria outlined in Texas Water Code § 15.001(14). In the majority of plans, rural WUGs outnumbered urban WUGs. For instance, the 2022 plan showed 1041 (64%) rural versus 577 (36%) urban WUGs. Similarly, in 2017, there were 775 (57%) rural versus 402 (30%) urban WUGs (13% of WUGs were not categorized as either urban or rural).

Across both magnitude and percentage, urban projections consistently underestimated the population more than rural projections when compared to census data in both draft and final population projections because urban WUGs are more highly populated. A notable example is large cities, such as Dallas and Houston were underestimated in the 2017 and 2022 draft and final plans (Table 7). The differences were significant in magnitude and percentage differences in both draft and final plans. Urban WUGs show greater underestimation (ranging from 45%–50% of urban WUGs in the 2017 and 2022 plans) compared to rural WUGs (20%–25% of rural WUGs in the 2017 and 2022 plans) (Figure 15a and 15b).

Specifically, 5%–15% of urban WUGs and less than 5% of rural WUGs exhibited underestimations exceeding 5,000 people. In contrast, 10%–15% of urban WUGs and less than 2% of rural WUGs exhibited overestimations exceeding 5,000 people. These percentage ranges account for variations between draft and final projections across both the 2017 and 2022 SWP. This pattern occurs because larger urban populations naturally produce higher numerical variance.

Underestimation percentage differences by more than 25% (relative to corresponding census population) in urban WUGs ranged from 8%–12% relative to 1%–5% in rural WUGs. Conversely, urban WUGs exhibited a smaller percentage of overestimation difference compared to rural areas. Specifically, urban overestimations were found in 5%–15% of urban WUGs, with

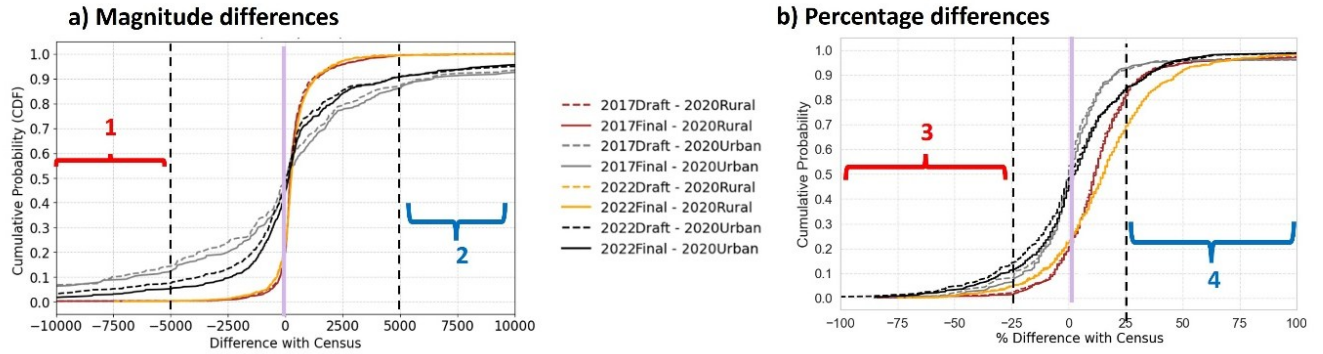
discrepancies exceeding 25% (relative to corresponding census population), compared to rural overestimations observed in 20%–35% of WUGs, also exceeding 25% (relative to corresponding census population).

In large urban centers, such as Austin, Dallas, El Paso, Fort Worth, Arlington, Houston, and San Antonio, the final projections generally aligned better with the census data than the draft projections (Table 7 and Figure 15c). Conversely, certain plans resulted in draft projections that provided closer estimates to the census data than the final projections. For example, Austin's final projection showed the greatest error relative to the draft projection (Table 7). Other regional discrepancies included Harlingen's discrepancies of 4% (2012 projection for 2010 and 2012 projection for 2020), Houston's discrepancy of 1% (2002 projection for 2010 and 2002 projection for 2020), and El Paso's discrepancy of 1% (2007 projection for 2020) (Figures 15c). However, isolated and limited instances were noted where the draft projections appeared more consistent with the census than the final projections (Table 7 and Figure 15c). However, the final projections were more consistent with the census data than the draft projections for most plans in Austin, Dallas, El Paso, Fort Worth, Arlington, Houston, and San Antonio (Table 7 and Figure 16).

Table 7: Draft and final State Water Plan (SWP) population projections percentage differences with census of select cities.

Plan year	Plan year	Percentage difference with census (%)											
		Austin Draft	Dallas Draft	El Paso Draft	Fort Worth Draft	Arlington Draft	Houston Draft	Austin Final	Dallas Final	El Paso Final	Fort Worth Final	Arlington Final	Houston Final
2002	2000	-5	-11	12	-7	-4	-5	-1	-10	12	-7	-4	-5
2002	2010	-4	-9	15	-28	-8	0	-1	-7	15	-28	-8	1
2002	2020	-2	-14	29	-37	-7	6	1	-12	29	-37	-7	7
2007	2010	0	14	-3	-16	33	7	0	10	-2	-15	33	7
2007	2020	0	17	4	-22	113	9	2	11	6	-14	113	9
2012	2010	0	10	-2	-15	33	7	1	10	-2	0	33	7
2012	2020	2	11	6	-14	113	9	1	8	6	3	113	9
2017	2020	-1	-7	8	-5	8	-2	2	-5	8	4	8	-2
2022	2020	5	-5	8	5	7	-4	8	-5	8	5	7	-4

CDF of 2017 and 2022 urban and rural draft and final population projections for 2020 with census 2020 (WUGs)



- More underestimation in Urban (45% - 50% in 2017 and 2022) than Rural (20% -25% in 2017 and 2022)
- Less difference in magnitude in rural
- Less percent difference in Urban

c) Magnitude differences between draft and final 2017 and 2022 population projections against census (WUGs)

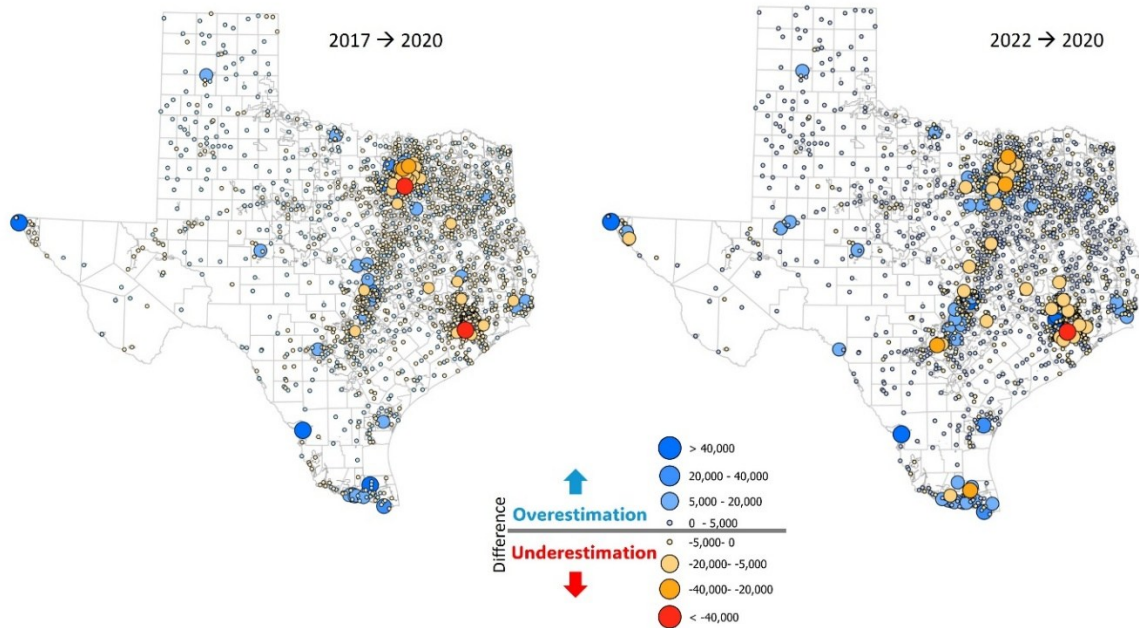


Figure 15: Cumulative Distribution Function (CDF) of a) magnitude b) percent differences between rural and urban State Water Plan (SWP) draft and final populations c) Spatial plot of final projections differences with census at Water User Group (WUG) Level, 2017 and 2020 highlighting locations of highest magnitude differences (Data provided in Table S4 and S12).

Draft and final projection differences with census in select cities

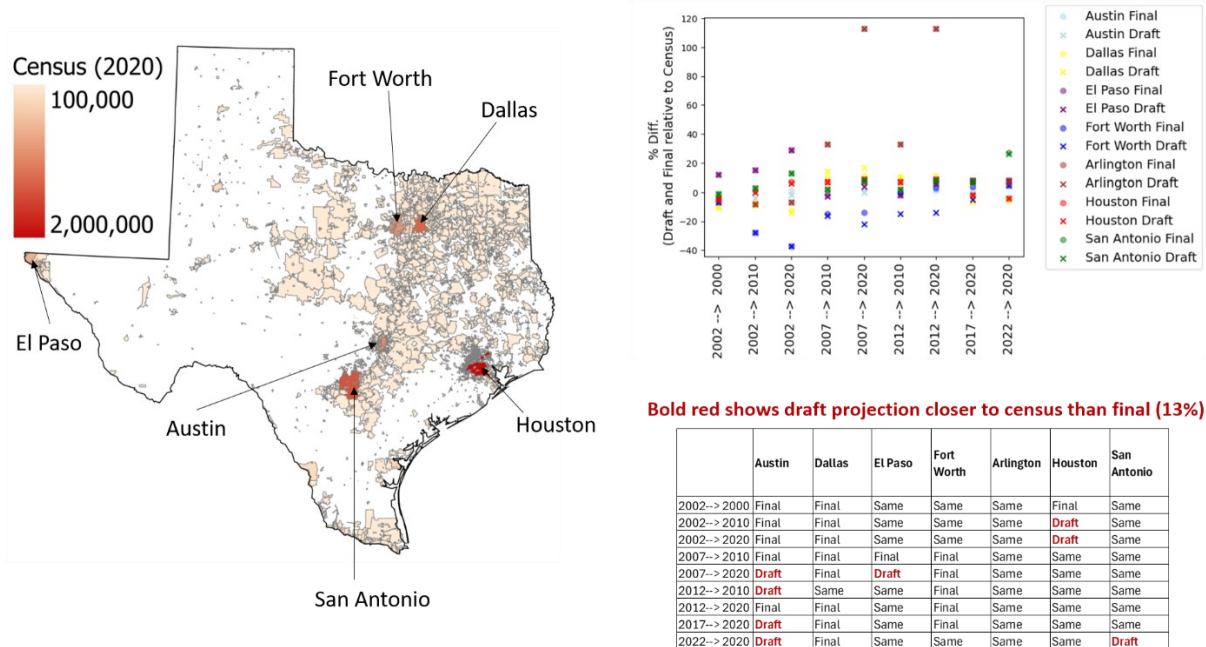


Figure 16: Draft and final population projection differences with census in select cities across the different planning and projection years. Red in the tables shows where draft projections were better fit to census than final (Data provided in Table S4 and S12). Spatial plot provided for reference for locations of the select cities.

e) Accuracy of County Other WUGs Population Projections

The threshold for County-Other WUG selection was set at 25% of the counties in each Regional Water Planning Area or at least four counties (excluding Region P, which has only three counties).

In recent plans (2017 and 2022), 25% of County-Other WUG underestimated compared to census (Table S18 and Figure S9). Brazoria (3,369) and Chambers (10%) recorded the largest magnitude and percentage-based underestimations compared to census (Table S18 and Figure S10). Conversely, Parker exhibited the largest magnitude overestimation (13,999), and Schleicher demonstrated the largest percentage-based overestimation (56%) between the final projection and the census data. Overall, there was no systematic pattern of over- or underestimation in County-Other WUG projected population when compared to the census population.

3.2. Water Demand Projections

Water demand projections are calculated by multiplying the projected population by the per capita water demand (Gallons per Capita per Day, GPCD). Because water demand is projected based on drought-of-record conditions, the data naturally incorporates a drought contingency buffer and is therefore expected to exceed actual water use. Below, we present an analysis regarding the accuracy of these water demand projections at different spatial levels.

Consistent with population evaluation findings, the water demand evaluations conducted at the RWPG, county, and WUG (for both draft and final versions) levels indicated that magnitude differences were larger in large population WUGs, while larger percentage differences were

observed in smaller population WUGs. Furthermore, both the magnitude and percentage differences increased as the projected year moved further into the future.

3.2.1. Water Demand Projections at the State Level relative to Actual Water Uses

A comparison of state-level water use and water demand projections reveals systematic overestimations across all plans, with the magnitude of overestimation increasing as the projection horizon extends. The most recent plans (2017 and 2022) overestimated water use by approximately 0.75 MAF. While avoiding underestimation is ideal when planning for drought of record, excessive overestimation is also problematic; the overestimation in recent plans remains high at 17% when compared to actual water use, indicating an area that may require attention. (Table S5a).

3.2.2. Water Demand Projections at the Regional Water Planning Group (RWPG) Level relative to Actual Water Uses

The 2022 plan recorded underestimations exclusively for Region L, while the 2017 plan exhibited no underestimations. This trend contrasts with prior instances of notable underestimation, which were observed in 2007 and 2012 for Region A and D, and in the 2002 plan, which showed a greater degree of underestimation across Regions A, B, D, H, and I (Figures 17a - 17e).

Regarding magnitude discrepancies, the most significant absolute errors are concentrated in the most densely populated RWPGs: Region C (Dallas-Fort Worth metroplex), Region H (Houston), and Region M (Laredo). In Region H, an underestimation occurred with the 2002 plan for 2000 (Figures 17a); conversely, overestimation was observed in all other plans, with the largest overestimation occurring in recent years (2017, 2022), reaching nearly 220,000 af (Figures 17d and 17e). Region C's error patterns are characterized by a persistent overestimation relative to actual water use across all planning periods, exemplified by the 2012 plan's projection for 2020, which showed the largest overestimation (603,247 af).

Specific regional trends confirm this pattern: Region D demonstrated a notable percent underestimation in the 2002 plan projections for both 2000 and 2010 (Figures 17a). Furthermore, Regions H and K displayed underestimation in earlier plans (2002, 2007, 2012), a discrepancy largely mitigated in the most recent plans (2017 and 2022) (Figures 17d and 17e). Conversely, less populated regions such as Region B and Region N consistently resulted in the largest percentage overestimation compared to actual water use data, with the sole exception being the 2002 plan projection for 2000. Regions K, M, and N warrant specific mention due to their consistently high magnitude and percentage overestimation across all planning periods (Figures 17a-17e).

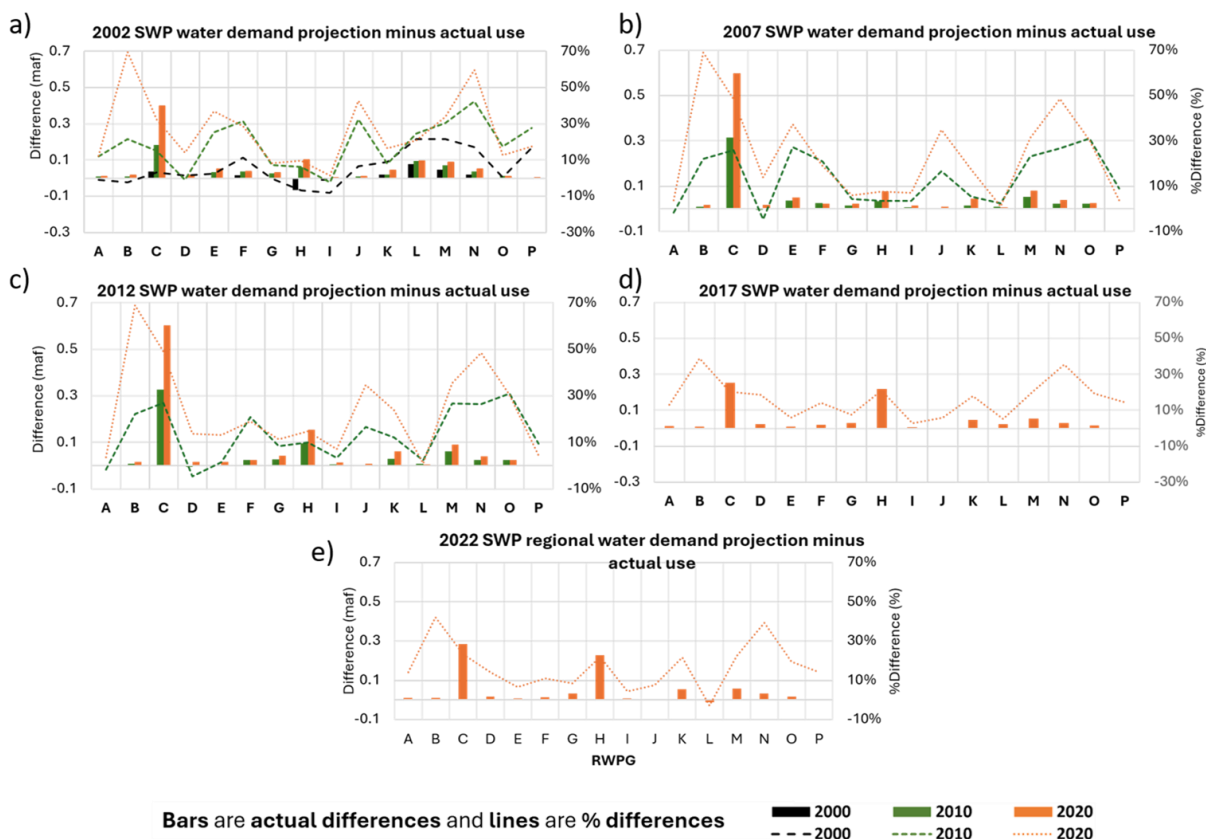


Figure 17: Comparison of final water demand projection to actual water use at Regional Water Planning Group (RWPG). Bars: absolute difference; dashed line, percentage difference (Data provided in Table S5).

3.2.3. Water Demand Projections at the County Level relative to Actual, 2011 and Maximum Water Uses

In addition to actual water use, this section compares projections against 2011 water use, which represents the drought of record for most of Texas and is therefore commonly used as a conservative planning benchmark, and against the maximum water use observed between 2000 and 2020. In some instances, a projection may precede the maximum water use year and may not account for intervening population growth. However, projected demand should ideally incorporate a sufficient buffer to absorb maximum water use.

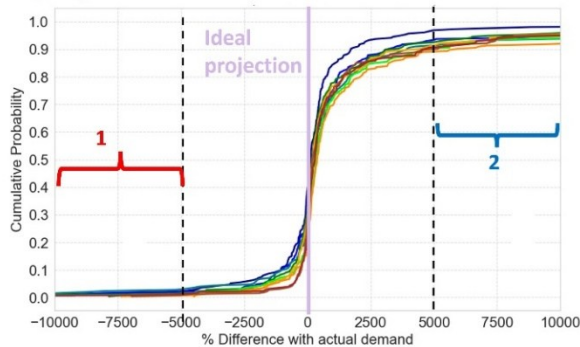
The underestimation in Counties when compared to the actual water use ranged from 20%–40% (Figure 18i). The underestimation was notably higher when compared to the 2011 drought water use (Figure 18ii), where a much larger percentage of counties (45%–60%) underestimated the 2011 water use. Furthermore, when evaluated against the maximum water use across 2000–2020 (which includes 2011), most counties (70%–80%) still underestimated this maximum use (Figure 18iii), indicating significant limitations in water demand projections for extreme scenarios. Maximum water use and 2011 drought water use coincide in some instances due to the severity of the 2011 drought.

Overall, county-level projections do not exhibit consistent magnitude differences. To highlight the sporadic nature of the results, we have listed several peculiar examples that show changes—

such as shifts from plan to plan, or from overestimation to underestimation, or vice versa, and transitions from larger to smaller magnitudes. Furthermore, we focused particularly on highly populated counties that resulted in larger differences. For more specific quantitative information, we have provided figures detailing the spatial distribution of magnitude differences using actual water use, 2011 water use, and maximum water use, alongside corresponding CDF plots (Figures 18-21). These visualizations are useful for filtering the percentage of counties exhibiting various magnitude differences.

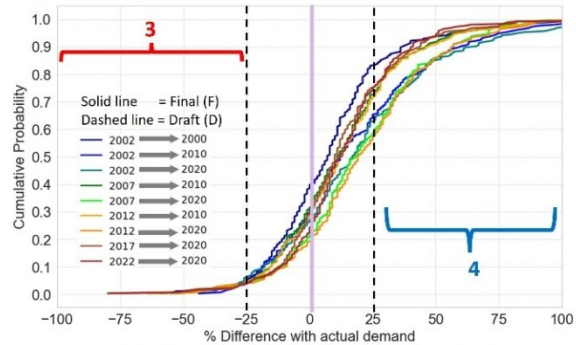
i) CDF of water projection against actual use at level (County)

a) Magnitude differences



- (1) <10% of counties underestimate by >1000 af
- (2) <30% of counties overestimate by >1000 af

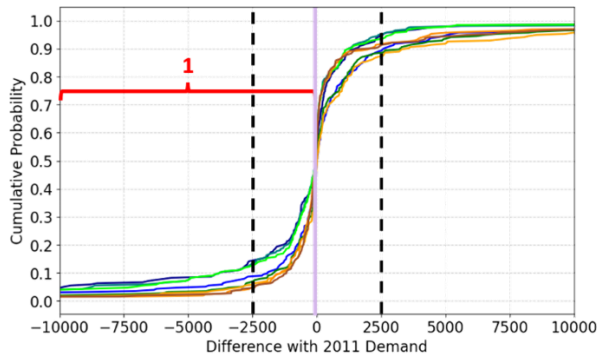
b) Percentage differences



- (3) <5% of counties underestimate by >25%
- (4) <40% of counties overestimate by >25%

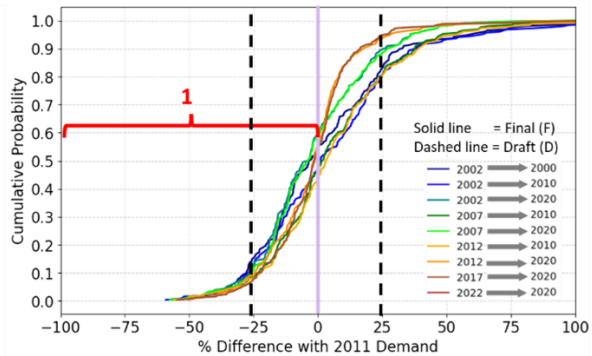
ii) CDF of water projection against drought year water use (2011) use (County)

a) Magnitude differences

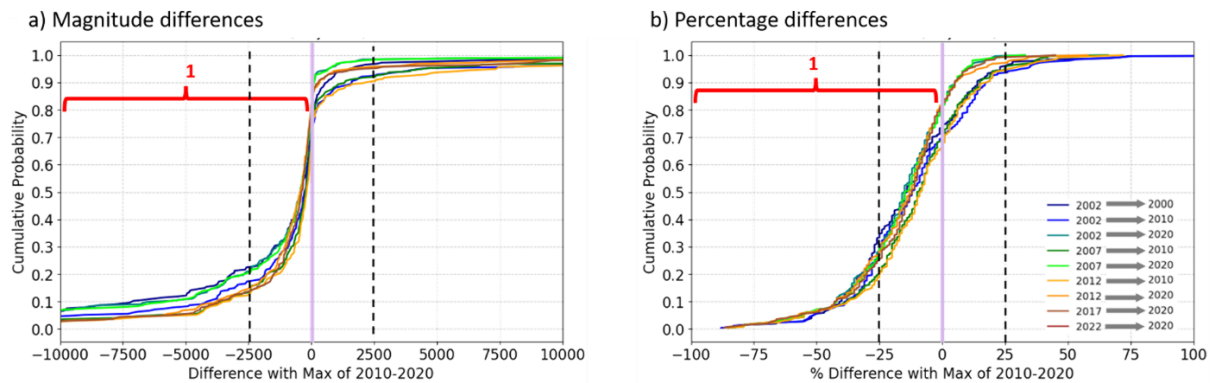


- (1) 45-60% of counties underestimate compared to the 2011 water use

b) Percentage differences



iii) CDF of water projection against maximum water use (2000-2020) use (County)



(1) Most Counties (70-80%) underestimate compared to the maximum demand

Figure 18: County level Cumulative Distribution Function (CDF) of draft and final water demand projections against i) actual ii) drought year (2011) ii) maximum (2000-2020) water uses a) magnitude and b) percentage differences (Data provided in Table S6a, S6b, S6c).

a) Magnitude Discrepancies in Water Demand Projections at County Level

Regarding underestimation, fewer than 5% of counties underestimated water use relative to actual water use by more than 2,500 af (Figure 18i (a)). Larger underestimation amounts were rare. A notable example of an underestimation by 22,930 af was observed in Bexar County in the most recent plan (the 2022 plan for 2020) (Figure 19a). Generally, the majority of underestimations were observed during the 2002 plan (Montgomery, Williamson, Jefferson, and Smith counties) and the 2007 plan (Williamson and Fort Bend counties), ranging in magnitude from 10,000–20,000 af. In contrast, a larger number of counties (5%–20%) overestimated the actual water use by more than 2,500 af. Highly populated counties, specifically Harris, Dallas, Travis, and El Paso, consistently overestimated water use by the largest magnitudes across all plans and projections, in contrast to underestimated population projections (Figure 19a).

In comparison to 2011 water use, fewer than 15% of counties underestimated water use by more than 2,500 af ((Figure 18ii (a))). Harris county underestimated the water use across all planning and projection years by more than 20,000 af (representing 3% of total 2020 water use) (Figure 20a). Furthermore, a notable underestimation of over 20,000 af was observed in both Bexar (21,696) and Harris (24,530) (counties within recent plans (2022 plan for 2020)). Tarrant and Travis counties, meanwhile, exhibited mixed patterns of over- and underestimation, depending on the specific plan and projection year. A total of 5%–15% of counties overestimated the 2011 water use by more than 2,500 af, with Dallas consistently overestimating water use across all plans and projections. El Paso showed higher overestimation values in earlier plans (by more than 20,000 af) compared to recent plans (2017 and 2022), where the magnitudes were lower (ranging from 6,000–7,000 af).

Large population counties demonstrated higher magnitudes of both underestimation and overestimation compared to maximum water use from 2000-2020. Specifically, 15%–25% of counties (out of the 254 counties) underestimated water use by more than 2,500 af relative to maximum water use (Figure 18iii (a)). Harris county consistently underestimated water uses across all plans and projections by 255,000 af (Figure 21a). Conversely, Travis County exhibited

significant underestimation, though in recent plans, it showed overestimation exceeding 22,485 af (2022 plan for 2020). Dallas generally showed overestimation in most plans, exceeding 20,000 af, except for recent plans where it displayed underestimations by ~50,000 af (2017 and 2022 plans). Regarding overestimation compared to maximum water use, fewer than 10% of counties overestimated by 2,500 af ((Figure 18iii (a))). For instance, when compared to maximum water use, El Paso overestimated in most plans by more than 20,000 af, though this overestimation was reduced in recent plans (2017 and 2022) by ~7,000 af (Figure 21a).

b) Percentage Discrepancies in Water Demand Projections at County Level

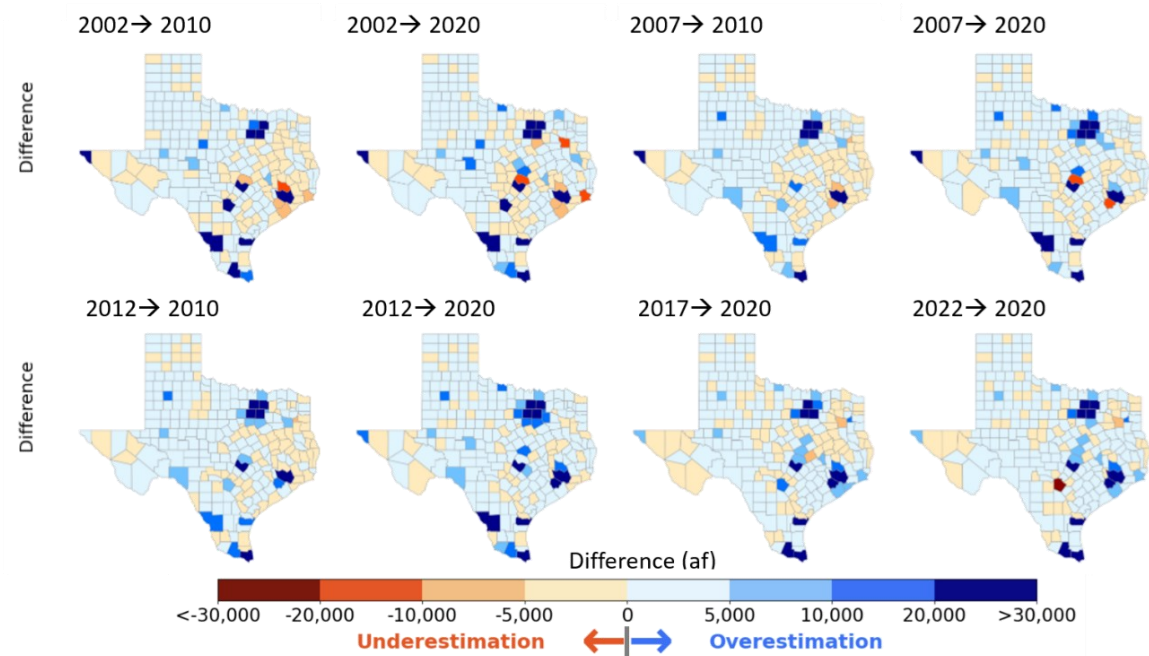
Fewer than 5% of counties underestimate actual water use by more than 25% (Figure 17i (b)). Both underestimation and overestimation percentages decreased in recent plans when compared with the actual water use, particularly those displayed in lighter colors (the 2017 and 2022 plans; Figure 18b). However, some counties continue to exhibit persistent discrepancies. Wheeler and Roberts, for instance, continue to display large percentages of underestimation, ranging from 25% to 50%, across multiple plans, including the recent 2017 and 2022 plans (Figure 18b). Milam similarly demonstrates an increased underestimation trend in recent plans, exceeding 50% in both 2017 and 2022, representing a significant increase compared to earlier underestimations of less than 50%. Furthermore, notable shifts are evident in other counties. Fisher transitioned from exhibiting overestimation (by less than 10%) to significant underestimation (by 25–50%). Fewer than 40% of counties overestimate water use by more than 25% (Figure 17i (b)). Most notably, Webb County, which displayed a substantial overestimation of more than 50% in earlier plans (2002, 2007, and 2012), this value was reduced to less than 10% in the recent plans (2017 and 2022).

In line with the actual water use comparison, both underestimation and overestimation when compared with 2011 water use generally decreased in recent planning cycles (represented by the lighter colors in the 2017 and 2022 plans; Figure 19b). Regarding underestimation, fewer than 15% of counties underestimated their water use by more than 25% compared to the 2011 values (Figure 17ii (b)). However, specific counties, such as Wheeler and Loving, maintained a persistently high percentage of underestimation across multiple plans, including the recent 2017 and 2022 projections. Conversely, counties like Oldham demonstrated a notable reduction in underestimation within these recent plans. Furthermore, several counties exhibited a shift in projection, transitioning from significant overestimation to significant underestimation. For instance, Lamar County transitioned from an overestimation (exceeding 50%) in earlier plans to a moderate underestimation (10%–25%) in the recent plans when compared with the 2011 water use. Similarly, regarding overestimation, fewer than 20% of counties overestimated their 2011 water use by more than 25%. A significant trend was observed among San Saba and Sutton counties, which previously exhibited overestimations exceeding 100% in earlier periods (2002, 2007, 2012). These counties successfully curtailed this projection, achieving less than 10% overestimation in the recent plans (2017 and 2022).

Comparison against maximum water use generated the largest degree of underestimation relative to preceding evaluations in most counties (20%–35% of counties (out of the 254 counties) underestimated by over 25% relative to maximum water use (Figure 17iii (b)). In the most recent plan (2022) Harris and Bexar counties underestimated by 10%–25% (Figure 20b). Despite this general trend, several notable counties exhibited occasional overestimation, even when

compared to maximum water use. For instance, Wise County demonstrated a slight underestimation (<10%) in 2002, but overestimated in 2007, 2012, 2017, and 2022 plans by 25%-50%. Conversely, Cameron County displayed consistent overestimation across all plans and projections. Furthermore, the percentage difference consistently maintained an inverse relationship with county population, mirroring the trend observed in prior evaluations.

a) Magnitude differences between final water use projections against actual water use (County) (af)



b) Percentage differences between final water use projections against actual water use (County)

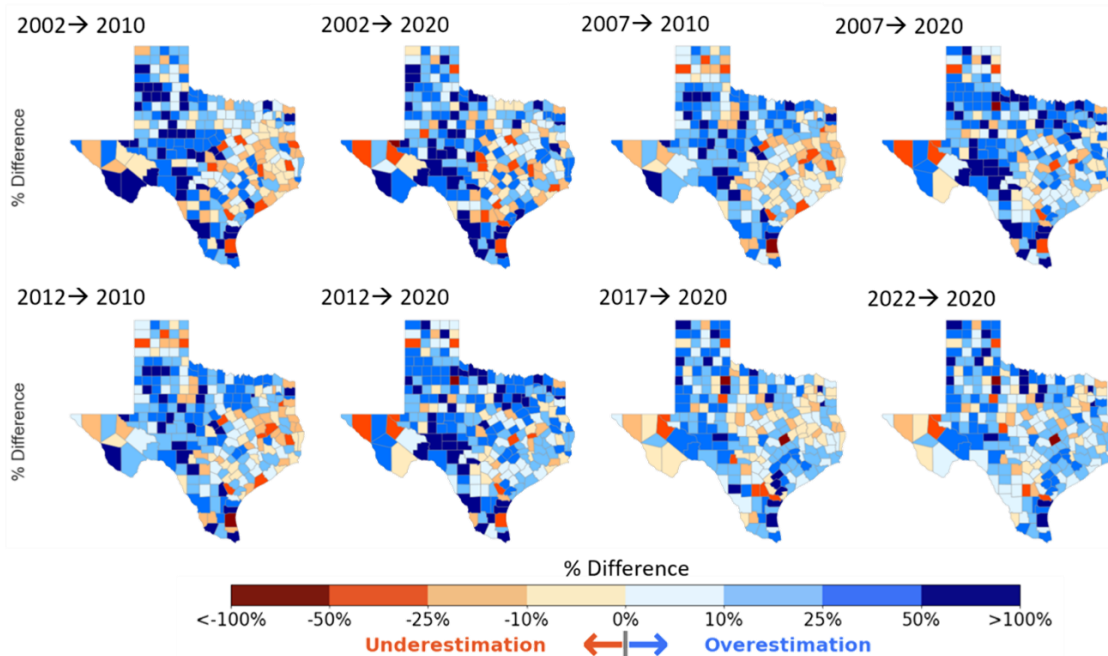
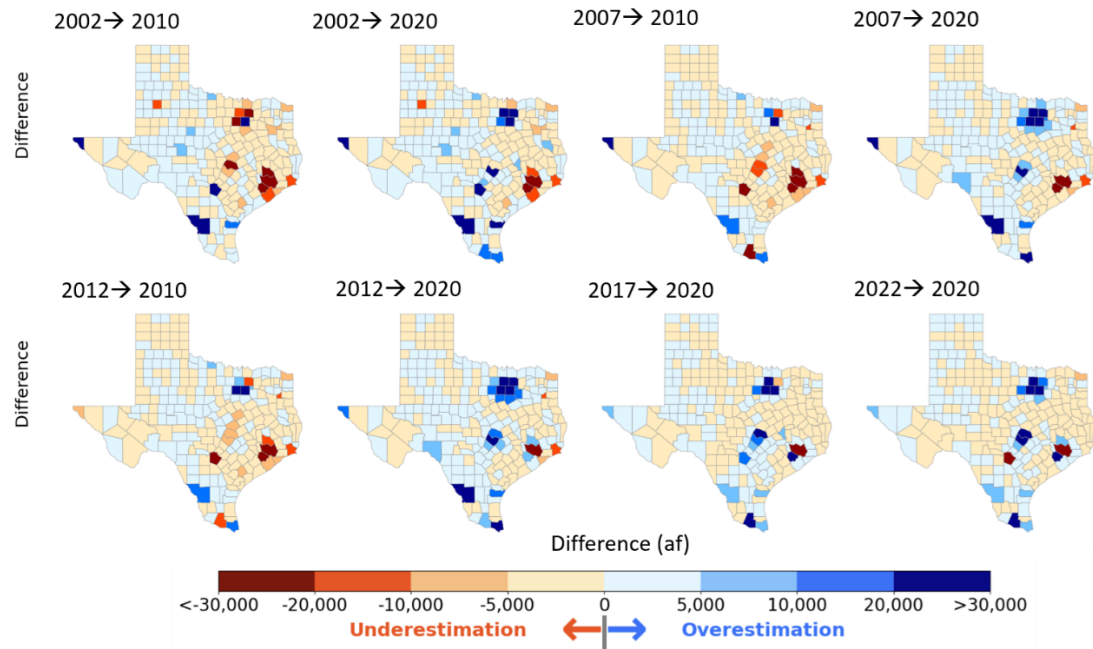


Figure 19: Spatial distribution of differences between final water demand projections with actual water use at county level a) magnitude of differences b) percentage differences (Data provided in Table S6a).

a) Magnitude differences between draft and final water use projections against 2011 water use (County) (af)



b) Percentage differences between final water use projections against 2011 water use (County)

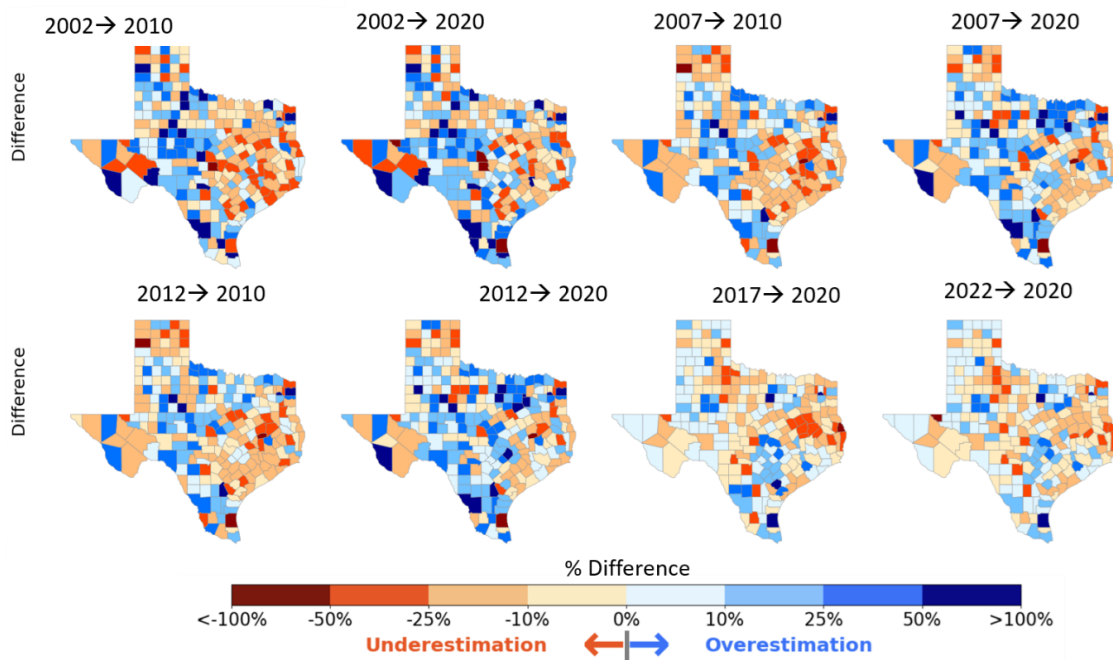
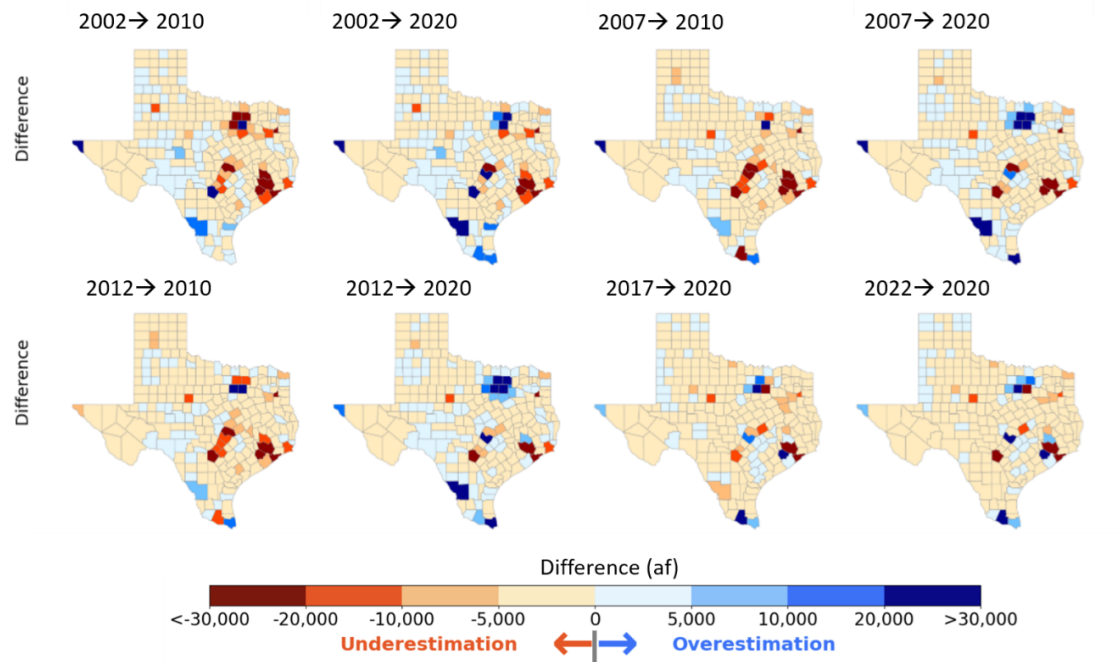


Figure 20: Spatial distribution of differences between final water demand projections with 2011 water use at county level a) magnitude of differences b) percentage differences (Data provided in Table S6b).

a) Magnitude differences between final water use projections against maximum water use (County) (af)



b) Percentage differences between final water use projections against maximum water use (County)

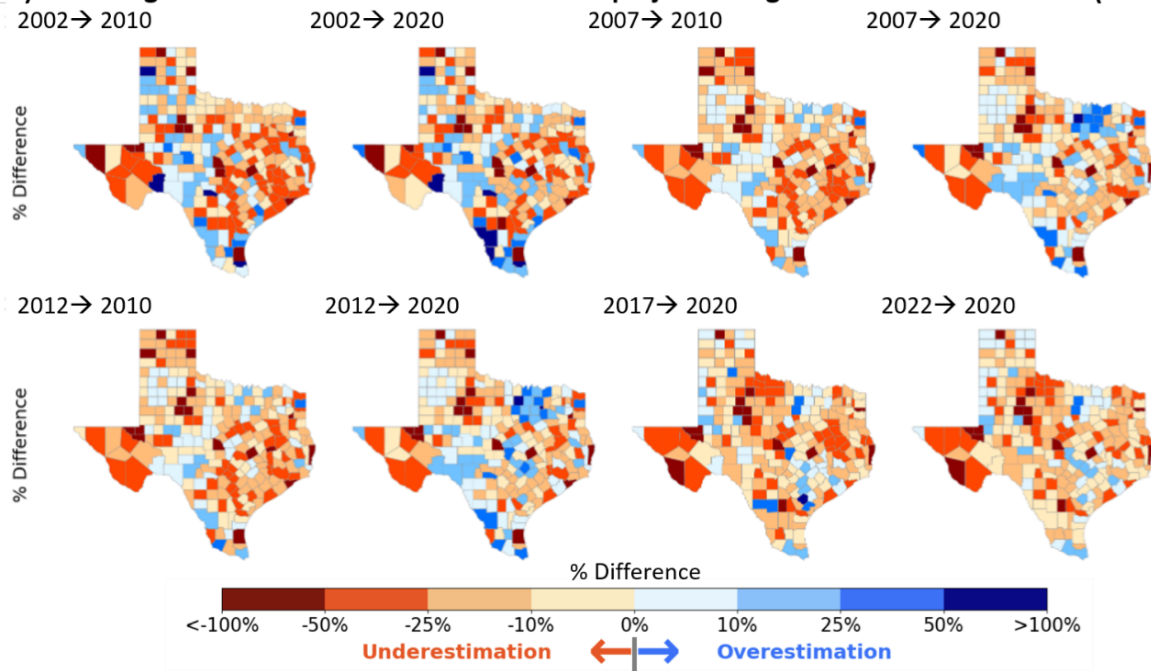


Figure 21: Spatial distribution of differences between final water demand projections with maximum (2000-2020) water use at county level a) magnitude of differences b) percentage differences (Data provided in Table S6c).

c) Comparison of Water Demand Projection Trends and Population Projection Trends

Discrepancies in projected water demand and actual water use was not primarily driven by population trends. Overall, the agreement between population trends and water demand trends

was relatively limited. To quantify this, we compared the over- and underestimations of water use trends against the corresponding final population projection trends (Figure 22).

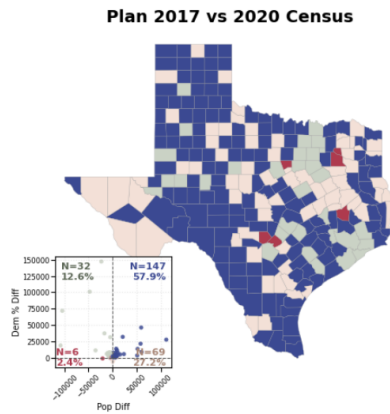
According to the projected water demand in the 2022 plan (compared against the actual water use), seven counties (3%) exhibited consistent underestimation (Figure 22a). Conversely, water and population overestimations were found in 164 counties (65%). Furthermore, in the 2017 plan, six counties (2%) showed underestimation in water use while 147 counties (58%) displayed overestimation in both population and water use. For the remaining counties, no agreement existed between population and water use trends: 83 counties (33%) in the 2022 plan and 101 counties (40%) in the 2017 plan, suggesting that water demand changes are likely not the result of population over or underestimation (Figure 22a).

Water demand projections were also benchmarked against the 2011 drought-of-record period, considered the most severe one-year drought in many regions, revealing significant discrepancies across various planning horizons. Regarding the 2020 projections, the 2022 plan indicated that 13 counties (~5.1%) underestimated both population and water demand when compared to the 2011 water use. Similarly, the 2017 plan for 2020 found that 12 counties (4.7%) were underestimated, while in 2022, 92 counties (36%) were found to have overestimated in both water use and population. Furthermore, the 2017 plan showed that 87 counties (34%) overestimated both population and water use. This trend of inconsistency persisted when examining non-conforming trends, where 149 counties (59%) showed no agreement in the 2022 plan, and 155 counties (61%) showed no agreement in the 2017 plan (Figure 22b).

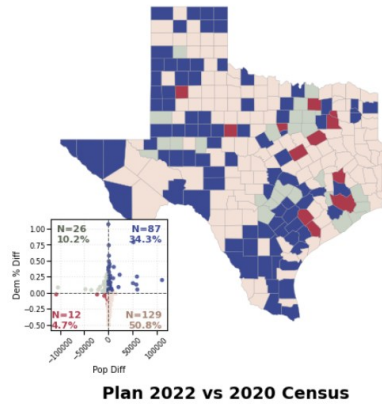
Furthermore, when assessing whether the projections accommodated the maximum observed water use between 2000 and 2020, the vast majority of counties showed no agreement in these scenarios: 187 counties (74%) in the 2022 plan and 191 counties (75%) in the 2017 plan.

Notably, major hubs such as Dallas, Harris, Galveston, and Bexar counties projected water use below their 2000–2020 historical maximum. This discrepancy was specifically linked to underestimated population growth in those particular areas (Figure 22c). Only 28 counties (11%) in 2022 and 27 counties (10.6%) in 2017 showed agreement in underestimation in both water use and population. For overestimation, only 39 counties (15%) in the 2022 plan and 36 counties (14%) in the 2017 plan agreed on the scenario where population was overestimated and water use exceeded historical maximum (Figure 22c).

a) Population trend vs actual water demand trend



b) Population trend vs drought year (2011) water demand trend
Plan 2017 vs 2020 Census



c) Population trend vs maximum water demand trend
Plan 2017 vs 2020 Census

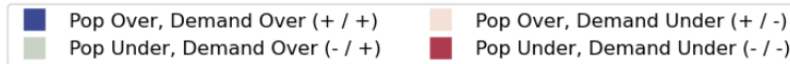
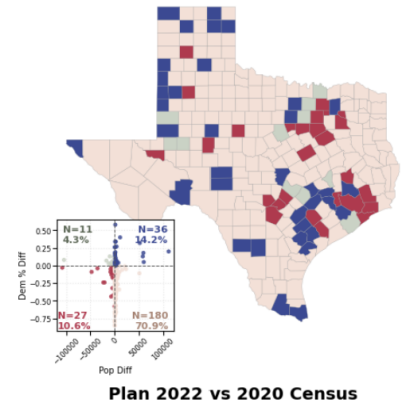


Figure 22: Comparison of 2017 and 2022 population projections difference with census with final water demand difference with a) actual b) drought year (2011) c) maximum (2000-2020) water uses (Data provided in Table S3 and S6).

d) Water Demand Projections Margin of Error and Uncertainty Analysis at County Level

The 2017 and 2022 regional water plans demonstrated marked improvements over historical planning cycles, yielding both reduced Mean Absolute Errors (MAEs) and narrower margins of error (Figure 23). In these recent planning cycles, the county-level MAE drops and stabilizes between 3,200 af and 3,500 af, accompanied by a contraction in the 95% confidence intervals. Given that the sample size remains constant across all cohorts, this simultaneous reduction in both absolute error and variance suggests measurable improvements in recent plans.

Beyond these recent iterative improvements, the broader dataset reveals a distinct relationship between forecasting horizons and error characteristics. Near-term projections consistently yielded lower MAEs than their longer-term counterparts, underscoring the compounding uncertainty inherent to extended projection windows. This horizon-driven uncertainty is vividly reflected in the margins of error; the 2002 and 2007 plan projections for 2020 exhibit the widest confidence intervals on the chart, signaling high regional volatility when predicting two decades into the future. Despite these overarching systemic trends, the 2002-2000 cohort maintains the lowest overall MAE and the tightest margin of error, driven by the exceptionally short timeline between that specific plan's formulation and its target year.

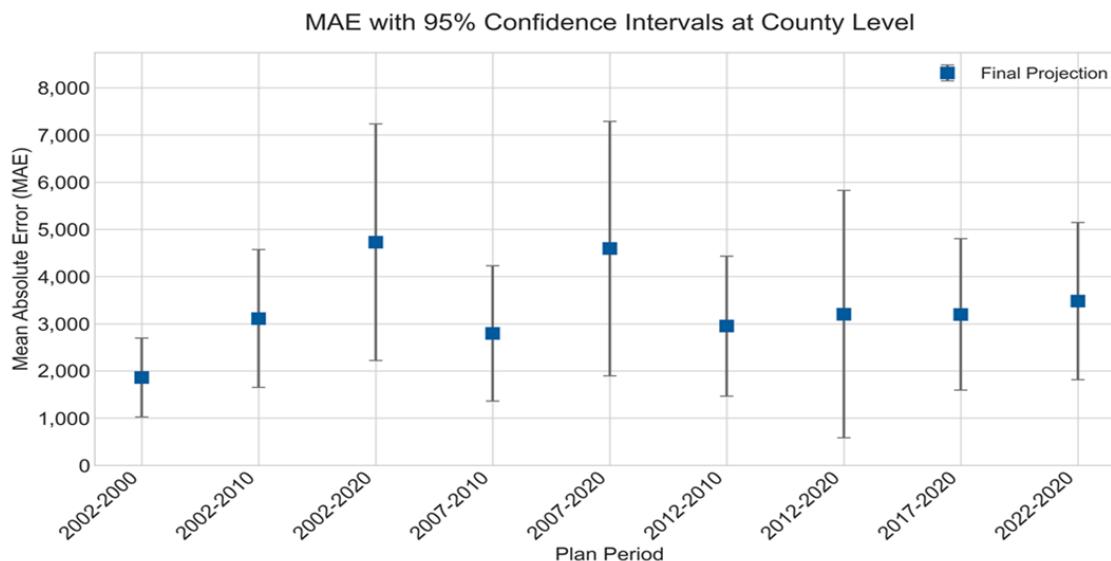


Figure 23: Margin Error (MOE) and 95% Confidence Interval (CI) for Mean Absolute Error (MAE) of water demand projection compared to actual water use at county level (Data provided in Table S13 and S16).

3.2.4. Water Demand Projections at the Water User Group (WUG) Level relative to Actual, 2011 and Maximum Water Uses

The draft and final projections of WUGs water use generally exhibited substantial similarity when compared with actual water use, suggesting minimal necessary revisions to the initial draft estimates. In most recent plans 2022 (2017), draft projections-maintained parity with the final projections for 88% (63%) of the WUGs (Figure 24). In 2022 (2017) plans only 0.3% (0.9%) of WUGs showed greater underestimation in the final projections compared to the draft, while conversely, 3% (6%) of WUGs saw the draft projections exceeding the final ones (while in percentage overestimation). Overall, these findings indicate that the final projections were generally improved the draft projections in areas where revisions were implemented.

Due to the complexity of cross-plan comparisons because of different number of WUGs, this analysis focused instead on high-population WUGs and recent plans. For a more detailed quantitative analysis, we provide figures and data detailing the spatial distribution of magnitude differences against actual water use, 2011 water use, and maximum water use, alongside corresponding Cumulative Distribution Function (CDF) plots (Figures 24–28). These visualizations are useful tools for analyzing the percentage of WUGs exhibiting various magnitude differences.

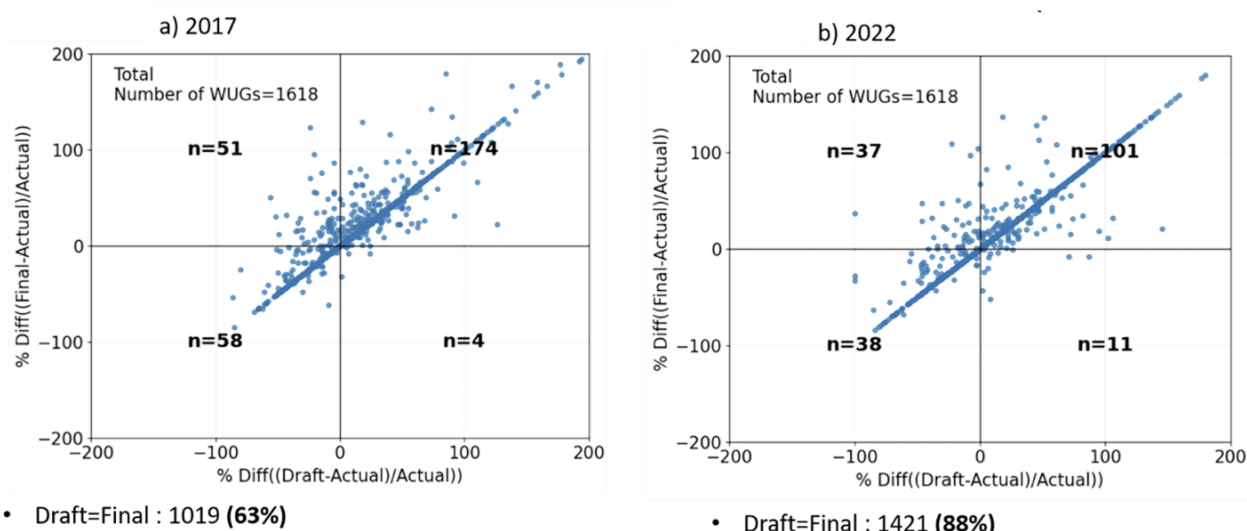


Figure 24: Water User Group (WUG) level quadrant plots of percentage differences between a) 2017 and b) 2022 draft and final water demand projections for 2020 with actual water use for 2020(Data provided in Table S7a). n is the number of counties where draft is different from final.

a) Magnitude Discrepancies in Water Demand Projections at Water User Group (WUG) Level

Regarding the comparison against actual water use, the findings show that fewer than 6% of WUGs underestimated the usage by more than 1,000 af (considering both draft and final) (Figures 25a, and 28i(a)). Large underestimation magnitudes were rare, with most under- and overestimations falling within the $\pm 10,000$ af range (Figures 25a). A notable underestimation compared to actual water use is San Antonio underestimating the actual water use by 23,000 af in the final projection in the most recent plan (2022) and Tyler underestimating by 8000 af. In both draft and final version in the most recent projection (2022) (Figures 25a). Fewer than 15% of WUGs overestimated the actual water use by more than 1,000 af. In sharp contrast, highly populated WUGs, such as Houston, Dallas, Fort Worth, Austin, and El Paso, consistently exhibited larger overestimation magnitudes (exceeding 20,000 af) across all plans and projections.

Compared to the 2011 water use, the under- and overestimation magnitudes are significantly larger compared to the actual water use comparison. Specifically, fewer than 10% underestimated the use by more than 1,000 af (considering both draft and final) (Figures 26a, and 27ii(a)). Houston consistently underestimated water use in all planning and projection years by more than 20,000 af. Any WUG that exhibits a significantly large magnitude of underestimation warrants further investigation, particularly because the planning estimates are based on drought-of-record water use. Although notable examples are provided here, the accompanying data and Figures specify which WUGs are underestimated (Figures 26a, and 28ii(a)). Regarding overestimation, <15% of WUGs overestimated the 2011 water use by more than 1,000 af (considering both draft and final). Dallas consistently overestimated all plans and projections, with the sole exception of the 2017 draft plan for 2022, where the overestimation was between

10,000 af and 20,000 af. Laredo also demonstrated consistent overestimation across all plans (exceeding 10,000 af), although this overestimation decreased in recent plans (to less than 10,000 af).

Compared to the maximum water use a higher proportion of WUGs underestimated the maximum water use by large magnitudes; specifically, fewer than 20% of WUGs underestimated this maximum water use by more than 1,000 af (considering both draft and final) (Figures 27a, and 28iii(a)). For instance, Houston consistently underestimated water use by more than 20,000 af, a pattern mirrored by San Antonio in the 2022 plan. Although Georgetown demonstrated larger underestimations in earlier plans, the magnitude notably reduced in the 2022 plan. Conversely, fewer than 5% of WUGs overestimated the water use by more than 1000 af. In contrast, Austin and Fort Worth tended toward overestimation in both the 2017 and 2022 plans. Specifically, Austin overestimated by >20,000 af in the 2022 final plan, and Fort Worth overestimated by >20,000 af in both the draft and final plans.

b) Percentage Discrepancies in Water Demand Projections at Water User Group (WUG) Level

In terms of percentage deviation, less than 20% of WUGs underestimated the actual water use by more than 25% (Figure 28i(b)). The largest instances of underestimation are notably concentrated within Water Supply Corporations (WSCs) and Special Utility Districts (SUDs) such as Western Cass WSC, Millersview-Doole WSC, and Coleman County SUD (Figure 25b). Conversely, 20%–60% of WUGs overestimated the actual water use by more than 25%. Overall, while both underestimation and overestimation decreased in recent plans, particularly those displayed in lighter colors (the 2022 and 2017 plans; Figure 25b), notable shifts persist. For instance, Dallas initially significantly overestimated the projection (by more than 40%) but subsequently reduced this deviation to 20%–40% in the 2022 plan.

Compared to 2011 water use the percentage difference in under- and overestimation was notably larger compared to the actual water use comparison. Fewer than 26% of WUGs underestimated the 2011 water use by more than 25% (Figure 28ii(b)). Specifically, Coleman County SUD, Lamar WUG, Red River County WSC consistently demonstrated underestimation across all plans, 20%–40% (Figure 26b). Conversely, large, populated WUGs such as Houston demonstrated consistent underestimation, although at smaller percentages, registering less than 5% across all plans. Regarding overestimation, 10%–44% of WUGs overestimated the 2011 water use by more than 25%. Populated WUGs such as Dallas, Fort Worth, Laredo, and San Antonio exhibited mixed patterns of under- and overestimation by smaller percentages. For instance, while Dallas showed greater overestimation in earlier plans (exceeding 40%), this trend reduced significantly in recent plans.

When comparing against the maximum water use between 2000 and 2020, a significantly greater proportion of WUGS underestimated the water use by large percentages. Specifically, 25%–45% of WUGS underestimated the maximum water use by more than 25% (Figure 28iii(b)). While large, populated WUGS—such as Houston, San Antonio, and Georgetown—tended to underestimate the maximum water use by less than 20% in recent 2022 plan (Figure 27b), the largest observed percentages of underestimation in recent plans are highly concentrated in WUGS featuring WSC or SUD in their names. In contrast, fewer than 20% of WUGs overestimated the water use by more than 25%. Austin and Fort Worth showed a tendency toward

overestimation by up to 5% in the 2017 and 2022 plans, a trend mirrored by Northern Texas WUGs. However, San Antonio remains an outlier, having specifically overestimated in the 2017 plan by more than 20%.

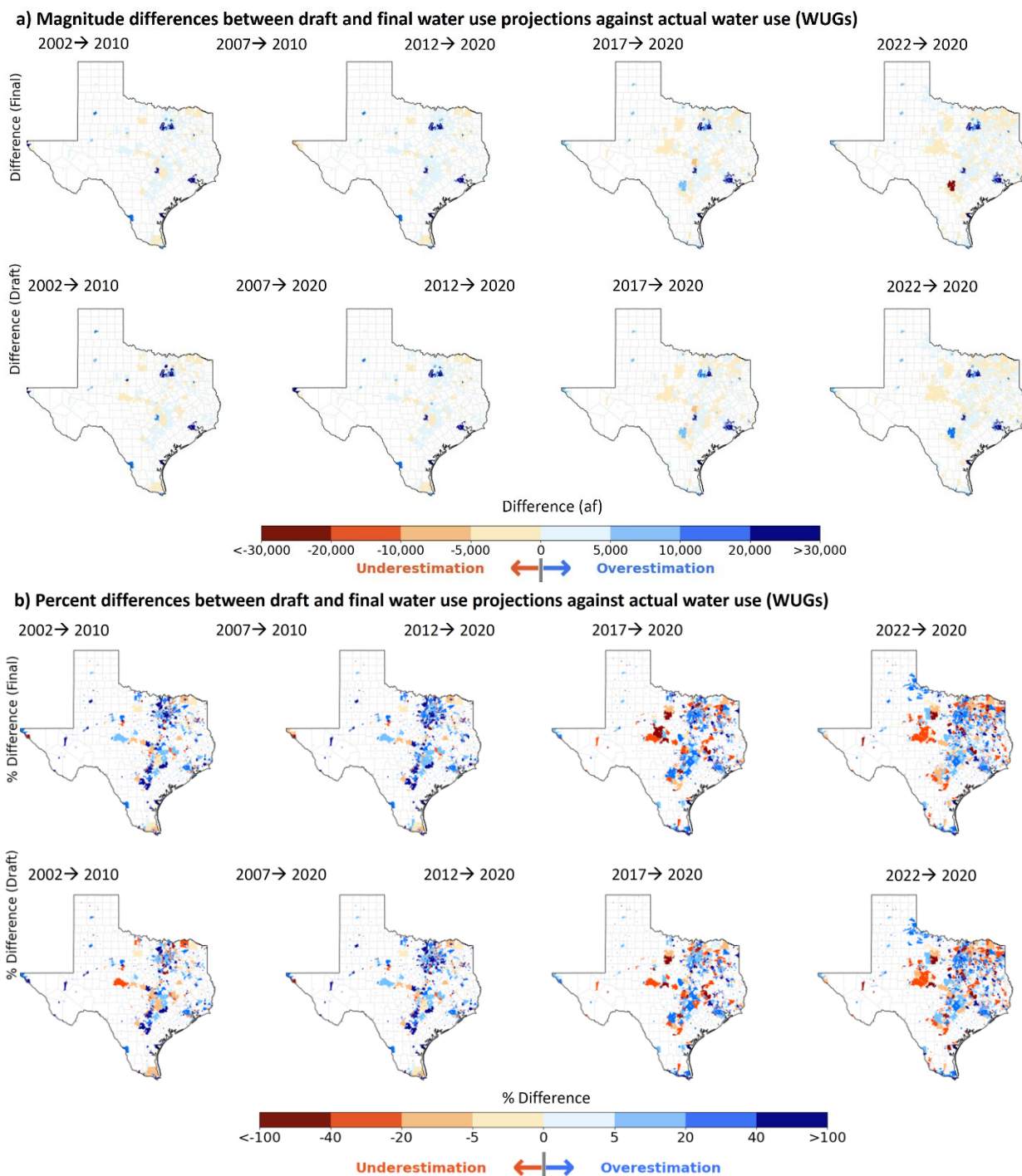
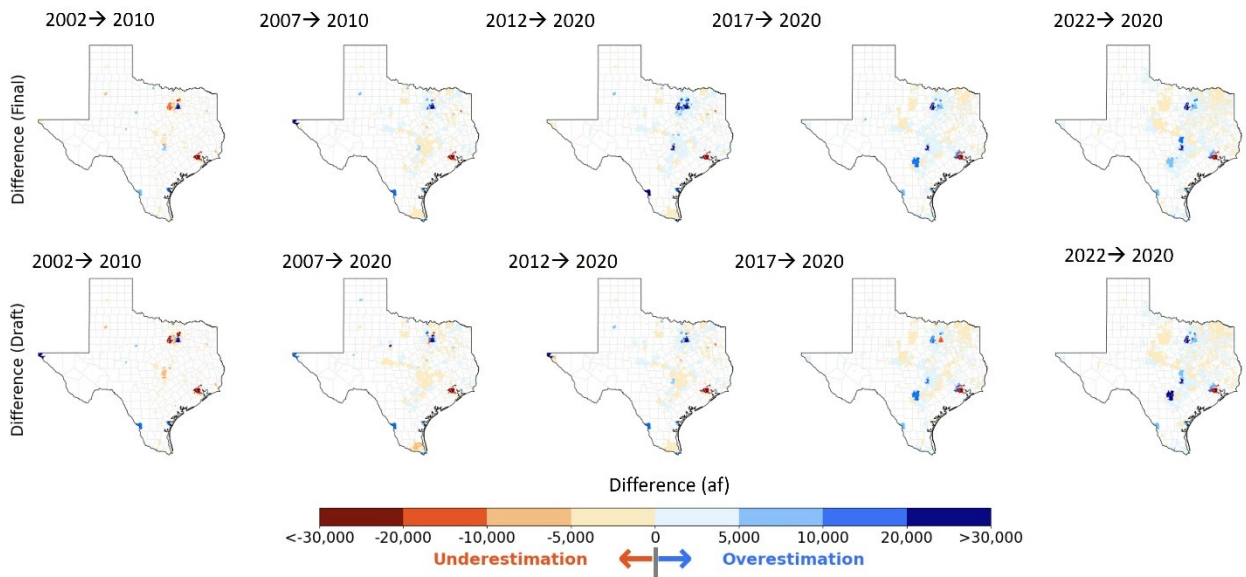


Figure 25: Spatial distribution of differences between draft and final water demand projections with actual water use at Water User Group (WUG) level a) magnitude of differences b) percentage differences (Data provided in Table S7a).

a) Magnitude differences between draft and final water use projections against 2011 water use (WUGs)



b) Percent differences between draft and final water use projections against 2011 water use (WUGs)

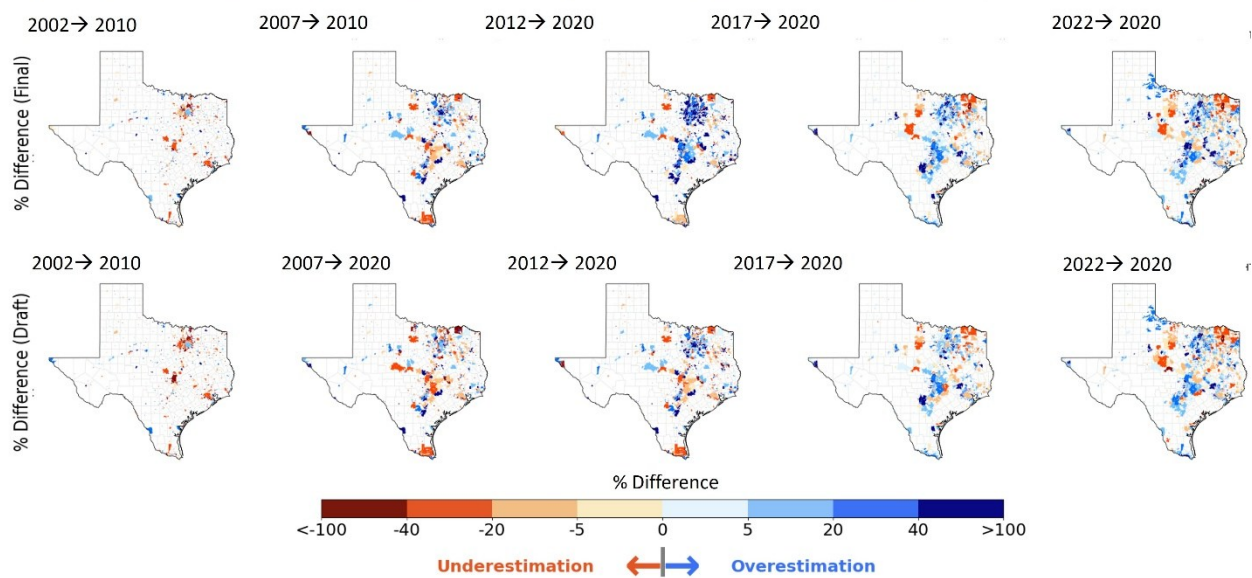
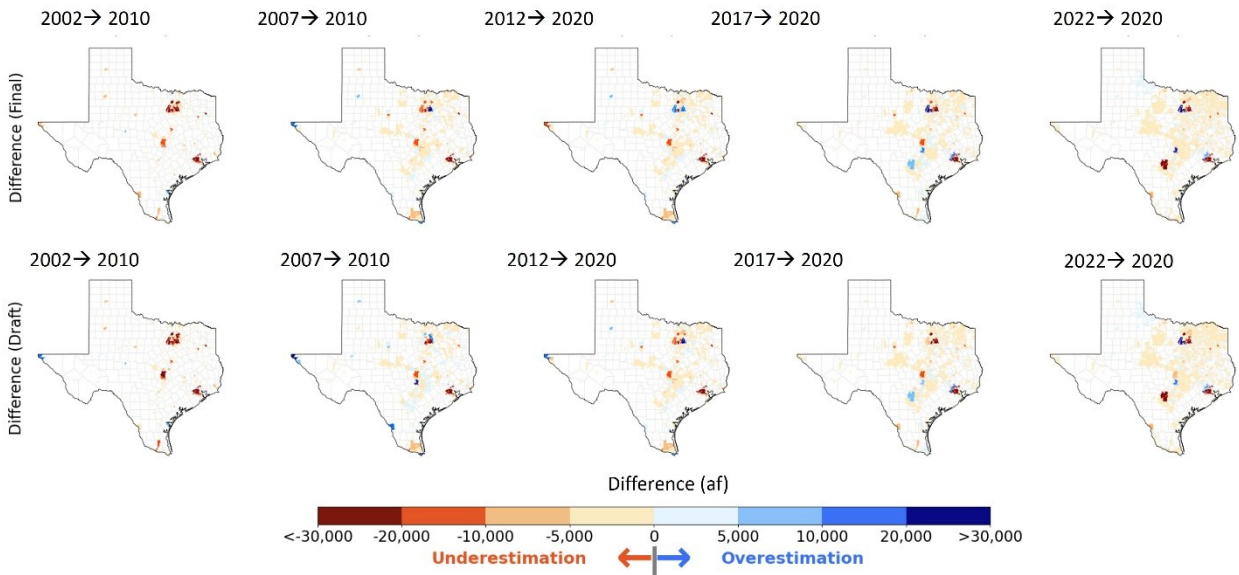


Figure 26: Spatial distribution of differences between draft and final water demand projections with drought year 2011 water use at Water User Group (WUG) level a) magnitude of differences b) percentage differences (Data provided in Table S7b).

a) Magnitude differences between draft and final water use projections against maximum water use (WUGs)



b) Percent differences between draft and final water use projections against maximum water use (WUGs)

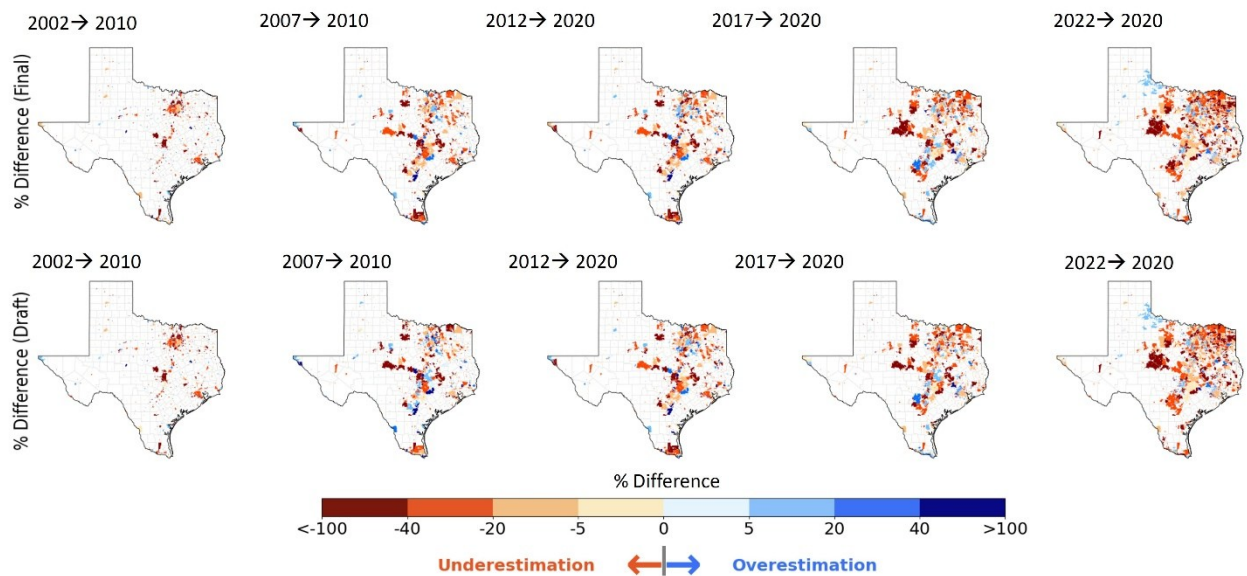
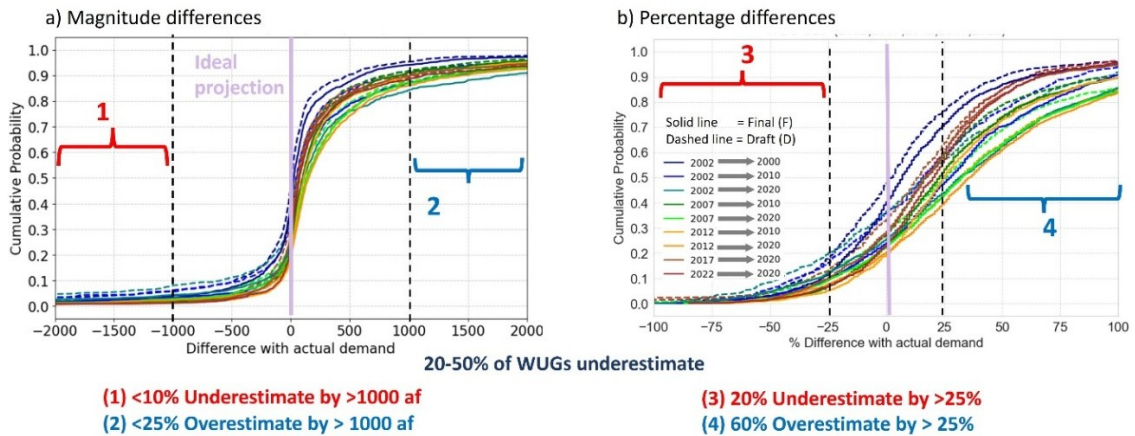
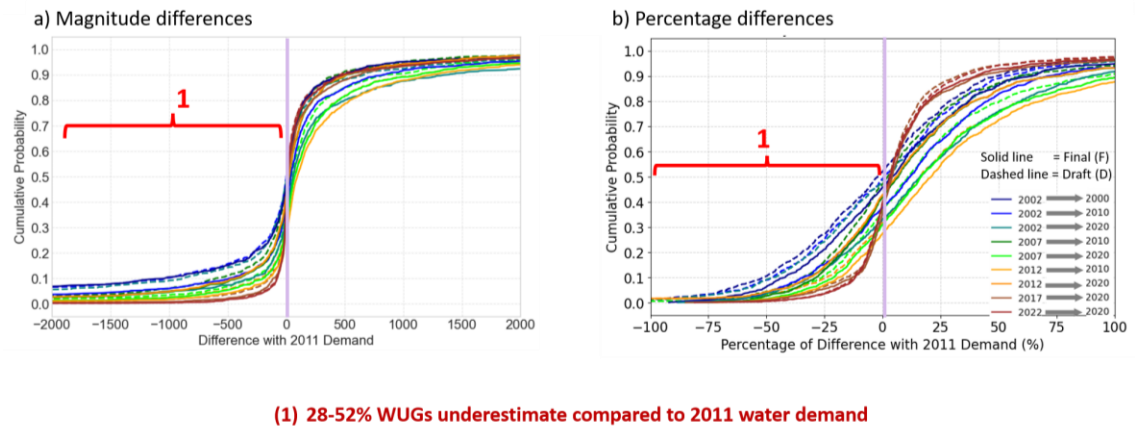


Figure 27: Spatial distribution of differences between draft and final water demand projections with maximum (2000-2020) water use at Water User Group (WUG) level a) magnitude of differences b) percentage differences (Data provided in Table S7c).

i) CDF of water projection against actual use at level (WUGs)



ii) CDF of water projection against 2011 water use (WUGs)



iii) CDF of water projection against maximum water use (WUGs)

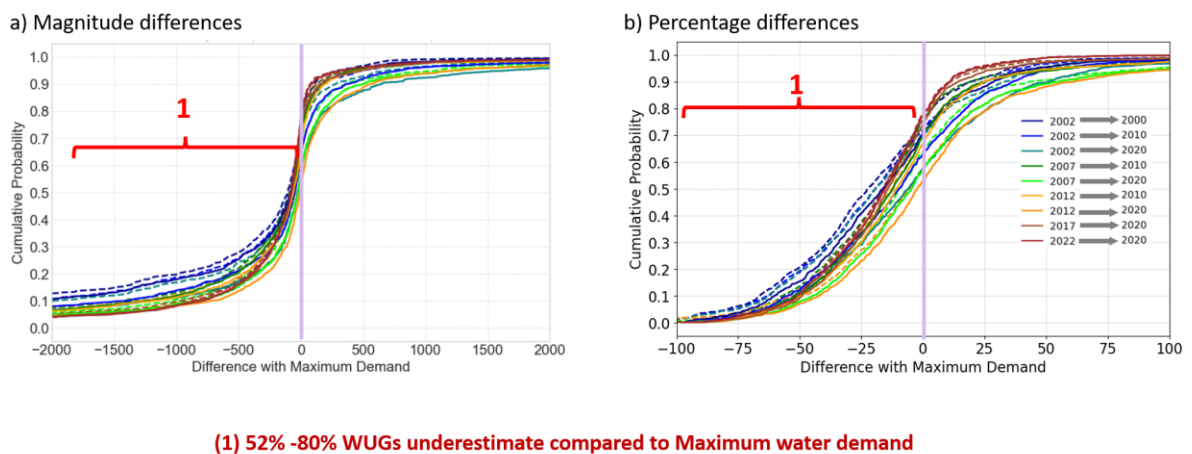


Figure 28: Water User Group (WUG) level Cumulative Distribution Function (CDF) of draft and final water demand projections against i) actual ii) drought year (2011) ii) maximum (2000-2020) water uses a) magnitude and b) percentage differences (Data provided in Table S7a, S7b and S7c).

c) Water Demand Projections Margin of Error and Uncertainty Analysis at Water User Group (WUG) Level

Across almost all evaluated plan periods, draft projections consistently yielded a lower Mean Absolute Error (MAE) compared to their finalized counterparts (Figure 29). The sole exception to this trend occurred in the 2002 plan's projection for the year 2000 (2002-2000), where the final projection achieved a lower MAE than the draft. For all subsequent planning cycles—culminating in the 2017 and 2022 plans, which recorded the lowest overall MAEs—the finalization process systematically increased the error magnitude. This recurring divergence indicates that the revision of draft estimates may have inadvertently introduced structural inaccuracies. Alternatively, this upward shift in final projections may represent a deliberate policy adjustment, incorporating a strategic safety buffer designed to prevent the underestimation of water use during severe drought conditions. Furthermore, while the 2002-2000 cohort exhibited a lower MOE, it is worth noting that the 2017 and 2022 plans evaluated a significantly higher number of WUGs. The smaller sample size of the 2002 plan may have artificially constrained its median error, complicating direct comparisons with more recent, data-dense planning cycles.

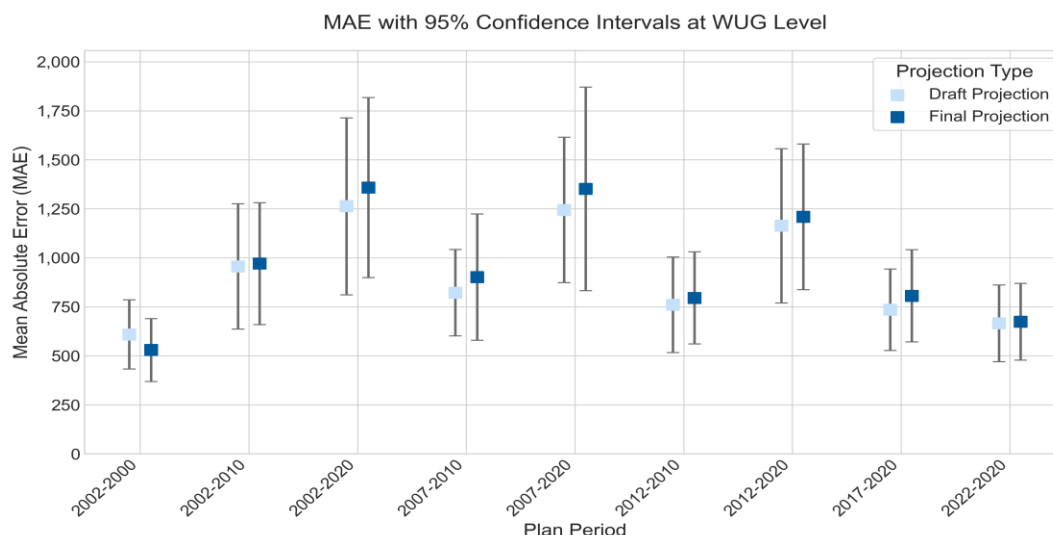


Figure 29: Margin Error (MOE) and 95% Confidence Interval (CI) for Mean Absolute Error (MAE) water demand projection compared to actual water use at Water User Group (WUG) level (Data provided in Table S7a and S17).

d) Accuracy of Urban and Rural Water User Group (WUG) Water Demand Projections

Urban and rural Water User Group (WUG) classifications were defined in accordance with the statutory criteria outlined in Texas Water Code § 15.001(14). Overall, urban areas exhibited larger magnitude errors compared to rural areas (Figure 30a), a finding likely attributable to their higher populations. Regarding underestimations, the magnitude was generally small (<10%), remaining below 5,000 af in most cases for both urban and rural settings. However, in percentage terms, a greater proportion of urban areas (11%–17%) compared to rural areas (7%–10%) were underestimated by more than 25% (Figure 30b). For overestimations, 5%–7% of urban areas showed values exceeding 5,000 af, whereas nearly <1% of rural areas reached this threshold. Percentage difference findings show 37%–42% of rural areas and 28%–35% of urban areas were

overestimated by more than 25%. Major urban WUGs overestimated when compared to actual water use (Table 8).

CDF of 2017 and 2022 urban and rural draft and final water use projections for 2020 with actual water use (WUGs)

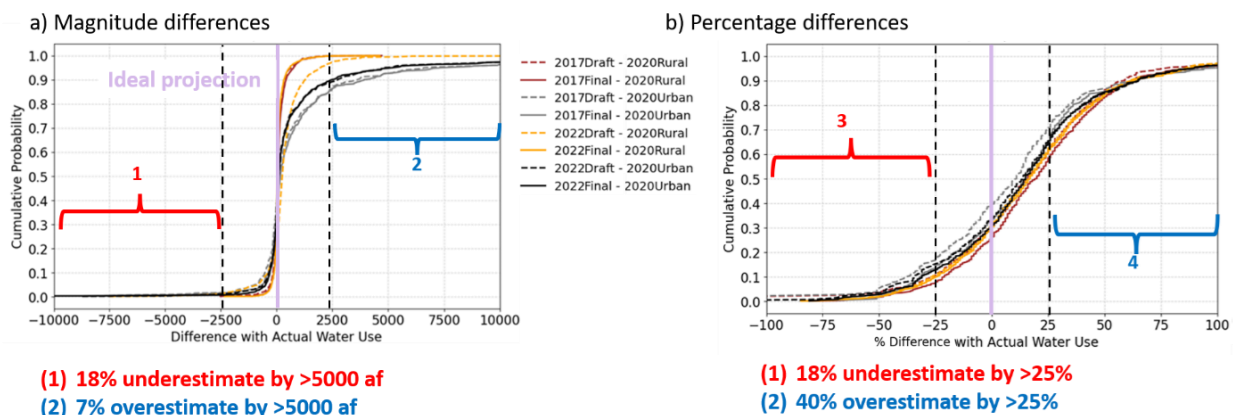


Figure 30: Water User Group (WUG) level Cumulative Distribution Function (CDF) of 2017 and 2022 SWP urban and rural draft and final water demand projections for 2020 with actual water use a) magnitude and b) percentage differences (Data provided in Table S7a). Figure a demonstrates that urban WUGs exhibit larger overall difference magnitudes than rural WUGs. This is indicated by the gray and dark lines extending farther outward to larger values across a relatively greater cumulative percentage of WUGs. e.g.; 10-15% of Urban WUGs have overestimations compared to actual water use by more than 2500 af and <2% of urban WUGs have underestimation by more than 2500 af. A total of 99% of rural WUGs have differences with actual water use below 2500 af (almost all differences are < 2500 af) and from these only <0.5 % of rural WUG differences fall below (underestimation) -2500 af. In Figure b, the gray and dark lines consistently sit above the orange and brown lines. This indicates that both the 2017 and 2022 draft and final plans underestimated urban demand slightly more frequently than rural demand: urban WUGs were underestimated at 32% (draft: 39%) in 2017 and 30% (draft: 33%) in 2022, compared to rural WUGs at 26% (draft: 30%) in 2017 and 30% (draft: 30%) in 2022. Notably, the 2022 final plan yields a nearly balanced distribution between under- and overestimation across WUGs.

Table 8: Discrepancies between draft and final water demand projections against actual water use in major cities for 2022 SWP

City	Difference (Draft-Actual) (af)	% Difference (Draft-Actual)/Actual (%)	Difference (Final-Actual) (af)	% Difference ((Final-Actual)/Actual) (%)
Austin	32427	23	43514	31
Dallas	60572	28	61423	29
El Paso Water	9153	9	9153	9
Fort Worth	45046	31	45046	31
Arlington	120071	22	119993	22
Houston	112641	34	112641	34
San Antonio	17045	7	23092	-9

e) Water Demand Projections in County Other Group

The threshold for County-Other WUG selection was set at 25% of the counties in each Regional Water Planning Area or at least four counties (excluding Region P, which has only three counties). Based on this selection, significant underestimation was observed in these WUGs, with 53% of County-Other WUGs experiencing underestimation compared to actual water use (Table S18 and Figure S11). Within the recent planning cycle (2022), Hays displayed the largest underestimation magnitude difference (3,763 af), while Wichita showed the greatest percentage underestimation (88%) when compared to estimated actual water use data. Conversely, within the same 2022 planning cycle, Brazoria (~3,500 af) and Cameron (190%) recorded the largest magnitude and percentage overestimations compared to actual water use. Overall, there was no systematic pattern of over- or underestimation in County-Other WUG water demand when compared to actual water use (Table S18 and Figure S12).

3.2.5. Accuracy of Gallons Per Capita per Day (GPCD) Estimates at the Water User Group (WUG) Level

The GPCD values used in the analysis largely align with the calculated GPCDs (Equation 2) across most WUGs. However, discrepancies were noted when comparing projections across different years: the 2022 projection for 2020 showed the largest spread in differences from the calculated GPCD, while projections for the 2007 and 2012 plans for 2010 exhibited the largest median differences (Figure 31). Furthermore, certain WUGs showed underestimations compared to the calculated GPCD, indicating potential water demand underestimation requiring closer evaluation. This finding is corroborated by the spatial plots of differences between the projected and actual GPCD (Figure 32), where red highlights underestimation. Specifically, some WSC and SUD WUGs—such as Richland SUD, which showed the largest underestimation magnitude (>300 gal/capita/day), and Coleman County SUD and Richland SUD—demonstrated underestimation exceeding 40% in recent plans (2017 and 2022). Population estimates for WSCs and SUDs can be skewed by spatial boundary mismatches between utility service areas and Census places, which subsequently distorts both total demand and GPCD estimates. For Richland SUD, final population was overestimated by 150%, while final demand was underestimated by 51%, resulting in a 55% underestimation of GPCD. In both Coleman SUD and Richland SUD, there was a discrepancy between the base-year GPCD and the historical and calculated GPCD. The calculated GPCD overestimated the base-year GPCD by 55% in Richland SUD. Although the lack of reported Census population data prevents direct confirmation that the GPCD spike resulted from population adjustments in Coleman SUD, the disparity between the base-year GPCD used and the historical GPCD was substantial (48%), suggesting that GPCD calculations in WSCs and SUDs should be checked for inconsistencies propagated from population estimates.

Historical municipal gallons per capita per day (GPCD) for major Texas cities—including Austin (125), San Antonio (126), Houston (127), El Paso (131), Fort Worth (137), and Dallas (149)—ranged from 104 to 149 GPCD. Among these, Dallas, Fort Worth, and Houston exhibited the largest historical GPCD estimates and projected GPCD metrics (Figures 33a and 33b). Notably, these values consistently fall below both the historical statewide municipal average of 154 GPCD and historical drought-year GPCD baselines.

The GPCD time-series data reveals episodic demand spikes during severe drought cycles since 2016 (the time series did not include the 2011 drought of record)—most notably in 2022 and 2023. These spikes are heavily driven by real physical water losses resulting from climate-induced infrastructure degradation, such as widespread water main breaks caused by shifting clay soils during prolonged dry spells. Independent utility assessments and engineering reports, including findings by Black & Veatch (2024) and Salinas (2024), correlate these extreme weather periods with historically high volumes of non-revenue water loss. For instance, during the 2023 drought, municipal water loss audits for the City of Austin indicated that unaccounted physical water loss escalated sharply, exceeding 15% of the utility's total system input (Austin Water, 2024). This infrastructure stress was felt on a statewide scale; self-reported audits to the TWDB revealed a collective loss of roughly 88 billion gallons—representing about 270,000 acre-feet and roughly 5% of the 2030 projected demand in the 2027 plan—of treated water across the state's most populous municipal systems during peak drought periods (Salinas II, 2024). While the water loss was characterized by a 30% spike in Houston (losing 31.8 billion gallons) and an 18% increase in Dallas (losing 17.6 billion gallons), the impact extended well into other major Texas metros (Salinas II, 2024). San Antonio recorded the state's second-highest volumetric shortfall, losing 19.5 billion gallons, while Fort Worth and El Paso faced substantial infrastructure strains, losing 5.9 billion gallons and 4.8 billion gallons, respectively (Salinas II, 2024). This widespread escalation highlights how severe heat and shifting clay soils accelerate water main failures, posing a systemic challenge to utilities throughout Texas. This phenomenon demonstrates how extreme weather can artificially inflate gross GPCD metrics through distribution system failures. Consequently, the historical GPCD data reveals a distinct lack of systematic, long-term downward temporal variations in GPCD (Figures 33a and 33b). This presents a stark contrast to the findings of Richter (2023), whose research documented steady, linear declines in GPCD across the Western United States driven by the widespread, structural implementation of toilet replacement rebates, plumbing retrofits, variable water-pricing structures, and turf removal. Furthermore, when evaluating long-term trends of GPCD, population, and water demand in major populated cities, the projected GPCD was found to be greater than the actual GPCD in all the major cities analyzed (Figures 33a and 33b). However overall, there was no clear systematic trend observed in GPCD across these urban areas.

3.2.6. Evaluation of urbanization and impacts on GPCD on USGS land use change data

Direct application of land use datasets is not applicable to the localized water use modeling utilized in TWDBs planning process. While land use changes drive changes in water use, water utilities and state-level planning agencies approach this data through fundamentally different frameworks.

Retail public utilities actively integrate land use factors into their long-range master plans. However, rather than utilizing coarse national datasets, such as the U.S. Geological Survey (USGS) National Land Cover Database (NLCD), utilities rely primarily on high-resolution, site-specific local data. This includes municipal zoning maps, local permitting pipelines, certificates of convenience and necessity (CCN) boundaries, and active property development tracts. This granular data allows utilities to project exact service connection growth and volumetric demands at the neighborhood or parcel level.

In contrast, the Texas Water Development Board (TWDB) manages state and regional water planning by projecting population growth and calculating baseline Gallons Per Capita Daily (GPCD) metrics, derived primarily from historical annual water use Surveys and U.S. Census Bureau data. Because the TWDB functions at a regional aggregate scale, it does not possess administrative access to, nor the data-processing capacity for, the highly localized zoning and utility-specific permitting data used by individual retail water suppliers. Consequently, while land use heavily informs local utility planning, the disparate scale of available data means macro-level land use datasets cannot be directly reconciled with the TWDB's regional water user group (WUG) water demand projection methodologies.

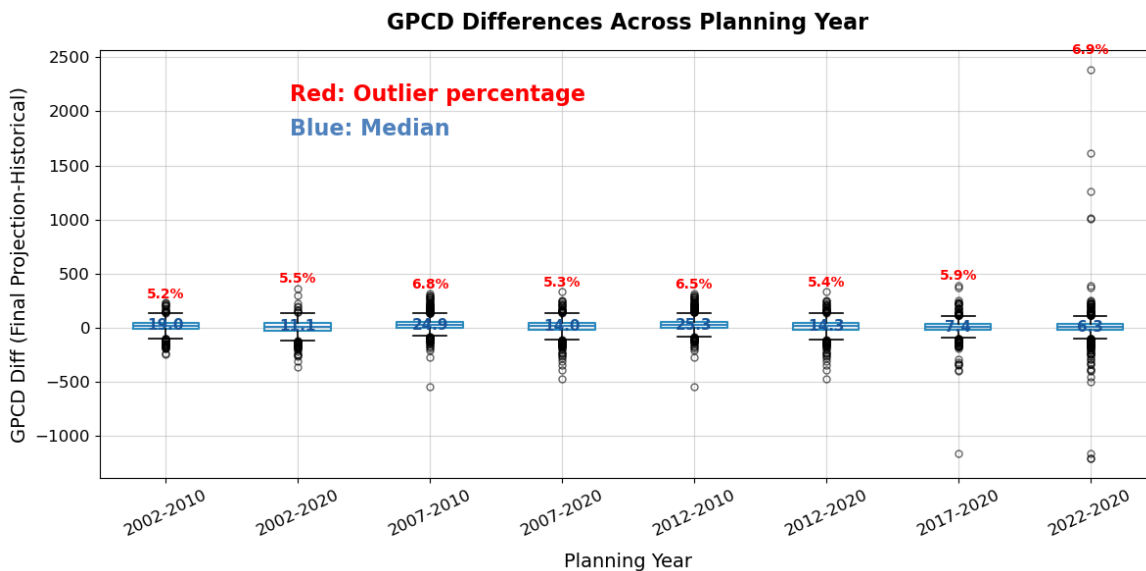


Figure 31: Difference between projected and actual Gallons Per Capita per Day (GPCD) across plans at Water User Group (WUG) level (Data provided in Table S13).

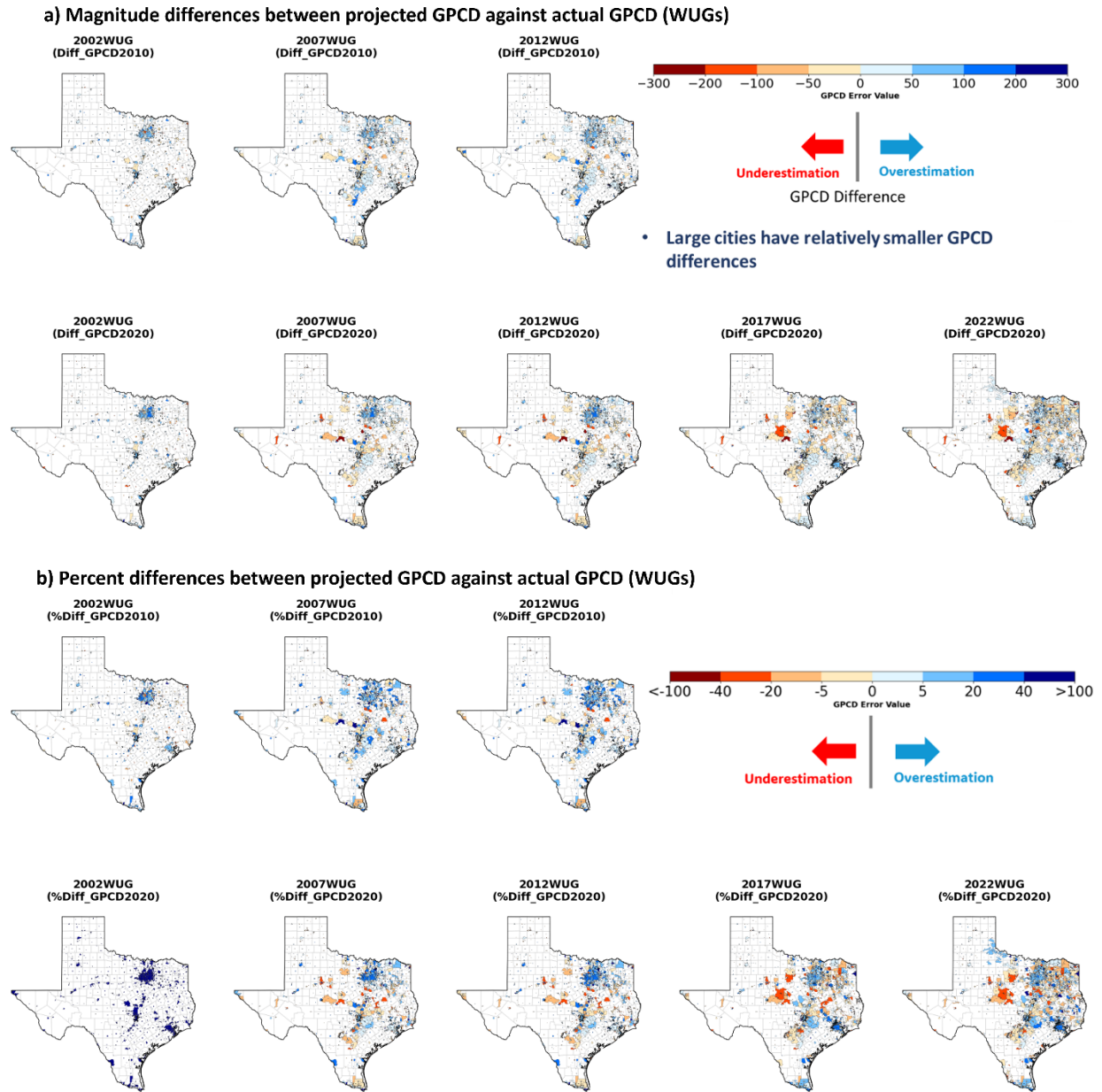
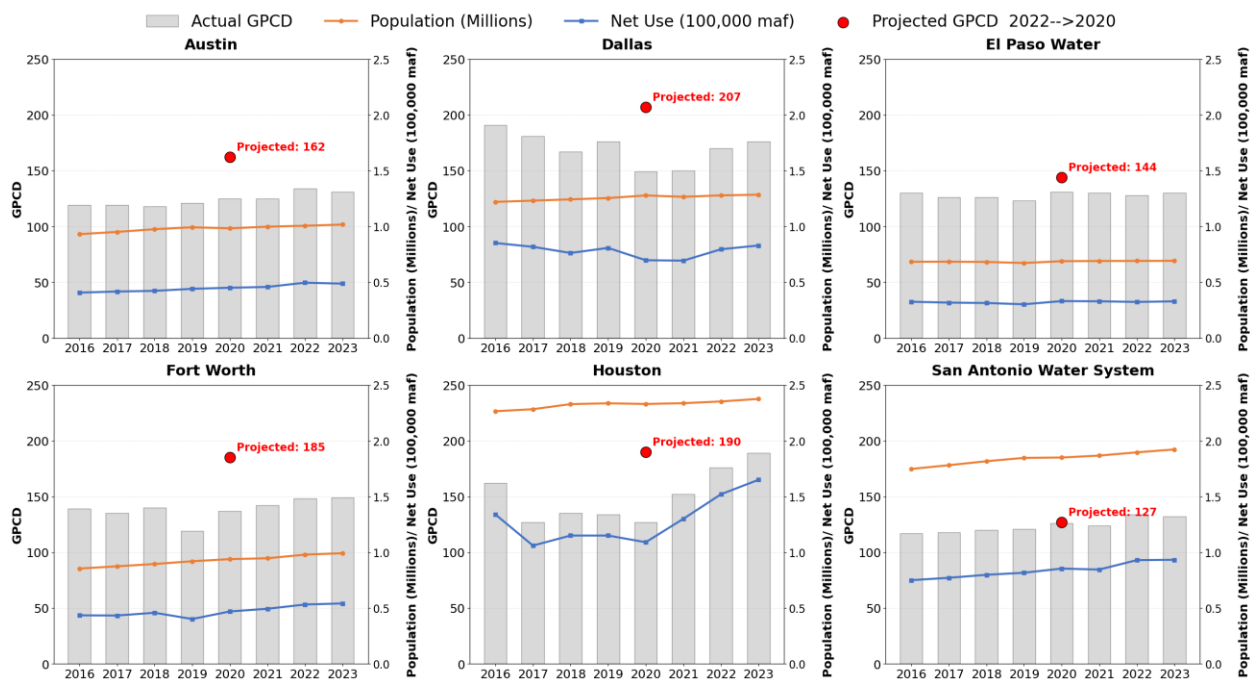


Figure 32: Spatial distribution of differences between projected and actual Gallons Per Capita per Day (GPCD) across plans at Water User Group (WUG) level a) magnitude differences b) percent differences (Data provided in Table S8).

a)



b)

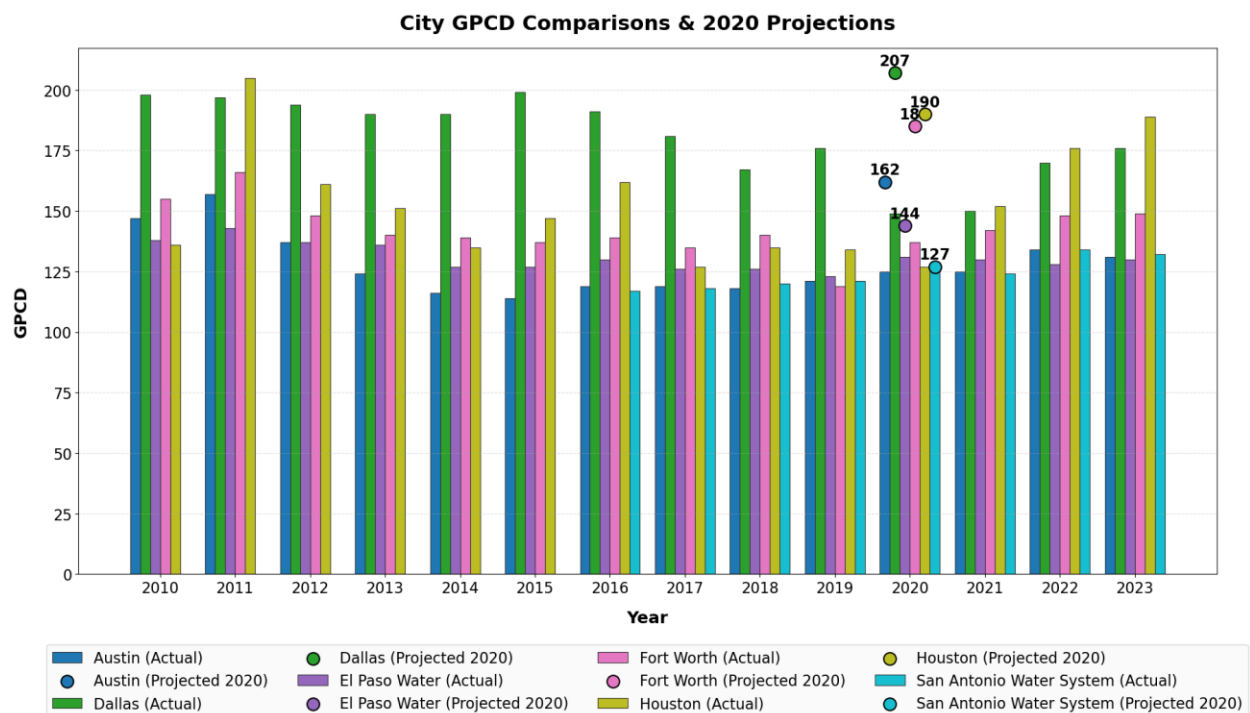


Figure 33: Major Cities a) Trend of population, Gallons Per Capita per Day (GPCD), and reported water use b) City GPCD comparisons (2016-2023) (Data provided in Table S9).

3.2.7. Water User Group (WUG) Level Population and Gallons Per Capita per Day (GPCD)

Error Attribution in Water Demand Across Plans

The error contributions to the plans were first estimated using the refined Laspeyres decomposition error attribution in equation 8-12, evaluating the respective contributions of population and GPCD. Since the interaction error was smaller than both the GPCD and population errors, this initially suggested GPCD as the main contributor to the total errors across plans (Figure 34). For instance, in the 2022 plan, 53% of the total error was attributed to GPCD, while 38% was attributed to population. However, the refined Laspeyres decomposition error attribution assumes an interaction error, which is not assigned to any specific contribution, potentially reducing conclusive interpretations.

Therefore, we utilized the Logarithmic Mean Divisia Index (LMDI) Decomposition Analysis (Figure 35 and S8). LMDI is a perfect decomposition analysis. LMDI is capable of breaking down changes in an aggregate indicator, such as water demand, into its contributing factors: population and GPCD. Using LMDI, GPCD emerged as the primary contributor in all plans. Specifically in the most recent 2022 plan, GPCD resulted in the largest percentage of responsibility for the total error (GPCD: 46%, Population: 44%). Even though the percentage of WUGs in over and under estimations are large in some plans, LMDI box plots show when the plan is missing water demand, the size of the failure is heavily dictated by the GPCD baseline, even if population shared the same (both over and underestimating) directional bias. This finding supports the results observed using the refined Laspeyres decomposition error attribution. Notably, such a substantial contribution from GPCD is consistent across all plans. The analysis identified WUGs, such as Tyler (Net Err: -8726) in the 2022 plan, which showed underestimation in both population and GPCD.

Across nearly all projections (specifically the 2002, 2007, and 2012 plans), GPCD consistently emerged as the primary driver of projection error, rather than population growth. This dominant pattern was further substantiated during the county-level analysis of both population and water use overestimations and underestimations.

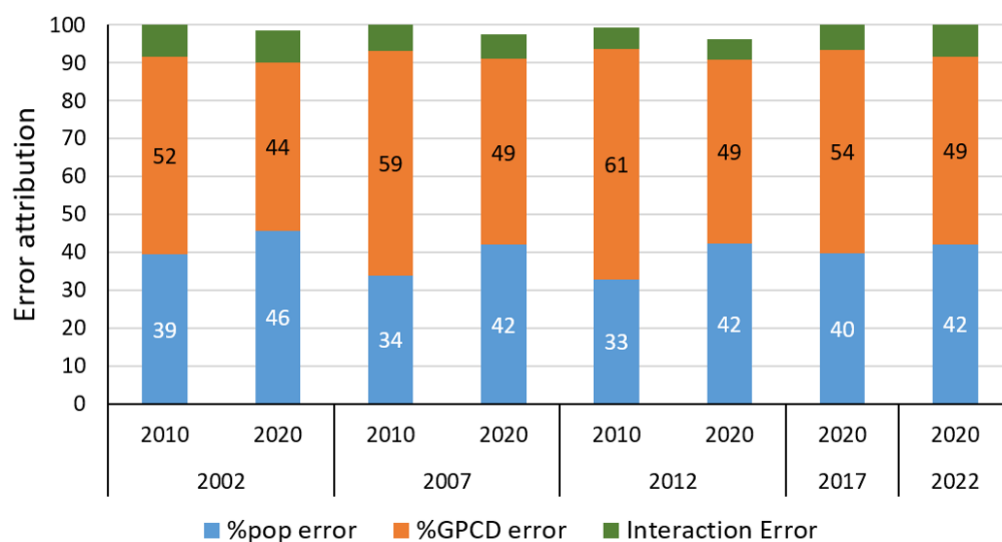
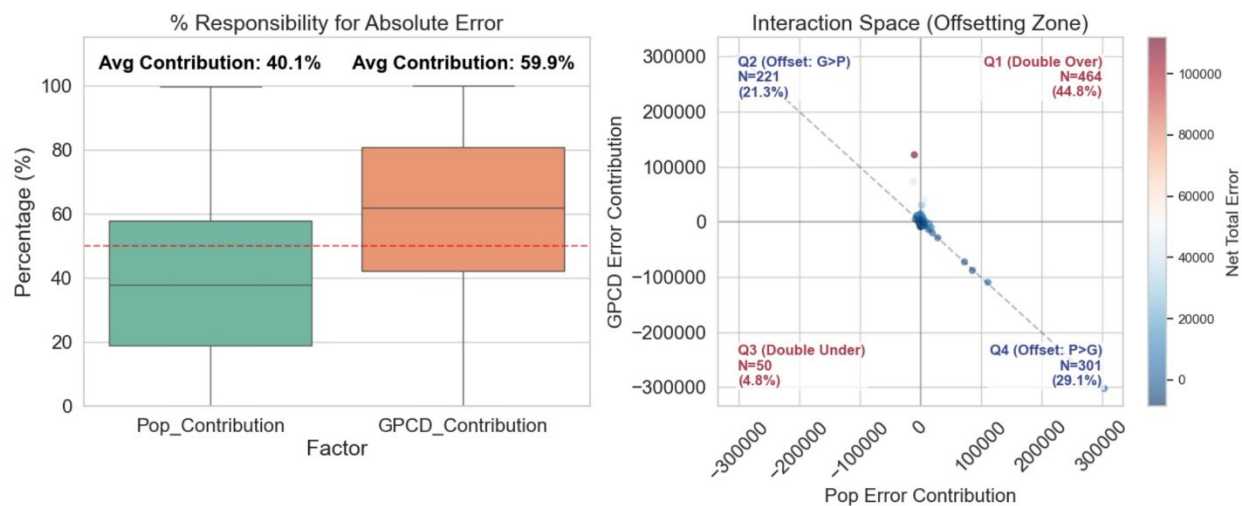


Figure 34: Population and Gallons Per Capita per Day (GPCD) error attribution across plans using refined Laspeyres decomposition error attribution (Data provided in Table S11).

a) LMDI Error Analysis: 2017 Plan Projection for 2020



b) LMDI Error Analysis: 2022 Plan Projection for 2020

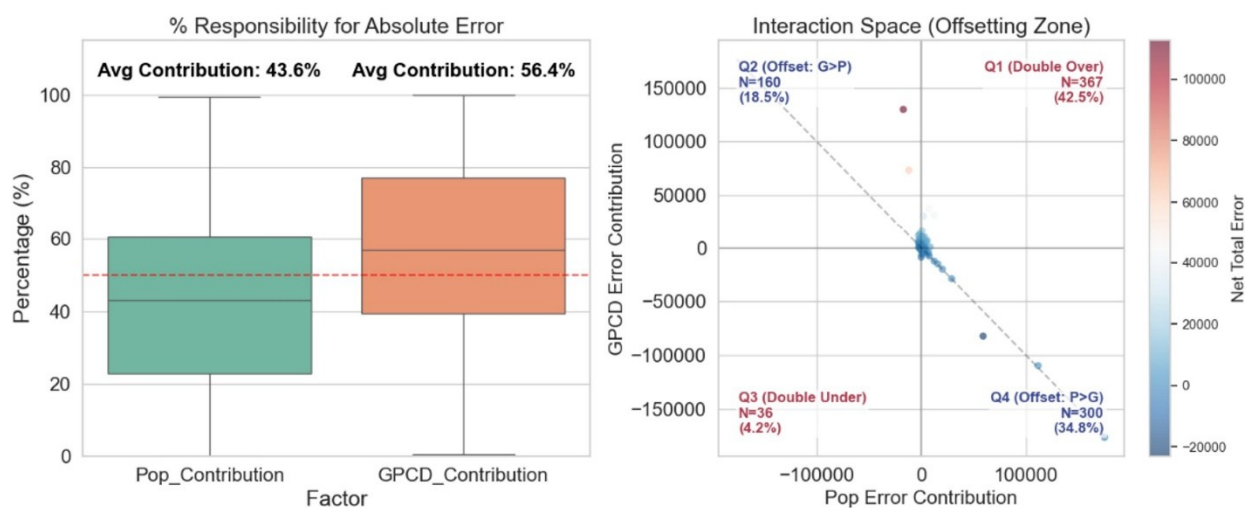


Figure 35: Population and Gallons Per Capita per Day (GPCD) error attribution: Logarithmic Mean Divisia Index (LMDI) Decomposition Analysis a) 2017 b) 2022 (Data provided in Table S12).

4. Summary

Assessing the methodology and reliability of population and municipal water-use projections developed by the Texas Water Development Board for the Texas State Water Plan (SWP) is important for water resources management in the state. The analysis reviews relevant literature and water plans from other states and Texas agencies for developing population and water demand projections. For the Texas SWP, the report includes evaluation of Texas Demographic Center (TDC) projections across various migration scenarios, alongside draft and final SWP population and water demand projections across multiple geographic scales: Regional Water Planning Groups (RWPGs), counties, water user groups (WUGs), and urban and rural WUGs. Water demand projections based on projected population and dry year gallons per capita per day (GPCD) were compared with actual water use, 2011 water use and maximum (of 2000-2020) water use. Furthermore, uncertainty quantification includes margins of error and sources of uncertainty, to determine the relative importance of population projections vs GPCD data on water demand estimates. Because the SWP is based on drought of record (dry year) conditions, projected underestimation of populations and/or GPCD are particularly important to ensure sufficient water supplies for the future.

The findings indicate that TDC population projections at the county level for 2007 and 2017 using the 0.5 (half) migration scenario compared marginally better than other migration scenarios (0.0 and 1.0) with US Census data.

Consistent with fundamental limitations in long-term forecasting, errors in both population and water-use projections increase across all state water plans as the projection horizon lengthens. Spatially, smaller geographic scales exhibited lower magnitude differences between projections and actual data; for example, magnitude differences were reduced when moving from RWPG to counties, and subsequently from counties to WUGs, for both population and water demand. Conversely, magnitude differences between population projections and census data generally increased with higher populations in the RWPG, counties, or WUGs, while percentage differences decreased with population size. Some instances with both large magnitude and percentage population differences with census warrant specific attention. Examples include Tyler (2020 Census Pop: 105,995, 30% final 2022 plan), Leander (2020 Census Pop: 59,202, by 24% in 2022 plan) and Edinburg (2020 Census Pop: 100,243, 11%).

Regarding planning cycle data, recent plans (2017 and 2022) demonstrated a notable reduction in the underestimation of both population (relative to census) and water-use (relative to actual water use) projections—in both draft and final versions—where data were available, when compared with earlier plans. At the RWPG and county levels, the most recent plans (2017 and 2022) showed the lowest percentage of underestimating counties compared to earlier plans in terms of both population and water demand. While comparing WUG-level population and water use results across plans was challenging due to variable WUG numbers, a general reduction in absolute errors in recent plans (compared to earlier plans) was observed.

Draft and final projections were developed for population and water demand at county and WUG levels. Both draft and final projections were identical for a large percentage of counties (91% in 2022 for population) and WUGs (86% of WUGs for population and 88% for water demand in 2022); therefore, only a small percentage of draft projections required revisions. For those

counties and WUGs that did revise their draft versions, the final population and water demand projections demonstrated less underestimation, suggesting that revisions were beneficial.

A direct comparison of projected water demand with actual water use reveals a consistent structural tendency toward overestimation across the RWPG, county, and WUG levels. This upward bias is expected, given that projections are fundamentally underpinned by GPCD for drought of record conditions. Underestimation of projected water demand relative to actual water use is particularly concerning and was found in a large percentage of counties (e.g. ~40% in 2022 plan). In addition, when evaluating projected water demand relative to water use during the drought year (2011) and to maximum historical water use (2000–2020), underestimation was found in a larger percentage of counties and WUGs relative to actual water use. Maximum water use aggregates peak drought-year water uses alongside acute, localized water-use spikes, resulting in larger underestimations. The underestimation observed relative to actual water use, actual 2011 water use, and maximum water use requires close examination and suggests that the GPCD under drought of record conditions may not be sufficiently conservative for planning purposes. Projections are intentionally developed for drought of record conditions and would not be expected to fall below observed water use, or during a known, severe historical drought year or the observed maximum water use.

Error attribution analysis identified uncertainties in gallons per capita per day (GPCD) rather than uncertainties in population as the main contributor to water-use estimation errors at both the county and WUG levels. This conclusion is strongly supported by comparing decoupled population and water-use trends at the county level. Specifically, instances where population is systematically overestimated while water use is simultaneously underestimated (or vice versa) demonstrate that water-use discrepancies are attributable more to inaccuracies in GPCD estimates rather than population errors. The WUG level refined Laspeyres decomposition error attribution and Logarithmic Mean Divisia Index (LMDI) decomposition analysis results further confirm that GPCD is the main contributor to uncertainties in water demand. These findings suggest that revisiting current GPCD estimation methods, or exploring alternative approaches, could improve water-use projections, especially given GPCD's high sensitivity to drought-year water-use assumptions and projected population values. Such improvements should provide a larger buffer to accommodate future droughts.

In addition to the comparative analysis across planning cycles and geographic levels presented herein, we provide detailed files and maps that precisely identify where population and water-use discrepancies are greatest across all evaluated plans, projection years, and geographic scales. These materials should provide valuable resources to guide future State Water Plan development and for targeting specific, data-driven improvements to draft and final projections.

5. Recommendations

Texas has one of the most comprehensive and rigorous municipal population and water demand projection programs in the United States. The review of other western states indicates that Texas conducts water planning at a level of detail and frequency unmatched by most states, many of which rely more heavily on utility-level planning and less formal statewide forecasting efforts. The analysis further demonstrates that TWDB's population and municipal water demand projections have improved over time and generally perform well. Nevertheless, rapid population growth, increasing uncertainty associated with drought and climate variability, and the need to ensure adequate supplies under drought-of-record conditions warrant some refinements to strengthen future planning efforts.

5.1. Consider Modifications to the Population Projection Framework while Explicitly Addressing Uncertainty

The Texas Demographic Center and TWDB population projection methodologies generally perform well and compare favorably with observed Census populations. More recent planning cycles show reduced underestimation and improved accuracy at regional, county, and WUG scales. Reduced population underestimation is important because it should translate into reduced underestimation of projected water demand. However, TWDB should consider removing the population constraints related to the statewide population and allow major urban centers to grow more in the future, which should result in a greater buffer in the projected water demand relative to drought of record conditions.

The analysis clearly demonstrates that uncertainty increases with projection horizon. Future State Water Plans should therefore supplement single-value projections with uncertainty ranges or scenario-based projections. Low-, medium-, and high-growth population scenarios could be developed for counties and RWPGs and linked directly to corresponding municipal water use estimates. Such an approach would better communicate uncertainty while allowing planners to evaluate risks associated with rapid growth, economic development, and demographic shifts.

5.2. Provide Greater Regional Flexibility in Allocating Future Growth

One of the important findings of this study is that regional review and revision of draft projections generally improved final projection performance. Local planners often possess information regarding utility service area expansions, annexations, housing developments, transportation investments, and economic growth that may not be fully reflected in statewide demographic models.

TWDB should establish a structured process that allows RWPGs greater flexibility to redistribute projected population growth among WUGs and counties within a region. Current projections are constrained by statewide population totals, which promotes consistency but may limit the ability to accommodate growth in rapidly expanding urban centers. Future planning cycles should evaluate whether limited adjustments to statewide allocations are warranted where substantial evidence supports sustained growth in major metropolitan areas. Such flexibility could improve projection accuracy while ensuring that future water supplies adequately reflect anticipated demand in high-growth regions.

5.3. Strengthen GPCD Methodology and Review Procedures

The analysis indicates that GPCD assumptions contribute more to municipal water demand projection errors than population projections. As a result, future methodological improvements should focus primarily on refining GPCD estimation procedures.

TWDB should develop a more transparent and standardized framework for selecting dry-year GPCD values, including documentation of:

- Drought years used for calibration
- Historical water demand trends
- Conservation assumptions
- Utility-specific operational characteristics
- Adjustments made during the review process

In addition, projected and observed GPCD values should be evaluated routinely after each planning cycle. Utilities with persistent discrepancies should receive targeted review.

Particular attention should be given to large urban utilities because errors in GPCD assumptions for these systems can translate into limited water availability to meet increased demand during drought conditions. TWDB should work closely with major utilities to ensure that projections utilize the best available information regarding customer growth, conservation trends, operational practices, and drought response measures.

5.4. Better Account for Drought Demand and System Leakage

The primary objective of the State Water Plan is to ensure adequate water supplies during recurrence of the drought of record. While regional-level comparisons show that recent projections generally align with actual water use, we would like to see the projections exceeding actual water use to provide a buffer for potentially extreme drought conditions in the future. Comparisons of projected water demand with drought-year and maximum historical water use suggest that some counties containing major urban centers may still underestimate future water requirements under severe drought conditions.

Future planning efforts should therefore evaluate projections against multiple benchmarks, including:

- Actual observed water use
- Drought-of-record water use
- Recent extreme drought conditions, e.g. 2011 drought water use.
- Maximum observed historical water use.
- Climate-adjusted drought scenarios, where appropriate.

In addition, TWDB should consider incorporating system leakage more explicitly into GPCD calculations and water demand projections. Recent data indicate that system leakage increased substantially during recent drought periods and represents a component of water use that utilities must accommodate regardless of customer conservation efforts. Consideration should be given to establishing minimum drought-year GPCD thresholds that include observed system leakage to provide additional planning margin and reduce the risk of underestimating future drought demands.

5.5. Improve Utility-Level Data Integration

The transition from city-based planning to utility-based planning represents a significant advancement because utilities are ultimately responsible for providing water service. Continued improvements in utility-level data collection would further strengthen future projections.

TWDB should work with utilities and RWPGs to improve information related to:

- Service area boundaries
- Population served
- Water sales and transfers
- Wholesale and retail relationships
- Conservation program implementation
- Infrastructure expansion plans
- System leakage and non-revenue water

Improved utility-level information will reduce uncertainty in both population allocation and GPCD estimation while strengthening the technical basis for future planning decisions.

5.6. Establish a Continuous Projection Performance Monitoring Program

TWDB now possesses more than two decades of projection history that can be used to systematically improve future planning efforts. Following each planning cycle, TWDB should conduct a retrospective assessment comparing projected and observed populations, GPCD values, and municipal water demand.

The resulting performance assessment should identify:

- Areas where projections performed well
- Systematic over- and under-estimation patterns
- Emerging demographic and water-use trends
- Recommended methodological refinements

Such a continuous improvement framework would allow projection methods to evolve based on observed performance and would increase confidence in future projections.

5.7. Overall Recommendation

The analysis indicates that TWDB's municipal population and water demand projection process is fundamentally sound and has improved substantially over time. Future efforts should focus on explicitly addressing uncertainty, strengthening GPCD estimation procedures, incorporating drought-related demand and leakage more fully into planning assumptions, improving utility-level data, and providing greater flexibility for regional planners. Collectively, these refinements would improve the reliability of municipal water demand projections, provide additional assurance that water needs can be met during drought-of-record conditions, and strengthen the long-term resilience of Texas water planning.

6. References

- Ang, B.W. (2005) The LMDI approach to decomposition analysis: a practical guide. *Energy Policy* 33, 867–871.
- Austin Water. (2024). Water Loss Program Review: Analysis and Optimization (Final Project Report). Prepared by Black & Veatch for Austin Water.
- Black & Veatch (2024), Water Loss Program Review: Analysis and Optimization, Final Project Report prepared for Austin Water, Black & Veatch Project No. 415677, variably paginated.
- Richter, B.D., 2023. Decoupling Urban Water Use from Population Growth in the Colorado River Basin. *J. Water Resour. Plan. Manag.* 149, 04022082.
<https://doi.org/10.1061/JWRMD5.WRENG-5887>
- Sun, J.W., 1998. Changes in energy consumption and energy intensity: A complete decomposition model. *Energy Econ.* 20, 85–100. [https://doi.org/10.1016/S0140-9883\(97\)00012-1](https://doi.org/10.1016/S0140-9883(97)00012-1)
- TWDB, 2027. Draft 2027 State Water Plan - Phase 1.

7. Appendix

7.1. Bibliography — with Abstracts and Planning Implications

1. ADWR (2014) Arizona's Next Century: A Strategic Vision for Water Supply Sustainability. Arizona Dept. of Water Resources, variably paginated. ([link](#))

Executive Summary:

The Challenge For over a century, Arizonans have faced challenges in ensuring that there are sufficient and sustainable water supplies and have successfully developed water supplies for agricultural, industrial and domestic uses. Arizona has aggressively taken the actions necessary to ensure that sufficient and dependable water supplies are available for its long-term economic stability. While diverse, these actions have shared a common premise of being solution-oriented, meeting not only the immediate needs of the State, but more importantly addressing the future challenges Arizonans would face. Following in that tradition of strategic planning and action, Arizona now must face its next challenge in water supply security and management. We are at the crossroads of having to decide what actions we will take to meet those challenges. Over the last five years, the Arizona Department of Water Resources (ADWR), in partnership with many in Arizona's water community has participated in the development of a comprehensive water supply and demand analysis for Arizona through the work of the Water Resources Development Commission (WRDC). At the same time, Arizona has also been actively working with the U.S. Bureau of Reclamation ("Reclamation") and the other six Colorado River Basin States (collectively, the "Basin States"), to identify projected supply and demand imbalances on the entire Colorado River system, culminating in the Colorado River Basin Water Supply and Demand Study ("Basin Study"). Through the work of the WRDC and the Basin Study, we have identified a long-term imbalance between available supplies and projected water demands over the next 100 years of up to 3 million acre-feet. Our challenge is to explore viable solutions to address this projected imbalance and initiate the action necessary to develop those solutions. Figure ES-1. Colorado River Basin Study Area (Reclamation, 2012) The process to meet these challenges has already begun on two fronts. First, in cooperation with Reclamation and the other Basin States, ADWR (along with several Arizona stakeholders) is actively participating in a process to identify multiple Basin-wide solutions including: demand management; reuse of reclaimed or recycled water; analyzing the viability of water transfers; analysis of alternative 9 January water management strategies (e.g., Water Banking in the Upper Basin); watershed management; and importation of water supplies from outside of the Colorado River Basin. Secondly, at the request of Governor Jan Brewer, ADWR has initiated a parallel process within Arizona to develop a Strategic Vision that identifies possible strategies and projects to pursue to reduce these imbalances. This Strategic Vision creates the framework for analysis of potential strategies and provides context for maximizing them to address the needs of multiple water uses across the State. This Strategic Vision for Arizona is a necessary first step in this process. We have completed the initial analysis of the challenges faced by Arizonans and have organized the State into twenty-two solution oriented "Planning Areas". The next logical step is to identify possible strategies to address projected imbalances. While many of the mechanisms necessary to address our future imbalances are available today, there are still limited

supplies. A comprehensive Strategic Vision that identifies viable strategies will assist all water users in Arizona to come together to address our needs.

Implications for planning: General relevance to long-range water planning and scenario analysis.

2. ADWR (2024) Arizona Department of Water Resources Annual Report, 73 p. ([link](#))

Overview: The Arizona Department of Water Resources works to ensure long-term, reliable water supplies to support the continued economic prosperity of the State.

Implications for planning: General relevance to long-range water planning and scenario analysis.

3. Anonymous (citizens of Kansas) (2015) A Long-Term Vision for the Future of Water Supply in Kansas. Final Report, 133 p. ([link](#))

Overview: In October 2013, Governor Brownback issued a call to action to his Administration to develop a 50-Year Vision for the Future of Water in Kansas stating, "Water and the Kansas economy are directly linked. Water is a finite resource and without further planning and action we will no longer be able to meet our state's current needs, let alone growth". Incorporating the Vision Action Items into the Kansas Water Plan will formalize the statutory process recognized in state law.

Their mission Statement: Provide Kansans with the framework, policy and tools, developed in concert with stakeholders, to manage, secure and protect a reliable, long term statewide water supply while balancing conservation with economic growth.

Implications for planning: General relevance to long-range water planning and scenario analysis.

4. Bateman, B., Kudlas, S., & Mucken, A. (Eds.). 2018. State Water Plans: Monographs from 17 States. American Water Resources Association, 97 pp. ([link](#))

Abstract: The American Water Resources Association (AWRA) convened its third National Leadership Institute (NLI) Workshop for State Officials during November 2017. Officials who have responsibility for developing state water plans gathered during a three-day period to compare notes about the process they use and technical pieces included in the final product. Their professions were diverse and included engineers, planners, scientists, economists and other disciplines.

Implications for planning: General relevance to long-range water planning and scenario analysis.

5. Berhanu, B. M., Shimabuku, M., Spurlock, S., Dery, J., Cooley, H., Riihimaki, C. A., Beck, N. G., & Conley, G. (2024). Untapped Potential: An Assessment of Urban Stormwater Runoff Potential in the United States. Oakland, CA: Pacific Institute, 87 p. ([link](#))

Abstract: Water is a precious and vital natural resource that is fundamental for human and ecological health and economic prosperity. In communities across the United States, however, water scarcity is a

growing risk due in part to natural hydrologic variability, population and economic growth, and the intensifying effects of climate change. Yet, traditional water sources, such as freshwater from rivers and streams and underground aquifers, are increasingly facing peak water limits. These constraints have led water providers to adopt water conservation and efficiency to reduce demand and develop new, alternative water supply strategies, such as reusing treated wastewater and capturing urban stormwater runoff. These strategies can help “close the gap” between existing and anticipated water supply and demand and support long-term water resilience. Perspectives on stormwater are changing—and it is increasingly viewed as an asset. Stormwater capture projects are being implemented in a growing number of communities to augment and diversify water supplies, as well as reduce flooding and pollution of nearby waterways. When using green infrastructure, stormwater capture projects can also support community greening and mitigate urban heat island effects. Despite growing interest, greater uptake of stormwater capture is hindered by a lack of comprehensive data characterizing the national volumetric potential of stormwater runoff. This assessment finds that the average annual stormwater runoff potential is 59.5 million acre-feet per year, equivalent to 53,100 million gallons per day. In this assessment, we quantify the volumetric potential for stormwater runoff in US Census Urban Areas across the entire United States. This assessment finds that the average annual volumetric potential for urban stormwater runoff is 59.5 million acre-feet per year (AFY), or 53,100 million gallons per day (MGD). This volume is equivalent to 93% of the water withdrawals for municipal and industrial uses in 2015, though not all of this runoff is necessarily feasible or desirable to capture. We estimate that 37% of this national volume (21.9 million AFY) is generated just in coastal areas, which presents an opportunity for increased stormwater capture in areas that are less likely to face challenges related to adverse impacts on downstream water rights holders. We also examine potential uses of stormwater capture across four case examples that highlight opportunities to incorporate stormwater capture as a pathway to achieve water supply planning goals (Texas and North Georgia) and support water supply sustainability and resilience (Arizona and Minnesota). These examples can serve as models for increasing the role of stormwater capture as a water supply and resilience strategy for communities who have not previously considered stormwater capture as a viable alternative or are interested in increasing adoption of stormwater capture projects.

Our findings suggest that stormwater capture can serve an expanded role beyond its current level of implementation in Urban Areas across the United States, but this requires additional efforts by researchers, policymakers and regulatory bodies, and implementers (e.g. utilities, municipalities, landowners) to elevate the role of stormwater capture in the national conversation. Here, we offer recommendations for helping to realize this untapped potential of stormwater capture.

Implications for planning: General relevance to long-range water planning and scenario analysis.

6. Berhanu, B. M. (2019). Investigating the role of decentralized water systems as strategies for urban water and wastewater management / by Bruk M. Berhanu. Austin, Tex, [University of Texas]. ([link](#))

Abstract:

In the face of population growth and climate change impacts, water supply planners and utilities have increased interest in decentralized water systems as a means to meet potable water demands and improve water supply resilience in times of drought. Decentralized water systems (DWS) refer to technologies that capture, treat, and recycle alternative water supplies (rainwater/stormwater, graywater/blackwater, foundation drainage, air-conditioned condensate, etc.) to supply non-potable water for uses including toilet/urinal flushing, clothes washing, and irrigation on a building site. These systems offer benefits to individual users including water/wastewater rate savings, stormwater reductions, and resilience to water/wastewater service interruptions. Benefits can also extend to centralized water and wastewater networks by reducing water and wastewater treatment needs, preserving water supplies, and reducing net energy demands for water/wastewater treatment and delivery. However, these systems have not seen widespread adoption across the United States nor internationally. For utilities and water providers wishing to promote adoption of these technologies, little information is available regarding expected efficacy and cost metrics that can be used to design policies tailored for their service area. Moreover, current methods to assess these systems at-scale typically rely on assumptions of homogeneous single-family residential service areas and/or adoption rates that do not consider individual-level differences in land use characteristics, customer types, or adoption criteria. This research provides a framework by which to integrate these factors into assessments of decentralized water systems at the service area scale. The research is presented in three steps; an investigation into the drivers of indoor and outdoor water demands for residential and non-residential customers, integration of these demands via customer type into daily time-scale simulations of DWS performance under uncertainty, and application of psycho-social influences combined with technical and economic performance criteria to the decision to adopt DWS over long-range planning horizons. The non-residential sector has not seen the same level of investigation as the residential sector, and so a classification and statistical analysis model using mixed-effects linear regression was developed to relate parcel-level attributes such as industry type, conditioned area, and employment level to total monthly water demands. Results from this model suggest that parcel-level water demand differs most across industry classifications, while estimates for effect of parcel attributes on demand are more similar between classifications. Moreover, the predictor variables studied accounted for over 90% of variance seen in monthly demand values, after accounting for individual-level random effects. The results from the statistical analysis were then incorporated, along with residential demand estimates, into a daily water balance simulation model of DWS performance. Results suggest that tradeoffs exist between capital cost and cost-effectiveness of DWS adoption and technical performance via non-potable demand reductions. Hybrid rainwater-graywater systems and graywater for indoor and outdoor uses were both found to meet 100% of non-potable demand across uncertainty ranges in demands and alternative water

supplies, though hybrid systems had higher capital costs primarily due to the need for a rainwater storage cistern. All systems incorporating graywater were capable of realizing net benefits under certainty conditions while solely rainwater-based configurations almost never saw such outcomes. The results from the first and second analyses were then integrated into a hybrid agent-based and discrete-event sequence model to simulate adoption of DWS technologies by customers in a synthetically generated neighborhood. The model applies Systems-of-Systems analysis concepts to integrate individual-level decision making and behavior with aggregate-scale exogenous factors to understand how technical, economic, and psycho-social factors might affect adoption rates of DWS and corresponding impacts to centralized water/wastewater infrastructure networks. Results suggest that non-residential customers are more heterogeneous in their adoption preference, with respect to DWS configuration, than the residential sector which primarily adopts graywater-based systems solely for outdoor use. Additionally, the tradeoff between capital cost and non-potable offsets for higher performing DWS configurations typically results in low adoption rates of these systems, but high per-system demand reductions that are commensurate with more widely adopted but lesser performing systems, such as sole rainwater for irrigation. These results highlight the importance of tailored DWS adoption decisions to adopter preferences and provide insight into possible policy instruments such as capital cost incentives, dual-reticulation mandates for new construction, and water demand offset requirements (without a technology prescription) that might promote adoption of these systems. When the results from these analyses are considered in context of a particular study area, this research provides a comprehensive set of methods by which to evaluate the opportunities for and potential impacts from parcel-level DWS adoptions from the perspectives of both the customer and the centralized water/wastewater service provider. Such a set of methods can be incorporated into long-range centralized water/wastewater infrastructure planning efforts to leverage the benefits of DWS adoption while managing the potential downsides

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Supports reuse/stormwater/alternative supplies in long-horizon portfolios.

7. Berhanu, B. M., Blackhurst, M., Kirisits, M. J., Jaramillo, P., & Carlson, D. (2017). Feasibility of Water Efficiency and Reuse Technologies as Demand-Side Strategies for Urban Water Management. *Journal of Industrial Ecology* 21(2): 320-331. ([link](#))

Abstract:

Summary Potable residential water efficiency and reuse technologies have seen increasing adoption in recent years and have been estimated to reduce demands by up to 50%. In this work, we used an engineering economic model to estimate the technically feasible levelized cost of water provided by seven above-code water efficiency (i.e., beyond that required by building code) and reuse technologies within the Lower Colorado River Authority (LCRA) in central Texas. Unlike other demand-side studies of residential water use, we model uncertainty and variation in technology adoption cost and performance;

include reuse technologies; and differentiate between new construction and retrofits. We developed a conservation supply curve to compare the levelized cost of efficiency and reuse technologies with conventional supply-side water management strategies. We estimate that efficiency and reuse in the residential sector can meet 85% of 50-year projected needs (the difference between projected demand and estimated supplies) for the LCRA service area. We also estimate lower levelized costs for immediate retrofits of most technologies, promoting incentives for early technology adoption. However, efficiency and reuse technology performance demonstrates considerable uncertainty and variability. The fraction of demands met by demand-side strategies range from around 60% to 100%. Occupancy drives much of the variability because it significantly affects demand. These results promote designing incentives for adoption of water efficiency and reuse technologies based upon use. We find that water-efficient showerheads and bathroom faucet aerators perform well over a variety of assumptions, indicating that these technologies should be a priority for municipalities seeking water demand reductions.

Implications for planning: Supports reuse/stormwater/alternative supplies in long-horizon portfolios.

- 8. Blount, K., Abdi, R., Panos, C. L., Ajami, N. K., & Hogue, T. S. (2021). Building to conserve: Quantifying the outdoor water savings of residential redevelopment in Denver, Colorado. Landscape and Urban Planning 214: 104178. ([link](#))**

Abstract:

Outdoor water use represents up to half of total urban water demand in many semi-arid and arid cities and presents a climate adaptation challenge in urban centers. As indoor efficiency and reuse improve, outdoor use amounts to an increasingly large portion of consumptive urban water demand. Infill development, or the redevelopment of single-family properties to more dense multi-family and mixed-use developments, is a growing trend in urban planning; however, the influences of infill on outdoor water demand are poorly understood. The current work utilizes a remote sensing-based methodology to calculate parcel-scale irrigation rates in Denver, Colorado and applies a novel resampling methodology to model the impacts of redevelopment on outdoor water use. Results for 2018 showed irrigation rates varied by almost 250 mm between park and commercial land uses, and mean single-family irrigation rates of 224 mm exceeded multi-family rates by 70 mm. In the Berkeley neighborhood, modeled redevelopment of 1,347 single-family parcels (39.5%) resulted in a 102,000 m³ (83 acre-feet, or 30.2%) reduction in outdoor use. Citywide analyses indicate reductions of 141,000 m³ (114 acre-feet, or 0.76%) of residential outdoor use per one percent increase in redeveloped single-family parcels. These savings are equivalent to new annual supply for 181 four-person households and may provide significant contributions towards climate adaptation. Results highlight the importance of the continued integration of land use and water supply for demand management within the urban planning process.

Implications for planning: Supports reuse/stormwater/alternative supplies in long-horizon portfolios. Highlights affordability and equity for rate design and customer assistance programs.

- 9.** Blount, K., Wolfand, J. M., Bell, C. D., Ajami, N. K., & Hogue, T. S. (2021). Satellites to Sprinklers: Assessing the Role of Climate and Land Cover Change on Patterns of Urban Outdoor Water Use. *Water Resources Research* 57(1): e2020WR027587. ([link](#))

Abstract:

Abstract Outdoor water use represents over 50% of total water demand in semiarid and arid cities and presents both challenges to and opportunities for improved efficiency and water resilience. The current work adapts a remote sensing-based methodology to estimate growing season irrigation rates at the census block group scale in Denver, Colorado. Results show that city-wide outdoor water use does not change significantly from 1995 to 2018, while per capita water use and total water use significantly decrease from 2000 to 2018. Because total water use, but not outdoor use, is decreasing, the percent of water used outdoors significantly increases across the city from 2000 to 2018. Climate variables account for one-quarter of interannual variation in mean irrigation rates due primarily to changes in temperature, not precipitation. Percent impervious land cover exhibits a significant inverse nonlinear relationship with irrigation rates at the census block group scale. Finally, 38% of Denver census block groups show significantly increasing irrigation rates between 1995 and 2018 driven primarily by increasing temperatures. The increasing proportion of water used for irrigation highlights the importance of outdoor demand management for urban water systems as indoor efficiencies improve. We advocate that resilient water systems necessitate integrated land use, infrastructure, and water planning in the face of urban growth and climate change. While minimizing irrigated urban areas may reduce demand, remaining green spaces should be designed to maximize multiple benefits including reductions in water demand and urban heat islands, stormwater management, and recreation to improve the sustainability of growing cities.

Implications for planning: Supports reuse/stormwater/alternative supplies in long-horizon portfolios. Guides urban demand programs, especially outdoor use and land-use change.

- 10.** Colorado Water Conservation Board (2019). Analysis and Technical Update to the Colorado Water Plan, Department of Natural Resources 254. ([link](#))

Overview: An array of foundational data sets that describe current and future water supplies and needs are compiled to support the Colorado Water Plan.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 11.** Colorado Water Conservation Board (2023). The Colorado Water Plan, Colorado Water Conservation Board: 254. ([link](#))

Vision: Broader Vision for Collaboration Beyond its primary purpose of balancing water conservation and development, the Water Plan sets a vision for meeting Colorado's water challenges. It identifies a wide range of state and local actions and also directs stakeholders to Water Plan grants that help implement

the plan. Water Plan updates provide opportunities to coordinate with other agencies and stakeholders who are implementing their own complementary water-related plans. Some of those plans, like the Department of Local Affairs' Colorado Resiliency Framework, are similar to the Water Plan in their approach to working within an agency's capacity but also focusing on cross-agency and external collaboration. An Inclusive Vision for Cities, Farms, Streams, and People. The Water Plan strives for holistic planning that considers multiple stakeholder relationships, shared purposes, and benefits. Equal focus is placed on four action areas that relate to cities, farms, streams, and people. The action areas are called Vibrant Communities, Robust Agriculture, Thriving Watersheds, and Resilient Planning. While each action area is distinct, they are functionally interconnected. Each area has a future-looking vision of the work that needs to be achieved by 2050 (the Water Plan's planning horizon) including ten agency actions that support the vision. Additionally, the Water Plan includes a fifth set of agency actions CWCB will take that are largely administrative. Collectively, the Water Plan has 50 agency actions - the actions CWCB and collaborating agencies will implement. There are also project-level examples that make up approximately 50 partner actions - actions stakeholders can take to advance the Water Plan. Ongoing Bold Action is a Shared Responsibility Local stakeholder as well as federal, Tribal, state, and local governments take actions every day that shape our water future. Truly bold action requires continued commitment to a shared vision by a wide range of water users. The CWCB does not build projects, but it funds many. The Water Plan Grant Program aligns with Water Plan implementation. The CWCB uses its own agency resources to support established programs and implement new actions it has committed to in the plan. Often these actions help advance promising emerging ideas, supporting tools, and analysis. However, stakeholder action through grants or other means can work across a full range of established, emerging, or even exploratory concepts - testing ideas that push technology, research, and thought to new limits.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 12.** Idaho Water Resource Board (2012). Idaho State Water Plan, Idaho Department of Water Resources: 90. ([link](#))

Overview: The Idaho State Water Plan establishes policies to guide the conservation, development, management, and optimum use of Idaho's water resources.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 13.** Oklahoma Water Resources Board (2012). 2012 Oklahoma Comprehensive Water Plan: Executive Report, Oklahoma Water Resources Board: 160 pp. ([link](#))

Abstract: The Oklahoma Comprehensive Water Plan evaluates water supply availability and future demand to identify potential shortages and recommend strategies.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 14.** Oklahoma Water Resources Board (2024). Oklahoma Comprehensive Water Plan: OWRB Fact Sheet, Oklahoma Water Resources Board. ([link](#))

Abstract: The Oklahoma Comprehensive Water Plan provides guidance to ensure reliable water supplies to meet future municipal, industrial, agricultural, and environmental needs.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 15.** Bolorinos, J., Ajami, N. K., & Rajagopal, R. (2020). Consumption Change Detection for Urban Planning: Monitoring and Segmenting Water Customers During Drought. *Water Resources Research* 56(3): e2019WR025812. ([link](#))

Abstract:

Abstract Demand management is a powerful way for water utilities to address the challenges of population growth and climate change. Although active conservation efforts have been studied extensively, recent evidence suggests households respond to many external events beyond a utility's control, including political responses to extreme climatic episodes and corresponding mass media coverage. Despite their importance, these external factors are difficult to analyze in a controlled setting, and few tools exist to evaluate their influence on customers. Here, we present a consumption change detection (CCD) method that offers new insights into how climate-related mass media and policy events affect conservation by pinpointing the timing and magnitude of customer-level water use shifts. We use CCD to monitor and segment the responses of residential water customers to policy and media events in Costa Mesa, California, during the severe 2012–2016 drought. Our results show consumption reductions among 75% of customers. Of these, 80% reduced water use before mandatory restrictions were imposed, coincident with intensifying state policy responses and spikes in media coverage that affected all customer types during 2014. Analysis of standardized drought consumption trajectories indicates that 16% of conserving customers increased consumption in 2015–2016. Conservation and rebound were both more likely among affluent and educated customers, suggesting that CCD can identify engaged and informed water savers who make suitable targets for water-efficient retrofit incentive schemes. This study demonstrates CCD's potential as a novel demand analysis tool in an interconnected world where external social, political, and climatic stressors can exert an important influence on customer behavior.

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Highlights affordability and equity for rate design and customer assistance programs.

- 16.** Bolorinos, J., Rajagopal, R., & Ajami, N. K. (2022). Do water savings persist? Using survival models to plan for long-term responses to extreme drought. *Environmental Research Letters* 17(9): 094032. ([link](#))

Abstract:

Water utilities must maintain reliable service in a world where climate shocks and other socio-economic and health stressors are likely to disrupt water availability and demand more frequently. Understanding short- and long-term customer responses to these salient events is critical for infrastructure planning and capital investment. Although the short-term demand impacts of extreme droughts and related policy measures have been studied extensively, less is known about how these impacts persist—especially when driven by public awareness, media coverage, or other external drivers. Here, we introduce a novel approach combining survival models and change detection to assess water demand conservation ‘survival’ and rebound, using this method to analyze residential water demand in Costa Mesa, California after the state’s record-breaking 2012–2016 drought. We find that, of 54% of customers with detected savings in 2014–2015, just 25% rebounded to prior consumption levels after 5 years, implying mean conservation survival of 8 years. Survival was greater in young and politically progressive neighborhoods, smaller in residences with occupancy changes, and not significantly associated with water-efficiency rebates. Comparing the 2012–2016 drought to California’s milder 2007–2009 drought shows no evidence that drought severity associated with water savings persistence. This study presents an innovative approach to measure impacts of various stressors and their long-term water demand impacts. Our method enables utilities to more accurately discern structural changes in water demand, better informing strategic planning for short- and long-term water reliability and security.

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity.

17. Chinnasamy, C. V., Arabi, M., Sharvelle, S., Warziniack, T., Furth, C. D., & Dozier, A. (2021).

Characterization of Municipal Water Uses in the Contiguous United States. *Water Resources Research* 57(6): e2020WR028627. ([link](#))

Abstract:

This study investigates municipal water use patterns across the Contiguous United States (CONUS). The objectives of this study are to explore temporal trends in water use, improve characterization of indoor and outdoor uses, and improve characterization of commercial, industrial, and institutional (CII) water use in cities across the CONUS. A comprehensive survey was conducted to compile monthly water use data from 126 municipalities for the period 2005–2017 with specific information about residential and CII water use categories. Changes in liters per capita per day and the CII to Residential water use ratio were related to climatic, urban-geologic and socio-economic variables. Results indicate an overall decreasing trend in municipal water uses with higher reductions achieved in residential sector. Both residential and CII water use exhibit high seasonality over an average year. The CII to Residential ratio increases with city population and is highest in cities in the Northeast Census region. Cities in South and West Census regions have high municipal water uses and highest reductions in annual per capita-day water use. Cities in arid climate regions have the highest water uses, compared to other cities, due to landscape irrigation. April precipitation, annual vapor pressure deficit, number of employees in the manufacturing (or, other services except public administration) sector, total percentage of houses built before 1950 and total

percentage of single-family houses explain much of the variation in CII to Residential water use ratio across the CONUS. This study guides improved characterization of municipal water uses and water demand management strategies.

Implications for planning: Guides urban demand programs, especially outdoor use and land-use change. Provides demographic/spatial inputs that justify horizon length and update cadence.

18. Great Lakes Commission (2023). Annual Report of the Great Lakes Regional Water Use Database Representing 2023 Water Use Data. ([link](#))

Overview: Overview Improving Data Quality Together with the GSGP, the GLC works with the states and provinces to improve data collection, reporting, quality, accuracy and compatibility. To guide the preparation of 2023 water use data and this report, several steps have been taken to improve data quality. Starting with the 2014 water use year, the GLC collected information from each jurisdiction that describes water use data and includes information related to data sources, rates of reporting compliance (i.e., the percentage of users submitting the required reports to their respective jurisdiction) by water use sector, the year from which the data was collected, significant changes in the data between the current year and previous years and reasons for those changes. To achieve this, the GLC created an online data management system that assists in the creation of metadata. For this report, the states and provinces submitted metadata along with its associated 2023 water use data to the GLC. Project staff met by phone with representatives from each jurisdiction to discuss changes in compliance rates and reported water use from the previous year. Implementing this process has resulted in improvements to the database in both compliance rates and data quality. The GLC will continue to work with the states and provinces to identify additional areas for improvement. While this report contains the best available information as of its publishing date, the states and provinces may continue to update their data in the online water use database (<https://waterusedata.glc.org/>). Discrepancies between the data online and those summarized in this report may appear. In all cases, the online database will contain the most current available data. In compiling this report, the GLC noted specific steps taken by each jurisdiction to improve reporting compliance and data quality. The states and provinces have reporting programs in place that require users to report their water use each year to their respective jurisdictions. Reporting compliance varies across the basin by jurisdiction and sector, affecting the quality of the data. Table 1 summarizes reporting compliance rates by jurisdiction in 2023. Illinois, Minnesota, New York, Ohio, and Pennsylvania each indicated 100% reporting compliance by water users in their respective jurisdictions. Beyond compliance, the number of reported users can also vary from year to year due to a change in status as a threshold facility. Only water use data from facilities that withdraw more than 100,000 gallons per day (or 380,000 liters per day) averaged over a 30-day period (referred to as the trigger level for reporting) are included in the database, per the Compact and Agreement. Some facilities that tend to

withdraw water in volumes close to the reporting trigger level may therefore change from being a threshold facility (defined as a water user withdrawing water at or above the trigger level) from one year to the next based on weather conditions, business operations or other factors. Water use sectors that see more interannual variability in use (e.g., self-supply irrigation) may have greater changes in the number of threshold facilities than other use sectors. These changes are discussed in the jurisdiction report sections.

Implications for planning: General relevance to long-range water planning and scenario analysis.

19. North Dakota State Water Commission (2021). North Dakota Water Development Plan. North Dakota State Water Commission, 87 p. ([link](#))

Executive Summary: Those involved in water project development know that existing projects evolve, and new projects are continuously being considered by local water managers. For that reason, it is necessary for the state to assemble updated water project information on a biennial basis to coincide with the state's budget cycles. In the past, the Department of Water Resources (DWR) has produced and printed that information in a detailed Water Development Plan. Today, DWR and the State Water Commission are providing that same information electronically through a Water Development Plan Dashboard (Dashboard) - along with highlights included in this printed Executive Summary.

The following information outlines funding available for critical water supply, flood protection, and other general water management projects; a prioritized summary of water development financial needs that were collected directly from project sponsors; and summaries of revenue streams that support projects. In addition to the aforementioned information, the Dashboard includes large project overviews, long-term funding needs, aging water supply infra structure survey results, current purpose funding tracking, and more!

Implications for planning: General relevance to long-range water planning and scenario analysis.

20. South Dakota Water Commission (2024). South Dakota 2024 State Water Plan. South Dakota Water Commission, 74 p. ([link](#))

Overview: The South Dakota State Water Plan presents an overview of the state's water resources and identifies priorities for future water management.

Implications for planning: General relevance to long-range water planning and scenario analysis.

21. Texas Dept. of Transportation (2024). Connecting Texas 2050: Statewide Long-Range Transportation Plan. Texas Dept. of Transportation, 125 p. ([link](#))

Overview: The Connecting Texas 2050 plan provides a long-range framework for transportation policy and investment to support population growth and economic development.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 22.** Cooley, H., Thebo, A., Abraham, S., Shimabuku, M., Gleick, P., & Diringer, S. (2022). The Untapped Potential of California's Urban Water Supply: Water Efficiency, Water Reuse, and Stormwater Capture. Oakland, CA: Pacific Institute. ([link](#))

Executive Summary: Water is the lifeblood of California, providing for the household needs of nearly 40 million people and supporting one of the most productive agricultural regions in the world, the health and viability of the state's aquatic and terrestrial ecosystems, and an economy that would make it the fifth wealthiest country in the world after the United States, China, Japan, and Germany. Persistent water challenges, the ongoing severe drought, and the intensifying effects of climate change all highlight the vulnerability of California's water systems, but they also offer a new opportunity to rethink the state's water policies and strategies. The good news is that we are already seeing communities throughout the state rethink water "supply" and "demand." There has been tremendous progress across California in reducing water use through water conservation and efficiency and augmenting local supplies through water reuse and stormwater capture. Without these efforts, our current challenges would be much worse, demands on limited water supplies would be even higher, and ecosystem destruction would be more severe. In this assessment, we quantify the potential for a range of water strategies in urbanized parts of California to both reduce inefficient and wasteful water uses and expand local water supplies. This assessment finds that urban water-use efficiency improvements could reduce statewide urban water use by 2.0 million to 3.1 million acre-feet per year (AFY). The reuse potential of municipal wastewater is 1.8 million to 2.1 million AFY, and the stormwater capture potential is 580,000 AFY in a dry year to as much as 3.0 million AFY in a wet year. Previous assessments have shown that these efficiency and supply options are more cost effective than traditional – and increasingly hard to implement – options to expand supply. Programs to tap this potential would tremendously help solve California's long-standing water problems.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 23.** Oklahoma Water Advisory Council (2015). Water for 2060 Oklahoma Water Advisory Council, variably paginated. ([link](#))

Overview: Water for 2060 establishes a statewide goal of using no more fresh water in 2060 than was used in 2010 while supporting population growth.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 24.** Daniel, I., Ajami, N. K., Castelletti, A., Savic, D., Stewart, R. A., & Cominola, A. (2023). A survey of water utilities' digital transformation: drivers, impacts, and enabling technologies. *npj Clean Water* 6(1): 51. ([link](#))

Abstract:

Climate change and urbanization challenge utilities' pursuit of water security worldwide. While water utilities are directly impacted by climate change, their operations also contribute to greenhouse gas emissions. Digital technologies have proven effective in improving utilities' operations, leading to a more sustainable urban water cycle. However, the global progress of digital water transformation remains largely understudied. Here, we present the results of an online survey involving 64 utilities from 28 countries investigating the impacts of digital transformation on the water utility sector, its drivers, and key-enabling technologies. We found that the water distribution system is the entry point to further adoption of digital technologies in the whole urban water cycle. Furthermore, technology adoption is driven primarily by economic benefits, followed by government regulation and hydroclimatic factors. Starting from the survey results, we point out avenues for further research targeting a better understanding of the influence of regulation, corporate mindset, and consumer involvement for successful digital transformation.

Implications for planning: Guides urban demand programs, especially outdoor use and land-use change. Relevant to utility data modernization and adaptive planning analytics.

- 25.** Diogo, V., Jacobs-Crisioni, C., Baranzelli, C., & Lavalley, C. (2023). Integrated Spatial Simulation of Population and Urban Land Use: a Pan-European Model Validation. *Applied Spatial Analysis and Policy* 16(4): 1463-1492. ([link](#))

Abstract:

Spatial models jointly simulating population and land-use change provide support for policy-making, by allowing to explore territorial developments under alternative scenarios and resulting impacts in the environment, economy and society. However, their ability to reproduce observed spatial patterns is rarely evaluated through model validation. This lack of insight prevents researchers and policy-makers of fully grasping the ability of existing models to provide sensible projections of future land use and population density. In this article, we address this gap by performing a model validation of the LUISA Territorial Modelling Platform, a spatial model jointly simulating population and land use at a fine resolution (100 m) in the European Union and United Kingdom. In particular, we compare observed and simulated patterns of population and urban residential land-use change for the period of 1990–2015, and evaluate the model performance according to different degrees of urbanization. The results show that model performance can vary depending on the context, even when the same data and methods are uniformly applied. The model performed consistently well in urban areas characterized by compact urban growth, but poorly where residential development occurred predominantly in scattered patterns across rural areas. Overall, the model tends to favor the formation of densely populated, highly accessible urban conglomerations, which often do not entirely correspond to the observed patterns. Based on the validation results, we propose directions for further model improvement and development. Model

validation should be regarded as a critical step, and an integral part, in the process of developing models for policy support.

Implications for planning: Guides urban demand programs, especially outdoor use and land-use change. Provides demographic/spatial inputs that justify horizon length and update cadence.

26. Diringer, S., Heather Cooley, Matthew Heberger, Rapichan Phurisamban, Kristina Donnelly, Andrea and M. Turner, and Mary Ann Dickinson. (2018). Integrating Water Efficiency into Long-Term Demand Forecasting. No. 4495. The Water Research Foundation. ([link](#))

Overview: Improved integration of water efficiency into long-term demand forecasting can significantly reduce projected future water needs.

Implications for planning: General relevance to long-range water planning and scenario analysis.

27. Office of the State Engineer (2023). New Mexico State Water Plan 5-Year Review New Mexico Office of the State Engineer, Interstate Stream Commission 38. ([link](#))

Overview: This review summarizes progress on statewide water planning efforts and identifies key priorities for improving water resilience.

Implications for planning: General relevance to long-range water planning and scenario analysis.

28. Wyoming Water Development Commission. (2007). Wyoming Framework Water Plan, Vol. 1. Report prepared for the Wyoming Water Development Commission, 314 p. ([link](#))

Introduction: The Wyoming Framework Water Plan has two objectives. Volume I is an inventory of the state's water resources and related lands, a summary of the state's present water uses, a projection of future water needs, and an identification of alternative decisions to meet the indicated future water needs. The second objective, and the subject of Volume II of the Framework Water Plan, is to provide future water resource planning direction to the State of Wyoming. This executive summary encompasses both volumes of the Wyoming Framework Water Plan. Seven basin plans were completed - one for each of the major drainage basins of the state. These efforts were undertaken by the Wyoming Water Development Commission (WWDC) and its consultants between 2000 and 2006. The Wyoming Framework Water Plan Report, Volume I presents the information from the separate basin reports on a statewide basis. Projections of future water needs presented in Volume I were used to identify alternative water resource projects that may be required for the future. The Framework Water Plan is also presented on the World Wide Web and available for any user with a web browser and internet connection. A PDF version and GIS products can be downloaded at: <http://waterplan.state.wy.us/frameworkplan.html>. In addition, a Presentation Tool provides an interactive, searchable interface to the entire Framework Water Plan. The Presentation Tool is hosted by the Water Resources Data System, College of Engineering, University of Wyoming, and is available at: <http://waterplan.wrds.uwyo.edu/fwp/>. The previous statewide

water planning process was completed in 1973 with the publication of the Wyoming Framework Water Plan. As with the current planning process, the process in the 1970s was performed basin-by-basin to capture the unique water situation and needs in each basin. Since 1973, technological advances have been made in water resource planning. Also, political and regulatory conditions in water resource management have changed. Therefore, it was necessary that Wyoming complete an updated statewide water planning report. This current Wyoming Framework Water Plan provides information for decision making for a 30-year planning horizon.

Implications for planning: General relevance to long-range water planning and scenario analysis.

29. WWC Engineering. (2007). Wyoming Framework Water Plan, Vol. 2. Report prepared for the Wyoming Water Development Commission, variably paginated. ([link](#))

Overview: Volume II of the Wyoming Framework Water Plan provides supporting technical analyses and regional assessments.

Implications for planning: General relevance to long-range water planning and scenario analysis.

30. U.S. EPA (2025). The First Community of WaterSense Labeled Homes Continues to Save and Perform Well. Case Study. United States Environmental Protection Agency, Office of Water. ([link](#))

Abstract: In 2014, WaterSense partner Cascade Water Alliance in Washington state looked at the impact of newly constructed and occupied WaterSense labeled homes in the zHome community in Issaquah, Washington. At the time, they found that these homes reduced water use by approximately 70 percent compared to typical homes. Just as importantly, residents reported they were overwhelmingly satisfied with their homes, including the WaterSense labeled products and other water-saving features installed. A decade later, not only do these homes still report water savings exceeding 70 percent year over year, residents still say they are happy with the performance of their WaterSense labeled homes and the water, energy, and utility cost savings they provide.

Implications for planning: General relevance to long-range water planning and scenario analysis.

31. US EPA (2025). Community Water System Service Area Boundaries. Shapefile 80c6912ef14f46e480f5afd807767b4b. Version 1. 2. EPA Office of Research and Development Community Water System Service Area Boundaries, February. ([link](#))

Overview: This dataset provides geospatial boundaries for community water systems across the United States.

Implications for planning: General relevance to long-range water planning and scenario analysis.

32. Freese and Nichols, I. (2024). 2024 North Texas Municipal Water Conservation Plan Final Report prepared for North Texas Municipal Water District, variably paginated. ([link](#))

Foreword: The North Texas Municipal Water District (NTMWD or the District) developed the following water conservation plan with assistance from Freese and Nichols, Inc. (FNI). This Plan is prepared pursuant to Texas Commission on Environmental Quality (TCEQ) rules. This updated water conservation plan is a replacement for the most recent District water conservation plan dated January 2019.

This 2024 Water Conservation Plan is based on the Texas Administrative Code included in Appendix B. In 2007, the Texas Legislature created the Water Conservation Advisory Council (WCAC), a council with expertise in water conservation representing various interests, and charged it to regularly review existing Best Management Practices (BMPs) and add new BMPs as appropriate. WCAC's recommendations have been included in guidance materials published and made publicly available by the Texas Water Development Board (TWDB). In 2021, a collaborative effort between the District and other North Texas water providers (Dallas Water Utilities, Tarrant Regional Water District, and Upper Trinity Regional Water District) published BMPs specifically for North Texas water conservation programs. These recommendations for BMPs have been reviewed and considered in the preparation of this Plan.

Implications for planning: General relevance to long-range water planning and scenario analysis.

33. Freese and Nichols, I. (2024). North Texas Municipal Water District, 2024 Water Resource and Emergency Management Plan. Final Report prepared for the North Texas Municipal Water District, variably paginated. ([link](#))

Foreword: This 2024 Water Resource and Emergency Management Plan (which is an update to the 2019 Water Resource and Emergency Management Plan) was prepared by Freese and Nichols, Inc. (FNI) for the North Texas Municipal Water District (NTMWD or the District), pursuant to Texas Commission on Environmental Quality (TCEQ) rules governing drought contingency plans.

Some material is based on NTMWD's previous water conservation and water resource and emergency management plan listed in Appendix A. This water resource and emergency management plan is based on the Texas Administrative Code included in Appendix B.

Implications for planning: General relevance to long-range water planning and scenario analysis.

34. Gonzales, P. and Ajami, N. (2017). Social and Structural Patterns of Drought-Related Water Conservation and Rebound. Water Resources Research 53(12): 10619–10634. ([link](#))

Abstract

Water use practices and conservation are the result of complex sociotechnical interactions of political, economic, hydroclimatic, and social factors. While the drivers of water demand have been extensively studied, they have traditionally been applied to models that assume stationary relationships between these various factors, and usually do not account for potential societal changes in response to increased scarcity awareness. For example, following a period of sustained low demand such as during a drought, communities often increase water use during a hydrologically wet period, a phenomenon known as rebounding water use. Previous experiences show the extent of this rebound is not a straightforward function of policy and efficiency improvements, but may also reflect short-term or long-lasting change in community behavior, which are not easily captured by models that assume stationarity. In this work, we develop a system dynamics model to represent water demand as a function of both structural and social factors. We apply this model to the analysis of three diverse water utilities in the San Francisco Bay Area between 1980 and 2017, identifying drought response trends and drivers over time. Our model is consistent with empirical patterns and historical context of water use in California, and provides important insights on the rebound phenomenon that can be extended to other locations. This comparative assessment indicates that policies, public outreach, and better data availability have played a key role in raising public awareness of water scarcity, especially with the rise of the internet era in recent years.

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Relevant to utility data modernization and adaptive planning analytics.

35. Gonzales, P. and Ajami, N. K. (2017). An integrative regional resilience framework for the changing urban water paradigm. *Sustainable Cities and Society* 30: 128–138. ([link](#))

Abstract:

The water sector is going through a paradigm shift. Many communities are incorporating decentralized solutions such as water reuse and recycling, stormwater capture, and demand-side management in order to address both short-term and long-term water resources challenges due to population increase, economic growth, intensified climate variability, as well as environmental concerns. For these projects to be sustainable, local characteristics including social and institutional contexts must be incorporated in the planning process. This paper presents a flexible and bottom-up framework that facilitates integration of such characteristics in evaluation of various water resource management strategies. It incorporates various locally-driven factors such as water use efficiency, stress on existing supplies, and adaptation capacity potential, to identify how various local and regional solutions affect resiliency at the utility and regional levels. Rather than defining top-down resilience standards, this framework incorporates quantitative and qualitative assessments that can help decision-makers tailor adaptation measures to the needs and opportunities of a given location or community. A case study application of the framework in the San Francisco Bay Area highlights how community-level characteristics can be used to identify

opportunities and adaptation strategies in order to enhance both local and collective water resource resiliency.

Implications for planning: Supports reuse/stormwater/alternative supplies in long-horizon portfolios. Provides demographic/spatial inputs that justify horizon length and update cadence.

- 36.** Gross, M.-P., Ajami, N. K., & Cominola, A. (2023). Fast in the pandemic, durable after droughts, inequal during economic downturn: A 20-year multi-dimensional retrospective analysis of water demand change in Southern California. *Environmental Research Letters* 18(9): 094067. ([link](#))

Abstract:

Determining changes in water consumption behavior due to recurring external stressors (e.g. droughts and socio-economic fluctuations) and previously unseen shocks like the COVID-19 pandemic can support future demand-side management (DSM) programs and identifying vulnerable social groups. Yet, most studies analyzing external drivers of water consumption change are noncomparative as they examine only one stressor at the time, mainly droughts. Here we develop a multi-dimensional retrospective analysis (MDRA) to quantify residential water consumption changes in Southern California over the last two decades under compound hydroclimatic, economic, and pandemic stressors. We then uncover what socio-economic groups relate to predominant behavioral changes under each stressor. We observe a long-lasting decreasing water consumption trend for more than 76% of the analyzed households. Socio-economically vulnerable households were more likely to reduce water consumption during the economic and pandemic stressors. Differently, affluent neighborhoods tended to increase water consumption during or after droughts and the pandemic. Our MDRA supports utilities and policy makers to discern the impacts of different stressors on water demand and helps to identify social and economic sensitivities across a service area to develop adaptive DSMs and assistance programs. Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Highlights affordability and equity for rate design and customer assistance programs.

- 37.** Jeavons, D. and M. Verdone (2019). Updated Population Projections for Water Plan Scenarios Report prepared for Colorado Water Conservation Board: 22. ([link](#))

Overview: Population projections, by basin and for the state as a whole, are a primary driver in the municipal and industrial demand projections developed by Element Water. This memo describes the methodology used by BBC Research & Consulting (BBC) to develop updated population projections for each of the scenarios in the Water Plan.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 38.** Jones, B. and O'Neill, B. C. (2013). Historically grounded spatial population projections for the continental United States. *Environmental Research Letters* 8(4): 044021. ([link](#))

Abstract:

Large-scale spatial population projections are of growing importance to the global change community. Spatial settlement patterns are a key determinant of vulnerability to climate-related hazards as well as to land-use and its consequences for habitat, energy use, and emissions of greenhouse gases and air pollutants. Few projections exist of spatial distribution at national or larger scales, and while recent efforts improve on earlier approaches that simply scaled or extrapolated existing spatial patterns, important methodological shortcomings remain and models have not been calibrated to nor validated against historical trends. Here we present spatially explicit 100-year projections for the continental United States consistent with two different scenarios of possible socio-economic development. The projections are based on a new model that is calibrated to observed changes in regional population distribution since 1950, corrects for distorting effects at borders, and employs a spatial mask for designating protected or uninhabitable land. Using new metrics for comparing spatial outcomes, we find that our projections anticipate more moderate trends in urban expansion and coastal settlement than widely used existing projections. We also find that differences in outcomes across models are much larger than differences across alternative socio-economic scenarios for a given model, emphasizing the importance of better understanding of methods of spatial population projection for improved integrated assessments of social and environmental change.

Implications for planning: Guides urban demand programs, especially outdoor use and land-use change. Provides demographic/spatial inputs that justify horizon length and update cadence.

39. Flume Data Labs., (2024). Flume Customer Aggregated Water Use Dataset. Aggregated Dataset. April. Excel Workbook. ([link](#))

Their Vision: We are building stronger, more resilient communities, businesses, and ecosystems alongside our members and partners.

Our Sustainable Water Vision for 2030 envisions a world where water is properly valued in every form and proactively, efficiently, and sustainably managed throughout its entire cycle—from the water provider to the tap and back into our waterways. For more details, visit our Strategic Plans page.

Implications for planning: General relevance to long-range water planning and scenario analysis.

40. Lautenschlager, K., Boon, N., Wang, Y., Egli, T., & Hammes, F. (2010). Overnight stagnation of drinking water in household taps induces microbial growth and changes in community composition. *Water Research* 44(17): 4868-4877. ([link](#))

Abstract:

Drinking water quality is routinely monitored in the distribution network but not inside households at the point of consumption. Fluctuating temperatures, residence times (stagnation), pipe materials and decreasing pipe diameters can promote bacterial growth in buildings. To test the influence of stagnation

in households on the bacterial cell concentrations and composition, water was sampled from 10 separate households after overnight stagnation and after flushing the taps. Cell concentrations, measured by flow cytometry, increased (2–3-fold) in all water samples after stagnation. This increase was also observed in adenosine tri-phosphate (ATP) concentrations (2–18-fold) and heterotrophic plate counts (4–580-fold). An observed increase in cell biovolume and ATP-per-cell concentrations furthermore suggests that the increase in cell concentrations was due to microbial growth. After 5 min flushing of the taps, cell concentrations and water temperature decreased to the level generally found in the drinking water network. Denaturing gradient gel electrophoresis also showed a change in the microbial composition after stagnation. This study showed that water stagnation in household pipes results in considerable microbial changes. While hygienic risk was not directly assessed, it emphasizes the need for the development of good material validation methods, recommendations and spot tests for in-house water installations. However, a simple mitigation strategy would be a short flushing of taps prior to use.

Implications for planning: Highlights affordability and equity for rate design and customer assistance programs. Relevant to utility data modernization and adaptive planning analytics.

- 41.** McLaughlin, A. (2021). State Water Plan Review. Interstate Council on Water Policy (ICWP), 21 p. ([link](#))

Overview: This report reviews state water planning efforts and identifies opportunities for improving coordination and effectiveness.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 44.** Kansas Water Office, (2022). 2022 Kansas Water Plan: Kansas Water Office, 261 pp. ([link](#))

Overview: The Kansas Water Plan outlines strategies to ensure long-term water supply reliability and sustainability.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 42.** EPA Office of Research and Development (2017). Updates to the Demographic and Spatial Allocation Models to Produce Integrated Climate and Land Use Scenarios (ICLUS) Version 2. EPA Office of Research and Development, EPA/600/R-16/366F. ([link](#))

Overview: The ICLUS model provides spatially explicit projections of population and land use under different socioeconomic scenarios.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 43.** Patterson, L. A., Bryson, S. A., & Doyle, M. W. (2023). Affordability of household water services across the United States. PLOS Water 2(5): e0000123. ([link](#))

Abstract:

Households that cannot be able to afford their water bills may lose access to drinking water and wastewater services. This study seeks to quantify how many households may struggle to pay for water services across 787 of the largest drinking water providers located within each state of the United States. Household water affordability is the ability for a household to pay for basic water services without undue hardship. Here, we select 6,000 gallons per month (22.7 m³/mo) as sufficient to meet basic needs and define undue hardship as spending more than 4.6% of household income (one day of labor each month) to pay for water services. Monthly bills are combined with census income data based on service area boundaries to determine how many households are spending more than 4.6% of their income on water services. We find that basic water services are unaffordable for 17% of the households (28.3 million persons) in this study. The median, or representative community, has one in seven households spending more than 4.6% of their income paying for water services. We developed a data visualization tool to allow users to explore how affordability challenges change across different volumes of water usage and levels of financial hardship (<https://nicholasinstitute.duke.edu/water-affordability/water-affordability-united-states>). This research shows that household water unaffordability is not a localized problem but rather is a challenge experienced by households in communities across the nation.

Implications for planning: Highlights affordability and equity for rate design and customer assistance programs.

- 44.** Montana Department of Natural Resources and Conservation (2014). A Watershed Approach to the 2015 Montana State Water Plan, Montana Department of Natural Resources and Conservation: 80 pp. ([link](#))

Overview: The Kansas Water Plan outlines strategies to ensure long-term water supply reliability and sustainability.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 45.** Plummer Associated, Inc. (2024). City of Fort Worth 2024 Water Conservation Plan. Final Contract Report prepared for the City of Fort Worth, variably paginated. ([link](#))

Overview: Montana's State Water Plan uses a watershed approach to assess water availability and guide long-term management strategies.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 46.** Plummer and Associated, Inc. (2024). City of Houston 2024 Water Conservation Plan. Final Report prepared for City of Houston, 43 p. ([link](#))

Background: SUBJECT: 2024 Water Conservation Plan and 2024 City of Houston Drought Contingency Plan. RECOMMENDATION: Adopt an ordinance approving the 2024 City of Houston Water Conservation Plan and 2024 City of Houston

Drought Contingency Plan, and adopt an ordinance amending Chapter 47 of the Code of Ordinances, Houston, Texas, relating to water shortages.

SPECIFIC EXPLANATION: The Texas Water Development Board (“TWDB”) and the Texas Commission on Environmental Quality require utilities that provide treated water service to 3,300 or more connections to adopt a water conservation plan that meets the minimum requirements set forth in Title 30, Chapter 288 of the Texas Administrative Code, and to adopt an updated water conservation plan every five years. The 2024 City of Houston Water Conservation Plan (the “Water Conservation Plan”) is the required five-year update to the 2019 City of Houston Water Conservation Plan. The Water Conservation Plan meets statutory requirements and describes Houston’s water system and customer base, explains Houston’s current conservation goals and targets, and discusses current and future programs to meet those goals and targets. TWDB requires that the Water Conservation Plan include a copy of Houston’s drought contingency plan that meets the requirements set forth in TWDB’s Water Conservation Plan Guidance Checklist, Form TWDB-1968. The 2024 City of Houston Drought Contingency Plan (the “Drought Contingency Plan”) meets those requirements and establishes the procedures Houston will follow in case of a water

shortage emergency consistent with Chapter 47, Article VII of the City of Houston Code of Ordinances (“Water Shortages”). The Drought Contingency Plan has been updated to reflect its adoption in 2024 and is amended to make such non-substantive changes to the Code as are necessary to conform to the provisions adopted in this Ordinance. These changes include: Update the administrative procedures and re-define water shortages stages Provide clarity on water shortage restrictions, variances, and penalties for water customers; and Ease burdens on water customers during water shortages These changes provide our customers with greater flexibility in how each chooses to conserve water, while enabling the City to better manage and mitigate water shortages. The community will benefit from improved water reliability, ensuring long-term water availability and reducing the impacts of severe droughts. The Water Conservation Plan and the Drought Contingency Plan were presented to the Service Delivery Implications for planning: General relevance to long-range water planning and scenario analysis.

47. Potter, L. (2024). Transportation and Demographic Characteristics and Trends in Texas. Texas Dept. of Transportation Commission, 24 p. ([link](#))

Overview: Analysis of trends and characteristics of transportation development in Texas.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 48.** Quesnel, K. J., Agrawal, S., & Ajami, N. K. (2020). Diverse paradigms of residential development inform water use and drought-related conservation behavior. *Environmental Research Letters* 15(12): 124009. ([link](#))

Abstract:

Widespread urbanization has led to diverse patterns of residential development, which are linked to different resource consumption patterns, including water demand. Classifying neighborhoods based on urban form and sociodemographic features can provide an avenue for understanding community water use behaviors associated with housing alternatives and different residential populations. In this study, we leveraged built environment data from the online real estate aggregator Zillow to develop neighborhood typologies and community clusters via a sequence of unsupervised learning methods. Five distinct clusters, spatially segregated despite no geospatial inputs, were associated with unique single-family residential water use and conservation patterns and trends. The two highest-income clusters had divergent behavior, especially during and after a historic drought, thus unraveling conventional income–water use and income–water conservation relationships. These clustering results highlight evolving water use regimes as traditional patterns of development are replaced with compact, water-efficient urban form. Defining communities based on built environment and sociodemographic characteristics, instead of sociodemographic features alone, led to 3% to 30% improvements in cluster water use and conservation cohesion. These analyses demonstrate the importance of smart development across rapidly urbanizing areas in water-scarce regions across the globe.

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Highlights affordability and equity for rate design and customer assistance programs.

- 49.** Quesnel, K. J. and Ajami, N. K. (2017). Changes in water consumption linked to heavy news media coverage of extreme climatic events. *Science Advances* 3(10): e1700784. ([link](#))

Abstract:

Media-related public awareness of extreme drought in California is linked to changes in urban water use behavior. Public awareness of water- and drought-related issues is an important yet relatively unexplored component of water use behavior. To examine this relationship, we first quantified news media coverage of drought in California from 2005 to 2015, a period with two distinct droughts; the later drought received unprecedentedly high media coverage, whereas the earlier drought did not, as the United States was experiencing an economic downturn coinciding with a historic presidential election. Comparing this coverage to Google search frequency confirmed that public attention followed news media trends. We then modeled single-family residential water consumption in 20 service areas in the San Francisco Bay Area during the same period using geospatially explicit data and including news media coverage as a covariate. Model outputs revealed the factors affecting water use for populations of varying demographics. Importantly, the models estimated that an increase of 100 drought-related articles in a bimonthly period was associated with an 11 to 18% reduction in water use. Then, we evaluated high-

resolution water consumption data from smart meters, known as advanced metering infrastructure, in one of the previously modeled service areas to evaluate breakpoints in water use trends. Results demonstrated that whereas nonresidential commercial irrigation customers responded to changes in climate, single-family residential customers decreased water use at the fastest rate following heavy drought-related news media coverage. These results highlight the need for water resource planners and decision makers to further consider the importance of effective, internally and externally driven, public awareness and education in water demand behavior and management.

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Guides urban demand programs, especially outdoor use and land-use change.

- 50.** Quesnel, K. J. and Ajami, N. K. (2019). Large Landscape Urban Irrigation: A Data-Driven Approach to Evaluate Conservation Behavior. *Water Resources Research* 55(1): 771–786. ([link](#))

Abstract:

Nonresidential irrigation is a unique and important yet understudied urban water sector. Knowing how urban irrigators use water is critical for projecting future demands, planning diverse supply portfolios, and designing conservation strategies. In this study, we developed a holistic, analytical approach to advance knowledge about the temporal and spatial dimensions of nonresidential outdoor water use, also known as large landscape irrigation. Our approach employed data from two forthcoming technologies: dedicated irrigation meters and smart meters (i.e., advanced metering infrastructure). We then applied our methodology to a case study city in the San Francisco Bay Area, California, from 2013 to 2016 during a historic, high-profile drought. Importantly, we uncovered behavioral differences between customers with potable versus recycled water connections and different subsectors of large landscape irrigation. Overall, conservation patterns mimicked those across California. Although they saved at lower rates, customers with recycled water followed similar conservation trends despite receiving no mandates. A weekly water use model revealed drivers of water demand, while spatial analyses showed hot and cold spots of conservation, with those in higher-income areas conserving less as the drought progressed. A conditional inference tree partitioned diverse customers based on their conservation rates, identifying characteristics of customers who could provide the most savings in future droughts. As increasing water scarcity and population growth prompt water suppliers to optimize resources through supply diversification and demand-side management, large landscape irrigation presents one avenue for achieving those goals. Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Supports reuse/stormwater/alternative supplies in long-horizon portfolios.

- 51.** Rayej, M., Juricich, R., Groves, D. G., & Yates, D. (2011). Scenarios of Future California Water Demand Through 2050: Growth and Climate Change. *World Environmental and Water Resources Congress* 2011, 4423-4432. ([link](#))

Abstract: This paper describes key activities conducted by the California Department of Water Resources (DWR) to develop and quantify scenarios of future statewide water demand through 2050 as part of the California Water Plan, Update 2009. The California Water Plan, mandated by state law and updated every five years, is used to guide statewide water policy decisions. A stakeholder driven process was used to develop three narrative scenarios describing future growth: Current Trends, Slow and Strategic Growth, and Expansive Growth. These narrative scenarios express three plausible themes or storylines that highlight important uncertainties surrounding future water demands. Water demands were quantified statewide and for the ten hydrologic regions used by the California Water Plan. Across the three scenarios there is a wide potential range of future water demand depending on the specific assumptions for growth, development patterns, climate change, agricultural land use, and background conservation. Without considering climate change total statewide water annual demand by 2050 ranges from a decrease of about 2.5-million-acre feet under the Slow and Strategic Growth scenario to an increase of 6 million acre-feet for the Expansive Growth scenario. All scenarios show higher water demands by 2050 when climate change is factored in. The hydrologic region-based scenarios presented in this paper are an initial effort that is part of a larger strategy to conduct a robust evaluation of future demands and alternative water management strategies in light of the many uncertainties facing water managers. Implications for planning: General relevance to long-range water planning and scenario analysis.

- 52.** Rayej, M., Kibrya, S., Shipman, P., & Correa, M. (2019). Future Scenarios of Water Supply and Demand in Central Valley, California through 2100: Impacts of Climate Change and Urban Growth. California Water Plan Update 2018 Supporting Document. California Department of Water Resources, 123 p. ([link](#))

Executive Summary: A fully integrated water supply and demand model based on the Water Evaluation and Planning (WEAP) analytical tool was used to project future water conditions in the California's Central Valley in support of the California Water Plan Update 2018. The projections are based on a combination of five urban growth and 20 updated climate scenarios recommended by the California Department of Water Resources' (DWR's) Climate Change Technical Advisory Group (CCTAG). The combination of urban growth and climate change scenarios resulted in 100 scenarios of alternative futures, accounting for uncertainties in population growth, urbanization, land use pattern, and climate factors. The projections provide annual variations of water demand, supply deliveries, and the gap between the demand and the delivered supplies starting from the base year of 2006 through the end of the century (2100). This technical report describes the approach, methodologies, and results of applying WEAP Central Valley Planning Area integrated model to quantify future water demands in urban and agricultural sectors, as well as supply deliveries to meet those demands. Factors considered affecting future water demand in urban and agricultural sectors include population growth and urbanization, as well as loss of agricultural lands because of urban encroachment. These factors were coupled with climate factors affecting urban outdoor landscape and agricultural crop consumptive demand. Climatic

factors (temperature, precipitation, and relative humidity) not only affect the demand side of the water balance, they also affect the supply side which includes stream flows and snowmelt runoff. Use of a fully integrated water and supply model facilitated the analysis intended for this study. The five urban growth scenarios used in this study include:

- A low-population growth coupled with high-density housing to bracket the low end of urban water use.
- A high-population growth coupled with low-density housing to bracket the high end of urban water use.
- A medium current-trend population (CTP) growth scenario coupled with three housing densities (low, medium, and high) to give three medium urban water-use scenarios.

ES-1 Future Scenarios of Water Supply and Demand in Central Valley These combinations resulted in five urban growth scenarios. The 20 updated future climate scenarios of temperature and precipitation projections, recommended by DWR CCTAG, are based on the results of 10 global climate models coupled with two representative concentration pathways greenhouse gas emission scenarios. The emission scenarios reflect the increase in atmospheric entrapments of solar radiative forcing of +4.5 watts per square meter (w/m²) and +8.5 w/m² by 2100 relative to 2000. The combinations resulting from five urban growth scenarios and 20 climate scenarios resulted in 100 future scenarios. The results include long-term projections of monthly and annual future water demand, supply deliveries, and unmet demand in urban (indoor and outdoor) and agricultural sectors over the span of approximately 100 years at planning area scale of the three hydrologic regions (HRs) (Sacramento River, San Joaquin River, Tulare Lake) in the Central Valley. The results generally indicate that future urban indoor and outdoor demands will increase over time in all three hydrologic regions under the scenarios of population and urbanization studied. Urban outdoor demand was further influenced by climate factors including precipitation and temperature affecting outdoor landscape consumptive demand resulting in inter-annual variations over the projection period. Also included are the results of vulnerability analysis and vulnerability maps developed based on statistical frequencies to quantify future likelihoods of unmet demands (supply shortfalls) in urban sector. Vulnerability is defined as the percentage of the time that a certain level of demand (demand threshold) is not met. Results of the vulnerability analysis show future likelihoods and risks of supply shortages can be managed when some levels of demand reduction are adopted. For example, under a 95 percent demand threshold, which assumes adoption of a 5 percent demand reduction, vulnerability in Sacramento River HR under an example set of climate and urbanization scenario (climate scenario ACCESS_10.0_4.5 and urban growth scenario current trend population-current trend density [CTP_CTD]) is 0 percent, as shown in Figure ES-1. This indicates a positive response to demand reduction because of resilient available supplies in the region. San Joaquin River HR shows a similar response. In contrast, vulnerability of the Tulare Lake HR is approximately 6 percent, indicating a persistent vulnerability resulting from ES-2 Future Scenarios of Water Supply and Demand in Central Valley lack of reliable supplies in the region. This should not be deemed conclusive across all 100 sets of future scenarios because results may vary under different sets of conditions. The online Tableau Dashboard provides more information on the vulnerabilities under various conditions. Figure ES-1 Urban Sector Vulnerability in the Three Hydrologic Regions under 95 Percent Demand Threshold (5 Percent Demand Reduction Plan) for Climate scenario ACCESS_1.0_4.5 and Urban Growth Scenario CTP-CTD

Note: CTP-CTD = current trend population-current trend density, SJ = San Joaquin River Hydrologic Region, SR = Sacramento River Hydrologic Region, TL = Tulare Lake Hydrologic Region The agricultural sector shows an overall downward trend in water demand because of loss of irrigated lands resulting from urbanization in the three hydrologic regions of the Central Valley. Vulnerability maps in this sector show, even with downward trend in future agricultural water demand, all three regions had high vulnerabilities when compared with those in the urban sector. This is because the agricultural sector was given lower priority in water supply allocation for meeting demands in the current application of the WEAP model. Under a 95 percent demand threshold (adoption of a 5 percent demand reduction), vulnerability in the Sacramento River Hydrologic Region is approximately 10 percent, as opposed to a much higher vulnerability of 32 percent in the San Joaquin HR and 49 percent in the Tulare Lake HR (Figure ES-2). This again indicates more reliable sources of supplies in Sacramento River HR than those in San Joaquin River and Tulare Lake HRs. When demand threshold is reduced to 90 percent (adoption of 10 percent ES-3 Future Scenarios of Water Supply and Demand in Central Valley demand reduction), vulnerability in the Sacramento River HR is reduced to 0 percent (Figure ES-3). In San Joaquin River HR vulnerability drops to about 9 percent, while in Tulare Lake it remains high at 33 percent. These results demonstrate that vulnerability in the agricultural sector would persist in southern parts of Central Valley even with a 10 percent demand reduction. Figure ES-2 Agricultural Sector Vulnerability in the Three Hydrologic Regions under 95 Percent Demand Threshold (5 Percent Demand Reduction Plan) for Climate Scenario ACCESS_1.0_4.5 and Urban Growth Scenario CTP-CTD Note: CTP-CTD = current trend population-current trend density, SJ = San Joaquin River Hydrologic Region, SR = Sacramento River Hydrologic Region, TL = Tulare Lake Hydrologic Region Figure ES-3 Agricultural Sector Vulnerability in the Three Hydrologic Regions under 90 Percent Demand Threshold (10 Percent Demand Reduction Plan) for Climate Scenario ACCESS_1.0_4.5 and Urban Growth Scenario CTP-CTD Note: CTP-CTD = current trend population-current trend density, SJ = San Joaquin River Hydrologic Region, SR = Sacramento River Hydrologic Region, TL = Tulare Lake Hydrologic Region

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 53.** Rehiring, J., Wooten, A., & Carollo Engineers. (2025). Oklahoma Comprehensive Water Plan: Programmatic Workplan. Project Memorandum prepared for Oklahoma Water Resources Board, 27 p. ([link](#))

Overview: The Oklahoma Water Resources Board (OWRB) is preparing the statutorily required update of the Oklahoma Comprehensive Water Plan (OCWP or /0/1 OCWP). It will build upon the previous OCWP update (/03/ OCWP) and will focus on the following key activities: • Advance /03/ OCWP policy recommendations by identifying actions necessary to continue implementation of these. • Model and assess water availability, water demand projections, and water quality trends, and identify basins with projected challenges or opportunities. • Evaluate, develop, and recommend water management strategies for all water-use sectors, consider the cost of doing nothing, and develop innovative new

funding mechanisms to support their implementation. • Integrate the OCWP with Oklahoma’s first Statewide Flood Plan. • Conduct focused engagement throughout the process to identify the most pressing current issues and develop best practicable solutions in collaboration with representatives from all water use sectors, Tribal Nations, interested water planning groups, state agencies and legislators, local entities, and federal organizations. This Programmatic Work Plan and Engagement Plan (PWP/EP) provide a roadmap to complete the OCWP key activities by describing necessary tasks and work products. Figure 3 provides an overview of the major phases of work and tasks in the PWP. Phase 3 work was initially completed in /0/3, with periodic updates being made to the PWP/EP over time if needed. Additional detail (subtasks, etc.) is provided in the PWP outline (Appendix A). Note that some tasks may be broken into smaller tasks for phased development, based on available funding and/or timing. For example, Task <B. Implications for planning: General relevance to long-range water planning and scenario analysis.

54. State Water Resources Control Board (2022). 2022 Annual Water Supply and Demand Assessment Summary Report. Report submitted to the State Water Resources Control Board, 39 p, (link). ([link](#))

Overview: This report summarizes water supply and demand conditions across California and evaluates potential shortages.

Implications for planning: General relevance to long-range water planning and scenario analysis.

55. California Department of Water Resources (2023). California Water Plan Update 2023, California Department of Water Resources: 334. ([link](#))

Overview: The California Water Plan provides a comprehensive framework for managing the state’s water resources sustainably.

Implications for planning: General relevance to long-range water planning and scenario analysis.

56. Nebraska Dept. of Natural Resources (2025). Water Management in Nebraska Brochure: Nebraska Dept. of Natural Resources. ([link](#))

Overview: Nebraska manages water resources through integrated groundwater and surface water planning.

Implications for planning: General relevance to long-range water planning and scenario analysis.

57. Nevada Division of Water Planning. 1999. Nevada State Water Plan, Part 1: Background and Resource Assessment. Nevada Department of Conservation and Natural Resources, Carson City, Nevada. 180 pp. ([link](#))

Overview: The Nevada State Water Plan provides a comprehensive assessment of water resources and outlines strategies for future needs.

Implications for planning: General relevance to long-range water planning and scenario analysis.

58. Utah Division of Water Resources (2017). Utah State Water Plan. Utah Division of Water Resources, 136 p. ([link](#))

Overview: Utah's State Water Plan outlines strategies to ensure a sustainable water future.

Implications for planning: General relevance to long-range water planning and scenario analysis.

59. Richter, B. D. (2023). Decoupling Urban Water Use from Population Growth in the Colorado River Basin. *Journal of Water Resources Planning and Management* 149(2): 04022082. ([link](#))

Abstract:

Decreases in river flows and rapidly declining reservoir levels pose grave water security risks to urban water utilities reliant upon the Colorado River Basin. This study evaluated multidecadal trends (2000–2020) in urban water use for 28 utilities with a combined service population of 23 million people that depend in part or wholly upon water supplies from the river and its tributaries. It was found that more than half of cities surveyed have substantially decoupled their water demands from population growth by greatly reducing their per capita water use. Total water deliveries to the cities surveyed dropped by 18% even though their combined service population increased by 24%. Median per capita water-use rates for total and residential use decreased by 30% and 28%, respectively. The most common water conservation strategies included toilet replacement rebates and other plumbing retrofits, variable water-pricing structures, and turf removal. Given considerable variability in total per capita water uses and rate of per capita reductions, many cities should be able to substantially reduce water demands to attain the per capita water-use levels of top performers. In contrast with overall declines in water use, utilization of the Colorado River Basin as a water source has not declined but instead increased by 1%. These results suggest that opportunity may exist for reducing pressure on the Colorado River Basin if per capita water-use rates continue to decline and utilities increase their use of other water sources—including water reuse, desalination, and stormwater capture as well as other rivers and aquifers—that can be prioritized over the use of Colorado River supplies.

Implications for planning: Supports reuse/stormwater/alternative supplies in long-horizon portfolios.

Guides urban demand programs, especially outdoor use and land-use change.

60. Richter, B. D., Benoit, K., Dugan, J., Getacho, G., LaRoe, N., Moro, B., Rynne, T., Tahamtani, M., & Townsend, A. (2020). Decoupling Urban Water Use and Growth in Response to Water Scarcity. *Water* 12(10): 2868. ([link](#))

Abstract: Many cities in the western US face difficult challenges in trying to secure water supplies for rapidly growing urban populations in the context of intensifying water scarcity. We obtained annual data from urban water utilities across the western US to document trends in their water usage and service populations. We found that many cities have been able to accommodate population increases while simultaneously reducing their volume of water use, thereby decoupling growth from water use. This outcome is largely attributable to reductions in per-capita residential use. We identify additional untapped potential that can sustain and widen this decoupling for many cities.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 61.** Richter, B. D., Benoit, K., Dugan, J., Getacho, G., LaRoe, N., Moro, B., Rynne, T., Tahamtani, M., & Townsend, A. (2020). Decoupling Urban Water Use and Growth in Response to Water Scarcity. *Water* 12(10): 2868. ([link](#))

Abstract:

Many cities in the western US face difficult challenges in trying to secure water supplies for rapidly growing urban populations in the context of intensifying water scarcity. We obtained annual data from urban water utilities across the western US to document trends in their water usage and service populations. We found that many cities have been able to accommodate population increases while simultaneously reducing their volume of water use, thereby decoupling growth from water use. This outcome is largely attributable to reductions in per-capita residential use. We identify additional untapped potential that can sustain and widen this decoupling for many cities.

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Guides urban demand programs, especially outdoor use and land-use change.

- 62.** Richter, B. D., Blount, M. E., Bottorff, C., Brooks, H. E., Demmerle, A., Gardner, B., Herrmann, H., Kremer, M., Kuehn, T., Kulow, E., Lewis, L., Lloyd, H., Madray, C., Mauney, C. I., Mobley, B., Stenseth, S., & Strick, A. W. (2018). Assessing the Sustainability of Urban Water Supply Systems. *Journal AWWA* 110(2): 40-47. ([link](#))

Abstract: The perpetual need for safe water presents communities and utilities with 21st-century challenges; a recently developed series of indicators can help in establishing and monitoring water sustainability efforts.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 63.** San Antonio Water System (2024). 2024 Water Management Plan. San Antonio Water System, variably paginated. ([link](#))

Overview: The plan explains how SAWS will serve 617,000 more customers by 2040, continuing a legacy of water conservation and ensuring water supply security for generations to come.

Implications for planning: General relevance to long-range water planning and scenario analysis.

65. San Antonio Water System (2024). SAWS 2024 5 Year Water Conservation Plan. San Antonio Water System, 140 p. ([link](#))

Executive Summary: WHAT CAN WE STILL ACCOMPLISH? We are confident that our per capita water usage will continue to decline over time from a variety of water efficiency initiatives. The most recent analysis of future potential per capita usage declines was accomplished using a sophisticated disaggregation model that is widely used by other leading utilities. This model, and our experience, indicate that per capita usage will continue to decline at a gradual rate eventually reaching a total GPCD of 87 by 2075. CONSERVATION IS PART OF SUPPLY DIVERSIFICATION SAWS has deployed the strategies of water conservation, supply diversification and drought demand management in water plans for more than two decades. These three strategies combined with careful analysis of expected population growth and how supplies change during drought have positioned our community to be water secure even in the face of expected prolonged and severe drought periods. After more than two decades of supply diversification from the Edwards Aquifer, SAWS has access to 13 water supply projects from seven different water sources. The current supply portfolio includes groundwater, surface water, Aquifer Storage and Recovery water, and brackish groundwater desalination. The Vista Ridge groundwater project is SAWS' latest addition. It has performed beautifully, bringing 50,000 acre-feet per year to the San Antonio area even during intense drought periods. It is important to note that long-term water savings have made more water available to future customers than any single water supply project. Had per capita consumption not declined over the past several decades, our community would have needed the equivalent of more than two Vista Ridge projects completed by now. "Conservation is not just a practice but a source of pride in San Antonio. We have been so successful with it that it is treated as a water source within our diverse water supply portfolio. That success has allowed us to forgo expensive water projects, saving ratepayers hundreds of millions of dollars. SAWS remains steadfast in leading the nation in novel, innovative conservation practices."-ROBERT PUENTE, PRESIDENT AND CEO OF THE SAN ANTONIO WATER SYSTEM 2024 SAWS CONSERVATION PLAN EDWARDS AQUIFER PERMIT CUTBACKS DURING DROUGHT Expanded supplies have meant that Edwards Aquifer permit cutbacks are not catastrophic to normal water operations and daily life in our community. However, our largest supply source is still the Edwards Aquifer from which SAWS can draw varying amounts of water depending on how deep a drought stage we are in and how severe a critical period cut back SAWS must make to remain in compliance with aquifer regulations. The Table below shows the lowest (worst) and highest (best) estimated water availability from the Edwards Aquifer based on the 2022 volume of SAWS permitted groundwater rights. Best indicates no critical period cutbacks to permitted supplies while the Edwards Aquifer volume of 155,651 acre-feet per year represents the most severe cutback of 44 percent that could be imposed. In 2024 SAWS expects to have 256,993-acre feet available from the Edwards Aquifer. Based on current and projected drought conditions at the time this was published, that volume is

GPCD (Historical) High Forecast Average Forecast assumptions will no longer hold over time. If demand remains at this high trajectory during a drought, it can become necessary to impose emergency level restrictions on outdoor water usage that go beyond the once per week watering rules our community has come to expect. Analysis was done on water use patterns to understand why long-standing Low Forecast of new irrigation systems and associated landscapes is a necessary strategy to prevent increased demand in hot, dry summers. Most homes and nearly all businesses are being drought regulations were no longer getting the same results. Community conversations began to discuss options to revise the drought plan. After a year of discussion and community input, rules were updated by the SAWS Board of Trustees and City Council in June of 2024. More details on these changes can be found in Chapter 4. In addition to updating drought rules, SAWS also determined an investment in inspection “Vista Ridge and all the technology and diversification efforts that this utility has made over the last many years has made our community competitive and a very quality place to live. We don’t want to see that evaporate because we’re being care less with our water.” - RON NIRENBERG, MAYOR OF SAN ANTONIO-**RON 2024 SAWS CONSERVATION PLAN** built with automatic sprinkler systems. Unfortunately, the quality of these systems is such that many use more water than is necessary, and waste up to 20% of water applied. A SAWS irrigation plan review and inspection process should address the quality issues by ensuring that state statutes already codified requiring water efficiency in irrigation design and installation are followed. More on this can be found in Chapters 7 and 9. **MORE INITIATIVES TO MITIGATE OUTDOOR WATER USAGE IN THE FUTURE** While the updated drought rules focusing on quality irrigation are a good start, there is more we need to accomplish. We need to meet our long-term per capita goal in both dry and wet years. Making sure resilient landscapes that can thrive with less water during periods of reduced rainfall is crucial. Efforts will include education, incentives and updated regulations. Potential new initiatives that will be discussed in the community and with impacted stake holders during the next year include:

Implications for planning: General relevance to long-range water planning and scenario analysis.

66. San Antonio Water System (2025). SAWS 2025 water management plan. San Antonio Water system, 223 p. ([link](#))

Abstract: San Antonio Water System (SAWS) is one of the largest municipal water utilities in the nation, providing water, wastewater, and recycled water services to more than two million people in San Antonio and adjacent suburban cities. In 2022, The SAWS Board of Trustees and management recognized significant changes have occurred since adoption of the 2017 Water Management Plan, requesting a new round of water supply planning. The updated water management plan ensures the utility and the community it serves are navigating a secure water future together. The 2025 Water Management Plan is the organization’s guiding document to meet San Antonio’s long-term water needs through 2075. SAWS’ first Water Management Plan was developed in 1998, with subsequent plans published in 2005, 2009, 2012 and 2017. Each plan incorporated changes in population projections, water demand patterns, regulations, climate change, water supply options, and public input providing a clear direction for the

community. Twenty-five years ago, at the turn of the 21st century, SAWS was 100 percent reliant on the Edwards Aquifer to meet the potable water needs of the community. Since then, SAWS has developed a robust diversified water supply portfolio to ensure a sustainable, reliable water supply during times of drought, increased resilience in managing any climate-related impacts, and the community continues to embrace a water conservation ethic, significantly reducing daily water use. As San Antonio closes the chapter on the first quarter-century of the millennium, the SAWS 2025 Water Management Plan charts the course to meet the mid-century water needs and continues a legacy of water conservation for a rapidly growing community and thriving economy. Rather than complete the Water Management Plan (WMP) in 2022 as originally scheduled, planning pivoted to evaluate and utilize actual data from the drought which started in 2020 and in particular, the record low rainfall and record high temperatures of 2022 and 2023. SAWS staff analyzed customer demand, the yield of SAWS' water supply portfolio under extended drought stressed conditions, real and apparent water loss, and the maximum distribution from the Aquifer Storage and Recovery (ASR) facility. This just-in-time data is incorporated into the 2025 Water Management Plan. Since the adoption of the 2017 Water Management Plan, SAWS added the Vista Ridge Project, the largest non-Edwards Aquifer supply in SAWS' history, stored a record volume in the ASR facility, continued the downward trend of reducing daily water use, and met customer demand throughout the record drought and heat of 2022 and 2023. [saws.org](https://www.saws.org) 3 SAWS 2025 Water Management Plan The 2025 Water Management Plan further improves on the 2017 Water Management Plan by updating population projections, refining the supply and demand model to include water loss reduction targets, evaluating the additional years of operational experience of groundwater and surface water supplies during all weather conditions, analyzing customer demand patterns, and undertaking an intensive review of potential local climate change impacts. Implementing the 2025 Water Management Plan will require incorporation into SAWS' annual operations and capital improvement budgets, as well as revisions to several City of San Antonio ordinances approved in 2024. Through the South-Central Texas Regional Water Planning Group (Region L), components of this plan will be included in the 2027 State Water Plan. The 2025 Water Management Plan builds upon previous plans through the inclusion of targeted water loss reduction goals and two new chapters:

- **Water Loss Reduction Targets:** The SAWS Board has established key milestones for the water loss reduction initiative to reduce water loss from 73 gallons per connection per day (GCD) in 2025 to 61 GCD by 2028 and 43 GCD by 2035, thereby improving water distribution efficiency.
- **Water Equity:** Building water security for marginalized and vulnerable communities.
- **Strategic Energy Management (SEM):** A new conservation component equally dedicated to proactively maximizing energy use wisely. Strategic energy management seeks to save energy throughout the SAWS water and wastewater systems by reducing SAWS energy footprint and operating costs. The benefits of SEM to the energy-water nexus provides water security to SAWS customers ensuring SAWS electrical resiliency when there is an outage and allows CPS Energy (CPSE) to operate the generators anytime CPSE deems beneficial. Additionally, this plan continues the tradition of planning and implementing varied water supply projects and innovative water conservation programs.

Implications for planning: General relevance to long-range water planning and scenario analysis.

- 67.** Sharvelle, S., Dozier, A., Arabi, M., & Reichel, B. (2017). A geospatially-enabled web tool for urban water demand forecasting and assessment of alternative urban water management strategies. *Environmental Modelling & Software* 97: 213-228. ([link](#))

Abstract:

This study develops and demonstrates the Integrated Urban Water Model (IUWM) for forecasting urban water demand with options to assess effects of water conservation and reuse. While water and energy balance drive hydrologic, storage and recycling simulations on a daily timestep, social and infrastructural processes are resolved by spatially distributed parameters. IUWM is deployed as an online tool with geographical information system (GIS) interfaces, enhancing its ease of use and applicability at building to municipal scales. The performance of the model at varying spatial scales was evaluated with extensive water metering data for the City of Fort Collins, Colorado. The calibrated model provided very good estimates of demands at individual block group as well as the municipal service area. The capacity of IUWM for the assessment of the spatiotemporal variability of water consumption and effects of water demand management strategies under climate and urban growth scenarios is discussed.

Implications for planning: Supports reuse/stormwater/alternative supplies in long-horizon portfolios. Guides urban demand programs, especially outdoor use and land-use change.

- 68.** Sleeter, B. M., Wilson, T. S., Sharygin, E., & Sherba, J. T. (2017). Future Scenarios of Land Change Based on Empirical Data and Demographic Trends. *Earth's Future* 5(11): 1068-1083. ([link](#))

Abstract:

Changes in land use and land cover (LULC) have important and fundamental interactions with the global climate system. Top-down global scale projections of land use change have been an important component of climate change research; however, their utility at local to regional scales is often limited. The goal of this study was to develop an approach for projecting changes in LULC based on land use histories and demographic trends. We developed a set of stochastic, empirical-based projections of LULC change for the state of California, for the period 2001–2100. Land use histories and demographic trends were used to project a business-as-usual (BAU) scenario and three population growth scenarios. For the BAU scenario, we projected developed lands would more than double by 2100. When combined with cultivated areas, we projected a 28% increase in anthropogenic land use by 2100. As a result, natural lands were projected to decline at a rate of 139 km² yr⁻¹; grasslands experienced the largest net decline, followed by shrublands and forests. The amount of cultivated land was projected to decline by approximately 10%; however, the relatively modest change masked large shifts between annual and perennial crop types. Under the three population scenarios, developed lands were projected to increase 40–90% by 2100. Our results suggest that when compared to the BAU projection, scenarios based on demographic trends may underestimate future changes in LULC. Furthermore, regardless of scenario, the

spatial pattern of LULC change was likely to have the greatest negative impacts on rangeland ecosystems.

Implications for planning: Guides urban demand programs, especially outdoor use and land-use change. Provides demographic/spatial inputs that justify horizon length and update cadence.

69. SPF Water Engineering, LLC. (2016). Treasure Valley DCMI Water-Demand Projections (2015-2065). Report prepared by SPF Water Engineering, LLC for Idaho Water Resource Board and Idaho Dept. of Water Resources, variably paginated. ([link](#))

Executive Summary: Water demand overlying the Rathdrum Prairie Aquifer (the Idaho portion of the Spokane Valley-Rathdrum Prairie Aquifer) was projected for 5-year increments between 2010 and 2060. The projections were made for the Idaho Water Resource Board (IWRB) and the Idaho Department of Water Resources (IDWR) as part of the Idaho Statewide Comprehensive Aquifer Planning and Management Program (CAMP). Approach The approach for projecting future water demand consisted of 1. Reviewing historic population growth trends and growth rates; 2. Estimating existing water demand based on community water system data, water right information, USDA crop data, and other information; 3. Reviewing climate projections from the University of Washington Climate Impacts Group relative to the northern Idaho area; 4. Quantifying water conservation potential; 5. Evaluating selected potential water-demand constraints; 6. Projecting future population and employment growth; 7. Projecting future water demand for indoor domestic, municipal, commercial, industrial, and irrigation uses; and 8. Developing "water-demand scenarios" to evaluate possible future water-demand outcomes that take into account various population growth rates, levels of water conservation, and the potential impact of climate variability. There are two general categories of factors that will shape future water demand: (1) exogenous factors over which local policies have limited influence and (2) local factors over which public policy and private incentives can have substantial influence. Exogenous factors include the strength of the national or global economy and national demographic trends that strongly influence regional population and job growth. Although local governmental policy can have some influence over these factors, the local economy is largely driven by national or global factors. One needs to look only at the recent economic recession to see that some of these national or global factors are difficult to control other local level. Exogenous factors also include potential effects of climate variability, over which local policy-making will have very little direct influence. In contrast, regional land-use policies, building codes, governmental policies, water delivery pricing, and other local measures can have substantial influence on future water demand. Local and state government, local water purveyors, and area residents have substantial influence over these factors. Idaho Water Resource Board Rathdrum Prairie Water Demand Projections Page ii July 2010 SPF Water Engineering/AMEC/Church/Taunton Thus, future water-demand scenarios were constructed to reflect the effect of both exogenous (external realm) and local influences (policy realm) on future water use. First, three primary scenarios were developed to reflect three different population growth scenarios: low population growth, medium-level ("baseline") population growth, and

high population growth. Then, three sub-scenarios were constructed within each of the population-growth scenarios to reflect various water conservation levels. The three primary population-growth scenarios, each with three water conservation sub-scenarios, result in nine different projections of potential future water demand. Finally, the effects of potential climate variability were illustrated with a scenario representing baseline population growth and moderate water-conservation.

Implications for planning: General relevance to long-range water planning and scenario analysis.

70. Veatch, B. (2024). Water Loss Program Review: Analysis and Optimization. Final Project Report prepared for Austin Water, Black & Veatch Project No. 415677, variably paginated. ([link](#))

Executive Summary: Austin Water (AW) within the City of Austin retained Black & Veatch (B&V) to conduct an analysis of the existing water loss program after staff noted increasing losses in recent years. Black & Veatch (B&V) performed the Water Loss Control Program Review, Analysis & Optimization to address Austin Water's NRW issues and to meet goals as part of AW's Water Forward program. This document outlines the analyses conducted and recommendations for future work by AW to monitor, evaluate, and reduce all non-revenue water (including water loss) in the system.

Non-Revenue Water (NRW) is water that is treated and pumped into the distribution system but does not generate revenue by being physically lost or not properly accounted for. To address NRW, B&V reviewed the best available data from AW including (but not limited to) meter testing and accuracy, water production volumes and calibration, billing exceptions, and leakage analysis. The team utilized detailed data as well as Texas Water Development Board (TWDB) audits from 2010-2021 to analyze trends in apparent and real losses. B&V synthesized a Power BI dashboard which displayed trends in both the volume and cost of real and apparent losses. The team also conducted an AWWA Water Audit and a Real Loss Component Analysis to more accurately determine the source(s) of real and apparent loss in the system and potential mitigation strategies.

The Water Loss Control Program Review, Analysis, & Optimization utilizes these analysis and the City's current NRW reduction strategies to develop a 10-year plan of recommended strategies.

Implications for planning: General relevance to long-range water planning and scenario analysis.

71. Verburg, P. H., Alexander, P., Evans, T., Magliocca, N. R., Malek, Z., Rounsevell, M. D. A., & van Vliet, J. (2019). Beyond land cover change: towards a new generation of land use models. *Current Opinion in Environmental Sustainability* 38: 77-85. ([link](#))

Abstract:

Land use models play an important role in exploring future land change dynamics and are instrumental to support the integration of knowledge in land system science. However, only modest progress has been made in achieving these aims due to insufficient model evaluation and limited representation of the underlying socio-ecological processes. We discuss how land use models can better represent multi-

scalar dynamics, human agency and demand-supply relations, and how we can achieve learning from model evaluation. By addressing these issues, we outline pathways towards a new generation of land use models that allow not only the assessment of future land cover pattern changes, but also stimulate envisioning future land use by society to support debate on sustainability solutions and help design alternative solutions.

Implications for planning: Guides urban demand programs, especially outdoor use and land-use change. Relevant to utility data modernization and adaptive planning analytics.

72. Austin Water (2024). City of Austin Water Conservation Plan. Austin Water, 155 p. ([link](#))

Abstract:

The Texas Commission on Environmental Quality and the Texas Water Development Board require an update to the City of Austin's Water Conservation Plan every five years. This document outlines Austin Water's water conservation goals and how these goals will be met, implemented, and enforced by the city. Since 1983, Austin Water (AW) has a strong history of adopting and implementing water conservation strategies to meet the growing and dynamic challenges of Austin's water needs. These include rapid population growth, increasing frequency of extreme weather events due to climate change, and periods of ongoing drought. Current water conservation activities include incentive programs for residential, commercial, and multi-family customers; commercial regulatory programs; water-use restrictions; water reuse; and water loss control. Current incentive programs offered to residential customers include rebates for ten different indoor and outdoor water conservation activities. The most popular are rainwater harvesting, drought survival tools, irrigation upgrades, and waterwise landscape conversion. AW offers similar incentives for the commercial and multi-family sector, but the most utilized program with the greatest savings for these customers is the performance-based incentive, Bucks for Business. While incentive programs encourage customers to partner with AW to save water, mandatory water use requirements result in the greatest savings. In 2012, the City of Austin adopted updates to the Water Conservation Code, including the establishment of several commercial water-use assessment programs for facilities with irrigation systems, vehicle washes, and cooling towers. Also included in these updates was the adoption of outdoor watering restrictions. In 2016, outdoor watering became permanently limited to once-a-week watering for automatic irrigation and twice a week for hose-end sprinklers. Figure 1 illustrates the effect watering restrictions have had on lowering the increase in water consumption relative to population growth. However, recent years with very hot and dry summers, show an increase in water consumption relative to population growth. First offered by AW in 1974, reclaimed water helps provide a low-priced source of non-potable water. At present, over 170 metered customers use more than 1.4 billion gallons of reclaimed water annually for the irrigation of golf courses, ballfields, parks, and commercial properties, as well as for cooling towers, manufacturing processes, and toilet flushing. In 2021, the City of Austin began requiring development projects within a specified distance from reclaimed water lines to connect to the system and use reclaimed water for various significant non-

potable water uses. Beginning in March 2024, AW launched a new GoPurple program to increase use of reclaimed in and around Austin to make water usage more sustainable. Austin City Council approved additional requirements for large developments to connect to the reclaimed system or develop onsite water reuse systems. Water Conservation Plan and Utility Profile Page 6 of 155 To help manage water loss from leaks and aging infrastructure, AW conducts annual water loss audits. Other efforts to control water loss include AW's use of acoustic technology to inspect over 500 miles of water lines annually, implementation of Renewing Austin to replace aging water lines, and the full-scale deployment of the My ATX Water advanced metering system. AW has also contracted a water loss consulting firm to review the utility's water loss program, validate system input volume and meter accuracy, and provide recommendations for improvements. Beginning in 2020, the My ATX Water program has been replacing analog water meters with more accurate digital meters, offering water savings through leak notifications, customer awareness about water use, and the opportunity for the implementation of heightened water loss strategies in the future. By the end of 2024, the My ATX Water meter replacement program will be complete. As one of the fastest-growing metropolitan areas in the nation, Austin faces unique challenges to its water supply. Austin has successfully reduced peak water demand and delayed triggering renewal of the Lower Colorado River Authority contract for over 10 years, resulting in numerous benefits to AW and cost savings to its customers. This success has been achieved due to the development, adoption, and implementation of innovative water conservation.

Implications for planning: Informs drought-robust demand management and reliability planning under scarcity. Supports reuse/stormwater/alternative supplies in long-horizon portfolios.

73. Austin Water (2024). Water Forward 2024 Plan Report. Austin Water, 56 p. ([link](#))

Overview: Water Forward is Austin's integrated 100-year water resource plan. It outlines diverse, environmentally conscious strategies to adapt to growth, drought and climate change — ensuring a safe, reliable, equitable and affordable water future for all Austinites.

The Water Forward plan was developed in response to the historic drought Central Texas experienced from 2008–2016, during which the lakes supplying Austin's drinking water dropped to critically low levels. This experience revealed the need for a long-term, integrated approach to water supply planning that accounts for a growing population and the possibility of droughts more severe than those we have seen before.

The plan balances reliability, social and environmental benefits and economic considerations, with strategies ranging from major water supply projects to demand management and reuse. Austin Water implements the plan using an adaptive management approach, adjusting strategies as conditions change.

- Water Forward Guiding Principles (PDF)
- 2018 Water Forward Plan (PDF)
- 2018 Water Forward Strategies Summary (PDF)

Austin City Council first approved Water Forward in 2018, and since then we have implemented near-term strategies from the plan to help address water supply needs. Austin Water completed the plan's first five-year update in 2024, incorporating community input and guidance from the Water Forward Task Force. The updated plan reflects current climate and population projections for a range of possible futures.

Implications for planning: General relevance to long-range water planning and scenario analysis.

74. El Paso Water (2024). El Paso 2024 Water Conservation Plan. El Paso Water, variably paginated. ([link](#))

Highlights: Every five years, EPWater submits a Water Conservation Plan (WCP) update to the Texas Commission on Environmental Quality (TCEQ). The WCP serves both as a reporting requirement and as an aspirational blueprint for the next five years. In it, you will learn about EPWater's water systems, customer base, and conservation progress. The Water Conservation Plan gives El Paso Water staff the opportunity to review and assess our current conservation profile, recommit to or adjust conservation goals, and launch the next five years of programs.

Implications for planning: General relevance to long-range water planning and scenario analysis.

75. Zoraghein, H. and O'Neill, B. C. (2020). A Spatial Population Downscaling Model for Integrated Human-Environment Analysis in the United States., vol. 43, 2020, pp. 1563–606. ([link](#))

Abstract: Spatial population distribution is an important determinant of both drivers of regional environmental change and exposure and vulnerability to it. Spatial projections of population must account for changes in aggregate population, urbanization, and spatial patterns of development, while accounting for uncertainty in each. While an increasing number of projections exist, those carried out at relatively high resolution that account for subnational heterogeneity and can be tailored to represent alternative scenarios of future development are rare. We draw on state-level population projections for the US and a gravity-style spatial downscaling model to design and produce new spatial projections for the U.S. at 1 km resolution consistent with a subset of the Shared Socioeconomic Pathways (SSPs), scenarios of societal change widely used in integrated analyses of global and regional change. We find that the projections successfully capture intended alternative development patterns described in the SSPs, from sprawl to concentrated development and mixed outcomes. Our projected spatial patterns differ more strongly across scenarios than in existing projections, capturing a wider range of the relevant uncertainty introduced by the distinct scenarios. These projections provide an improved basis for integrated environmental analysis that considers uncertainty in demographic outcomes.

Implications for planning: General relevance to long-range water planning and scenario analysis.

76. Zoraghein, H. and O'Neill, B. C. (2020). U. S. State-level Projections of the Spatial Distribution of Population Consistent with Shared Socioeconomic Pathways. *Sustainability* 12(8): 3374. ([link](#))

Abstract: Spatial population distribution is an important determinant of both drivers of regional environmental change and exposure and vulnerability to it. Spatial projections of population must account for changes in aggregate population, urbanization, and spatial patterns of development, while accounting for uncertainty in each. While an increasing number of projections exist, those carried out at relatively high resolution that account for subnational heterogeneity and can be tailored to represent alternative scenarios of future development are rare. We draw on state-level population projections for the US and a gravity-style spatial downscaling model to design and produce new spatial projections for the U.S. at 1 km resolution consistent with a subset of the Shared Socioeconomic Pathways (SSPs), scenarios of societal change widely used in integrated analyses of global and regional change. We find that the projections successfully capture intended alternative development patterns described in the SSPs, from sprawl to concentrated development and mixed outcomes. Our projected spatial patterns differ more strongly across scenarios than in existing projections, capturing a wider range of the relevant uncertainty introduced by the distinct scenarios. These projections provide an improved basis for integrated environmental analysis that considers uncertainty in demographic outcomes.

Implications for planning: General relevance to long-range water planning and scenario analysis.

7.2. Projections of Population Growth and Water Demand in Western States of the United States

Contents_

7.2.1.	Summary of State Water Plans in the Western United States	112
7.2.2.	Arizona.....	113
7.2.3.	Arkansas	116
7.2.4.	California	118
7.2.5.	Colorado	122
7.2.6.	Idaho	124
7.2.7.	Iowa	126
7.2.8.	Kansas.....	127
7.2.9.	Louisiana.....	129
7.2.10.	Minnesota	130
7.2.11.	Missouri	131
7.2.12.	Montana.....	132
7.2.13.	Nebraska.....	133
7.2.14.	Nevada	134
7.2.15.	New Mexico.....	135
7.2.16.	North Dakota	137
7.2.17.	Oklahoma.....	138
7.2.18.	Oregon.....	139
7.2.19.	South Dakota	140
7.2.20.	Utah	141
7.2.21.	Washington	143
7.2.22.	Wyoming.....	144
7.2.23.	Glossary of Acronyms	145
7.2.24.	Planning horizons and updates.....	147
7.2.25.	SUPPLEMENTAL	148
7.2.26.	State Water Planning Summary – 22 States.....	149
7.3.	Select Texas Regional Water Plans	155
7.3.1.	North Texas Municipal Water District	155
7.3.2.	Harris Galveston Subsidence District (HGSD).....	156
7.3.3.	Fort Bend Subsidence District.....	157

7.3.4.	North Central Texas Council of Governments (NCT COG).....	158
7.3.5.	Texas Department of Transportation.....	159

7.2.1. Summary of State Water Plans in the Western United States

The review of water planning approaches in 22 western states highlights the unique scope, rigor, and frequency of Texas water planning. While nearly all states recognize population growth as an important driver of future water demand, relatively few develop detailed statewide population and municipal water-use projections comparable to those used by the Texas Water Development Board (TWDB).

Most states rely on population projections prepared by state demographic offices, universities, or census-based forecasting organizations rather than developing independent projections within water agencies. Examples include California, Colorado, Nevada, Utah, and New Mexico, all of which use official demographic projections as inputs to water planning. Many states, including Idaho, Montana, Nebraska, Oregon, and Wyoming, place greater emphasis on basin-level or local planning rather than statewide municipal demand forecasting.

A common feature among many states is the use of population multiplied by per-capita water use (gallons per capita per day, GPCD) to estimate future municipal demand. Arkansas, Colorado, Missouri, Oklahoma, and Utah explicitly use population projections combined with GPCD to forecast future municipal demand. However, most states derive GPCD from utility-reported water use and population served rather than using a standardized statewide methodology. Several states, particularly California, Colorado, Utah, and Arizona, increasingly treat GPCD as a dynamic variable that changes through time in response to conservation policies, efficiency improvements, drought response, climate change, and system losses.

Many western states have adopted scenario-based planning approaches that explicitly account for uncertainty in future growth, climate, and water demand. California, Colorado, Arizona, New Mexico, Idaho, and Wyoming evaluate multiple growth and climate scenarios rather than relying on a single forecast. These approaches allow planners to assess water system performance under a range of plausible futures and are increasingly used to address uncertainties associated with climate extremes and economic development.

Planning horizons vary substantially among states. Most states use planning horizons ranging from 20 to 50 years, with Texas, California, Colorado, New Mexico, Oklahoma, and Utah generally planning 50 years into the future. Arizona is unique in requiring demonstration of a 100-year assured water supply for new development within Active Management Areas. Planning update cycles range from approximately five years in California and Texas to ten years or longer in many other states. The comparison indicates that Texas combines one of the longest planning horizons with one of the most frequent update cycles among western states.

Overall, the review suggests that Texas has one of the most sophisticated and comprehensive state water planning frameworks in the western United States. The TWDB's statewide population projections, utility-level water demand projections, five-year planning cycle, and extensive stakeholder review process are more systematic than those used in most other states. At the same time, emerging practices from states such

as California, Colorado, Arizona, and New Mexico indicate opportunities for Texas to further strengthen its planning process through greater use of uncertainty analysis, scenario-based planning, climate stress testing, and enhanced integration of utility-level information into municipal demand projections.

The following sections provide details of the reviewed state water plans, focusing on 22 western states of the US and considers population growth and water demand projections by State.

7.2.2. Arizona

The Arizona Department of Water Resources (ADWR) does not develop regular, ongoing state water plans because this is not their charge. Periodically, as directed by the legislature or the Governor, ADWR has undertaken statewide assessments and projections, with each being developed differently based on the direction given by the legislature. The supply and demand data are described on the website (Supply Demand Assessments). The most recent strategic vision report was published in 2014 (ADWR, 2014). The Water Resources Development Commission reports were published by ADWR (2023a, 2023b).

The ADWR's Supply and Demand Reports (SDRs) are derived from the 2022 restructuring of the Water Finance Authority and are intended to help support local planning for water augmentation and conservation. The SDRs are structured as water budgets, focusing on total inflows and outflows at the basin scale. To create the SDRs, the ADWR made reasonable efforts to obtain local or specific estimates, but in cases where water data were unavailable, staff applied literature values or other types of averages and assumptions to generate water use estimates.

In Arizona, the Assured Water Supply Program requires that water providers or developers demonstrate water supplies are legally, physically, and continuously available for a period of 100 years and that water use will be consistent with the management goal and plan of the Active Management Area (AMA) before they can plat and sell new homes. This effectively requires long-term conjunctive land and water use planning. Providers and developers apply for determinations of assured water supply from ADWR with data on current, committed, and projected water demands and available water supplies. Those demands and supplies, along with other information, are incorporated into ADWR's AMA models to evaluate groundwater availability over the 100-year period at the AMA level. The requirements do not consider GPCD, but providers and developers are certainly considering population, persons per household unit, and water demands, including the efficiency of use. ADWR staff review those data as they evaluate the applications.

a) Population

Arizona does not develop statewide population projections because their water management is based on Assured and Adequate Water Supplied for 100 years generated by developers as described in the previous section

b) Gallons per Capita per Day

The ADWR staff calculate GPCD to understand and communicate trends at the AMA/groundwater basin or statewide level over time. Within the AMAs, where regulation is the most stringent, ADWR has detailed data reported by agricultural, municipal, and industrial water

users. Outside of the AMAs, the data is more limited. Community water systems throughout the state are required to report water supplied, sources and volume withdrawn, and population served. Within the Irrigation Non-Expansion Areas (INAs), there are also reported agricultural withdrawals and use. Outside of that, ADWR fills in data gaps with data from the USGS Water Use Program data.

Within the AMAs, all users--municipal, agricultural, and industrial--must comply with the requirements of regulatory management plans (MPs), designed to reduce withdrawals of groundwater over time. Large providers that are regulated under the GPCD program must meet GPCD targets that reduce over time. Targets are specific to the provider. How the GPCD target is calculated is described in the management plans. Providers report water withdrawn, supplied, losses, exchanges, population, etc. annually. The ADWR staff reviews the data and calculates GPCD to evaluate compliance, see the Phoenix AMA 5th Management Plan section 5.3.2 for more information. Statewide, domestic well owners using ≤ 35 gpm or less annually are exempt from the requirements to report their groundwater withdrawals.

In summary, within the AMAs, Arizona relies primarily on reported data. Outside of the AMAs, where users are not universally required to report on their water use, Arizona relies heavily on estimates. Reporting requirements are described on the ADWR website ([link](#)). Arizona's Fifth Management Plan is also described online (<https://www.azwater.gov/5MP/plans-concepts>).

c) Projection Period

Arizona considers different planning periods for different purposes. In central and southern Arizona, water planning is governed through Active Management Areas under the 1980 Groundwater Management Act. Each AMA must prepare periodic management plans (statutorily intended to cover 10-year "management periods") and include strategies to meet goals such as balancing groundwater withdrawals and recharge. Historically, these have been structured around successive decadal management periods (e.g., 1980–1990, 1990–2000, up to 2020–2025).

Arizona also requires individual System Water Plans from community water providers, which typically include projections of water supply and demand over future periods (commonly 5, 10, and 20 years into the future in many guidance documents).

Arizona's planning also considers long term periods, including 100 yr Assured Supply requirements for subdivision under Active Management Area law.

d) Arizona State Plan Citation:

Arizona Department of Water Resources. (2014). *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability*. Arizona Department of Water Resources. Retrieved March 7, 2026. ([link](#))

e) References

Arizona Department of Water Resources. (2014). *Arizona's next century: A strategic vision for water supply sustainability*. Arizona Department of Water Resources. ([link](#))

Arizona Department of Water Resources. (2022). *Management plan: Fifth management period*. Arizona Department of Water Resources. ([link](#))

Arizona Department of Water Resources. (2024). *Arizona Department of Water Resources annual report* (73 pp.). Arizona Department of Water Resources. ([link](#))
Arizona Revised Statutes § 45-401 et seq. (2024). *Arizona Groundwater Management Act*. ([link](#))

7.2.3. Arkansas

The State Water Plan was first published in 1979, updated in 1990, with the most recent Water Plan published in 2014 with the water demand updated in 2024. The State Water Plan is developed by the Arkansas Natural Resource Commission. The Water Plan includes current and projected water demand relative to current and projected surface water and groundwater availability, assesses discrepancies between demand and supplies, and recommends policies.

a) Population

Three sets of population projections were used for the State of Arkansas with projections of future population by county:

1. Woods & Poole Economic, Inc. (W&P) – projected through 2040, extended to 2050, usually the highest of the three forecasts.
2. University of Arkansas Institute of Economic Advancement (AIEA) – projected through 2030, extended to 2050, usually the middle of the three forecasts.
3. Arkansas Natural Resource Commission Water Resources Development Division (ANRC) –projected through 2050, usually the lowest of the three forecasts.

Note that not all counties are consistently high, medium, and low for each data source, so some exceptions occur to these categories of high, medium, and low on a county-by-county basis. All three sets of projections indicate that some counties will experience negative population growth.

A comparison of county population projections for 2020 from the 2014 Arkansas Water Plan (AWP) to Census 2020 county populations, the 2020 Census population was less than the 2014 projections for 51 counties, and greater than the 2014 projections for 4 counties, with 2020 Census population for 20 counties within the range of 2014 projections.

b) Gallons per Capita per Day

In Arkansas planners calculate GPCD from metered deliveries divided by service-area population over the number of days; state documents and utility reports provide the basis, with conservation and reporting frameworks shaping interpretation.

Water use among publicly supplied municipals (includes all publicly supplied users except some large water-using industries) water users by county is projected into the future based upon the rate of growth of the county population.

In the latest Arkansas plan, base period water use for each county was obtained from either the Department of Health (DOH) Sanitary Survey or the Water Use Database (WUDBS). WUDBS data are reported for water users with the capability to withdraw 50,000 gpd of groundwater or 1 acre-foot per year (AFY) of surface water. The WUDBS data for 2008 to 2010 were averaged to provide an average base period water use. Where public-supplied municipal water withdrawals are identified for mining or industrial use, these water volumes are subtracted from the volume of municipal water use and then accounted for in their respective sector.

The reported municipal water volume is divided by the reported population served to derive a gallon per capita per day (GPCD) rate of use for each municipality. The DOH data consists of community non-transient water systems data and reports annual average water demand for the reporting year. The DOH data are updated on a 3-year rotating basis and therefore may reflect

water use of any single year between 2008 and 2012. The reported municipal water volume is divided by the reported population served to derive a GPCD rate of use for each municipality. The GPCD rates from the WUDBS and DOH data for municipalities in each county are weighted by the respective population served to derive a county average GPCD to represent the base period publicly supplied municipal water use for each county. The weighted average per capita use for each county includes some imbedded commercial and industrial water use, as well as distribution system losses. The county average GPCD is multiplied by the county population that is served by municipal systems to derive an estimate of the publicly supplied municipal water demand. The USGS 2010 reports the percent of each county population that is served by municipal water systems.

Future publicly supplied municipal water demands are calculated by multiplying the future county population of each scenario times the percent of county population served by public systems, times the adjusted GPCD rate of water use for the county.

A water efficiency adjustment to the base per capita water use is made over time to account for the phasing out and replacement of older toilets (passive water conservation based on the 1992 Energy Policy Act that changed flow standards for certain plumbing fixtures). Thus, there is a "passive conservation" scenario in conjunction with each of the three population scenarios. The effect of the passive conservation from plumbing codes is about a 6% reduction in municipal water use by 2050.

The projection period is 40 years; however, the update frequency is not specified. The existing law indicated that the demand and supply forecasts should be updated continuously. Agriculture and industry should be evaluated every five years and population-related inputs should be assessed every 10 years, following the census. In accordance with the "Arkansas Ground Water Protection and Management Act" (AGPMA or Act), the Commission generates an annual report on the status of the state's groundwater resources, with recommendations on critical regions.

c) Projection Period

The projection period is 40 years; however, the update frequency is not specified. The existing law indicated that the demand and supply forecasts should be updated continuously. Agriculture and industry should be evaluated every five years and population-related inputs should be assessed every 10 years, following the census. In accordance with the "Arkansas Ground Water Protection and Management Act" (AGPMA or Act), the Commission generates an annual report on the status of the state's groundwater resources, with recommendations on critical regions.

d) Arkansas State Plan Citation:

Arkansas Natural Resources Commission. (2014). *Arkansas water plan update*. Arkansas Natural Resources Commission. ([link](#))

7.2.4. California

California’s State Water Plan (the California Water Plan) is prepared by the California Department of Water Resources (DWR) and includes an advisory committee comprising agricultural and urban water suppliers, local government, environmental interests, and other parties. The DWR uses demographic projections, including population growth estimates — as key inputs to model future water demand under different future scenarios.

a) Population

In the California Water Plan Update of 2023, the gallons-per-capita-per-day (GPCD) data are used as a key input for estimating urban water demand, but they are not treated as a fixed statewide constant. Instead, GPCD is handled as a dynamic planning variable influenced by conservation policy, efficiency standards, and regional conditions.

DWR does not create its own detailed demographic forecast. Instead, for statewide and regional population growth inputs, it generally relies on established demographic projections prepared by the California Department of Finance (DOF) and other planning agencies. The DOF produces official state and county population projections based on U.S. Census counts and vital statistics (births, deaths, migration) that serve as the baseline demographic foundation for state planning. DWR incorporates these DOF projections (and in some cases projections from councils of governments or metropolitan planning organizations [MPOs]) into its water planning analyses rather than creating an independent forecast. Population and economic conditions are projected using DOF data and, where relevant, projections from regional planning bodies. These become the core assumptions for future water demand scenarios.

These projections are used alongside other inputs, such as climate scenarios, land use, and urban water efficiency trends, to model how water supply and demand might evolve through 2070 and beyond.

Rather than a single “forecast,” the Water Plan uses multiple future scenarios to explore plausible variations in key drivers — including population. Scenarios often vary the assumed rates of population growth, land use changes, climate change impacts, and policy trends to test how sensitive water demand and system performance are to those assumptions. This allows planners to examine a range of possible futures (e.g., higher vs. lower population growth) and evaluate how different water management strategies perform under each.

Population projections feed into water demand and supply models used in the Water Plan’s analyses, including integrated simulations of supply reliability and water budgets (e.g., tools like Water Evaluation and Planning [WEAP] in the planning process). Population figures help determine future urban, agricultural, and environmental water needs under each scenario.

At higher resolution (e.g., urban or water service area planning), water suppliers and councils of governments may refine DOF projections using local data (e.g., service area boundaries, connections) for their specific populations. Those refined local projections can inform statewide planning inputs where available.

The Water Plan relies primarily on:

- Urban water supplier reporting (Urban Water Management Plans, UWMPs)
- Data submitted to the State Water Resources Control Board
- Historical demand and population data compiled by DWR
- These provide historical per-capita use trends at regional and statewide scales.
- Future GPCD is not assumed to remain constant. Instead, it reflects: Long-term conservation trends
- Implementation of SB 606 / AB 1668 “Making Conservation a Way of Life”
 - Indoor/outdoor efficiency standards
 - Drought response behavior
 - Climate impacts (e.g., hotter summers increasing outdoor use)
 - Recent state legislation shifts planning away from historical GPCD toward water use objectives:
 - Indoor residential standard (e.g., 55 → 52.5 → 50 GPCD over time)
 - Outdoor irrigation efficiency targets
 - Commercial/industrial/institutional (CII) performance standards
 - System water loss standards

Thus, future per-capita use in the Water Plan reflects compliance trajectories with these mandates rather than simply extrapolating historical averages.

As mentioned above, the DWR does not create its own detailed demographic forecast. Instead, for statewide and regional population growth inputs, it generally relies on established demographic projections prepared by the California Department of Finance (DOF) and other planning agencies. The DOF produces official state and county population projections based on U.S. Census counts and vital statistics (births, deaths, migration) that serve as the baseline demographic foundation for state planning. DWR incorporates these DOF projections (and in some cases projections from councils of governments or metropolitan planning organizations [MPOs]) into its water planning analyses, rather than creating an independent forecast. Population and economic conditions are projected using DOF data and, where relevant, projections from regional planning bodies. These become the core assumptions for future water demand scenarios.

These projections are used alongside other inputs, such as climate scenarios, land use, and urban water efficiency trends, to model how water supply and demand might evolve through 2070 and beyond. Rather than a single “forecast,” the Water Plan uses multiple future scenarios to explore plausible variations in key drivers — including population. Scenarios often vary the assumed rates of population growth, land use changes, climate change impacts, and policy trends to test how sensitive water demand and system performance are to those assumptions. This allows planners to examine a range of possible futures (e.g., higher vs. lower population growth) and evaluate how different water management strategies perform under each.

Population projections feed into water demand and supply models used in the Water Plan’s analyses, including integrated simulations of supply reliability and water budgets (e.g., tools like

Water Evaluation and Planning [WEAP] in the planning process). Population figures help determine future urban, agricultural, and environmental water needs under each scenario.

At higher resolution (e.g., urban or water service area planning), water suppliers and councils of governments may refine DOF projections using local data (e.g., service area boundaries, connections) for their specific populations. Those refined local projections can inform statewide planning inputs where available.

The primary emphasis in Update 2023's future scenarios is on climate uncertainty and system stress-testing, not on a fixed set of alternate population growth paths defined as percentages of a baseline (e.g., 80 % or 120 %). The analysis uses a decision-scaling approach that tests water system performance over a broad range of temperature and precipitation changes, exploring many combinations of climate outcomes (e.g., temperatures rising 0 °C to +5 °C and precipitation from –30 % to +30 %). Update 2023 moves toward a risk-based analysis where future conditions are stressed across wide ranges of climate change and associated impacts, with population projections drawn from official forecasts rather than defined as alternative percentage-based paths.

b) Gallons per Capita per Day

GPCD varies substantially across hydrologic regions because of climate (coastal vs. inland vs. desert), landscape irrigation demands, income and housing type, recycled water penetration, and density and lot size

The Water Plan evaluates these differences at the hydrologic region level, not as a single statewide number.

Under hotter, drier futures, outdoor irrigation demand may increase; however, efficiency standards offset some of that increase. Net future GPCD reflects both climate pressure and conservation policy. Therefore, GPCD becomes a scenario-dependent planning variable, not just a trend line.

c) Projection Period

The California Water Plan is updated every five years. The Plan includes near-term planning for ~20 years and long-term strategic planning over 50 years (up to 2070 to evaluate how water systems perform under population growth, land use change and climate change.

d) California State Plan Citation:

California Department of Water Resources. (2023). California Water Plan Update 2023. California Department of Water Resources. Retrieved March 7, 2026. ([link](#))

e) References

California Department of Water Resources. (2022). Annual water supply and demand assessment summary report (39 pp.). California Department of Water Resources. ([link](#))
California Department of Water Resources. (2023). California water plan update 2023: A roadmap for resilience. California Department of Water Resources. ([link](#))
California Water Code § 10720 et seq. (2014). Sustainable Groundwater Management Act.

- Cooley, H., Thebo, A., Abraham, S., Shimabuku, M., Gleick, P. H., & Diringer, S. (2022). The untapped potential of California's urban water supply: Water efficiency, water reuse, and stormwater capture. Pacific Institute. ([link](#))
- Gross, M.-P., Ajami, N. K., & Cominola, A. (2023). Fast in the pandemic, durable after droughts, unequal during economic downturns: A 20-year multi-dimensional retrospective analysis of water demand change in Southern California. *Environmental Research Letters*, 18(9), 094067. ([link](#))
- Rayej, M., Juricich, R., Groves, D., & Yates, D. (2011). Scenarios of future California water demand through 2050: Growth and climate change. In *Proceedings of the World Environmental and Water Resources Congress 2011* (pp. 4423–4432). American Society of Civil Engineers. ([link](#))
- Rayej, M., Kibrya, S., Shipman, P., & Correa, M. (2019). Future scenarios of water supply and demand in California's Central Valley through 2100: Impacts of climate change and urban growth (123 pp.). California Department of Water Resources. ([link](#))

7.2.5. Colorado

The Colorado Water Plan is developed by the Colorado Water Conservation Board within the Colorado Department of Natural Resources. The Water Plan was first directed by the Governor in 2013 and released following extensive stakeholder engagement, then finalized in 2015. The plan was updated and adopted again in January 2023 to reflect new conditions, priorities, and strategies. The plan outlines goals, strategies, and actions to help Colorado respond to Population growth and drought and climate change.

a) Population

Colorado's State Water Plan (the Colorado Water Plan) uses specific population data and projections as a key driver for estimating future water demand. Most of this demographic data are derived from the Colorado State Demography Office (SDO) and are then used in water demand modeling and scenario planning. The baseline and projected population figures used in the Colorado Water Plan are primarily sourced from the State Demography Office (SDO), which produces official population forecasts for the state and counties based on census data and economic/demographic trends. These forecasts include a "base" or medium projection for future years (e.g., up to 2050) that serve as the central case for planning. Water planning requires future, geographically detailed, and scenario-based projections.

In addition to the base SDO projections, the Technical Update to the Water Plan (often prepared by consultants like BBC Research & Consulting for the Colorado Water Conservation Board (CWCB)) develops alternative high and low growth scenarios and alternative distribution patterns around the SDO forecasts. These are used to model different possible futures and their impacts on water demand (e.g., "Business as Usual", "Weak Economy", "Hot Growth", etc.). These scenario projections are rooted in the SDO's demographic forecasts but are adjusted statistically or geographically to reflect different growth patterns. Colorado also considers basin-disaggregated population projections.

Municipal & Industrial Demand Forecasts: Population projections from the SDO directly influence estimates of future municipal and industrial water demand. Baseline population counts and 2050 projections inform the water volume needed under each planning scenario.

Scenario Planning: Five distinct growth scenarios are constructed using SDO projections as a foundation. These alter the demographic assumptions to test how different population growth patterns affect water demands and potential supply gaps across Colorado's river basins and counties.

The Colorado State Demography Office (SDO) data are built from U.S. Census data and then extended into the future. The US Census does not produce detailed long-term county-level projections tailored for Colorado's planning needs and is not the State of Colorado's "official" forecasting authority. Water plans require projections out to ~2050 or beyond — not just current counts. SDO starts with Census data but refines it using state-specific demographic modeling

that considers housing and economic trends and Colorado-specific policy and development patterns

b) Gallons per Capita per Day

In Colorado’s State Water Plan, GPCD is a key metric used to understand and project municipal water demand. The state water plan relies on observed water use data from utilities and statewide demand modeling to estimate current per-person use and then projects how that will change under different future scenarios. According to the 2019 Technical Update to the Colorado Water Plan, Colorado’s statewide average per-capita use was about 164 GPCD (gallons per person per day), down from about 172 GPCD in earlier planning (e.g., the 2010 Statewide Water Supply Initiative). These GPCD figures represent actual water deliveries per person per day statewide, including indoor and outdoor residential and other municipal uses.

Colorado’s approach to estimating GPCD combines several data inputs and methods, including utility-reported water use Data. Municipal water providers report water deliveries (total gallons delivered annually or monthly) to the Colorado Water Conservation Board (CWCB) through reporting systems like the Water Efficiency Data Portal. These utility records form the basis for calculating total system usage per person. The utility usage is divided by population figures from Colorado’s official forecasts to calculate per-person use (GPCD). The plan’s Technical Update includes projections where GPCD changes over time under different conservation and growth scenarios. For example, statewide GPCD is forecast to decrease to a lower value by 2050 in active conservation scenarios. GPCD in Colorado includes all municipal use (indoor, outdoor landscape irrigation, system losses, etc.). Individual utilities may have much lower or higher GPCD values — for example, larger cities with conservation programs (like Aurora with reported ~115 GPCD) differ from statewide averages.

Colorado’s State Water Plan uses observed municipal water delivery data reported by water utilities, divided by state population projections, to calculate statewide GPCD for current and future demand. The plan then applies these estimates in its demand forecasting and scenario modeling.

c) Projection Period

The Colorado Water Plan is updated about every 10 years with implementation tracking annually. The long-term planning horizon is 2050. Scenario planning is used to evaluate multiple possible futures (e.g., population growth, climate change) affecting water supply and demand by 2050.

d) Colorado State Plan Citation:

Colorado Water Conservation Board. (2023). *Colorado Water Plan*. Colorado Water Conservation Board.

<https://cwcb.colorado.gov/colorado-water-plan> ([link](#))

e) References

- Blount, K., Abdi, R., Panos, C. L., Ajami, N. K., & Hogue, T. S. (2021). Building to conserve: Quantifying the outdoor water savings of residential redevelopment in Denver, Colorado. *Landscape and Urban Planning*, 214, 104178. ([link](#))
- Colorado Revised Statutes § 31-23-206 (2020). *Local government master plans; water conservation policies*. ([link](#))
- Colorado Water Conservation Board. (2019). *Analysis and technical update to the Colorado Water Plan* (254 pp.). Colorado Department of Natural Resources. ([link](#))
- Colorado Water Conservation Board. (2023). *Colorado Water Plan*. Colorado Water Conservation Board. ([link](#))
- Jeavons, D., & Verdone, M. (2019). *Updated population projections for water plan scenarios* (22 pp.). Report prepared for the Colorado Water Conservation Board. ([link](#))
- Richter, B. D. (2023). Decoupling urban water use from population growth in the Colorado River Basin. *Journal of Water Resources Planning and Management*, 149(2), 04022082. ([link](#))
- Water Education Colorado. (n.d.). Water policy and planning resources. Water Education Colorado. ([link](#))

7.2.6. Idaho

The Idaho State Water Plan itself (2012 and its updates) does not include a detailed statewide water demand forecast based on long-range population projections. The statewide plan focuses on overarching policy, and much of the detailed assessment work (including population/demand modeling) is done in basin-level plans or related studies prepared separately. Some basin plans (e.g., older Snake River basin plans) estimate domestic water demand from population in the basin multiplied by average per-day use rates (using regional demographic and water use data). These reports generally cite external demographic forecasts or simple growth trends as the basis.

a) Population

State population projections (from sources such as the Idaho Department of Labor or other state/county projections) show ongoing growth and are used in separate infrastructure and system planning reports. Many local and regional water plans (cities, counties, utilities, basin planning efforts) incorporate their own population forecasts based on US Census trends and regional forecasts.

b) Gallons per Capita per Day

Idaho does not publish a single statewide GPCD assumption in the State Water Plan document. Basin plans and local water supply planning often use per-capita or similar per-person use assumptions to estimate domestic and municipal demand as population changes. These per-capita values are typically derived from USGS water-use reports, local utility reported deliveries/usage and service area populations, and/or historical trend analysis for specific regions or water systems. For example, an aquifer water demand study for the Rathdrum Prairie

region used population-weighted per-capita water use average of about ~270 GPCD for municipal systems in that area.

c) Projection Period

Projection periods and update cycles differ by program; see state plan citations for current cycles.

d) Idaho State Plan Citation:

Idaho Water Resource Board. (2012). *State water plan* (planning portal). Idaho Department of Water Resources. ([link](#))

e) References

Idaho Code § 42-233a (2024). *Idaho Ground Water Management Act*. ([link](#))

SPF Water Engineering, LLC. (2016). *Treasure Valley DCMI water-demand projections (2015–2065)*. Report prepared for the Idaho Water Resource Board and Idaho Department of Water Resources. ([link](#))

7.2.7. Iowa

Iowa does publish “Iowa’s Water Plan,” but it is primarily a water quality / nonpoint source strategy (not a statewide water-supply/demand plan built around population and GPCD forecasts).

a) Population

The Iowa DNR does not list population projections as a stand-alone section, but the underlying data and modeling for water resources often include future population estimates.

b) Gallons per Capita per Day

GPCD values are most often found in local facility plans and engineering/design standards and in regulatory contexts (rather than a single statewide “plan GPCD”). For example, Iowa regulatory analysis includes per-capita limits for certain authorizations.

c) Projection Period

Projection periods for water planning are not specific. However, guidance for projection planning can be found in the plan. ([link](#))

d) Iowa State Plan Citation:

Iowa Department of Natural Resources. (n.d.). *Iowa’s Water Plan*. Iowa Department of Natural Resources. ([link](#))

7.2.8. Kansas

The Kansas State Water Plan does not have a single official statewide population projection series. The Water Plan primarily focuses on water resource conditions and resource management issues across the state and river basins rather than modeling detailed population growth and future demand drivers.

a) Population

Historically, Kansas researchers have explored methods of linking population estimates with water demand trends — for example, estimating future population based on historical water use and Census counts — but this is not incorporated into the official Water Plan process.

b) Gallons per Capita per Day

Municipal water use reporting (required annually by the Kansas Department of Agriculture, Division of Water Resources) collects population served data from utilities as part of water use data submissions, which are then used to calculate per-capita use metrics. While Kansas planners use U.S. Census Bureau population estimates and counts as background context for understanding demographic trends in the state, there's no clear statement in the publicly accessible Water Plan summary that Census data are used as the official basis for future population projections within the plan itself. Instead, population figures are derived primarily from sources such as annual utility reporting forms (which supply the “population served” for municipal water systems) and are used to calculate usage metrics like GPCD.

Kansas does not publish a single statewide GPCD assumption in the Water Plan's main text, but per-capita water use statistics are regularly compiled using municipal water system reporting. GPCD figures for Kansas are derived from annual municipal water use reports collected by the Division of Water Resources. These reports include total water withdrawn and sold by public suppliers and the “population served” by each supplier. The reported water use and population numbers are then used to calculate per-capita water use (GPCD) for each municipality or region. While the State Water Plan itself does not appear to mandate a statewide GPCD planning assumption, Kansas publishes separate municipal water use reports and conservation plan guidelines that use GPCD metrics for evaluating conservation goals and water use efficiency. For example, municipal water conservation plan guidelines instruct utilities to set conservation targets based on regional GPCD figures.

c) Projection Period

The state water plan is updated every five years. Projection periods are not specific but guidance is provided. ([link](#))

d) Kansas State Plan Citation:

Kansas Water Office. (2022). *Kansas Water Plan*. Kansas Water Office.
<https://www.kwo.ks.gov/water-plan/water-plan> ([link](#))

e) References

Kansas Water Office. (2022). 2022 Kansas Water Plan (261 pp.). Kansas Water Office. ([link](#))

Kansas Water Office (2015). A long-term vision for the future of water supply in Kansas (Final report, 133 pp.). Kansas Water Office. ([link](#))

7.2.9. Louisiana

Louisiana does not have a comprehensive statewide water management plan. However, Louisiana does produce large-scale water-related “plans” in specific domains—most notably the Coastal Master Plan, which includes explicit population projection work for coastal planning.

a) Population

The state guidance document for water planning advises the use of Census data for population projections in addition to local information sources related to population change. Focus is put on water quality and watershed health.

b) Gallons per Capita per Day

Per-capita water-use metrics are commonly sourced from USGS water-use compilations and Louisiana reporting that includes per-capita withdrawal rates (often reported at parish scale).

c) Projection Period

Louisiana has start its “New Vision 2.0” approach where long term planning, and watershed prioritization and restoration is the most current and comprehensive Louisiana has ever had on a planning horizon (2023-2032 planning horizon).

d) Louisiana State Plan Citation:

Coastal Protection and Restoration Authority of Louisiana. (2023). *Louisiana coastal master plan*. Coastal Protection and Restoration Authority of Louisiana. Retrieved March 7, 2026, from <https://coastal.la.gov/our-work/coastal-master-plan/> ([link](#))

7.2.10. Minnesota

Minnesota is legislatively required to have a State Water Plan coordinated by the Environmental Quality Board every 10 years (e.g., the 2020 State Water Plan: Water and Climate).

Population projections:

a) Population

The Environmental Quality Board plan explicitly discusses future population growth expectations; population inputs are typically grounded in official demographic projections (used to frame statewide demand trends). The EQB also maintains statewide water-use information and categories.

b) Gallons per Capita per Day

Minnesota tracks per-capita water-use performance through supplier reporting and statewide assessments (e.g., statewide reporting on residential GPCD performance in water availability/assessment reporting). Minnesota Dept. of Natural Resources also maintains statewide water-use information and categories.

c) Projection Period

Projection periods are discussed in 10-year cycles for lakes, streams, and groundwater. However, metro planning areas may have shorter and/or multiple projection years.

d) Minnesota State Plan Citation:

Minnesota Environmental Quality Board. (2020). *Minnesota State Water Plan*. Minnesota Environmental Quality Board.

[\(link\)](#)

7.2.11. Missouri

Missouri publishes a Missouri Water Resources Plan (e.g., the 2020 plan), intended to identify future shortfalls and options.

a) Population

Census population projections play a key role in 2020 update. These projections are then compared to watershed and water source changes that may occur as a result of migration.

b) Gallons per Capita per Day

The plan's demand forecasting explicitly combines population projections with per-capita use. Missouri planning materials indicate per-capita assumptions and demand inputs derived from sources such as the Major Water Users Database and utility survey information (used to estimate municipal and related sector demands).

c) Projection Period

Projection periods extend to 2060 using Census data projections.

d) Missouri State Plan Citation:

Missouri Department of Natural Resources. (2020). Missouri water resources plan (2020 update). Missouri Department of Natural Resources. ([link](#))

7.2.12. Montana

Montana’s planning approach is more qualitative and policy-oriented than the detailed quantitative statewide water demand forecasts used in other states. The Plan acknowledges that population may grow or shrink, and that this will affect future water demand, but it does not itself maintain or publish a single statewide demographic forecast for water demand. Instead, population is treated as one of several variables that influence water demand, together with climate, agricultural practices, and industrial activity.

The 2015 State Water Plan is the first comprehensive statewide update in many decades. The Plan was developed by the Department of Natural Resources and Conservation.

a) Population

The State Water Plan does not include a designated “official” population projection model like some other states use (e.g., a state demographer projection). Instead, Montana planning documents often rely on general population estimates and trends as context in water availability discussions; specific demographic forecasts are more likely developed in local, regional, or basin planning efforts rather than centrally in the statewide plan. Planners and utilities typically rely on the U.S. Census Bureau estimates for historic population data, and local/county planning projections when forecasting water system needs. Water demand assessments related to the Plan are most often sourced indirectly from available demographic data when needed, rather than based on long-term forecast within the Plan itself.

b) Gallons per Capita per Day

The Montana State Water Plan itself does not publish a single statewide GPCD assumption used for future forecasts — because its primary focus is on resource availability and policy, not standardized future municipal demand numbers. Montana partners with federal and state agencies (notably the U.S. Geological Survey (USGS)) to compile water-use statistics (including public supply and domestic use). These can be used to derive per-capita water use estimates for regions and specific systems. USGS estimates show the statewide distribution of water use by category — irrigation, public supply, thermoelectricity, etc. — at county levels, which can be used to infer per-capita use when paired with Census population data.

A technical guide associated with Montana water planning (designed for municipalities) illustrates how GPCD is calculated and projected in practice based on population and historical water use used to compute per-capita use for a community. Per-capita water use is calculated in local system planning from utility data and USGS water use compilations and referenced in Montana water planning materials.

c) Projection Period

The 2015 Montana Water Plan indicates that it was designed to guide water management for the next 20 years to 2035. The 2015 Plan indicates that it will be updated periodically.

d) Montana State Plan Citation:

Montana Department of Natural Resources and Conservation. (2015). Montana state water plan. Montana Department of Natural Resources and Conservation. ([link](#))

7.2.13. Nebraska

Nebraska does not develop a single statewide “state water plan” document; however, statewide planning is implemented through the Nebraska Department of Natural Resources and the Natural Resources Districts (NRDs) which develop integrated management plans and basin-wide plans focused on conjunctive (connected) groundwater–surface water management.

a) Population

Population projections are generally derived from local/Natural Resource District/project-specific data, typically using Census-based estimates and recognized local/state sources in facility and regional planning contexts.

b) Gallons per Capita per Day

Nebraska does not publish one statewide GPCD; however, per-capita use is generally used in utility and project planning (engineering demand projections), not as a single statewide standard within the Nebraska Dept. of Natural Resources and Natural Resource Districts integrated planning framework.

c) Projection Period

Projection periods and update cycles differ by program; see state plan citations for current cycles.

d) Nebraska State Plan Citation:

To repeat from above, Nebraska does not develop a single statewide “state water plan” document; however, statewide planning is implemented through the Nebraska Department of Natural Resources and the Natural Resources Districts (NRDs) which develop integrated management plans and basin-wide plans focused on conjunctive (connected) groundwater–surface water management. ([link](#))

7.2.14.Nevada

a) Population

The plan (and supporting technical analysis) incorporates population forecasts from the Nevada State Demographer as one of its core population datasets. These forecasts provide statewide and county-level projections based on demographic trends. NDWR also develops its own modified population forecasts for key planning areas (especially rapidly growing counties like Clark and Washoe), which may differ slightly from the State Demographer's estimates. The State Water Plan documentation compares these forecasts. Population forecasts are used to estimate future water demands across sectors, especially for domestic and municipal supply planning, by linking projected persons to expected water use.

b) Gallons per Capita per Day

Nevada's State Water Plan includes water use intensity tracked from regional data and related conservation plans. In Southern Nevada, the major water provider — the Southern Nevada Water Authority (SNWA), tracks and publishes GPCD goals and trends. SNWA has set a long-term conservation target of 86 GPCD by 2035 as part of its conservation planning and water-resource strategy. Historical GPCD for the Las Vegas region has been estimated in other technical reports (e.g., declines from roughly 189 GPCD in 1998 to around ~113 GPCD by 2018), reflecting conservation progress. National water use compilations such as the U.S. Geological Survey (USGS) water-use dataset include per-capita public supply use estimates for Nevada (as part of broader water use inventories). These estimates are often referenced in technical water planning or demand analyses even if not explicitly listed as the plan's assumption.

c) Projection Period

Projection periods extend ~40 years and include potential utility service expansion and population estimates.

d) Nevada State Plan Citation:

Nevada Division of Water Resources. (1999). Nevada State Water Plan (Part 1: Background and Resource Assessment). Nevada Division of Water Resources. Retrieved March 7, 2026. ([link](#))

e) References

Nevada Division of Water Resources. (1999). Nevada state water plan, Part 1: Background and resource assessment (180 pp.). Nevada Department of Conservation and Natural Resources. ([link](#))

Nevada Division of Water Resources. (n.d.). State water plan (update in progress). Nevada Department of Conservation and Natural Resources. ([link](#))

Nevada Revised Statutes § 278.0228 (2019). Local government water resource plans. ([link](#))

7.2.15. New Mexico

The 2018 Parts II Technical Report includes demographic information such as population trends and forecasts as part of the water demand analysis. This planning report used Census data and estimates to assess past growth and to project future populations at regional and statewide scales for planning.

a) Population

Specifically, historical Census data (e.g., 2000, 2010, and 2013 estimates) were reviewed to understand where and how the population had changed, then used to develop high and low growth forecasts for future years (e.g., projections to ~2060). The plan relies on regional planning and technical analyses rather than a single statewide forecast from a dedicated demographer.

b) Gallons per Capita per Day

The New Mexico Office of the State Engineer (NMOSE) has developed a GPCD calculator tool to help quantify water use on a per-person basis for municipal systems. This tool is intended for use by public water systems and water planners to estimate per-capita use in different categories, based on metered water deliveries and local population figures. The GPCD calculator has been used in water conservation planning and reporting, and cities like Las Cruces and Rio Rancho have applied it to track and report their system's per-capita water use.

Planning documents and ongoing reporting programs show that New Mexico's water agencies track GPCD using the NMOSE methodology for municipal water systems. The State Water Plan's technical analysis relies on water use and demand data (including municipal categories), which can be informed by these GPCD assessments and related water use reports (e.g., water use by categories reports).

c) Projection Period

Projection periods extend up to 50 years and can vary depending on purpose. The Bureau of Business & Economic Research (BBER) produces detailed population estimates from demographer mentioned above.

d) New Mexico State Plan Citation:

New Mexico Interstate Stream Commission. (2018). *New Mexico state water plan*. New Mexico Interstate Stream Commission. ([link](#))

e) References:

New Mexico Interstate Stream Commission. (2018). *New Mexico State Water Plan*. New Mexico Interstate Stream Commission. ([link](#))

New Mexico Statutes Annotated § 72-14-3.1 (2024). *New Mexico Water-use Data and Planning*. ([link](#))

Office of the State Engineer & Interstate Stream Commission. (2023). *New Mexico State Water Plan: Five-year review*. State of New Mexico. ([link](#))

7.2.16. North Dakota

North Dakota's statewide planning is the State Water Commission's Water Development Plan, which provides a framework for managing, protecting, and developing water resources and prioritizing projects.

a) Population

Population projections are derived from census-based estimates and projections used within major regional studies and water supplier planning (often at county/area scale rather than one statewide municipal demand model).

b) Gallons per Capita per Day

GPCD is computed from metered deliveries divided by service-area population and days; state documents and utility reports provide the basis, with conservation and reporting frameworks shaping interpretation.

North Dakota commonly uses per-capita concepts in water-supply planning and program criteria (e.g., program documents and planning studies reference/benchmark per-capita availability/needs).

c) Projection Period

Projection periods follow a two-year biennium cycle where multi-biennium funding commitments are reviewed.

d) North Dakota State Plan Citation:

North Dakota State Water Commission. (2021). *North Dakota Water Development Plan* (87 pp.). North Dakota State Water Commission. ([link](#))

7.2.17. Oklahoma

Oklahoma's statewide water plan is called the Oklahoma Comprehensive Water Plan (OCWP) and is used to guide water planning across Oklahoma's river basins and use sectors. The OCWP was initially developed decades ago (with historic updates such as 2012) and is being updated on a regular cycle tied to the U.S. Census and planning needs, with a 2025/2075 planning horizon currently in progress. It provides a 50-year assessment of supply and demand across sectors such as public supply, irrigation, industrial, energy, and self-supplied domestic use.

a) Population

For demand forecasting, especially public supply and self-supplied domestic demand, the OCWP uses county-level population projections. The draft 2025 OCWP Water Demand Forecast document projects population for each county through 2075. These projections are based on population estimates for each county and extend them into the future to estimate future demand. Public Supply Water Demand is forecast by applying population projections to current municipal demand. It assumes future public supply demand increases approximately in proportion to population growth (i.e., a constant per-person use assumption absent explicit conservation changes). The plan uses 2020 Census spatial population data in geographic analyses to allocate projected water demand by basin and census tract. Population projections (to 2075) drive the public supply demand forecast by assuming demand increases in step with population growth.

b) Gallons per Capita per Day

For public water suppliers, the OCWP demand forecast assumes water demand grows proportionally to population, which implicitly requires a per-capita use assumption. Although the public supply section does not explicitly list an overall statewide GPCD number in the demand forecast summary, it uses population projections combined with recent water use totals to derive future public supply demand.

The plan explicitly uses GPCD estimates for "Self-Supplied Domestic" households (i.e., households not connected to public systems) to project that sector's demand. These GPCD values are drawn from United States Geological Survey (USGS) water use estimates (2015 data) and vary by county. Examples from the 2025 draft forecast show county regional GPCD values ranging from about ~76 to ~157 GPCD, with a statewide average of 88 GPCD used for self-supplied domestic users.

c) Projection Period

Projection periods were not specific. Their plan targets management of industry and watershed health and water use ([link](#)).

d) Oklahoma State Plan Citation:

Oklahoma Water Resources Board. (2012). *2012 Oklahoma comprehensive water plan: Executive report* (160 pp.). Oklahoma Water Resources Board. ([link](#))

e) References

Oklahoma Water Advisory Council. (2015). *Water for 2060*. Oklahoma Water Advisory Council. ([link](#))

7.2.18. Oregon

Population projections and municipal demand forecasts are generally handled at regional or basin scales, not through one statewide demand modeling exercise. Oregon's IWRS does not rely on a single long-term population forecast to drive a supply-demand gap analysis. Instead, the plan is based on basin-level water planning, climate change impacts, water supply resilience, ecosystem and instream flow protection, infrastructure investment needs, and data gaps and monitoring.

a) Population

Oregon uses Census population data along with other infrastructure and consumption-based scenarios to support state regional water planning. Their forward-looking framework is built with the intention to look backwards, and frequently compare projections in their forward-looking approach.

b) Gallons per Capita per Day

GPCD is usually drawn from utility-reported production/use and served population within basin and municipal planning efforts (not one single statewide GPCD).

c) Projection Period

Projection periods include five-year cycles as well as 20-30 year outlooks.

d) Oregon State Plan Citation:

Oregon Water Resources Department. (2025). *Integrated water resources strategy*. Oregon Water Resources Department. ([link](#))

e) References

Oregon Revised Statutes § 537.110 et seq. (2024). *Oregon Water Rights Act*. ([link](#))

Oregon Water Resources Department. (2017). *Integrated water resources strategy*. Oregon Water Resources Department. ([link](#))

7.2.19. South Dakota

a) Population

Population data are typically project-/utility-specific, derived from local planning and service-area projections used to justify facilities. Population projection and usage details will be elaborated in the next revision based on utility or basin plans. South Dakota

b) Gallons per Capita per Day

Data on GPCD are derived from facility/project planning (design demand, service population, etc.) rather than a single statewide GPCD value in the State Water Plan.

c) Projection Period

Projection periods extend to 10 years and short-term planning coincides with legislative biennium every two years.

d) South Dakota State Plan Citation:

South Dakota Department of Agriculture and Natural Resources. (2024). *South Dakota State Water Plan*. South Dakota Department of Agriculture and Natural Resources. ([link](#))

7.2.20. Utah

a) Population

Utah's Division of Water Resources uses population projections from the University of Utah's Kem C. Gardner Policy Institute to estimate future population growth through ~ 2070 at the state and county level. These projections form the basis for water demand forecasting. Utah's Population Committee releases official state and county population estimates (e.g., 2024 estimates) based on recent Census data and demographic trends; these are often used as a current baseline in planning.

b) Gallons per Capita per Day

GPCD data are integrated into the state water plan through reporting programs that feed into the plan's data system. The UDWR's municipal/industrial reporting program includes all potable and non-potable water delivered to customers in a service area — residential, commercial, institutional, and industrial — which makes Utah's GPCD figures comparatively high because they capture more types of use than some other states. Population used in GPCD calculations is based on U.S. Census Bureau-estimated permanent resident population within each water provider's service area.

Utah tracks per-capita water uses statewide and regionally to set regional conservation goals (e.g., targets for 2030), monitor trends over time and assess how conservation affects demand, and support the water demand model through actual historic usage data tied to population. The 2021 plan uses observed water use trends and measured GPCD inputs rather than a single assumed per-capita value for future forecasting.

Therefore, Utah combines population forecasts from the Kem C. Gardner Policy Institute (distributed into county/area projections) with historical municipal & industrial water delivery data collected by UDWR to derive GPCD from these data to model water demand trends, evaluate conservation progress, and support planning decisions.

c) Projection Period

Projection periods use 30-year projections and updates occur no less than every 10 years by law.

d) Utah State Plan Citation:

Utah Division of Water Resources. (2017). *Utah State Water Plan* (136 pp.). Utah Division of Water Resources. ([link](#))

e) References:

Utah Code § 73-10-1 et seq. (2024). Utah water planning and development. ([link](#))

Utah Division of Water Resources. (2017). Utah state water plan (136 pp.). Utah Division of Water Resources. ([link](#))

Utah Governor's Office of Planning and Budget. (2022). Utah's coordinated action plan for water. State of Utah. ([link](#))

Van Ness Feldman LLP. (n.d.). Utah water planning and policy resources. Van Ness Feldman LLP.
([link](#))

7.2.21. Washington

a) Population

The Washington guidebook to water planning suggests the use of Census data. [331-068 Water System Planning Guidebook](#)

b) Gallons per Capita per Day

GPCD is computed from metered deliveries divided by service-area population and days; state documents and utility reports provide the basis, with conservation and reporting frameworks shaping interpretation.

c) Projection Period

Projection periods and update cycles differ by program; see state plan citations for current cycles.

Washington State Plan Citation:

Washington State Department of Health & Office of Financial Management. (n.d.). *Water system planning and population forecast framework*. State of Washington. ([link](#))

7.2.22. Wyoming

a) Population

Wyoming has a formal Wyoming State Water Plan, organized largely through basin plans and statewide syntheses/updates. Basin plans include explicit population projection memoranda/tables that are based on different scenarios.

WH Engineering Consulting, C. P. Assoc., I. Greenwood Mapping, and S. W. W. R. Corporation (2007), Wyoming Framework Water Plan, Vol. 1, Rep., 314 pp, Report prepared for the Wyoming Water Development Commission.

b) Gallons per Capita per Day

Basin technical memoranda also project domestic water use (rural/municipal) using per-capita assumptions and related methods that vary by basin.

c) Projection Period

Projection periods are not specified. Planning prepared at basin extents.

d) Wyoming State Plan Citation:

Wyoming Water Development Commission. (2007). *Wyoming Framework Water Plan*. Wyoming Water Development Commission. ([link](#))

e) References

Wyoming Statutes Annotated § 41-2-107 (2024). *Wyoming water development program*. ([link](#))

Wyoming Water Development Commission. (2007). *Wyoming framework water plan*. Wyoming Water Development Commission. ([link](#))

Wyoming Water Development Office. (n.d.). Wyoming state water plan (planning and data portals). Wyoming Water Development Office. ([link](#))

WH Engineering Consulting, Clough & Associates, Greenwood Mapping, & SWWR Corporation. (2007). *Wyoming framework water plan, Volume 1* (314 pp.). Report prepared for the Wyoming Water Development Commission. ([link](#))

7.2.23. Glossary of Acronyms

Acronym	Context	Example Source
ADWR	Arizona	ADWR (2014), Arizona's Next Century: A Strategic Vision for Water Supply Sustainability, Arizona Dept. of Water Resources, variably paginated.
AWSDA	Colorado	Colorado Dept. of Water Resources (2022), 2022 Annual Water Supply and Demand Assessment Summary Report, Report submitted to the State Water Resources Control Board, 39 p, (link). https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency/Annual-Water-Supply-and-Demand-Assessment/FINAL-DWR-2022-AWSDA-Report-to-SWB_11-22-22.pdf .
AWWA	various	Richter, B. D., et al. (2018), Assessing the Sustainability of Urban Water Supply Systems, Journal AWWA, 110(2), 40-47.
CWCB	Colorado	CWCB (2019), Analysis and Technical Update to the Colorado Water Plan, Rep., 254 pp, Department of Natural Resources
DCMI	Idaho	SPF Water Engineering, L. (2016), Treasure Valley DCMI Water-Demand Projections (2015-2065), Report prepared by SPF Water Engineering, LLC for Idaho Water Resource Board and Idaho Dept. of Water Resources, variably paginated.
DWR	Colorado	Colorado Dept. of Water Resources (2022), 2022 Annual Water Supply and Demand Assessment Summary Report, Report submitted to the State Water Resources Control Board, 39 p, (link). https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency/Annual-Water-Supply-and-Demand-Assessment/FINAL-DWR-2022-AWSDA-Report-to-SWB_11-22-22.pdf .
FINAL-DWR	Colorado	Colorado Dept. of Water Resources (2022), 2022 Annual Water Supply and Demand Assessment Summary Report, Report submitted to the State Water Resources Control Board, 39 p, (link). https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency/Annual-Water-Supply-and-Demand-Assessment/FINAL-DWR-2022-AWSDA-Report-to-SWB_11-22-22.pdf .
ICLUS	Various	EPA Office of Research and Development (2017), Updates to the Demographic and Spatial Allocation Models to Produce Integrated Climate and Land Use Scenarios (ICLUS) Version 2, EPA Office of Research and Development, EPA/600/R-16/366F.
ICWP	national	McLaughlin, A., C. Schwab, and K. Tucker (2021), State Water Plan Review, Rept., 21 pp, Interstate Council on Water Policy, ICWP.
IWRB	Idaho	IWRB (2012), Idaho State Water Plan, Rep., 90 pp, Idaho Department of Water Resources.
JSTOR	various	Zoraghein, H., and B. C. O'Neill (2020), A Spatial Population Downscaling Model for Integrated Human-Environment Analysis in the United States." vol. 43, 2020, pp. 1563–606. JSTOR, https://www.jstor.org/stable/26967851 . Accessed 3 Nov. 2024., Demographic Research, 43, 1563–1606.
NPJ	various	Daniel, I., N. K. Ajami, A. Castelletti, D. Savic, R. A. Stewart, and A. Cominola (2023), A survey of water utilities' digital transformation: drivers, impacts, and enabling technologies, NPJ Clean Water, 6(1), 51.

OWRB	Oklahoma	OWRB (2012), 2012 Oklahoma Comprehensive Water Plan: Executive Report, Rep., 160 pp, Oklahoma Water Resources Board.
PART	Nevada	N Dakota Office of Water Resources (1999), Nevada State Water Plan PART 1 — Background and Resource Assessment, Rep., 180 pp, Department of Conservation and Natural Resources.
PLOS	Various	Patterson, L. A., S. A. Bryson, and M. W. Doyle (2023), Affordability of household water services across the United States, PLOS Water, 2(5), e0000123.
SAWS	Texas	SAWS (2024), SAWS 2024 5 Year Water Conservation Plan, San Antonio Water System, 140 p. .
SPF	Idaho	SPF Water Engineering, L. (2016), Treasure Valley DCMI Water-Demand Projections (2015-2065), Report prepared by SPF Water Engineering, LLC for Idaho Water Resource Board and Idaho Dept. of Water Resources, variably paginated.

7.2.24. Planning horizons and updates

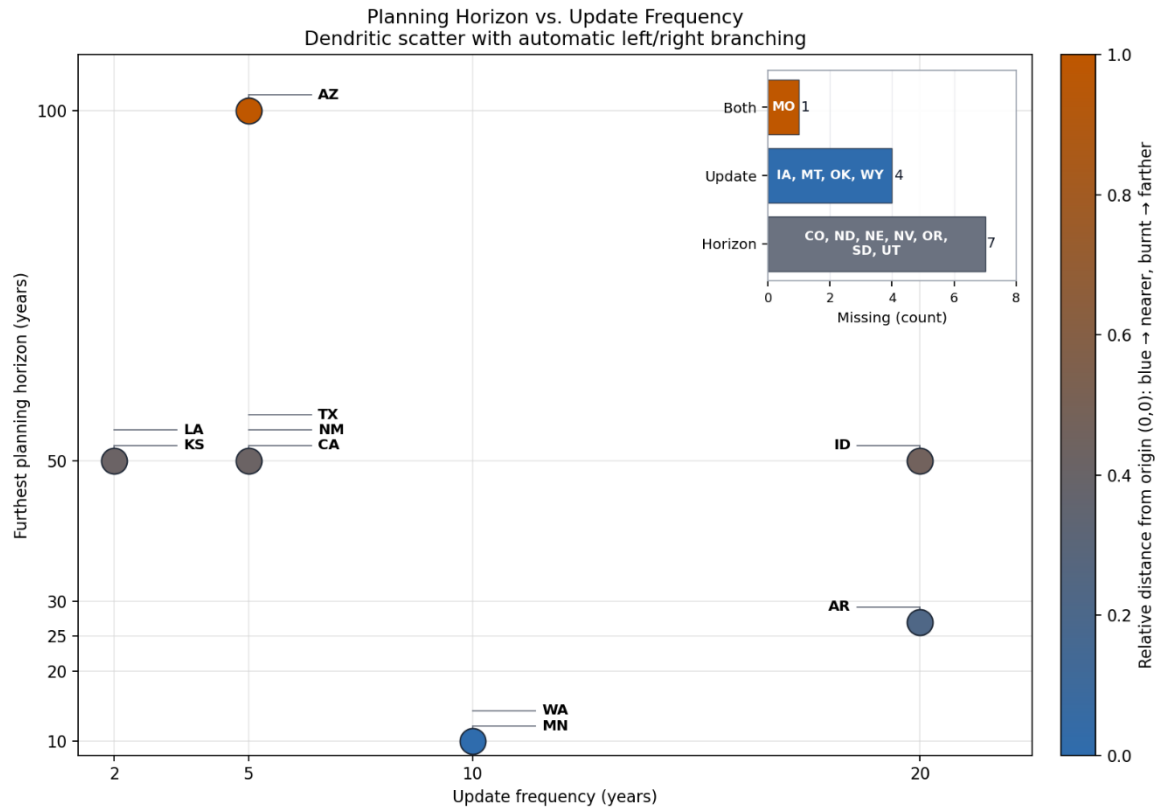


Figure 36. Planning horizon frequency and update goals for the 22 states west of the Mississippi River.

7.2.25.SUPPLEMENTAL

7.2.26.State Water Planning Summary – 22 States

Table A – Planning Properties

State	Planning_Horizon	Update_Frequency	Population_Projection_Source_Method	Uses_LMH_Scenarios
Arizona	Multiple: SDRs project ~53 years; AWS modeling uses 100-year tests in AMAs	SDRs ongoing by basin; AMA Management Plans per management periods (5MP 2020–2025)	No single statewide population series; SDR “Growth” scenario considers population growth qualitatively; AMA AWS uses provider/developer-submitted demand & population tested in 100-yr groundwater models	Yes (SDR scenarios: Status quo, Growth, Conservation, Technology, Climate)
California	~50 years (e.g., to 2070) with 5-year Water Plan updates	Every 5 years (Water Code); Update 2023 released 2024	Official California Department of Finance (DOF) state & county projections used; utilities refine in UWMPs	Water Plan uses multi-scenario futures (climate, demand); population growth from DOF baseline
Colorado	To 2050 (Technical Update & 2023 Water Plan)	Water Plan ~decadal; Technical Update 2019 with basin updates (2022)	State Demography Office official forecasts underpin scenarios; basin disaggregation in Technical Update	Yes—multiple M&I demand scenarios
Idaho	Commonly 50 years in CAMP basin plans (e.g., Rathdrum Prairie)	Basin plans updated as needed; CAMP adopted 2011 with subsequent reports	Basin-specific studies project population/employment using Census trends and regional sources	Yes—Rathdrum Prairie varied population, conservation, climate
Montana	~20 years (2015 plan)	Periodic; policy-focused	No single statewide forecast; uses Census trends/regional inputs; USGS estimates for water-use	Not specified statewide
Nevada	State Water Plan update underway (~2025); local plans vary (e.g., SNWA to 2072)	State Plan modernizing; utility conservation plans every 5 years (NRS 540)	Nevada State Demographer official county projections; agencies/utilities may modify for planning	Varies; SNWA stress-tests hydrologies; state plan compiling projections/resources
New Mexico	Regional plans to ~2060; statewide 5-year review (2018 plan reviewed 2023)	Review at least every 5 years (statute)	UNM GPS cohort-component projections for state/counties; Census trends	Yes—2018 technical report developed high/low growth forecasts and drought vs average conditions
Oregon	Strategy horizon long-term; IWRS updates 2012, 2017, 2025; future ≤8-year cycle	≤8 years (statute/policy direction)	Statewide framework; detailed forecasting handled in basin/local plans; IWRS calls for regular updates	Not a single statewide population scenario; Strategy addresses pressures incl. population growth and climate
Utah	To ~2065/2070 (Gardner Institute projections); state tracks M&I use annually	Plan chapters updated (e.g., 2021); projections updated periodically by Gardner Institute	Kem C. Gardner Policy Institute statewide & county projections (official for planning)	Not explicit L/M/H in state plan; scenario commentary in briefs
Wyoming	~30 years in river basin plans	Basin plans updated periodically; statewide framework tables maintained	Basin plans develop Low/Moderate/High using time-series, cohort-survival, employment-driven approaches	Yes—explicit L/M/H scenarios by basin
Arkansas	To ~2050 in AWP 2014; comprehensive update	Plan updates as directed; 2024	AWP uses multiple sources and technical appendices (e.g.,	Not standardized statewide; scenarios

	launched 2023 under EO 23-27	Programmatic Work Plan outlines phased update	demography appendix) to derive regional forecasts used in sector demand	developed in planning regions
Iowa	No single statewide supply-demand plan; focus on water quality strategies and basin plans	Programmatic documents updated periodically (e.g., Nutrient Reduction Strategy, WQIPs)	Demographic inputs used in local planning (Iowa DNR/State Data Center); statewide plan emphasizes policy/quality rather than projections	Not applicable at statewide level
Kansas	Kansas Water Plan updated 2022; rolling 5-year updates	Every ~5 years; annual State of the Resource report	Relies on Census trends and regional inputs; municipal “population served” in DWR reports used for per-capita metrics	Not formal L/M/H statewide; basin and regional analyses vary
Louisiana	Coastal Master Plan uses 50-year horizon; updated every six years	CMP updated 2023; ongoing annual CPRA plans	CMP integrates demographic and risk modeling inputs to assess coastal futures; statewide water-use compiled by USGS	CMP uses climate/SLR and storm scenarios; not L/M/H population branches
Minnesota	EQB 10-year State Water Plan (e.g., 2020 plan) with long-term strategies	Decadal plan; ongoing DNR reporting	Plan references official state demographic work; regional/local plans refine	Not L/M/H; climate resilience scenarios addressed
Missouri	State Water Resources Plan update completed 2020; long-range through 2060 scenarios	Periodic updates; ongoing major water users reporting	Plan uses Census and state projections with scenario planning; regionalization emphasis	Scenario planning framework rather than strict L/M/H
North Dakota	Comprehensive Water Development Plan maintained biennially; basin-based project inventory	Biennial updates aligned with state budget cycle	Project-driven; uses Census and state data in project/basin analyses	Not formal L/M/H; project stress-testing and prioritization used
Nebraska	Integrated water management through joint NeDNR-NRD plans; basin-wide and district plans updated on cycles	Ongoing; plan adoptions and revisions published; annual evaluations (FAB reports)	Local NRDs and NeDNR use Census and state methods to allocate by basin/district	Scenario tools used in basin plans; not fixed L/M/H statewide
Oklahoma	OCWP 50-year planning horizon (to 2060) with 2012 update; 2025 update in progress	Major updates roughly every decade; implementation ongoing	OCWP develops basin demands using projections; statewide infrastructure needs assessed	Hot-spot basin vulnerability analyses and climate stress testing
South Dakota	State Water Plan is a rolling project list; Facilities Plan projects typically span multi-year; system covers water/wastewater/stormwater	Board considers applications annually; documents published each year (e.g., 2026 plan)	Project sponsors use Census/local projections in facility planning	Not applicable; project eligibility framework
Texas	50-year horizon (e.g., to 2070) in the State Water Plan; five-year planning cycles	Regional plans every 5 years roll into State Water Plan (e.g., 2022 SWP)	TWDB board-adopted projections using Texas Demographic Center data; municipal demand = population × baseline GPCD with plumbing code savings	Scenario planning via strategies portfolios; drought-of-record basis statewide
Washington	Utility Water System Plans (WSPs) typically cover ~6–10 years; validity often extended upon DOH approval; climate resilience element required in new WSPs (2024–2025 rule updates).	WSP updates generally every 6–10 years; DOH reviews/approves; climate resilience element effective June 13, 2024 with statutory	Utilities use Washington Office of Financial Management (OFM) official population estimates/projections to develop demand forecasts; local planning consistency required.	Not statewide L/M/H branches; utilities forecast demand and include conservation/WUE and climate resilience analyses per DOH guidance.

		compliance by June 30, 2025.		
--	--	---------------------------------	--	--

Table B – Methods and Notes (click numbers)

State	Municipal_Demand_Method	GPCD_Meth od Definition	Accuracy_Assessment_ or_Notes	Primary Refs	MoreR efs
Arizona	In AMAs, providers regulated via Total GPCD or NPCCP; AWS designations require 100-yr supply/demand evaluation; SDR municipal demand varies by scenario	Total water supplied ÷ population served ÷ 365; provider-level targets under AMA Municipal Conservation; audited via annual reports	SDRs note data gaps; literature values/averages used when local data unavailable; Phoenix AMA groundwater model technical memos and sensitivity analyses	[1] [2] [3] [4] [5]	[1] [2] [3]
California	Draws from supplier UWMPs; shift from historic per-capita to water-use objectives under SB606/AB1668	Traditional deliveries ÷ population ÷ days; policy emphasis on indoor/outdoor standards, CII performance, system loss standards	DOF methods documented; Water Plan methods and portfolios; UWMPs reviewed by DWR	[1] [2] [3] [4] [5]	[1] [2]
Colorado	Statewide demand models combine SDO population, per-capita trends, sectoral drivers, conservation assumptions by basin	Utility-reported deliveries divided by population; used to track per-capita and parameterize scenarios	CWCB notes uncertainties; interactive tools and document detail assumptions; basin plans refine local conditions	[1] [2] [3] [4]	[1] [2]
Idaho	Projected population × per-capita use with conservation/climate modifiers; employment-based adjustments for CII	Derived from utility/USGS data and applied per service area in basin studies	Technical memos document assumptions and ranges; CAMP emphasizes adaptive management	[1] [2] [3] [4]	[1] [2]
Montana	Local/basin planning uses population × per-capita and USGS estimates	Per-capita derived from USGS/public-supply withdrawals ÷ served population where reported	USGS notes data limits; some per-capita estimates extrapolated	[1] [2] [3]	[1] [2]
Nevada	Regional utilities forecast using service-area population, indoor/outdoor splits, reuse credits; conservation embedded	SNWA reports regional GPCD and targets (e.g., 86 GPCD by 2035)	State Demographer methods published; state plan complements local plans	[1] [2] [3] [4]	[1] [2]
New Mexico	Regional plans: demand = population × GPCD with conservation scenarios; statewide integrates regional results	NMOSE GPCD Calculator standardizes per-capita from metered deliveries and service-area population	UNM GPS documentation for methods; OSE tool requires metered data and notes limitations	[1] [2] [3] [4] [5]	[1] [2]
Oregon	Handled in basin/regional plans; IWRS actions include improving measurement/reporting	Determined in local/basin plans; no single statewide GPCD standard in IWRS	IWRS emphasizes data gaps and improved monitoring; 2025 IWRS sets priorities and workplans	[1] [2] [3] [4] [5] [6]	[1] [2]

Utah	DWR compares Gardner projections to supplies; uses observed M&I deliveries and conservation trajectories	Utah GPCD includes all potable & non-potable M&I deliveries within provider service area ÷ service-area population	Gardner methods document assumptions; DWR Open Water Data for transparency	[1] [2] [3] [4] [5] [6]	[1] [2]
Wyoming	Service-area population × per-capita rates from WWDC surveys; rural additions; scenario-based demand	Per-capita from WWDC Municipal Water System Survey applied by system	Technical memoranda document methodology; statewide tables summarize current vs projected uses	[1] [2] [3] [4]	[1] [2]
Arkansas	County/utility demand linked to population and per-capita; emphasis on shifting irrigation to surface water to relieve groundwater	Per-capita computed from reported volumes and served population in plan datasets	2014 plan notes data gaps and calls for expanded monitoring; 2024 work plan defines tasks and stakeholder engagement	[1] [2] [3]	[1]
Iowa	Utility/basin plans use population × per-capita; managed locally	Derived from supplier reports; no fixed statewide GPCD	State materials emphasize nonpoint strategies and watershed-specific planning	[1] [2]	[1]
Kansas	Demand tracking via DWR annual municipal water use reporting; conservation plan guidelines use GPCD metrics	Calculated from annual municipal water use and population served reported to DWR	KWO portal provides interactive plan and implementation framework	[1] [2] [3]	[1]
Louisiana	Per-capita and sectoral use from USGS and local reporting inform planning; CMP focuses on risk and restoration rather than municipal demand modeling	USGS parish/county compilations support per-capita estimates; utilities report to agencies	USGS notes major users & categories tracked; CMP provides technical appendices and data portals	[1] [2]	[1]
Minnesota	DNR compiles water use from permit holders; municipal planning uses observed deliveries and conservation reporting	Derived from supplier reporting; conservation reporting framework supports per-capita tracking	Plan highlights climate pressures; DNR provides dashboards and datasets	[1] [2]	[1]
Missouri	Demands based on population and historical use; Major Water Users reporting feeds datasets	Computed from reported use volumes and populations; state tracks major users (≥100k gpd capacity)	Plan identifies potential shortfalls and infrastructure needs	[1] [2] [3]	[1]
North Dakota	Local providers & state programs develop demand tied to population and system needs	Derived within utility planning; not fixed statewide	Statutory authority requires a basin-organized plan and stakeholder meetings	[1] [2]	[1]
Nebraska	Managed locally by NRDs/municipalities; conjunctive management of surface & groundwater	Derived from utility/NDEQ reporting within local plans	Nebraska's IMPs mandated for fully or over-appropriated basins; robust stakeholder processes	[1] [2]	[1]
Oklahoma	Municipal/public supply demands linked to	Per-capita use tracked via supplier reporting	OCWP provides Executive Report and watershed reports;	[1] [2] [3]	[1]

	population; Water for 2060 conservation framework	and plan datasets; reuse and efficiency emphasized	implementation includes monitoring and reuse framework		
South Dakota	Engineering reports use population × per-capita and design standards	Derived in facility planning reports; no fixed statewide value	Plan managed by DANR Board of Water and Natural Resources; inclusion can influence funding	[1]	[1]
Texas	Water management strategies identified per region; municipal based on projections and conservation/efficiency; utility service-area based WUGs	Derived from TWDB Water Use Survey for baselines; projections incorporate code savings and local adjustments	Interactive plan & datasets; amendments and dashboards published; methodology and data hub documented	[1] [2] [3] [4]	[1]
Washington	Water System Plans include demand forecasts using OFM population, metered consumption, peaking factors, conservation/WUE; distribution leakage standard ≤10% and goal-setting with public process.	Per-capita typically computed from metered production/consumption ÷ service population ÷ 365; utilities track GPCD and leakage under WUE rules.	DOH WSP rule (WAC 246-290-100) and WUE rule (WAC 246-290-800) set planning/efficiency requirements; 2024–2025 updates add climate resilience; Ecology’s Municipal Water Law framework governs municipal rights.	[1] [2] [3] [4] [5]	[1] [2]

7.3. Select Texas Regional Water Plans

7.3.1. North Texas Municipal Water District

The following description was obtained from the North Texas Municipal Water District (NTMWD) Water Conservation Plan (2024).

NTMWD is a wholesale water supplier serving:

- 13 Member Cities (Allen, Frisco, McKinney, Plano, Garland, etc.)
- 34 additional direct customers
- Indirect customers supplied through member cities
- Future committed service areas in Fannin County

The service area covers ~2,200 square miles across Collin, Dallas, Denton, Fannin, Grayson, Hopkins, Hunt, Kaufman, Rains, Rockwall, and Van Zandt Counties

Population projections explicitly include:

- Current member cities and customers
- Future customers NTMWD has committed to serve (e.g., Bois d’Arc MUD, Honey Grove, Leonard, etc.)

a) Population Projections

Population projections are developed up to 2080 as part of the NTMWD Long Range Water Supply Plan (LRWSP) (NTMWD, 2024). The historical population has increased from 1.89 million (2019) to 2.19 million (2023) and is projected to increase to 3.54 million (2050) and 4.5 million (2080).

The LRWSP also includes adjusted expected growth, high-growth scenario, low-growth scenario, 2013 Capital Improvement Program (CIP) comparison scenario, and 2024 NTMWD Water Conservation Plan.

Thus, NTMWD evaluates demand across multiple growth scenarios, but the Water Conservation Plan (WCP) uses the “expected adjusted” scenario for conservation planning.

b) Gallons per Capita per Day

The WCP uses Total GPCD that refers to total raw water diverted for potable use minus wholesale sales divided by total population (NTMWD, 2024). Residential GPCD refers to retail residential gallons sold divided by residential population. Because NTMWD is largely a wholesale supplier, it focuses mostly on total per capita use and category-level treated water use (residential vs Integrated Capital Improvement Model (ICIM) etc.)

Per capita demand peaked around 2000 (~200+ GPCD) and shows a long-term decline due to conservation. Current per capita use is ~150 GPCD range. The 5-year rolling averages are tracked. Conservation has reduced projected 2025 dry year demand by 95 MGD and projected 2080 demand by 260 MGD compared to year 2000 GPCD levels. NTMWD explicitly compares water demand with (reduced GPCD) and without (year 2000 GPCD) conservation.

7.3.2. Harris Galveston Subsidence District (HGSD)

a) Population Projections

The HGSD aligns its population forecasts with broader regional water planning data typically developed or coordinated with the Texas Water Development Board (TWDB), particularly as part of the Region H water planning process (which includes Harris and Galveston counties).

- HGSD’s planning efforts (including population and water demand projections through 2100) explicitly state that they “*develop updated population and water demand projections through 2100 ... grounded with the latest 2020 census data and coordinated with the TWDB so that they can be adapted for the 2026 Region H Water Plan.*”
- The Region H planning process and the TWDB both maintain and publish TWDB adopted population forecasts by county and municipal water user groups that are widely used for municipal water demand projection in Texas

In earlier technical reports and planning documents, population projections for HGSD studies were developed using independent demographic modeling from research partners, including:

- Metrostudy, Inc. (short-term projections)
 - University of Houston Center for Public Policy (long-term projections)
- These were used historically to support regional modeling and groundwater/subsidence scenario analysis.

Together, HGSD’s approach integrates census-based estimates, TWDB projections, and modeling from academic/industry partners to produce the forecasts used in regulatory planning.

b) GPCD (Gallons Per Capita per Day) Source

HGSD itself does not generate its own independent GPCD baseline. Instead, GPCD values used in HGSD analyses are derived from water use data and projections developed by or coordinated with state and regional planning sources, similar to how population forecasts are handled. The TWDB collects municipal water use data from utilities statewide, including total system water sales and population served. These data are core to calculating baseline GPCD values and projecting future water demands. When HGSD incorporates water demand projections (which inherently rely on GPCD projections), the initial GPCD assumptions are typically based on TWDB water use surveys and projection methodologies used in the Region H water planning process.

In many subsidence modeling and regulatory planning scenarios, HGSD employs water demand forecasts from regional planning efforts and water providers, which include GPCD estimates based on historical use and future conservation/plumbing code trends. These are often drawn from or consistent with the TWDB’s municipal demand projection dataset adopted for regional plans.

7.3.3. Fort Bend Subsidence District

a) Population Projections

Fort Bends Subsidence District's (FBSD) current long-range planning work (Joint Regulatory Plan Review / District planning) indicates the projections are anchored to U.S. Census data and coordinated with the Texas Water Development Board (TWDB) / Region H so they can be used consistently in regional water planning. FBSD also describes developing fine-scale (census block-level) population projections by decade (example noted as 2010–2070 using the 2010 Census as the base in their “Science and Research” materials) ([link](#)).

b) Gallons per Capita per Day (GPCD)

FBSD's subsidence/regulatory planning typically uses per-capita municipal demand (i.e., GPCD or equivalent) as part of projecting future water needs (paired with the population projections) in their Joint Regulatory Plan Review work. The standard statewide planning source for municipal GPCD inputs in Texas is used by the FBSD. This includes the TWDB “Board-adopted population and municipal demand projections”, where municipal demand is explicitly a function of population projections, baseline GPCD, and projected plumbing-code savings (efficiency).

7.3.4. North Central Texas Council of Governments (NCT COG)

a) Population Projection

Recent NCTCOG demographic modeling and regional planning documents indicate substantial population growth across North Central Texas over the next several decades. The region (particularly the Dallas–Fort Worth metro area) is projected to continue growing strongly through 2045 and beyond. Estimates for the metro population suggest growth from the current population of ~ 7 million to over 11 million people by 2045–2050 ([link](#)). A 2045 NCTCOG Demographic Forecast (used for long-range transportation planning) shows year-2030 and year-2045 population control totals at the county level for the metro area. The 2045 Forecast covers the 12 counties in the Metropolitan Planning Area (MPA) and is released at 2010 Census Block Group geography to ease integration with other readily available data. The following description is based on the report provided by the NCTCOG 2045 Forecast Description ([link](#)). “The model uses a long time series of satellite imagery along with cadastral-based land use data to quantify the trend relationship between urban land use/land cover change and estimates of the control totals during that time. Small-area socioeconomic data, terrain and land cover descriptor data, and proximity variables were evaluated to create a set of logistic regression models for the probability of 30-by-30-m cells becoming urbanized into different land uses. The logistic regression models were used along with locally adopted future land use plans and the trend relationship to the control totals to predict future urban expansion based on “building forward” from the 2015 Small Area Estimates.

Densities of the newly built grid cells is determined by regression-based algorithms using similar

variables subject to adjustments to match the control totals. The grid cell allocations of 2030 and

2045 were tabulated by 2010 Block Group to arrive at draft 2030 and 2045 forecasts sent out for

local review. Detailed information on the selection, calibration, training, and testing of the

algorithms along with validation of the overall process is available in Folden et al. (2017). The population estimates are available at the following [link](#). The Texas Demographic Center 2024 vintage projections provide county-level population projections (2020–2060) used by planning agencies such as NCTCOG and the Texas Water Development Board (TWDB) ([link](#)).

b) Gallons per Capita per Day (GPCD)

NCTCOG itself does not publish standalone “GPCD projections,” but *water demand forecasting* tied to population growth in the region follows the methodology used by the Texas Water Development Board (TWDB) as part of the Regional Water Planning process (Region C, which includes the NCTCOG area).

Folden, M. (2017). *High Resolution Demographic Forecasting: A Data Science and Remote Sensing Approach to Small Area Forecasting* (External Documentation for UrbanGrowthModel / Forecast2045). North Central Texas Council of Governments. Retrieved from <https://rdc.dfwmaps.com/pdfs/>

7.3.5. Texas Department of Transportation

a) Population Projections

The Texas Dept. of Transportation (TxDOT) relies on established population growth trends to estimate future travel demand, roadway needs, and multimodal service requirements in its long-range planning products such as *Connecting Texas 2050* (a statewide long-range plan). These plans cite growth projections (e.g., Texas expected to add tens of millions of people by 2050) to justify and guide investment strategies. TxDOT *does not independently produce* the underlying population projections (e.g., county or city population forecasts). Instead, it uses population forecasts from agencies like the U.S. Census and the Texas Demographic Center as inputs for transportation modeling and forecasting work. This is standard practice in state DOT planning. The Texas Demographic Center (TDC) produces official population projections (2020-2060) used by agencies, including TxDOT and planning partners, for growth assumptions in infrastructure planning (e.g., housing, transportation) ([link](#)).

Texas Department of Transportation. (2024). *Connecting Texas 2050: Statewide long-range transportation plan*. Texas Department of Transportation. <https://www.txdot.gov/content/dam/docs/division/tpp/connecting-texas-2050-slntp-508c.pdf>

Texas Demographic Center, 2024, Vintage 2024 Population projections ([link](#))