TEXAS METRO OBSERVATORY

PEOPLE, LAND, AND WATER:

Stories of Metropolitan Growth

PLANET TEXAS 2050
A UT Grand Challenge

The University of Texas at Austin
Bridging Barriers
Office of the Vice President for Research

TEXAS

METRO

OBSERVATORY

PEOPLE, LAND, AND WATER:
Stories of Metropolitan Growth

PLANET TEXAS 2050

"Texas' population could double by the year 2050. Extreme weather events will bring more floods, more droughts, and more heat. Our state's resources can't support those demands. Making Texas resilient is our grand challenge."

PLANET TEXAS 2050
A UT Grand Challenge

The University of Texas at Austin
Bridging Barriers
Office of the Vice President for Research

CONTRIBUTORS

COLLABORATING INVESTIGATORS

Katherine Lieberknecht, Ph.D., Assistant Professor. Community and Regional Planning. School of Architecture.

Michael Oden, Ph.D., Associate Professor. Community and Regional Planning. School of Architecture.

Fernanda Leite, Ph.D., Associate Professor. Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering. Cockrell School of Engineering.

Patrick Bixler, Ph.D., Assistant Professor of Practice. RGK Center for Philanthropy and Community Service. LBJ School of Public Affairs.

Juliana Felkner, Ph.D., Assistant Professor. School of Architecture.

Steven Richter, Ph.D. Candidate. Community and Regional Planning. School of Architecture.

Sarah Wu, Assistant Director of Research. Center for Sustainable Development. School of Architecture.

GRADUATE RESEARCH ASSISTANTS

Lucy Hall, MS Community and Regional Planning Candidate. School of Architecture.

Rachel Thomas, MS, Community and Regional Planning. School of Architecture.

Ji Ye Song, M Architecture Candidate. School of Architecture.

Alvaro Zilveti, MS Civil Engineering Candidate. Cockrell School of Engineering.

Samer Atshan, MS & MPaff, Research Associate, RGK Center for Philanthropy and Community service, LBJ School of Public Affairs.

Julien Brown, B Architecture Candidate, School of Architecture.

TEXAS
METRO
OBSERVATORY

TEXAS
METRO
OBSERVATORY

TABLE OF CONTENTS

EXECUTIVE SUMMARY I

Endnotes ii

INTRODUCTION 03

Metros and the Future of Texas 03

People, Land, and Water - Patterns of Growth and Change in Texas Metros 05

Endnotes 06

PEOPLE 07

Introduction: People and Places in Texas 09

Texas Metros: Engines of Texas Growth and Development 09

Population Growth Characteristics of Texas Metros 11

Patterns of Urban and Suburban Change 13

Increasing Diversity in Texas Metros 14

An Increasingly Educated Population in Texas Metros 16

Poverty in Texas Metros 17

Implications of Metro Change for the Future 17

Endnotes 20

LAND 21

Introduction 23

Statewide Summary 23

Trends and Analysis 26

Conclusion 37

Endnotes 38

WATER 39

Introduction 41

Texas' Water Resources 43

Historic and Current Metro Water Use 44

Breakdown of Metro Water Use by Sector 49

Geographic Patterns of Metro Water Use 49

Metropolitan Water Needs and Plan 53

Texas' Water Futures 55

Endnotes 59

FUTURE WORK 61

Sustainable Residential Development 63

Urban Densification And Housing Retrofit For Climate Change Mitigation 63

Metropolitan Governance Indicators 65

Endnotes 68

LIST OF FIGURES

INTRODUCTION

Figure 1: *Texas' 25 MSA's* 01-02

Figure 2: *Texas Metro vs. Rural Population Shares (1910-2015)* 04

PEOPLE

Figure 3: *Percentage of Population Change, 17 Texas Metros with over 200,000 People (1990-2015)* 11

Figure 4: *Urban-Suburban Population Shares (1990-2015)* 13

Figure 5: *Change in Racial/Ethnic Shares of Total Population, Texas Metros with over 200,000 People (1990-2015)* 15

Figure 6: *Change in Racial/Ethnic Shares of Urban Population, Texas Metros with over 200,000 People (1990-2015)* 15

Figure 7: *Change in Racial/Ethnic Shares of Suburban Areas of Metros, Texas Metros with over 200,000 People (1990-2015)* 15

Figure 8: *Share of Population over 25 with Bachelor's Degree or Greater, Texas Metros with over 200,000 People (1990-2015)* 16

Figure 9: *Urban and Suburban Shares of MSA Population Living in Poverty* 17

LAND

Figure 10: *Austin-Round Rock MSA Census Places* 24

Figure 11: *Austin-Round Rock MSA Land Cover* 25

Figure 12: *Five Year Land Metrics Trends for Metropolitan Texas (2001-2016)* 27

Figure 13: *Five Year Urban Expansion per Capital Trends for Metropolitan Texas (2001-2016)* 27

Figure 14: *Urban Expansion per Capita by MSA Size* 28

Figure 15: *Population Growth by MSA Size* 28

Figure 16: *Five Year Trends in Urban Expansion per Capita* 28

Figure 17: *Density Delta by MSA Size* 28

Figure 18: *Development Density (2016) vs Population Growth (2001-2006)* 31

Figure 19: *Development Density (2016) vs Urban Expansion per Capita (2001-2016)* 32

Figure 20: *Development Density (2016) vs Average Imperviousness (2016)* 33

Figure 21: *Density Data (2001-2016) vs Average Imperviousness Delta (2001-2016)* 34

Figure 22: *Population Growth (2001-2016) vs Imperviousness* 35

Figure 23: *Population Growth (2001-2016) vs Imperviousness Delta (2001-2016) (2016)* 36

WATER

Figure 24: *Comparison of Metro to Non- Metro Historic Water Use* 44

Figure 25: *Municipal Gallons per Capita per Day Metro Summary* 46

Figure 26: *Percent Change in Municipal Gallons per Capita per Day (GPCD) (1980-2016)* 47-48

Figure 27: *Sectoral Breakdown of Metropolitan Total and Groundwater Use* 50

Figure 28: *Reliance on Surface vs Groundwater (1974 vs 2016)* 51

Figure 29: *Sectoral Breakdown of Houston MSA Use* 52

Figure 30: *2070 Water Needs (volume in acre-feet represented by circle size) by Metro Region* 53-54

Figure 31: *Historic and Project Municipal GPCD including Demand Reduction and Reuse* 55

Figure 32: *Breakdown of 2070 Strategies by Source and Type* 57-58

FUTURE WORK

Figure 33: *Energy Use Impact of Building Refurbishments* 64

Figure 34: *Urban Densification and Housing Typology for Climate Change Mitigation* 64

Figure 35: *Civic Association Participation in Governance Networks* 66

LIST OF TABLES

PEOPLE

Table 1: *Texas Metropolitan Areas (2015)* 10

Table 2: *Population Change (1990-2015)* 12

Table 3: *Population Change in Texas Metros (1990-2015)* 12

Table 4: *Change in Urban Share of Metro Population (2010-2015)* 13

Table 5: *Metro, Urban, and Suburban Poverty Population (1990-2015), 17 Texas Metros Over 200,000 Population* 17

LAND

Table 6: *Descriptions of Land Cover Metrics* 23

Table 7: *Summary of Land Metrics for Metropolitan Texas (2001-2016)* 26

Table 8: *MSA Summary of Population Growth and Land Metrics* 29-30

WATER

Table 9: *Change in GPCD over Time (1980-2016)* 47

FUTURE WORK

Table 10: *Proposed Metropolitan Governance Indicator* 65

Austin, Texas

Source: Ryan Conine Downtown @shutterstock (https://www.thecrazytourist.com/where-to-stay-in-austin-neighborhoods-area-guide/)

EXECUTIVE SUMMARY

Texas is an urbanized and diverse state that has experienced some of the nation's fastest growth rates over the past several decades. The state contains five of the 11 fastest-growing US cities and four of the eleven most populous US cities.[1] In addition, its largest cities top the list of the most economically segregated cities in the nation.[2] Texas is home to at least 11 different ecological regions and substantial water and energy resources. However, it also leads the US as the state with the highest frequency and variety of natural disasters.

In an era of climate change, rapid urbanization, and population expansion, Texas is truly a bellwether state. The state's social, economic, and environmental characteristics make Texas an ideal test bed for research focused on the benefits and costs of contemporary metropolitan growth. Numerous regions in the US and internationally are experiencing rapid urbanization and increasing socioeconomic and environmental stresses, making research about Texas relevant and important to the nation and society at large.

The Texas Metro Observatory (TMO) is a communication and data platform dedicated to sharing information and ideas about Texas' communities, understanding common problems, and developing solutions across the state's metropolitan areas (also referred to in this report as metros, MSAs, or Metropolitan Statistical Areas).[3] TMO will provide researchers, community members, and policy makers access to metropolitan-scaled data (economic, environmental, health, demographic, governmental, etc.) for all metros in the state. The TMO platform will also produce unique data visualizations, infographics, and analysis tools that will provide a deeper understanding of the changes shaping the communities where Texans live.[4] This report presents a sampling of findings from the Texas Metro Observatory's first year of research and development.

The following report focuses on three key areas that will significantly influence the future of Texas metros: people, land resources, and water supply. The information summarized below tells a story of a state that has experienced remarkable growth in its population alongside steady changes in socioeconomic characteristics and environmental performance over the past several decades.

In terms of aggregate growth patterns in metropolitan areas, there has been a significant suburbanization trend over the past 25 years. The urban share of total metro population fell from 66 percent in 1990 to 59 percent by 2015, while the suburban population share increased by 7.2 percent over the period, equaling 41 percent of the total metro population by 2015. However, there are some intriguing hints that this suburbanization process may be changing in several Texas metros where the urban population grew faster than the suburban population since 2010.

Texas metros have experienced a remarkable increase in the racial and ethnic diversity of their populations since 1990. While the White, Non-Hispanic/Latino population in the 17 metros that we focused on increased by 1.95 million over the 1990-2015 period, its share of the total metro population decreased from 57.7 percent in 1990 to 40.5 percent in 2015. The largest increases in metro populations were due to rapid growth in Hispanic/Latino residents. Places within metro regions will be challenged to insure access and inclusion to all residents and leverage the advantages of diversity to sustain vibrant, opportunity rich communities.

Along with an increasingly diverse population, Texas metro residents have significantly higher levels of educational attainment than in 1990. About 33 percent of the U.S. population over 25 had a bachelor's or higher degree as of 2015. Statewide, Texas has a lower level of educational attainment than the nation, with 28.1 percent of the adult population with a bachelor's or higher degree in 2015. In the 17 Texas metros studied here, this measure of educational attainment increased significantly, growing from about 22.8 percent of the adult population in 1990 to over 30.7 percent in 2015. Over this period, educational attainment in suburban areas of metro regions increased at a faster rate than in urban areas. By 2015, the suburban share of resident with higher educational attainment was 31 percent compared to 30.5 percent in urban areas.

A final, more challenging trend is that of the suburbanization of poverty. Over the 25-year study period, the growth rate in the number of people living in poverty in suburban areas exceeded the growth rate in urban areas. It appears that this trend will continue into the future, putting increased pressure on suburban areas to generate more, better-paying jobs and provide supportive social services.

Analysis of land change in metro areas from 2001 to 2016 demonstrates a few important trends. First, the expansion of developed lands slowed, both in terms of total acres developed and per capita consumption of land. Such reductions might have been expected during the Great Recession, but the vast majority of reduction came after 2011. Despite reductions in land consumption, there remains room for further reductions. Large Texas metros consumed 88 acres per 1,000 new residents in the most recent five-year period, but this is still one-third higher than the national average (66), and more than three times that of California (28).

Other important trends involve increases in population density and the imperviousness of developed lands, an important environmental indicator of how land is developed. Higher levels of imperviousness are associated with a wide array of ecological, health, and safety threats, including reduced water quality, increased stormwater runoff and flooding, and increased temperatures due to urban heat island effect. Despite overall statewide increases, changes in density and imperviousness vary widely across the state. A few metros became slightly less dense and only one became less impervious, suggesting that both patterns are difficult to reverse once increased. This should be of particular concern to metros across Central Texas, a region that exhibits the most rapid increases of imperviousness.

Increasingly efficient development of land is a welcome sign in a state expecting continued and rapid population growth, but the risks posed by denser, more intense development must be monitored and mitigated.

All trends suggest that metro water use will continue to exceed non-metro water use in the state. On a positive note, metro water conservation likely will continue to increase, contributing toward an encouraging trend of declining per capita water use in metropolitan areas, measured as gallons per capita per day (GPCD). However, metro population growth rates will likely exceed future reductions to metro per-capita water use. We therefore expect overall metro water use will continue to increase due to Texas' predicted population growth.

The astonishing growth of Texas and its metro areas has inevitably driven a rapid pace of demographic and environmental change. Residents of Texas metros are more diverse, better educated, and more prosperous than in the past. In terms of land and water consumption, recent trends are moving in the right direction. However, poverty remains a stubborn problem for both cities and suburbs, and brisk population growth continues to outrun falling per-capita consumption of environmental resources.

As a result, metro areas will be under pressure to accelerate recent improvements in water conservation ("demand reduction") and limit future dependence on surface water. Innovative water strategies, such as water reuse and rainwater harvesting, likely will continue to grow from their relatively small current shares in metros current water portfolios. At the same time, Texas metro areas likely will continue to depend on sensitive and limited groundwater during times of drought.

In some ways, Texas' changes over the past several decades point to a brighter future: one in which Texans use less water and develop less land per person, leaving more of these limited resources to support other systems that also depend on them. In turn, these thriving water and land systems will provide economic and health benefits to people, whether in the form of open land for hiking and hunting, vibrant water bodies for boating and fishing, or cleaner water supplies. In our metro areas, more people will reap the economic benefits of higher education, while increasing racial and ethnic diversity will contribute to cultural and economic vibrancy within our urban and suburban communities.

However, projected population growth increases will outweigh these gains in water and land efficiency. Likewise, suburbanization of poverty requires that we quickly focus attention on developing better-paying jobs and needed services and infrastructure investments. In terms of resource use, Texans could harness their frontier spirit and develop new technologies and social changes that will contribute to a more durable future—one in which every Texan has enough land and water while leaving enough resources to provide for systems that support our state. In a similar way, our state needs to recognize and grapple with the implications of suburbanization of poverty. This report provides some sign posts along the road to Texas' future. We have time to change course, but it will require translating the data we share here into actions that support our metropolitan communities and the ecological and social systems that maintain them.

ENDNOTES

[1] US Census Bureau. 2016. Five of the Nation's Eleven Fastest-Growing Cities are in Texas, Census Bureau Reports. May 19, 2016. http://www.census.gov/newsroom/press-releases/2016/cb16-81.html

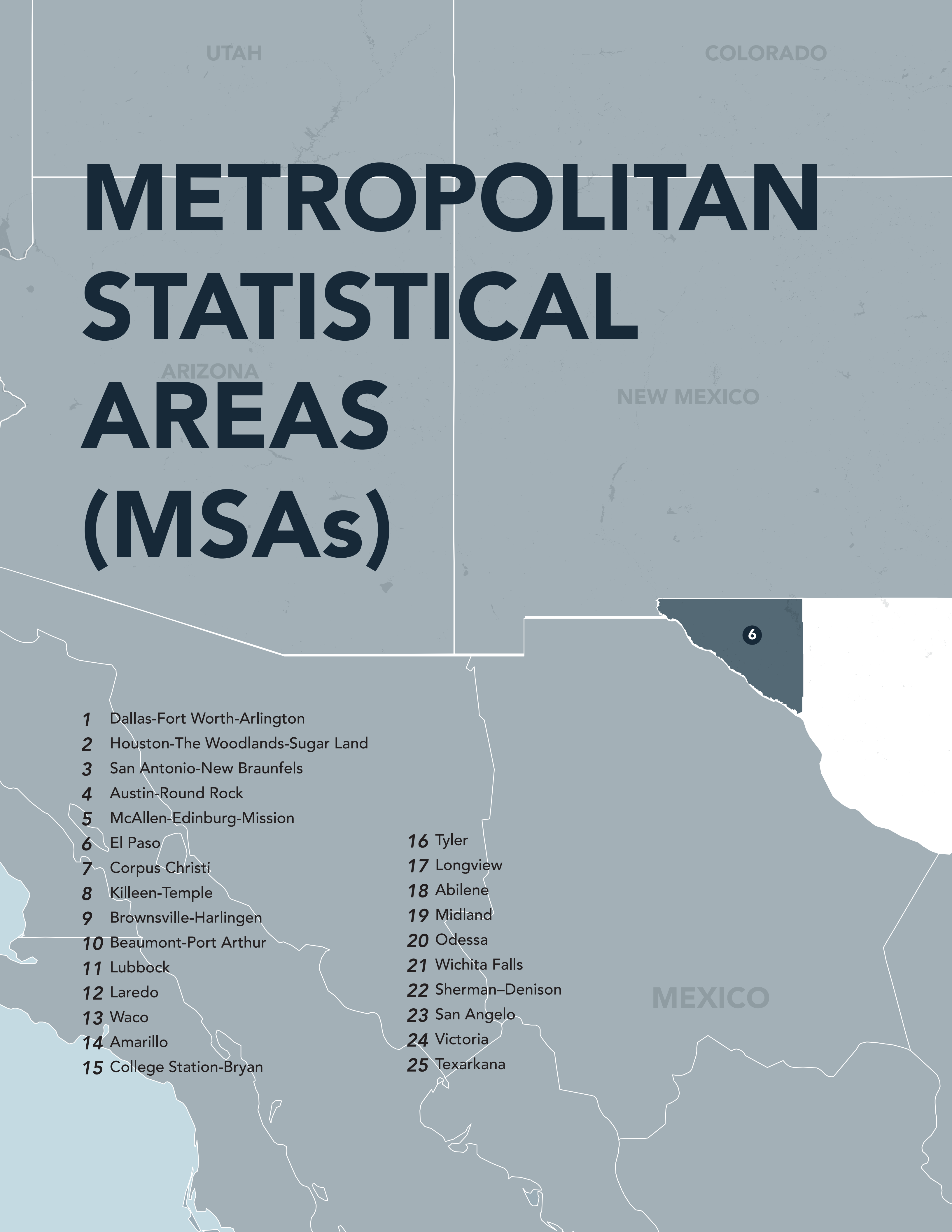
[2] Pew Research Center. 2012. The Rise of Residential Segregation by Income. http://www.pewsocialtrends.org/files/2012/08/Rise-of-Residential-Income-Segregation-2012.2.pdf; Martin Prosperity Institute. 2016. Segregated City: The Geography of Economic Segregation in America's Metros. http://martinprosperity.org/media/Segregated%20City.pdf

[3] In this report, we define metropolitan areas as the Census-designated Metropolitan Statistical Areas (MSAs), which are "core areas containing a large population nucleus, together with adjacent communities that have a high degree of economic and social integration with that core" US Census Bureau. 2011. Metropolitan Area. https://www2.census.gov/geo/pdfs/reference/GARM/Ch13GARM.pdf. MSAs contain urban, suburban, and even rural communities that are connected by integrated economic, social, and infrastructure systems.

[4] Bixler, R. P., Lieberknecht, K., Leite, F., Felkner, J., Oden, M., Richter, S. M., … Thomas, R. (2019). An Observatory Framework for Metropolitan Change: Understanding Urban Social–Ecological–Technical Systems in Texas and Beyond. Sustainability, 11(13), 3611. https://doi.org/10.3390/su11133611

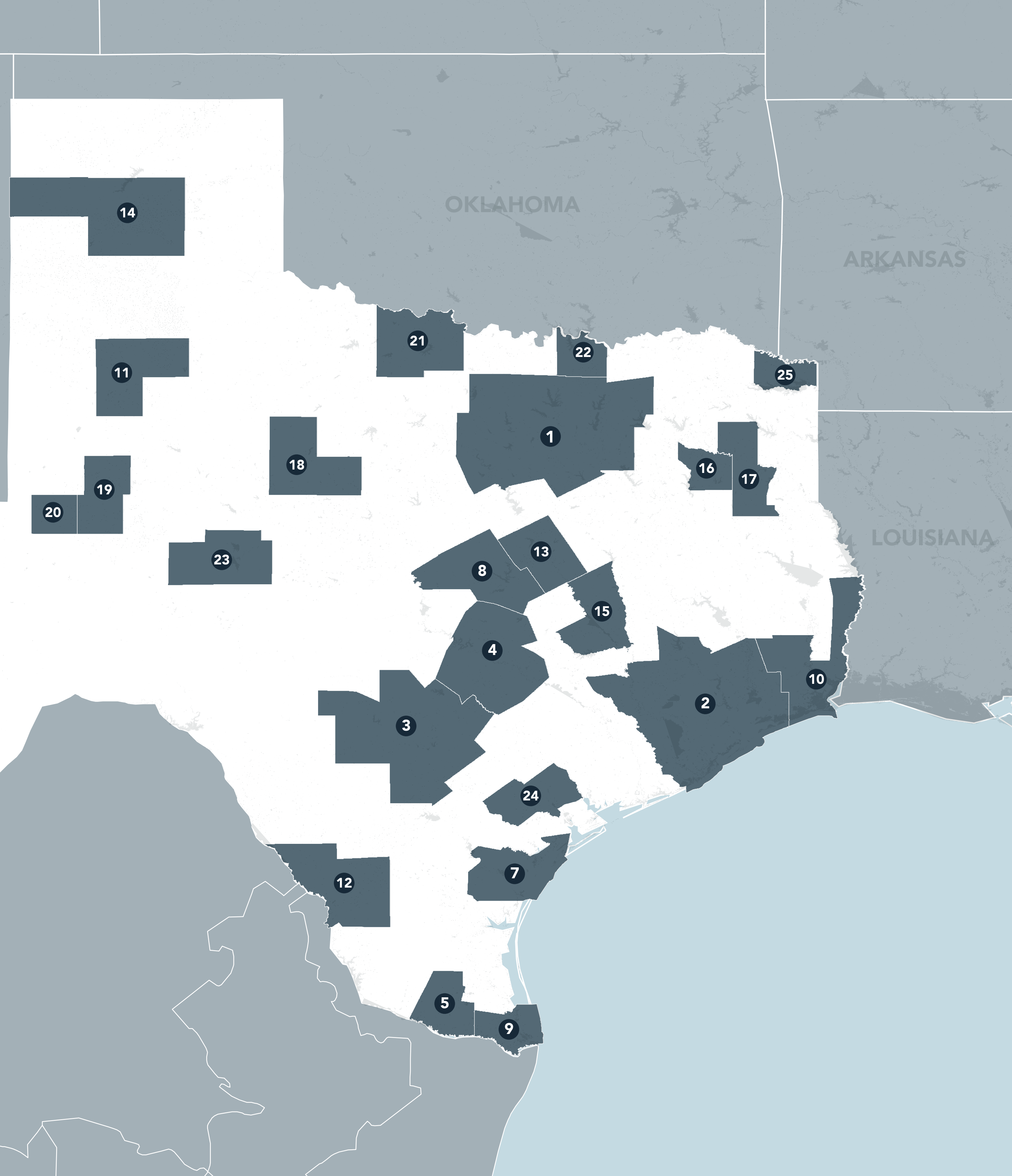
Houston, Texas
Source: https://clubquartershotels.com/locations/club-quarters-hotel-houston

METROPOLITAN STATISTICAL AREAS (MSAs)



1 Dallas-Fort Worth-Arlington
2 Houston-The Woodlands-Sugar Land
3 San Antonio-New Braunfels
4 Austin-Round Rock
5 McAllen-Edinburg-Mission
6 El Paso
7 Corpus Christi
8 Killeen-Temple
9 Brownsville-Harlingen
10 Beaumont-Port Arthur
11 Lubbock
12 Laredo
13 Waco
14 Amarillo
15 College Station-Bryan
16 Tyler
17 Longview
18 Abilene
19 Midland
20 Odessa
21 Wichita Falls
22 Sherman–Denison
23 San Angelo
24 Victoria
25 Texarkana

FIGURE 1: TEXAS' 25 METROPOLITAN STATISTICAL AREAS



INTRODUCTION

METROS AND THE FUTURE OF TEXAS

Almost 29 million people live in Texas, in towns and cities represented by 1,214 local governments. The state has experienced rapid population growth since its incorporation into the union in 1845. By 1900, Texas was the sixth most populous state in the U.S. Over the 20th and 21st centuries, Texas has been one of the fastest-growing, most dynamic states in the nation. Texas added over 24 million residents between 1900 and 2015, ranking only behind California in absolute population increase.

All indications are that the state will continue to experience rapid population growth in decades to come. As we think of the future of our state, continued population growth must be understood in light of socioeconomic challenges and environmental constraints. What might current trends tell us about ensuring more equitable opportunities for all current and future residents of the state? How can we ensure that continued growth can be sustained by more efficient use of our land, water, and other resources as the effects of climate change intensify?

To address these questions, it can be challenging to find a scale that helps isolate crucial patterns of change and make informative comparisons across Texas' communities. As noted, the large territory of Texas boasts numerous cities, towns, and rural communities. In this report, we examine Texas through the lens of metropolitan areas, which are core areas that contain a large population center and are integrated with smaller, adjacent communities that are linked economically.

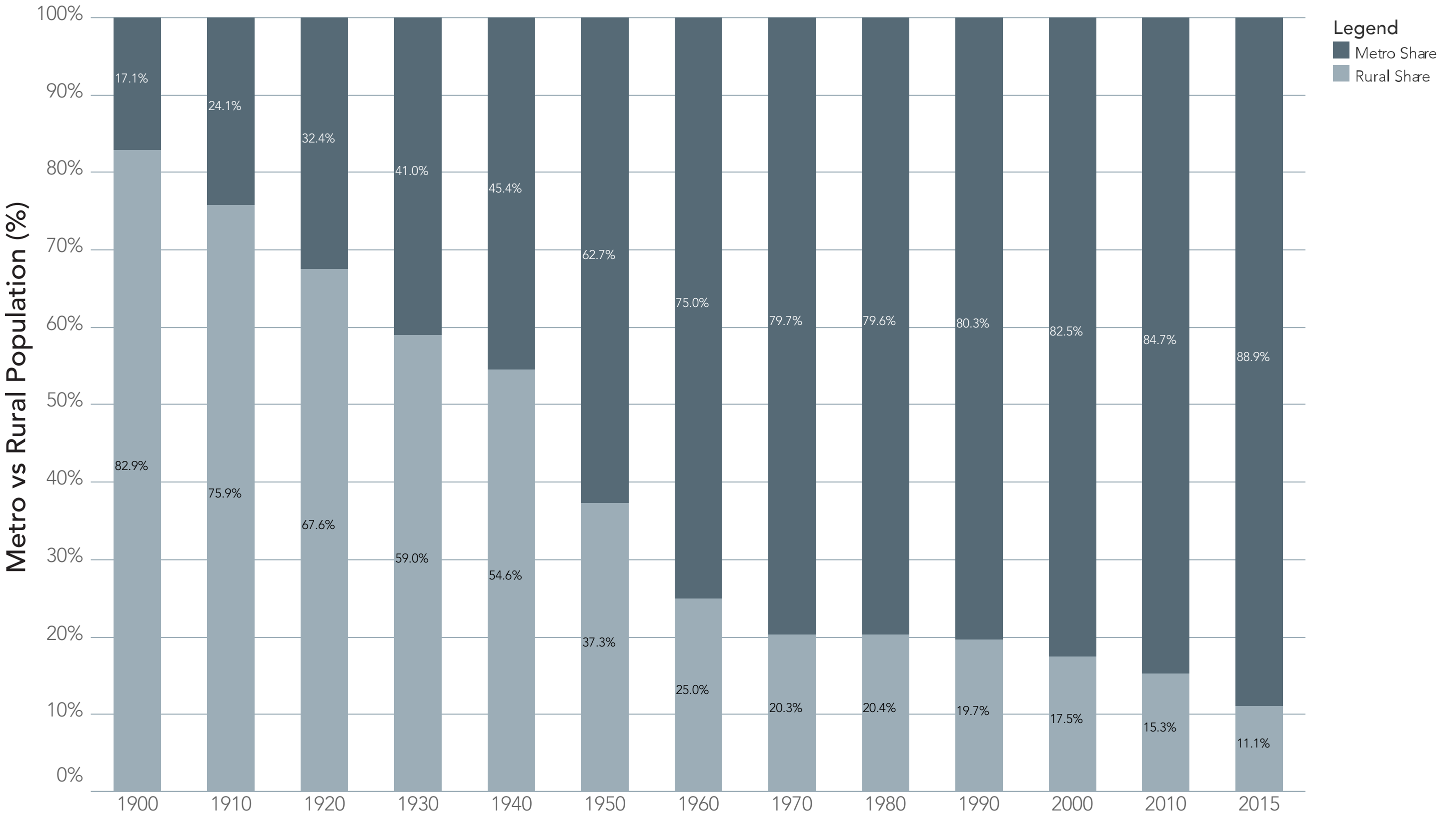
The concept of metropolitan areas arose in the early 20th century when researchers observed that rapidly expanding cities were beginning to run into one another, forming larger "conurbations."[1] The proliferation of water systems, energy infrastructure, transportation networks, and communication systems allowed cities to decentralize while remaining highly connected economic and social systems.[2] The US Census later recognized this pattern by establishing "Standard Metropolitan Areas" in 1949, and eventually "Metropolitan Statistical Areas" (MSAs) in 1983.[3] MSAs are assembled using development trends, economic data, and commuting patterns; they are the geographic foundation for this report.

The majority of Texas growth in the 20th and 21st centuries occurred in the state's metropolitan areas as Texas transitioned from a rural to an urban state. Over the decade of the 1940s, Texas transformed into a state where most residents lived in or around urban centers. By 2015, almost nine out of ten Texans lived in a metropolitan region.[4]

Using metro areas as a unit of analysis is also critical because urban systems are not constrained by formal municipal boundaries. Over the past century, people left core urban areas to live in new and expanding suburban communities, changing the spatial socio-economic patterns across metros. As population settlement decentralized, this led to rapid land cover change (i.e., the change from a vegetated landscape to an urbanized one characterized by impervious cover). These patterns of metro growth, sometimes labeled urban sprawl, have been associated with a range of negative effects such as reduced watershed health, increased flooding, and urban heat islands. For instance, as roads, parking, and roofs were built, the increase in impervious cover reduced the capacity for soils to absorb floodwater, resulting in increased flooding and impaired water quality. In a similar way, increased impervious cover and reduced vegetation results in higher than normal temperatures, creating urban heat islands in which nighttime temperatures can be as much as 10°F warmer in urban centers when compared to rural areas. Thus, the metropolitan area as the central locus of future population growth becomes an essential unit of analysis for understanding social and environmental challenges facing Texas over the coming decades. The evolution of our urban systems will shape economic opportunities, access to housing and services, water and energy supplies, and urban ecosystem elements such as tree cover and park systems.

This report focuses on the census designation of MSA as our unit of analysis and comparison. Texas currently has 82 counties that are in MSAs and 172 counties classified as non-metropolitan or rural. This report focuses on the Census designation of MSA as our unit of analysis and comparison. Texas currently has 25 designated MSAs (Figure 1).

Figure 2: Texas Metro vs. Rural Population Shares (1910-2015)



Source: U.S. Bureau of the Census. Decennial Census 1900 - 2010, U.S. Bureau of the Census. American Community Survey 2013-2017, ACS 5-year Estimates

PEOPLE, LAND, AND WATER: PATTERNS OF GROWTH AND CHANGE IN TEXAS METROS

To better understand some of the issues associated with evolving patterns of metropolitan growth in our state, this report is organized into three sections. In the following section, we focus on demographic and socioeconomic changes in the 17 largest metros over the past 25 years. Patterns of urban versus suburban change are examined in detail to determine if longer-term suburbanization trends of metro areas are shifting in terms of population shares and demographic characteristics of suburban areas.

In the next section, we analyze the characteristics of land cover change, focusing on how physical use of land has changed as Texas metro population has exploded over the past 15 years. Drawing upon the National Land Cover Database, we examine how metro population growth has related to developed land, development density, and average development impervious cover. These characteristics of land consumption and use can provide hints about certain environmental pressures that may stem from future growth in Texas metros.

We examine water use patterns, water supply limitations, and future water use opportunities in Texas metro areas in the last section of the report. This analysis focuses on the availability of water resources in Texas, as well as key surface and groundwater supplies that each metro areas draws upon, highlighting major differences in the composition of supply across the state's 25 metro areas. We explore historic and current water use, and consider new ways to expand supply through water reuse or other forms of collection. Lastly, we review some implications of the 2017 State Water Plan, which forecasts how metro areas can meet future needs by combining new water supply and more aggressive conservation to meet the demands of rapidly growing populations.

ENDNOTES

[1] Geddes, P. (1915). Cities in Evolution: An Introduction to the Town Planning Movement and to the Study of Civics. London: Williams and Norgate.

[2] Melosi, M. V. (1990). Cities, Technical Systems and the Environment. Environmental History Review, 14(1/2), 45–64. https://doi.org/10.2307/398462

[3] The formal Census definition of an MSA has two principle components: 1) the Core Based Statistical Areas (CBSAs) that includes one or more counties that contain a city of 50,000 or more inhabitants, or contain a Census Bureau-defined urbanized area (UA) and have a total population of at least 100,000 (75,000 in New England); 2) Outlying counties where at least 25 percent of the workers living in the county work in the CBSA, or at least 25 percent of the employment in the county is accounted for by workers who reside in the central county or counties of the CBSA. Source: U.S. Bureau of the Census. 2018."Metropolitan and Micropolitan" https://www.census.gov/programs-surveys/metro-micro/about.html.

[4] Texas Demographic Center. 2017. "Urban Texas," August and U.S. Bureau of the Census. Web: www.census.gov.

[5] Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C., & Zumbrunnen, C. (2003). Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. BioScience, 53(12), 1169–1179. https://doi.org/10.1641/0006-3568(2003)053[1169:IHIEOA]2.0.CO;2

TEXAS METRO OBSERV

PEOPLE LAND WATER

09 *Introduction: People and Places in Texas*

09 *Texas Metros: Engines of Texas Growth and Development*

11 *Population Growth Characteristics of Texas Metro Regions*

13 *Patterns of Urban and Suburban Change*

14 *Increasing Diversity in Texas Metros*

16 *An Increasingly Educated Population in Texas Metro Regions*

17 *Poverty in Texas Metro Regions*

17 *Implications of Metro Change for the Future*

20 *Endnotes*

VATORY

INTRODUCTION: PEOPLE AND PLACES IN TEXAS

When we think about the people of Texas, one important dimension is the places where they live and work. In this regard, metropolitan areas are the dominant nexus of economic activity and population in the state. How these metros are growing and changing will strongly shape socioeconomic and environmental outcomes over the next decades. In this section, we examine the changing patterns in where Texans live over the past 25 years and zoom in on some interesting patterns of change over the past five years. This section will focus on 17 metros with populations over 200,000, highlighting patterns of metropolitan growth across the state. Our analysis presents a story of rapid change and transformation in the state's patterns of population settlement and discusses some implications of these changes for the future.

TEXAS METROS: ENGINES OF TEXAS GROWTH AND DEVELOPMENT

This report analyzes demographic and socioeconomic changes across this subset of Texas metros. While there is an abundance of research about the state's "big four" (Austin, Dallas Ft-Worth, Houston, and San Antonio) there is more limited information on other important Texas metros. This report seeks to address this discrepancy, outlining distinct patterns of demographic and socioeconomic change across the set of 17 metros and shifting patterns of growth between urban and suburban areas within these metros.

Table 1: Texas Metropolitan Areas (2015)

	Texas Metro Regions	Total Population 2015
1	**Dallas-Fort Worth-Arlington**	**7,104,415**
2	**Houston-The Woodlands-Sugar Land**	**6,636,208**
3	**San Antonio-New Braunfels**	**2,377,507**
4	**Austin-Round Rock**	**2,000,590**
5	**McAllen-Edinburg-Mission**	**839,539**
6	**El Paso**	**838,527**
7	**Corpus Christi**	**450,183**
8	**Killeen-Temple**	**432,797**
9	**Brownsville-Harlingen**	**420,201**
10	**Beaumont-Port Arthur**	**408,663**
11	**Lubbock**	**309,722**
12	**Laredo**	**269,624**
13	**Waco**	**263,009**
14	**Amarillo**	**261,827**
15	**College Station-Bryan**	**248,554**
16	**Tyler**	**222,277**
17	**Longview**	**216,934**
18	Abilene	169,000
19	Midland	165,430
20	Odessa	155,744
21	Wichita Falls	150,940
22	Sherman–Denison	126,146
23	San Angelo	118,498
24	Victoria	99,028
25	Texarkana	93,635
	All Metros	24,378,998
	State of Texas	27,419,612

Bold font indicates the 17 MSAs with populations greater than 200,000.

Source: U.S. Bureau of the Census. American Community Survey 2013-2017, ACS 5-year Estimates, Accessed through American Factfinder, https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t.

POPULATION GROWTH CHARACTERISTICS OF TEXAS METRO REGIONS

When we examine the full set of metros with populations over 200,000, we see diverse patterns of growth relative to the population growth rate of the state of Texas as a whole.

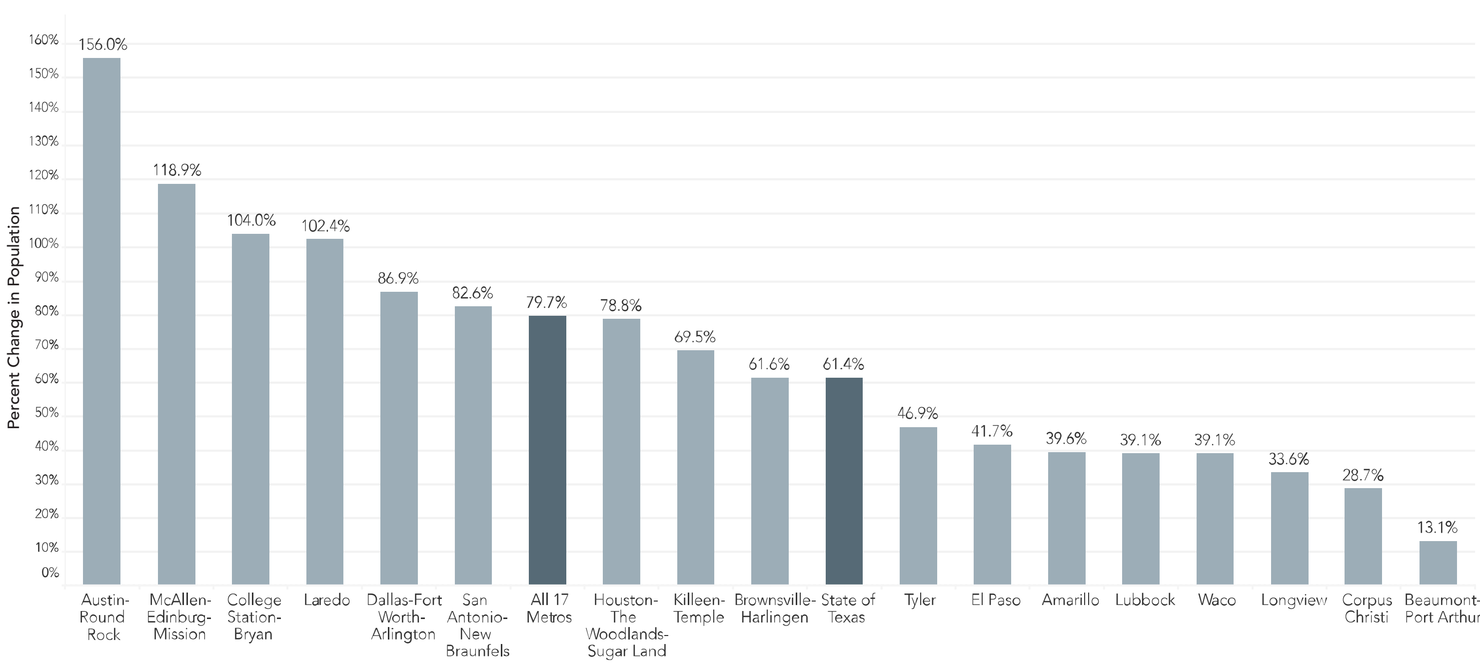
Over this 25-year period, population growth in the State of Texas equaled 61%, while growth in the 17 metros combined growth was close to 80%. The 17 metros in our study set added over 10.3 million residents over the 1990-2015 period. Texas metro regions accounted for almost all of the total population growth in the state over this period, but there was a considerable divergence in the growth patterns across this set of communities.

The metro areas that grew faster than the 17-metro average of 80% over the 1990-2015 years were in the Texas Triangle (a large region anchored by Dallas-Fort Worth at the north and Houston and San-Antonio on the southeastern and southwestern edges) or on the U.S.-Mexico border. The three metros that grew less rapidly than the 17-metro average, but exceeded state population growth, were also in these two larger zones. Metros that grew at a slower pace than the state were dispersed more widely across the state's geography (Table 2). The U.S. population growth rate between 1990 and 2015 was 28%. Only one metro, Beaumont-Port Arthur, grew at a slower rate than the nation.

These longer-term growth trends shifted somewhat over the recent 2010-2015 period. All metro areas that had growth equaling or exceeding the aggregate growth rate for the 17 metros (10.6%) were in the Texas Triangle region, and the state's big four metros dominated population growth in this period. The exception was the Waco MSA, which jumped its long-term growth trend with a 12.1% population growth rate over this period.

Also noteworthy is the relative slowdown of some border MSAs, whose populations all grew at a slower rate than the state of Texas as a whole (8.8%). While recent population growth is dominated by growth in the largest metros, these short-term patterns are subject to change and should not be over-interpreted. However, as noted, long-term aggregate population growth in Texas has been strongly shaped by growth in its four major metros.

Figure 3: Percentage of Population Change, 17 Texas Metros with over 200,000 People (1990-2015)



Source: U.S. Bureau of the Census. Decennial Census and American Community Survey 2013-2017, ACS 5-year Estimate.

Table 2: Population Change (1990-2015)

Booming Metros:	
Austin-Round Rock	156%
McAllen-Edinburg-Mission	119%
College Station-Bryan	104%
Laredo	102%
Dallas-Fort Worth-Arlington	87%
San Antonio-New Braunfels	83%
Fast Growing Metros:	
Houston-The Woodlands-Sugar Land	79%
Killeen-Temple	70%
Brownsville-Harlingen	62%
Slower Growing Metros:	
Tyler	47%
El Paso	42%
Amarillo	40%
Lubbock	39%
Waco	39%
Longview	34%
Corpus Christi	29%
Beaumont-Port Arthur	13%

Source: U.S. Bureau of the Census. Decennial Census, 1990, 2000, 2010 and American Community Survey 2013-2017, ACS 5-year Estimate.

Table 3: Population Change In Texas Metros (2010-2015)

Booming Metros:	
Austin-Round Rock	15.5%
Houston-The Woodlands-Sugar Land	12.3%
Waco	12.1%
Dallas-Fort Worth-Arlington	11.1%
San Antonio-New Braunfels	10.6%
Fast Growing Metros:	
College Station-Bryan	9.1%
Lubbock	8.9%
Slower Growing Metros	
McAllen-Edinburg-Mission	8.4%
Laredo	7.7%
Killeen-Temple	6.7%
Tyler	6.0%
Beaumont-Port Arthur	5.2%
Corpus Christi	4.9%
El Paso	4.7%
Amarillo	4.6%
Brownsville-Harlingen	3.5%
Longview	1.3%

Source: U.S. Bureau of the Census. 2010 Decennial Census 1990, 2000, 2010 and American Community Survey 2013-2017, ACS 5-year Estimate

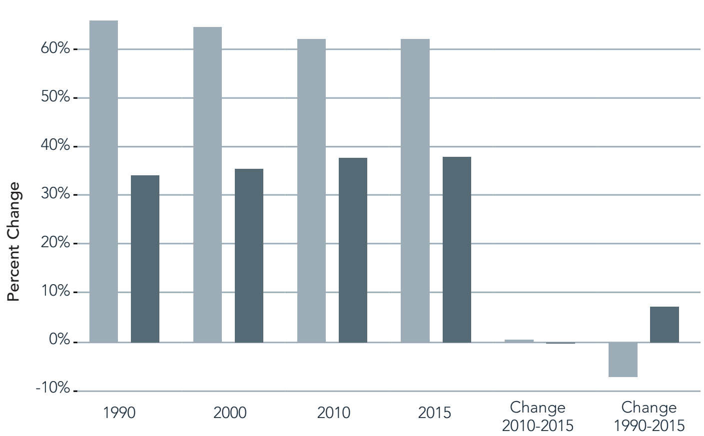
PATTERNS OF URBAN AND SUBURBAN CHANGE

As the state's population increasingly urbanized over the post-WW II period, there was robust growth in both urban and suburban areas. There are multiple ways of conceptualizing urban versus suburban (or non-urban) areas within a metropolitan region.[1] For the purposes of our analysis, we define urban areas of an MSA as: 1) all incorporated jurisdictions and census places with over 25,000 population in a metro; and 2) that have 75% or less single detached housing as a share of total housing units. These urban jurisdictions also exhibited more diverse land uses in general and functioned more as economic and employment centers than other areas that we label as suburban.

In terms of aggregate patterns for the 17 study metros, there was a significant suburbanization trend as the urban share of the total metro population fell from 66% in 1990 to 59% by 2015. The suburban population share increased by 7.2% over the period, equaling 41% of the total metro population by 2015.

It is striking that this steady suburbanization trend inflected over the 2010-2015 period. There was a very small uptick in the urban share of total metro population, which increased from 58.8% in 2010 to 59.1% in 2015. This surprising change in urban-suburban growth patterns is consistent with a national resurgence in core urban areas and shifting preference for city life discussed in numerous popular and scholarly reports.[2] Some have called this shifting pattern of metro growth an "urban inversion" where higher-income residents are moving back to more urbanized areas after a half century of flight to suburban communities.[3] However, the reversal of suburbanization trends over the 2010-2015 period for the 17 Texas metros is not significant enough to claim that Texas metros are clearly experiencing an urban inversion process. First, the urban share of the total metro population only increased in seven of the 17 metros. In the other ten, the suburban population share continued to increase over the 2010-2015 period. Second, this single short time period is not adequate to make statements about a reversal of more durable trends. If urbanization trends persist and spread based upon evidence from the 2020 decennial census, this would add support to a broader urban inversion dynamic. All we can confidently say from these short-term trends is that Texas has not been exempt from national urbanization trends over the 2010-2015 period.

Figure 4: Urban-Suburban Population Shares (1990-2015)



Source: U.S. Bureau of the Census. Decennial Census 1990, 2000, 2010 and American Community Survey 2013-2017, ACS 5-year Estimate.

Table 4: Change in Urban Share of Metro Population (2010-2015)

Waco	-6.02%
Beaumont-Port Arthur	-4.63%
Killeen-Temple	-2.17%
Houston-The Woodlands-Sugar Land	-1.75%
Amarillo	-1.09%
Lubbock	-1.01%
San Antonio-New Braunfels	-0.61%
Brownsville-Harlingen	-0.46%
Tyler	-0.38%
El Paso	-0.38%
Longview	0.24%
Laredo	0.41%
17 MSAs	0.49%
McAllen-Edinburg-Mission	0.58%
Corpus Christi	0.76%
College Station-Bryan	2.12%
Dallas-Fort Worth-Arlington	2.13%
Austin-Round Rock	5.97%

Source: U.S. Bureau of the Census. Decennial Census 1990, 2000, 2010 and American Community Survey 2013-2017, ACS 5-year Estimate.

INCREASING DIVERSITY IN TEXAS METROS

Texas has been a racially and ethnically diverse state relative to many other states in the nation throughout its history. However, since 1990, Texas metros have experienced a rapid increase in the racial and ethnic diversity of their populations. While the White, Non-Hispanic/Latino population in the 17 metros increased by 1.95 million over the 1990-2015 period, its share of the total metro population decreased from 57.7% in 1990 to 40.5% in 2015. The African American population of these metros grew by almost 1.3 million over the period, but the share of African Americans in the metro population remained almost unchanged, falling slightly from 13% in 1990 to 12.7% in 2015 (Figure 5).

The largest increases in metro population were due to rapid growth in Hispanic-Latino and Asian residents. The Hispanic/Latino metro population grew by 5.8 million over the period, increasing its total share of the metro population from about 27% in 1990 to 40% by 2015. Asian residents of the 17 metro areas saw the largest percentage increase of any group of a relatively small base in 1990. The Asian population in this set of metros increased from roughly 302,000 in 1990 to 1.2 million by 2015, an increase of 298%.

This increase in diversity in Texas metros has occurred in both urban and suburban areas. In urban areas, the White, Non-Hispanic/Latino population increased by 190,000 over the 25-year period, but its share of population decreased significantly, from 51.3% to 33.4% of the core urban population. The African American share of the urban metro population also declined slightly from 15.6% in 1990 to 14.4% in 2015. On the other hand, the Hispanic/Latino urban metro population boomed, with over 3.6 million additional urban residents added from 1990 to 2015. The Hispanic/Latino share of the urban metro population grew from 30.6% in 1990 to 45.5% by 2015. The Asian urban metro population also increased significantly, with its share of the urban metro population expanding from 2.1% of

Source: https://www.houstonchronicle.com/news/houston-texas/houston/article/Fall-in-oil-prices-does-little-to-slow-Houston-s-7004608.php

Figure 5: Change in Racial/Ethnic Shares of Total Population, Texas Metros with over 200,000 People (1990-2015)

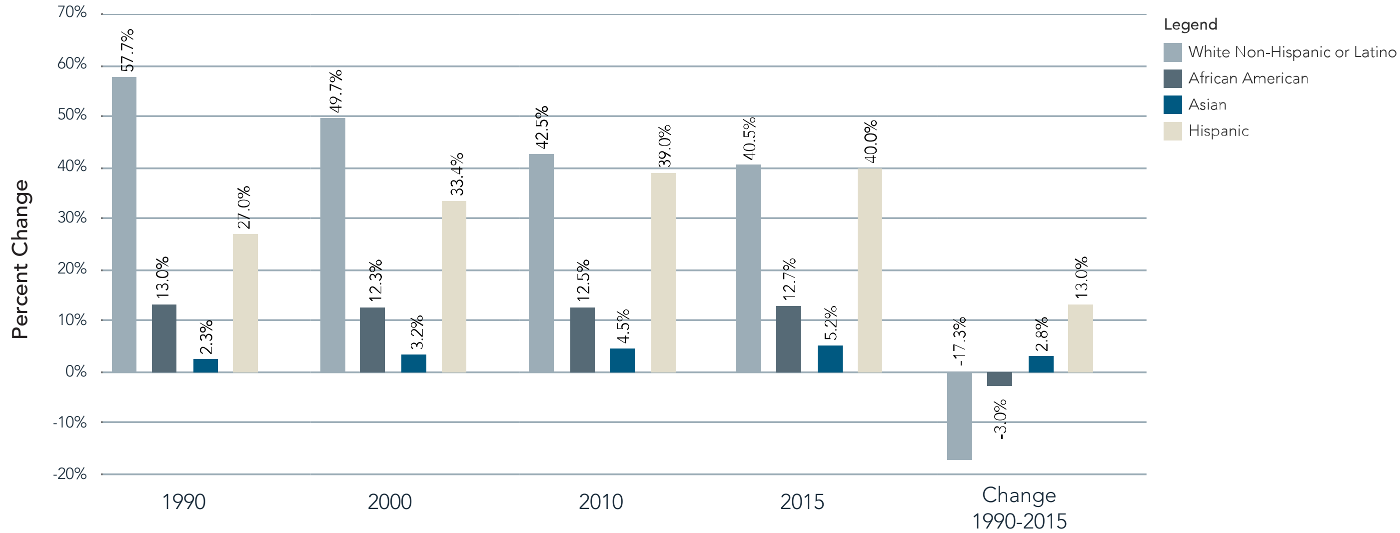


Figure 6: Change in Racial/Ethnic Shares of Urban Population, Texas Metros with over 200,000 People (1990-2015)

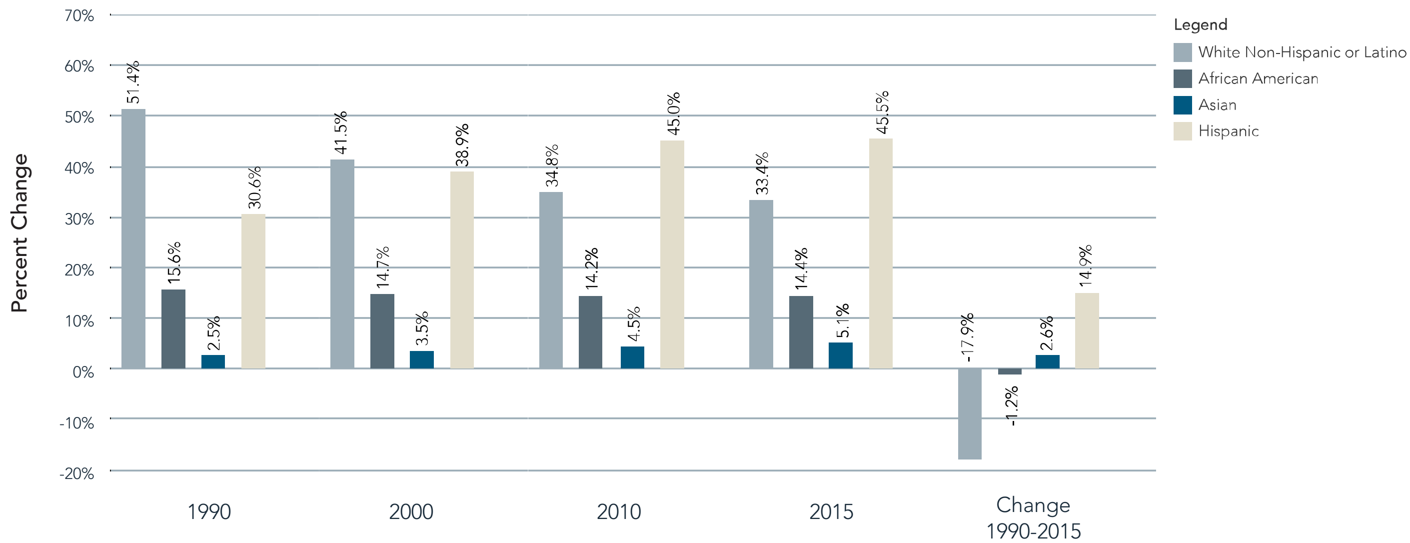
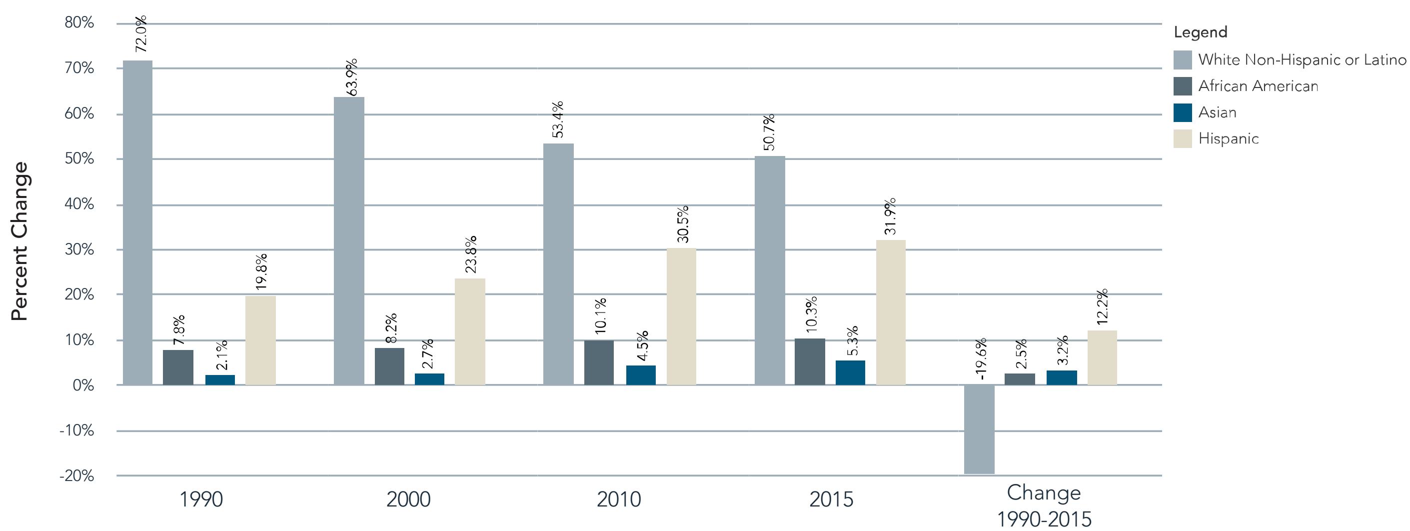


Figure 7: Change in Racial/Ethnic Shares of Suburban Areas of Metros, Texas Metros with over 200,000 People (1990-2015)



Source: U.S. Bureau of the Census. Decennial Census 1990, 2000, 2010 and American Community Survey 2013-2017, ACS 5-year Estimate.

the urban population in 1990 to about 5.1% by 2015 (Figure 6). Growing diversity in metros over the 25-year period was also experienced in suburban jurisdictions and areas outside core urban areas. The White, Non-Hispanic Latino share of suburban population fell at a greater rate than its share of the urban population, from 70.2% in 1990 to 50.7% in 2015. All other racial/ethnic groups saw their shares of the suburban metro population increase over the period (Figure 7).

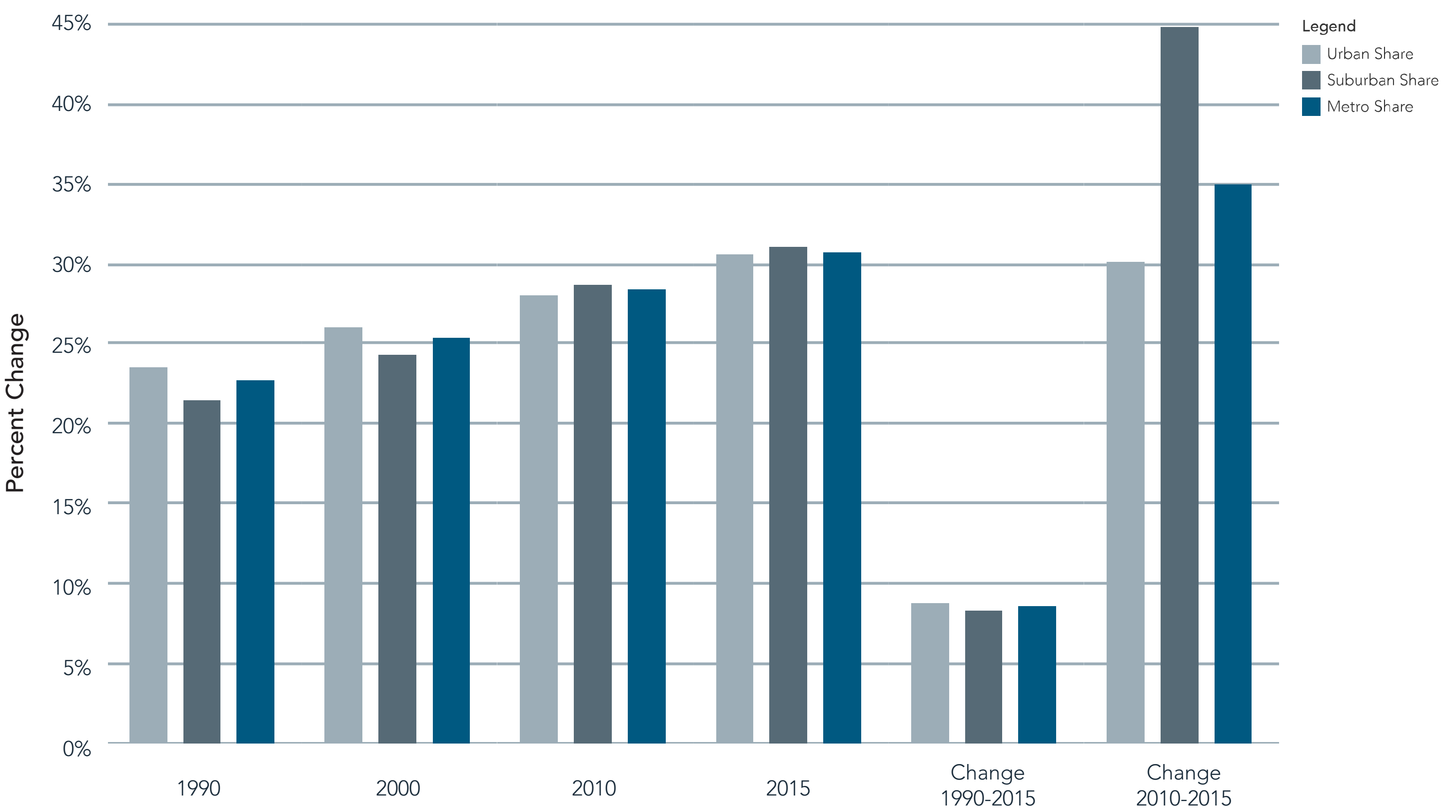
AN INCREASINGLY EDUCATED POPULATION IN TEXAS METRO REGIONS

Educational attainment as measured by population over 25 years of age with a bachelor's degree or more (advanced degrees beyond the bachelors) has been increasing in the U.S. for the past 60 years.[4] About 33% of the U.S. population over 25 had a bachelor's or higher degree as of 2015. Texas has a lower level of educational attainment than the nation by this measure, with 28.1% of the adult population with a bachelor's or higher degree in 2015. In the 17 Texas metros studied here, over 30.7% of the adult population had a bachelor's or higher degree. This measure of educational attainment increased significantly in the Texas metros, growing from about 22.8% of the adult population in 1990.

There was a modest shift in this educational attainment measure over the 1990-2015 period between urban and suburban areas of the metro regions. Over this period, educational attainment in suburban areas of metros increased at a faster rate than in urban areas. In 1990, the share of the population over 25 with a bachelors or advanced degree in urban areas was 23.5% versus 21.5% in suburban communities. By 2015, the suburban share with higher educational attainment was 31% compared to 30.5% in urban areas.

However, this trend of faster growth in educational attainment in the suburbs stalled over the 2010-2015 period. The urban share of the total metro population with higher educational attainment increased by about .5% while the suburban share decreased by .5% between 2010 and 2015. Like the recent modest population shift toward urban areas (see above), this very small increase in the urban share of the population with

Figure 8: Share of Population over 25 with Bachelor's Degree or Greater, Texas Metros with over 200,000 People (1990-2015)



Source: U.S. Bureau of the Census. Decennial Census 1990, 2000, 2010 and American Community Survey 2013-2017, ACS 5-year Estimate higher educational attainment is consistent with the urban inversion story. It seems that over the 2010-2015 period more highly educated residents are moving at slightly higher rates to urban areas of metros. However, this very modest shift in longer-term trends is not sufficient to support any definitive claims about changing urban-suburban growth processes.

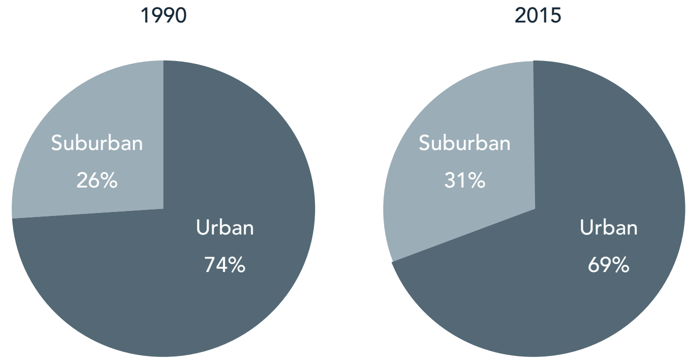
POVERTY IN TEXAS METROS

The total population in poverty in Texas steadily increased over the 1990-2015 period even as poverty rates of the population fluctuated in response to economic conditions. The population living in poverty increased by over 914,000 over the 25-year period, but poverty rates trended marginally downward. The share of total metro poverty in urban areas has significantly exceeded the share in suburban areas. However, this pattern is slowly changing as the suburban poverty population has grown at a faster rate than in urban areas.

Several authors have highlighted a national pattern of suburbanization of poverty.[5] Explanations of this phenomenon generally focus on increasing costs of living, especially housing in core urban areas. These cost pressures, it is argued, have pushed lower-income households to seek lower-cost suburban areas for more affordable housing and services.[6]

When we look at patterns across the 17 metro areas, the share of the metro poverty population residing in the suburbs has definitely been increasing over the 25-year period and over the 2010-2015 years. However, the growth in the suburban population in poverty has grown more slowly than the overall growth in the suburban population, leading to a fall in the suburban poverty rate.

Figure 9: Urban and Suburban Shares of MSA Population Living in Poverty



These data clearly demonstrate that the growth of the suburban population in poverty significantly exceeded the growth in both the metro and urban population in poverty. If this trend persists into the future, it will present important challenges for suburban communities and governments. Since services for low-income residents are concentrated in urban areas, many suburban areas will experience increased pressure to provide better job access and social and health services for this growing population.

IMPLICATIONS OF METRO CHANGE FOR THE FUTURE

The hothouse growth experienced by Texas metropolitan regions over the past 25 years has generated significant changes in the character and structure of where most Texans live. Metros of the state are significantly different places today than they were in 1990. Rapid growth has gone alongside

Table 5: Metro, Urban, and Suburban Poverty Population (1990-2015), 17 Texas Metros Over 200,000 Population

	1990	2000	2010	2010	Absolute Change '90-'15	Absolute Change '10-'15
Metro Poverty Population	1,320,098	1,502,159	2,142,273	2,234,679	914,581	92,406
Metro Poverty Rate	14.62%	12.83%	14.36%	13.34%	-1.27%	-1.02%
Urban Poverty Population	974,662	1,092,516	1,492,548	1,546,269	571,607	53,721
Urban Poverty Rate	16.10%	14.49%	16.83%	15.49%	-0.61%	-1.35%
Suburban Poverty Population	345,436	409,643	649,725	688,410	342,974	38,685
Suburban Poverty Rate	11.60%	9.82%	10.73%	10.18%	-1.43%	-0.56%
Urban Share of Poverty in MSA	73.83%	72.73%	69.67%	69.19%	-4.64%	-0.48%
Suburban Share of Poverty MSA	26.17%	27.27%	30.33%	30.81%	4.64%	0.48%

Source: U.S. Bureau of the Census. Decennial Census 1990, 2000, 2010 and American Community Survey 2013-2017, ACS 5-year Estimate an expansion of suburban and exurban settlement at metro edges. The swift expansion of suburban areas poses challenges in terms of land and resource consumption, transportation access, and ever-increasing demands for infrastructure and public services. Many studies suggest that sprawling urban development imposes significant environmental, social and fiscal costs compared to more compact urban development patterns.

The fact that suburbanization seems to have halted in some metros over the 2010-2015 period may signal a change in the evolution of metro settlement patterns. However, the data and trends presented here are too brittle to conclude that a widespread re-urbanization of Texas metros is underway. The growing urban shares of metro populations over the 2010-15 years only occurred in seven of the 17 metro areas analyzed in this report.

One powerful finding of this work is that Texas metros are dramatically more diverse places than they were in 1990. The broad increase in racial and ethnic diversity across Texas metros has been driven by large increases in Hispanic-Latino and Asian residents. The African American population has grown in step with overall metro growth, leaving the African American shares of metro populations more or less unchanged. It is noteworthy that the image of suburbs as being less diverse and more homogeneous places has been overturned by demographic change over the past 25 years. The White, Non-Hispanic-Latino share of suburban population fell at a greater rate than its share of the urban population, from 70.2% in 1990 to 50.7% in 2015. All other racial/ethnic groups saw their shares of the suburban population increase over the period. By all measures, Texas metros are currently more multi-cultural, cosmopolitan places than in the past.

Current residents of Texas metros have significantly higher levels of educational attainment than in 1990. In the 17 Texas metros studied here, over 30.7% of the adult population had a bachelor's or higher degree by 2015. This measure of educational attainment increased significantly, growing from about 22.8% of the adult population in 1990, to over 30.7% in 2015. Over the 25-year period, educational attainment in suburban areas of metros increased at a faster rate than in urban areas. However, the urban share of the total metro population with higher educational attainment increased by about .5% while the suburban share decreased by .5% between 2010 and 2015. Like the modest population shift toward urban areas between 2010 and 2015, this very small increase in the urban share of the population with higher educational attainment is not clear enough to establish a clear future trend.

A final challenging trend uncovered in this analysis is an increasing suburbanization of persons living in poverty. While poverty rates have varied and trended modestly downward, the number of people living in poverty continues to increase. Over the 25-year study period the growth of the suburban population in poverty significantly exceeded the growth in both the metro and urban population in poverty. Evidence suggests that this is a durable trend that will challenge suburban communities to generate living wage jobs and provide improved access and services to growing low-income populations.

San Antonio, Texas
Source: https://www.wje.com/office/san-antonio

ENDNOTES

[1] See for example, Forsyth, Ann. 2012, "Defining Suburbs," Journal of Planning Literature, Vol. 27, #3, pp. 270-281.

[2] See for example Barrington-Leigh, Christopher and Adam Millard –Ball. 2015, "A Century of Sprawl in the United States," Proceedings of the National Academy of Sciences, 112, pp. 8244-8249 and Hamdi, S., R. Ewing, I. Preuss and A. Dodds. 2015. "Measuring Sprawl and its Impacts: An Update," Journal of Planning Education and Research, Vol. 35, pp. 35-50, Myers, Dowell. 2015. Peak Millennials: Three Reinforcing Cycles that Amplify the Rise and Fall of Urban Concentration by Millennials," Housing Policy Debate, Vol. 26, pp. 928-947.

[3] See Ehrenhalt, Alan. 2013. The Great Inversion and the Future of the American City, New York: Vintage Press.

[4] Ryan, Camille and Kurt Bauman. 2016. "Educational Attainment in the United States: 2015," Current Population Reports, Washington: U.S. Census Bureau, March, p. 4.

[5] See Kneebone, Elizabeth, and Alan Berube. 2013. "Confronting suburban poverty in America," Washington, DC: Brookings Institution Press and Kneebone, Elizabeth and Emily Garr. 2010. The suburbanization of poverty: Trends in metropolitan areas, 2000 to 2008. Washington, DC: Brookings Institution Press.

[6] See Howell, Aaron and Jeffry Timberlake. 2016. "Racial and Ethnic Trends in the Suburbanization of Poverty in U.S. metropolitan Areas, 1980-2010," Journal of Urban Affairs, Vol. 36, No. 1, pp. 79-98.

TEXAS

METRO

PEOPLE **LAND** WATER

OBSERV

23 Introduction

26 Statewide Summary

26 Trends and Analysis

37 Conclusion

38 Endnotes

INTRODUCTION

Rapid growth in Texas manifests in a variety of ways, including physical changes on the land surface. This section looks at such changes, also known as land cover, to understand how Texas metros change physically as population increases. Measurement and analysis of land cover provide vital information for both urban and rural Texans. The density and intensity of development affect the quality of life for urban residents, and access to rural and natural lands will become scarcer as development continues. Expanding cities and growing populations mean there will be less land for more people, but also more people closer together can mean increased risk from natural disasters. To better understand how metros are growing physically, population will be analyzed against three metro land indicators: 1) Developed Land, 2) Development Density, and 3) Average Development Imperviousness (Table 6).

The three metrics are calculated using the National Land Cover Database (NLCD) as the source of information on land cover. The NLCD is produced by a consortium of federal agencies and provides reliable, fine-scale land cover data (30-meter resolution) on land cover from 2001 to 2016. NLCD leverages processed satellite imagery to identify 15 different land cover classes (forest, cropland, pasture, wetland, etc.). Past studies have leveraged land cover data to analyze physical patterns of growth, but this is the first to look at the recently released 2016 data.[1,2,3,4] It is also the first to simultaneously examine imperviousness, which estimates how much of the surface within a cell can be penetrated by water. Imperviousness is important for many reasons, including water quality, stormwater runoff, urban heat island effect (the increase in temperatures in urban, developed areas due to heat retained in constructed materials), and more. Land cover provides a physical perspective on metropolitan growth at a fine resolution. For comparison, the Austin-Round Rock MSA is comprised of 46 Census Places (cities, towns) but more than 19 million NLCD cells (Figure 10,11) providing an important basis for understanding metro growth.

Table 6: Descriptions of Land Cover Metrics

Indicator	Description
Developed Land	Areas with constructed materials including buildings, pavement, or other infrastructure
Development Density	Total residential population divided by total acres of developed land
Average Development Imperviousness	The percent of developed land surface that water cannot infiltrate

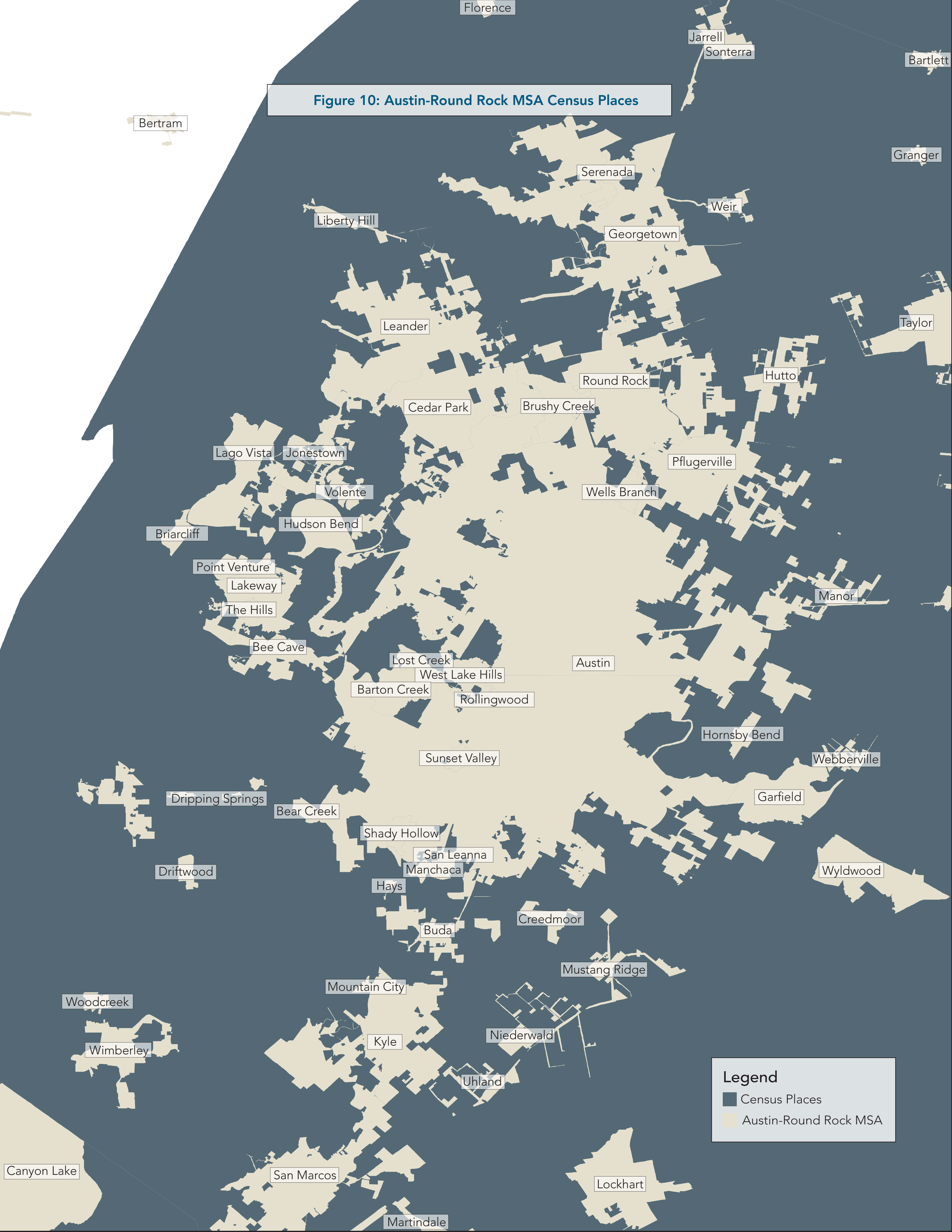


Figure 10: Austin-Round Rock MSA Census Places
Florence
Jarrell
Sonterra
Bartlett
Bertram
Granger
Serenada
Weir
Liberty Hill
Georgetown
Taylor
Leander
Hutto
Round Rock
Cedar Park
Brushy Creek
Lago Vista
Jonestown
Pflugerville
Volente
Wells Branch
Hudson Bend
Briarcliff
Point Venture
Lakeway
Manor
The Hills
Bee Cave
Lost Creek
Austin
West Lake Hills
Barton Creek
Rollingwood
Hornsby Bend
Webberville
Sunset Valley
Dripping Springs
Garfield
Bear Creek
Shady Hollow
San Leanna
Wyldwood
Driftwood
Manchaca
Hays
Creedmoor
Buda
Mustang Ridge
Mountain City
Woodcreek
Niederwald
Kyle
Wimberley
Uhland
Legend
Census Places
Austin-Round Rock MSA
Canyon Lake
San Marcos
Lockhart
Martindale

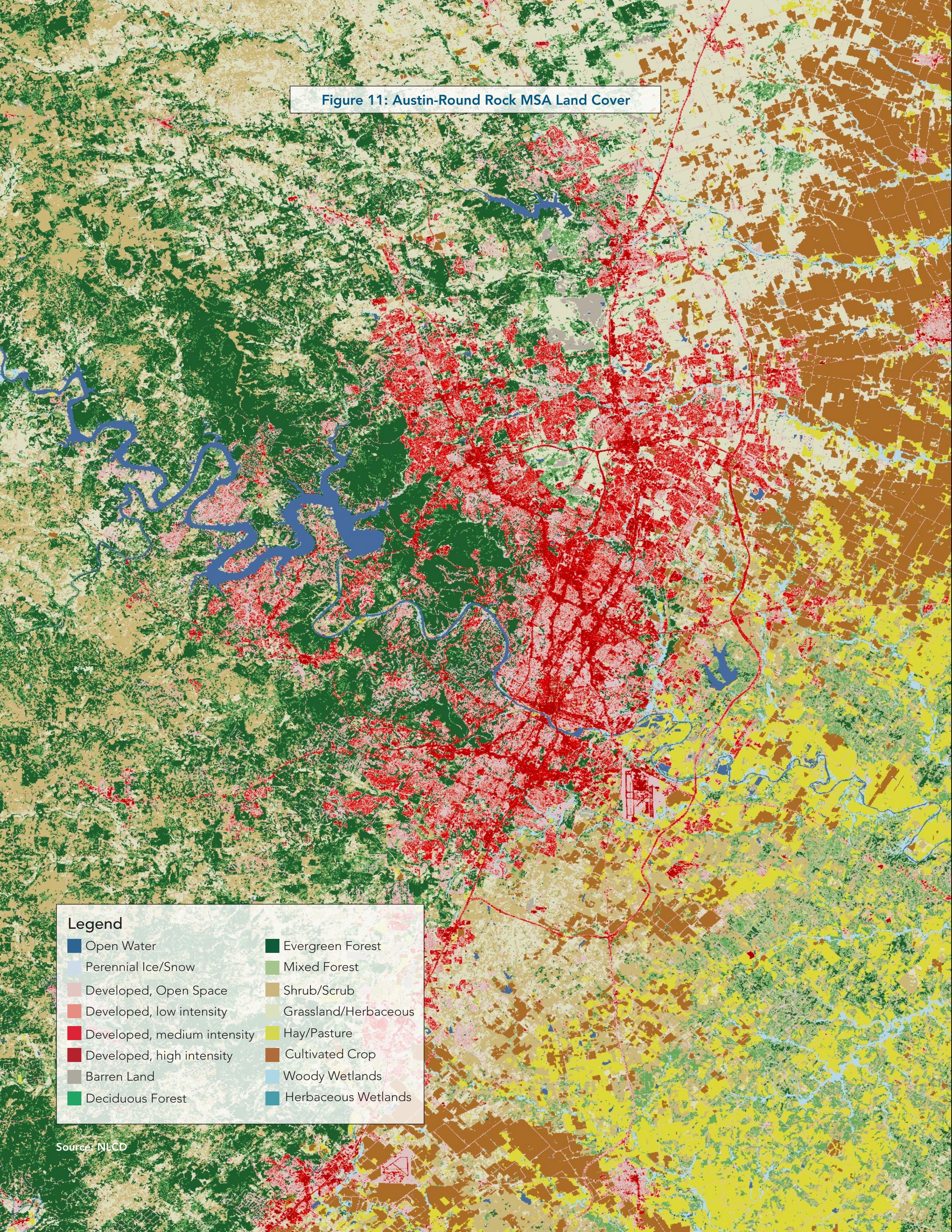


Figure 11: Austin-Round Rock MSA Land Cover
Legend
Open Water
Perennial Ice/Snow
Developed, Open Space
Developed, low intensity
Developed, medium intensity
Developed, high intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grassland/Herbaceous
Hay/Pasture
Cultivated Crop
Woody Wetlands
Herbaceous Wetlands
Source: NLCD

STATEWIDE SUMMARY

As home to several of the fastest growing metros in the United States, it is no surprise that Texas has experienced a significant increase in developed land since 2001. Table 7 provides a summary of metro land metrics for 2001, 2006, 2011, and 2016. While Texas population increased by nearly 6.5 million residents (35%), more than 865,000 (18%) acres were developed across Texas metros. That is roughly equivalent to 44,000 football fields of development each year, or 134 acres of new development per 1,000 new residents. Over the same period, the ***development density*** and ***average developed imperviousness*** also increased by 15% and 9%, respectively.

Figure 12 provides 5-year trends for population growth and each of the three land metrics. Population growth slowed slightly, though remains relatively high at 10% over the most recent 5-year period. The rate of land development over time, or ***urban expansion,*** slightly decreased in the middle period but saw a significant reduction in the most recent 5-year period. Simultaneously, ***development density*** saw a sharp increase, signaling the reduction of urban expansion from '11 to '16 was driven, in part, by a jump in the density of development across metro TX. These trends translate to a significant reduction in ***urban expansion per capita*** from 153 acres per 1,000 new residents to 106 acres per 1,000 new residents (Figure 13). ***The Imperviousness of Development*** increased over the study period, though the rate of change slowed down from 3.6% in '01 to '06 to 2.1% in '11 to '16.

TRENDS AND ANALYSIS

Statewide land metrics give an important summary of land trends across the state, but further analysis of the relationships between metrics reveals how land is used very differently across the state (Table 8).

For example, ***urban expansion per capita*** differs significantly by MSA size (Figure 14). Metros under 250k residents expanded at much higher rates (368 acres per 1,000 new residents) than large metros with over 750k residents (117 acres per 1,000 new residents). However, there is a large range even among similarly sized MSAs. Both Brownsville-Harlingen and Beaumont-Port Arthur MSAs are medium-sized (422k and 411k residents in 2016, respectively), but they have vastly different rates of ***urban expansion***. In fact, at 80 and 1,145 acres developed per 1,000 new residents, respectively, they represent the upper- and lower-limits within Texas.

Despite the variety within the data, there is a clear pattern about where growth is occurring – 89% of population growth since 2001 occurred in metros with over 750k residents (Figure 15). The concentration of growth in larger metros that are less consumptive of land is a driver for statewide levels of development, yet it does not explain the significant reduction in the rate of expansion over time. The proportion of statewide population growth in large metros stays relatively constant throughout the study period (min of 88.7% and max of 90.4%), yet the per capita rate of ***urban expansion*** in large metros decreased by 37.5% (Figure 16). Therefore, the changes in ***urban expansion per capita*** cannot be explained by shifting trends in population growth.

What is clear is the increasingly efficient use of land has been accompanied by rising densities. The largest drop in the rate of expansion occurred in large metros from '11 to '16, the same period as the largest increase in density (Figure 17). MSA scale land metrics alone do not provide sufficient information to understand why densification or reductions in land consumption are occurring, but given this relationship, analysis of the relationship between density and the other land metrics provides additional insight into metro development patterns.

The metros with the most population growth tend to be denser, with the cities on the Texas-Mexico border being the exception (especially El Paso) (Figure 18). As expected, the densest metros also are the least consumptive of land and tend to have higher levels of imperviousness (Figure 19). Finally, there appears to be a positive, but weak, relationship between changes in density and changes in imperviousness (Figure 20). It is possible to increase imperviousness without much densification (Killeen-Temple), to densify without increasing

Table 7: Summary of Land Metrics for Metropolitan Texas (2001-2016)

Year	Population	Developed Land (Acres)	Development Desity (ppl/acre)	Average Developed Imperviousness (%)
2001	18,326,474	4,911,989	3.73	31.92%
2006	20,431,822	5,233,652	3.90	33.07%
2011	22,537,171	5,543,076	4.07	33.98%
2016	24,790,657	5,781,213	4.29	34.70%

Excludes the Texarkana MSA, which falls in both Texas and Arkansas.

Source: 2001 and 2006 populations interpolated using 2000 and 2010 Census populations, 2011 and 2016 populations pulled from US Census Annual Estimates of the Resident Population; NLCD

Figure 12: Five Year Land Metrics Trends for Metropolitan Texas (2001-2016)

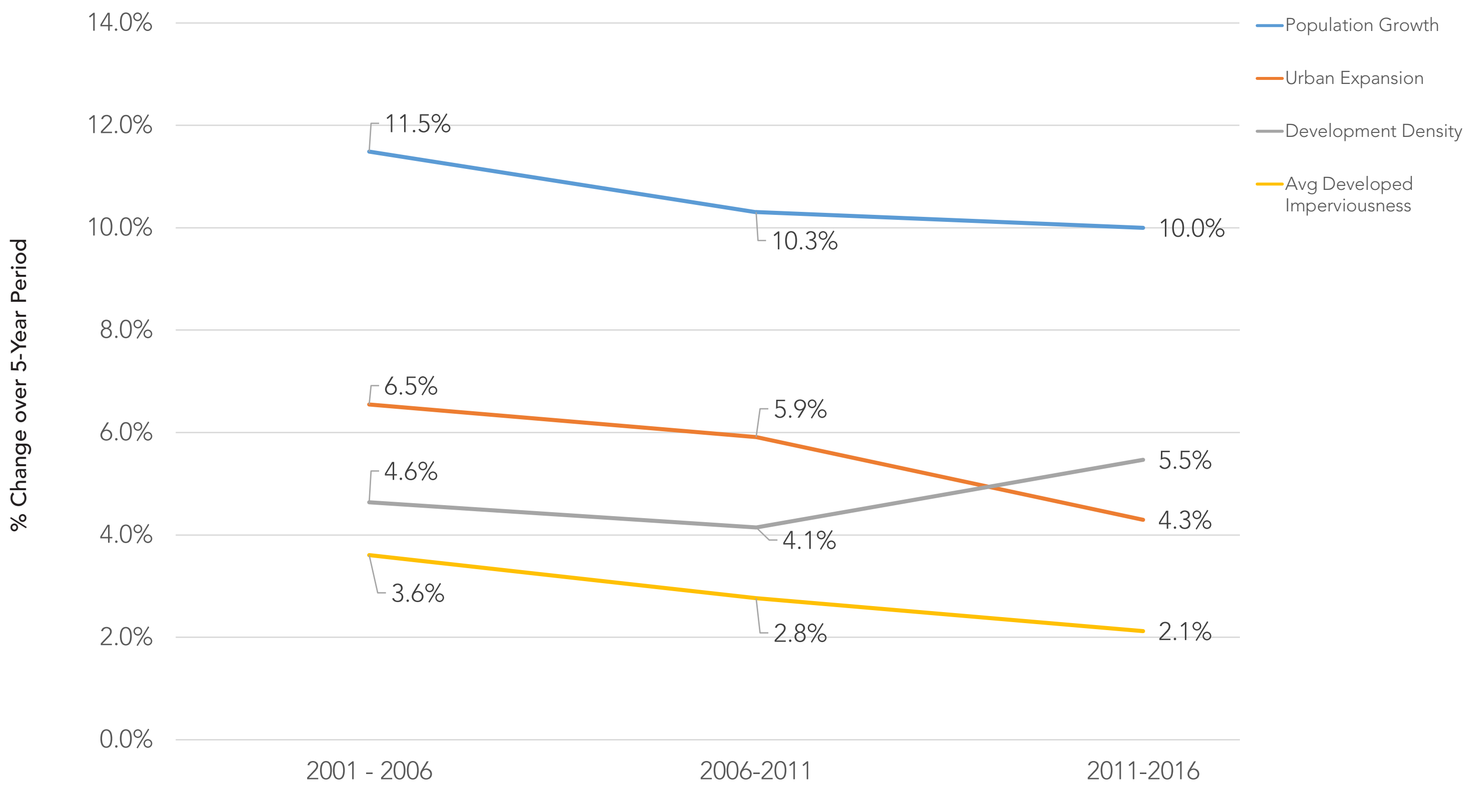
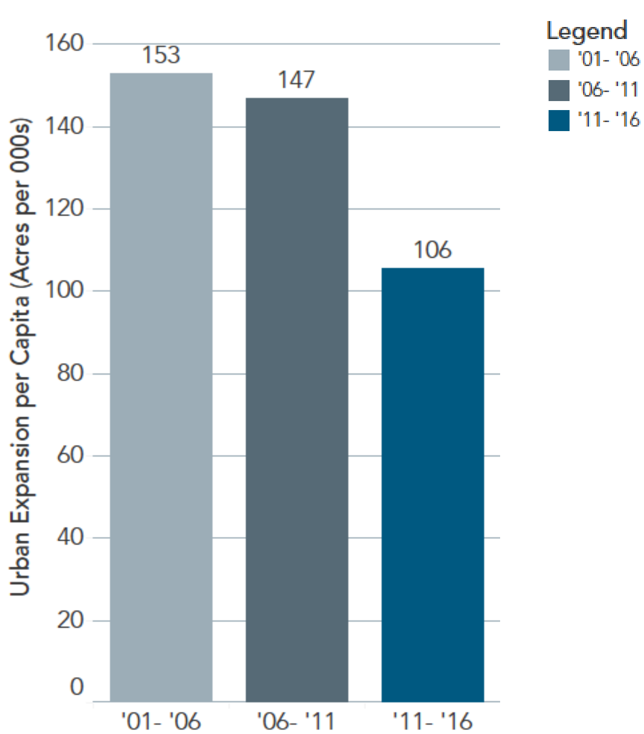


Figure 13: Five Year Urban Explansion per Capita Trends for Metropolitan Texas (2001-2016)



imperviousness (McAllen-Edinburg-Mission), or to become both more impervious and denser (Austin, TX) (Figure 21).

It is noteworthy that all but one Texas metro has increased in its average levels of imperviousness. The exception, Laredo, was the most impervious TX metro in 2001 and remains one of the two highest in 2016. Imperviousness has a mixed relationship with metro size (Figure 22). Large metros all have either medium or high levels of imperviousness. Smaller and medium-size metros have a wide range of imperviousness levels ranging from 19.4% (Abilene) to 41.0% (Laredo).

The relationship between metro size and changes in imperviousness is even more varied (Figure 23), perhaps because there are limits to how impervious a metro can become. The metros with the highest levels of imperviousness all experienced medium to small (or slightly negative) changes in imperviousness. The inverse is not necessarily true; metros with low levels of imperviousness (Odessa, Amarillo, Midland, Abilene) do not necessarily see it increase rapidly. Geographic location seems to be the best predictor of increasing imperviousness as four of the top five changes occurred in Central Texas (Austin, Killeen, San Antonio, and Waco).

Figure 14: Urban Expansion per Capita by MSA Size

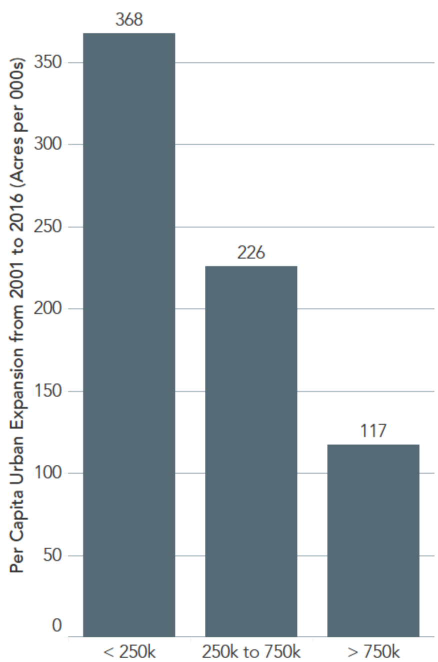


Figure 15: Population Growth by MSA Size

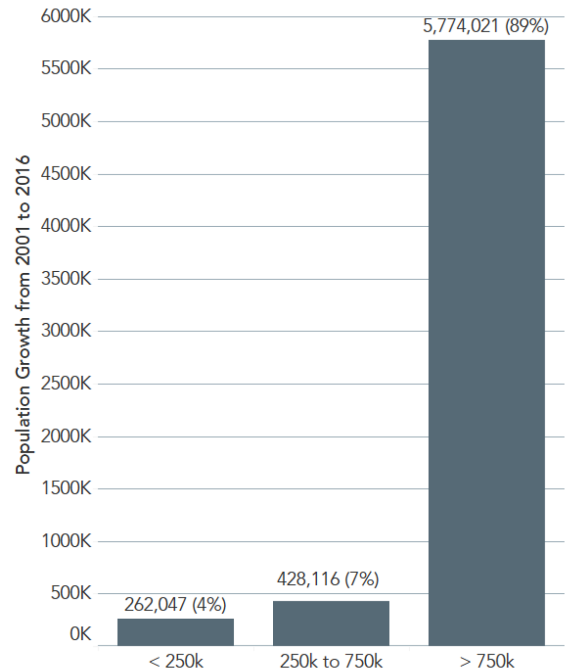


Figure 16: Five Year Trends in Urban Expansion per Capita

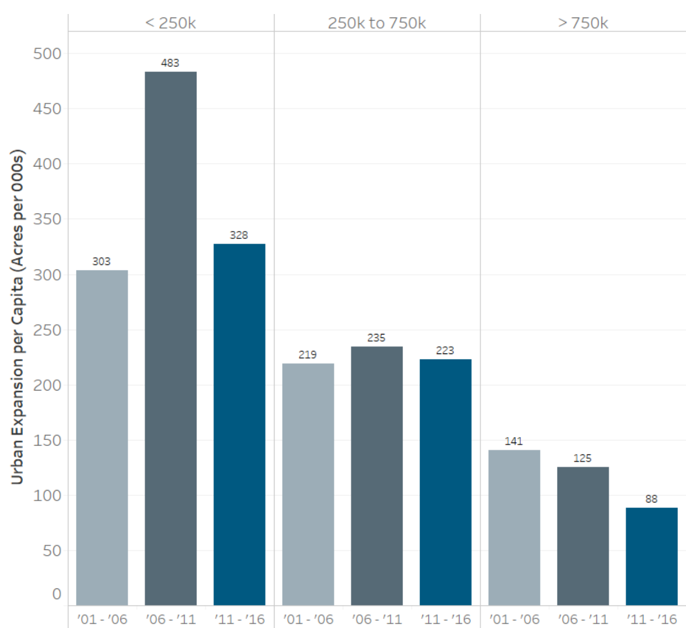


Figure 17: Change in Density Over Time by MSA Size

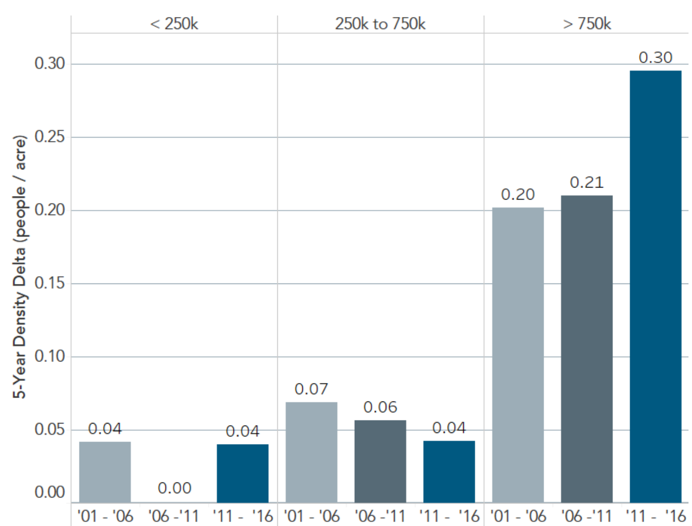


Table 8: Summary of MSA Popu

	Population			
MSA	2001	2016	Pop Growth	2001
Abilene, TX	160,824	170,018	9,194	92,836
Amarillo, TX	231,186	263,327	32,141	106,902
Austin-Round Rock, TX	1,298,021	2,062,211	764,190	316,001
Beaumont-Port Arthur, TX	400,639	411,263	10,624	195,865
Brownsville-Harlingen, TX	342,324	422,137	79,813	87,039
College Station-Bryan, TX	189,113	254,825	65,712	84,660
Corpus Christi, TX	405,793	454,299	48,506	123,993
Dallas-Fort Worth-Arlington, TX	5,328,351	7,262,951	1,934,600	1,179,680
El Paso, TX	695,753	842,260	146,507	111,525
Houston-The Woodlands-Sugar Land, TX	4,817,089	6,812,260	1,995,171	1,119,129
Killeen-Temple, TX	338,135	436,744	98,609	118,901
Laredo, TX	198,832	272,520	73,688	49,035
Longview, TX	196,046	217,322	21,276	112,697
Lubbock, TX	259,802	313,816	54,014	107,139
McAllen-Edinburg-Mission, TX	590,034	850,798	260,764	152,588
Midland, TX	122,969	169,500	46,531	54,767
Odessa, TX	122,807	157,805	34,998	42,170
San Angelo, TX	106,467	119,187	12,720	58,426
San Antonio-New Braunfels, TX	1,755,537	2,428,326	672,789	453,402
Sherman-Denison, TX	111,579	128,331	16,752	49,715
Tyler, TX	178,166	225,344	47,178	80,836
Victoria, TX	91,356	99,981	8,625	46,031
Waco, TX	234,239	264,960	30,721	94,612
Wichita Falls, TX	151,411	150,472	(939)	74,040

lation Growth and Land Metrics

Developed Land (Acres)			Development Density (ppl/acre)			Average Development Imperviousness (%)		
2016	Urban Expansion	Expansion per Capita (Acres per 000s)	2001	2016	Delta	2001	2016	Delta
97,308	4,472	486	1.73	1.75	0.01	17.7%	19.4%	1.8%
117,733	10,831	337	2.16	2.24	0.07	22.8%	23.9%	1.1%
397,715	81,714	107	4.11	5.19	1.08	25.6%	31.1%	5.5%
208,034	12,168	1145	2.05	1.98	-0.07	30.2%	31.4%	1.2%
93,394	6,355	80	3.93	4.52	0.59	35.3%	36.3%	1.0%
100,683	16,024	244	2.23	2.53	0.30	22.3%	26.2%	3.9%
136,856	12,863	265	3.27	3.32	0.05	35.7%	38.2%	2.5%
1,397,703	218,022	113	4.52	5.20	0.68	36.2%	39.0%	2.8%
137,548	26,023	178	6.24	6.12	-0.12	39.1%	41.1%	2.0%
1,365,042	245,913	123	4.30	4.99	0.69	38.3%	40.7%	2.4%
137,268	18,367	186	2.84	3.18	0.34	22.4%	26.8%	4.4%
66,040	17,004	231	4.05	4.13	0.07	41.6%	41.0%	-0.6%
120,995	8,298	390	1.74	1.80	0.06	30.1%	31.2%	1.1%
119,164	12,025	223	2.42	2.63	0.21	20.1%	22.1%	2.0%
176,985	24,397	94	3.87	4.81	0.94	34.0%	35.2%	1.2%
80,614	25,847	555	2.25	2.10	-0.14	20.8%	22.0%	1.2%
55,164	12,994	371	2.91	2.86	-0.05	24.6%	24.7%	0.2%
69,330	10,904	857	1.82	1.72	-0.10	23.6%	25.6%	2.0%
533,473	80,072	119	3.87	4.55	0.68	27.0%	30.9%	3.9%
52,273	2,558	153	2.24	2.46	0.21	21.5%	23.1%	1.6%
89,072	8,236	175	2.20	2.53	0.33	31.6%	33.4%	1.9%
49,745	3,714	431	1.98	2.01	0.03	19.4%	22.1%	2.6%
101,691	7,079	230	2.48	2.61	0.13	18.1%	21.3%	3.3%
77,384	3,344	N/A	2.04	1.94	-0.10	25.9%	27.7%	1.7%

Figure 18: Development Density (2016) vs Population Growth (2001-2006)

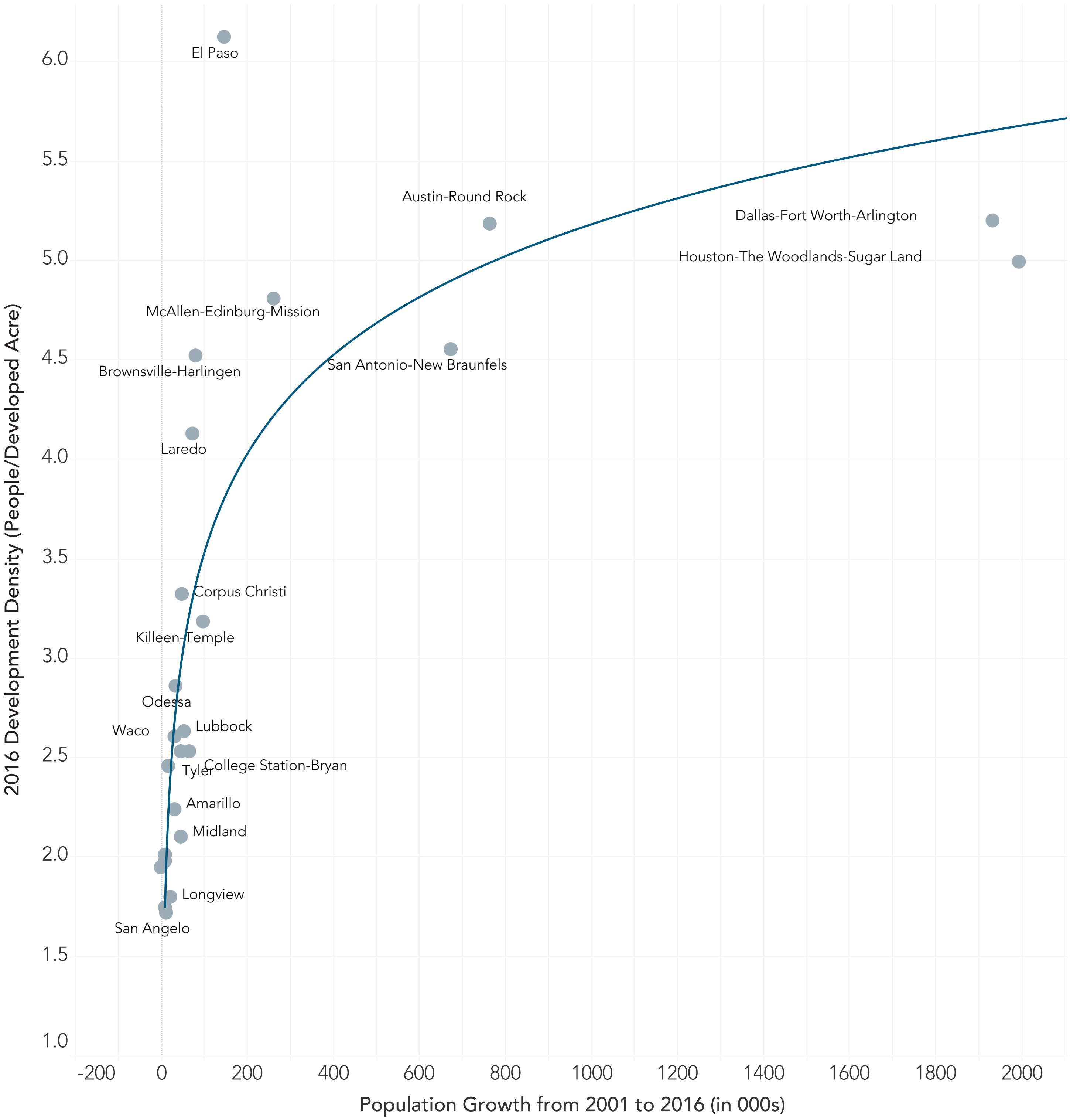


Figure 19: Development Density (2016) vs Urban Expansion per Capita (2001-2016)

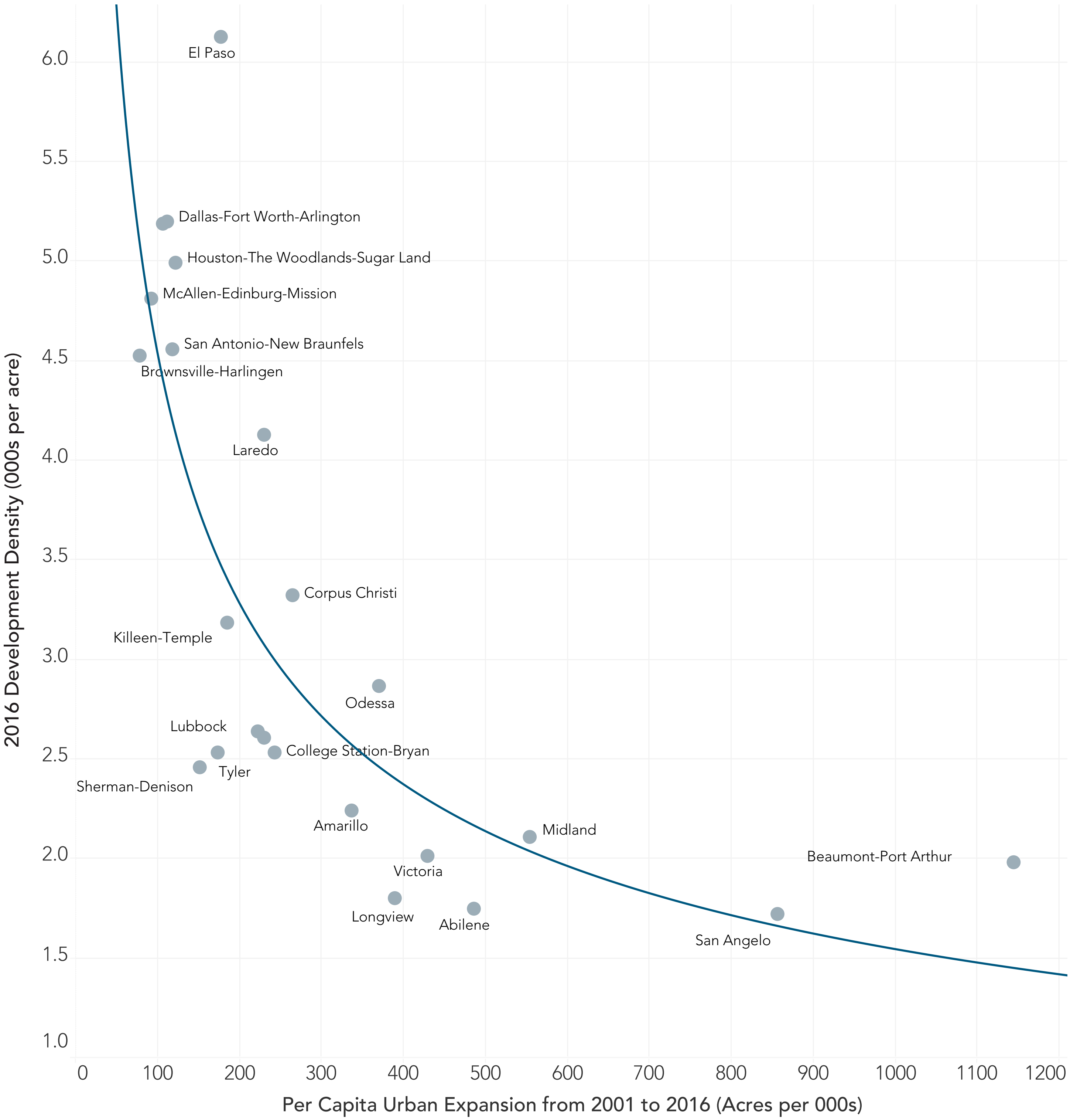


Figure 20: Development Density (2016) vs Average Imperviousness (2016)

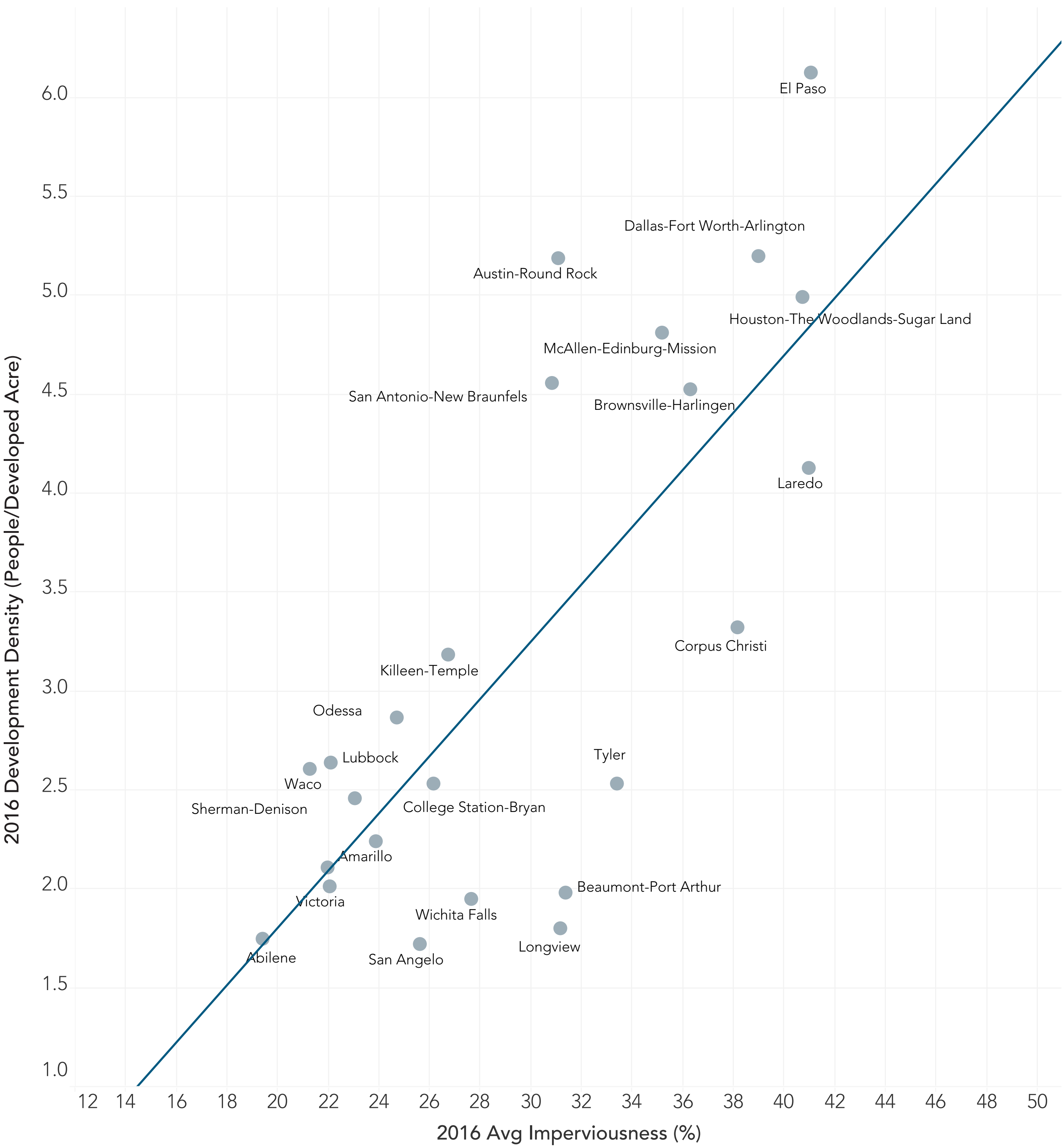


Figure 21: Density (2001-2016) vs Change in Average Imperviousness (2001-2016)

Figure 22: Population Growth (2001-2016) vs Imperviousness (2016)

Figure 23: Population Growth (2001-2016) vs Change in Imperviousness (2001-2016)

CONCLUSION

Texas has seen tremendous growth since 2001, both in terms of population and land development. The three land metrics presented here provide an informative summary of what is physically happening across Texas metros. Several trends have emerged. Population growth has mostly occurred in the largest metro areas. Growth in large metros consumes less land than does growth in smaller metros, but metros with little population growth can still experience expansion of developed land. Over time, land has been consumed more efficiently across Texas, driven by decreasing rates of expansion in the largest metros.

Since expansion is inversely related to density, this means people are living closer together in large metros (with the exception of El Paso which was already dense). That these settlements also tend to have higher levels of imperviousness is not surprising, but it does suggest a challenge to metro resilience. Higher levels of imperviousness have increased rates of runoff during storms, requiring large investments in flood mitigation to prevent flooding downstream. They also have significant impacts on water quality, threatening an essential economic, cultural, and ecological resource. Finally, the constructed materials that form impervious landscapes store more heat than do natural landscapes, leading to increased temperatures in urban areas. This has several impacts, including threatening human health and increasing demand for cooling (and associated energy and water use). Nearly all metros increased in imperviousness and many, like those across Central Texas, have seen significant increases. Land is an essential aspect of urban and rural life in Texas, and thus continued monitoring and study of these trends is an important aspect of metropolitan resilience.

Austin, Texas
Source: https://www.curbed.com/2018/1/9/16868250/2018-real-estate-markets-to-watch

ENDNOTES

[1]Alig, R. J., & Healy, R. G. (1987). Urban and Built-Up Land Area Changes in the United States: An Empirical Investigation of Determinants. Land Economics, 63(3), 215–226. https://doi.org/10.2307/3146831

[2]Fulton, W., Pendall, R., Nguyen, M., & Harrison, A. (2001). Who Sprawls Most? How Growth Patterns Differ Across the U.S. Retrieved from The Brookings Institution - Center on Urban & Metropolitan Policy website: https://www.brookings.edu/wp-content/uploads/2016/06/fulton.pdf

[3]Alig, R. J., Kline, J. D., & Lichtenstein, M. (2004). Urbanization on the US landscape: Looking ahead in the 21st century. Landscape and Urban Planning, 69(2), 219–234. https://doi.org/10.1016/j.landurbplan.2003.07.004

[4] McDonald, R. I., Forman, R. T. T., & Kareiva, P. (2010). Open Space Loss and Land Inequality in United States' Cities, 1990–2000. PLOS ONE, 5(3), e9509. https://doi.org/10.1371/journal.pone.0009509

TEXAS METRO OBSERV

PEOPLE LAND **WATER**

41 *Introduction*

43 *Texas' Water Resources*

44 *Historic and Current Metro Water Use*

49 *Breakdown of Metro Water Use by Sector*

49 *Geographic Patterns of Metro Water Use*

53 *Metropolitan Water Needs and Plan*

55 *Texas' Water Futures*

59 *Endnotes*

ATORY

INTRODUCTION

With its strong economy, relatively low cost of living, and warm climate, Texas' population continues to grow rapidly. This growth brings many advantages, such as a robust labor pool and housing market, but accommodating this expansion can also present economic, environmental, and social burdens. In particular, water systems— and their myriad relationships to metro areas and the residents within these areas— are characterized by several critical challenges, including declining water quality, increasing flood risk, the growing energy use required to supply, treat, and clean water, and diminishing access to reliable and affordable supplies of water.

This section of our report focuses on water supply, since supply is critical for growing metro areas; future reports may examine other aspects of water management. Understanding water use patterns, water supply limitations, and future water use opportunities in Texas metro areas is a key aspect of planning for a resilient Texas. Most Texans live in metro areas, and Texas is experiencing increasing water demand but decreasing water supply due to changes in precipitation and evaporation rates, as well as reservoir sedimentation. In addition, planning for growth requires sharing and management of scarce resources as well as evaluation of the cumulative impacts associated with different patterns of development.[1]

Since experiencing the "Drought of Record" in the 1950s, the state of Texas has established a strong record of planning for and developing water infrastructure, but meeting future demands requires confronting a different set of challenges than those faced decades ago. This section of the report first provides an overview of different water resources in the state, followed by an examination of historic and current water use data to better understand how water use has evolved by source, end-use (sector), and geographic region. Next, it briefly examines the Texas Water Development Board's 2017 State Water Plan to assess how metropolitan regions will meet future demand.

Mansfield Dam and Lake Travis: one of the Austin metropolitan area's water sources.
Source: https://www.lcra.org/water/dams-and-lakes/Pages/default.aspx

TEXAS' WATER RESOURCES

A brief overview of the state's water resources provides useful context before we examine water use by sector and geographic region. ***Surface water*** is water that is held above ground, on land, in forms such as lakes, wetlands, rivers, and creeks. Surface water is connected hydrologically to ***groundwater***, which is water that exists underground in soil or in rock. Texas law considers groundwater as a separate source of water, so the two are generally planned and managed as separate sources, even though they are connected physically. Texas' groundwater has different levels of salinity, with different aquifer systems (areas of porous rock) containing fresh, brackish, or saline groundwater. ***Brackish and saline groundwater*** both can be treated for freshwater use; in addition, brackish water can be used untreated for some industrial uses, such as fracking. In addition to surface water and groundwater, water also exists in surface soil and in the atmosphere; although humans do not usually directly use these resources, ***soil water*** and ***atmospheric water*** greatly impact human life through processes such as supporting vegetation and influencing weather systems.

Although most water used in Texas comes from surface water or groundwater sources, given that almost all surface water resources in the state are already legally allocated and that many groundwater resources are being over-withdrawn, future water use will depend in part on sources in addition to surface water or groundwater. These water resources are sometimes called alternative, auxiliary, or innovative water resources. These sources include rainwater, grey water, air conditioning condensate, reclaimed water, and conserved water; more information about these sources is provided below. Although many of these sources make up only a small percentage of overall state water use, some are growing in popularity.

Innovative water sources include water sources that result from the interaction of the water cycle with humans and our built environment. Precipitation such as ***rainwater*** (legally called ***diffused water*** in Texas) can be captured, stored, and used, although some municipalities require permitting to do so. Increasing rates of human water use and urbanization have also created more opportunities for residents, farmers, and industry to use additional innovative water resources, such as stormwater, grey water, and reclaimed water. ***Stormwater*** is rainwater that has been intercepted by the built environment, such as by a roof, parking lot, or a street. Like rainwater, stormwater can be captured, stored, and later used. Numerous

Rainwater collection cistern at the Lady Bird Johnson Wildflower Center
Source: https://www.wildflower.org/visit/gardens

projects around Texas use stormwater for landscape irrigation; in other water insecure places around the US and the world, stormwater is sometimes added to groundwater systems to increase groundwater availability.

Increasingly, municipalities and residents are creating systems that allow for water reuse. ***Grey water*** systems seek to reuse water that has been used once (such as in clothes washing machines); grey water use is difficult in most Texas municipalities, due to regulations. ***Air conditioning condensate*** (AC condensate) is the waste water created from air conditioning units. Although research about toxicity of AC condensate is still evolving, buildings throughout Texas have been designed to capture and reuse AC condensate, often for landscape irrigation. ***Reclaimed water*** (also sometimes called ***reused*** or ***recycled water***) is water that has been used once, collected, and then treated at municipal or utility wastewater treatment plants; after treatment, it is redelivered by a municipal water system or utility and then reused, usually for non-potable uses. It is possible to treat reclaimed water to potable standards (often called ***potable reuse***); ***indirect potable reuse*** is added back to reservoirs or aquifer and mixed with other water before being used, while direct potable reuse is piped directly back to customers through water supply infrastructure. The Colorado River Municipal Water District, which provides water to Big Springs, Texas, opened the nation's first direct potable reuse water plant in 2013. Due to growing adoption of this water resource, Texas Water Development

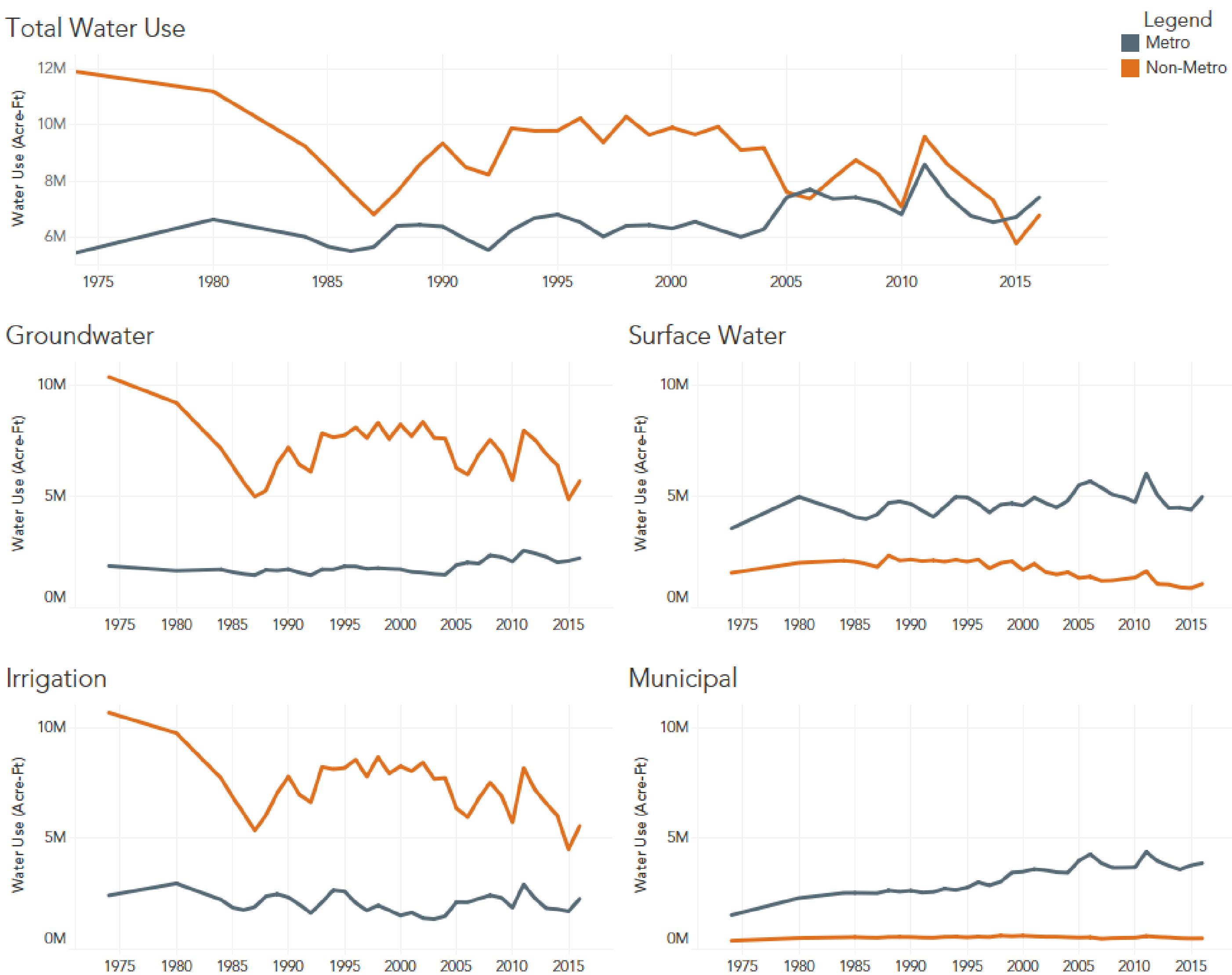
Board began to track reuse water in 2015.

A last category of water resources is ***conserved water,*** which is water that does not have to be used due to technological or behavioral changes that reduce expected water use. Conserved water is not technically a "new" source of water, but it is often considered a water supply strategy for planning purposes. The Texas Water Development Board has attempted to quantify conserved water and continues to build capacity for continual monitoring.[2] Despite the emergent nature of conservation data collection, conserved water (referred to as "demand reduction" in the State Water Plan) serves as an important "source" of water for many growing metro areas in the future, with early signs showing most regions are ahead of their 2020 demand reduction goals.[3] In a similar way, although reclaimed water makes up a small percentage of Texas' water use today, given that Texas' metro areas are projected to grow and produce more wastewater, reclaimed water will continue to expand as a source of water in future decades.

HISTORIC AND CURRENT METRO WATER USE

The Texas Water Development Board, Texas' water planning agency, divides the state's water use into several categories:

Figure 24: Comparison of Metro to Non- Metro Historic Water Use



Source: Texas Water Development Board, 2017. Water Use Survey. Historic Water Use Estimates.
US Census Bureau. 2000 and 2010 Decennial Census.
US Census Bureau, 2018. Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2018.

irrigation, livestock, manufacturing, mining, municipal, and steam electric.[4] In addition, the state of Texas is now required to consider environmental flows, which are the "quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems."[5]

Water utilities operating at the municipal or metropolitan scale provide water for household use (also called domestic use). About 10% of human water use globally can be attributed to domestic uses, and in Texas and the rest of the US, household use generally includes indoor uses such as water for drinking, cleaning, cooking, and hygiene, as well as outdoor uses such as household food production (gardens) and landscape uses (lawns and landscape plants). In places with hotter climates, such as Texas, outdoor landscape use can account for almost 50% of summertime household use.[6] In addition to household use, part of a municipal or metro water utility budget is used for public services as well as commercial and industrial uses. Public services include water for firefighting, municipal buildings, water and wastewater treatment, public pools, public parks and golf courses. In addition, up to almost 20% of supply may be unaccounted for because of leaks, flushing, tower maintenance, and other system losses.[7]

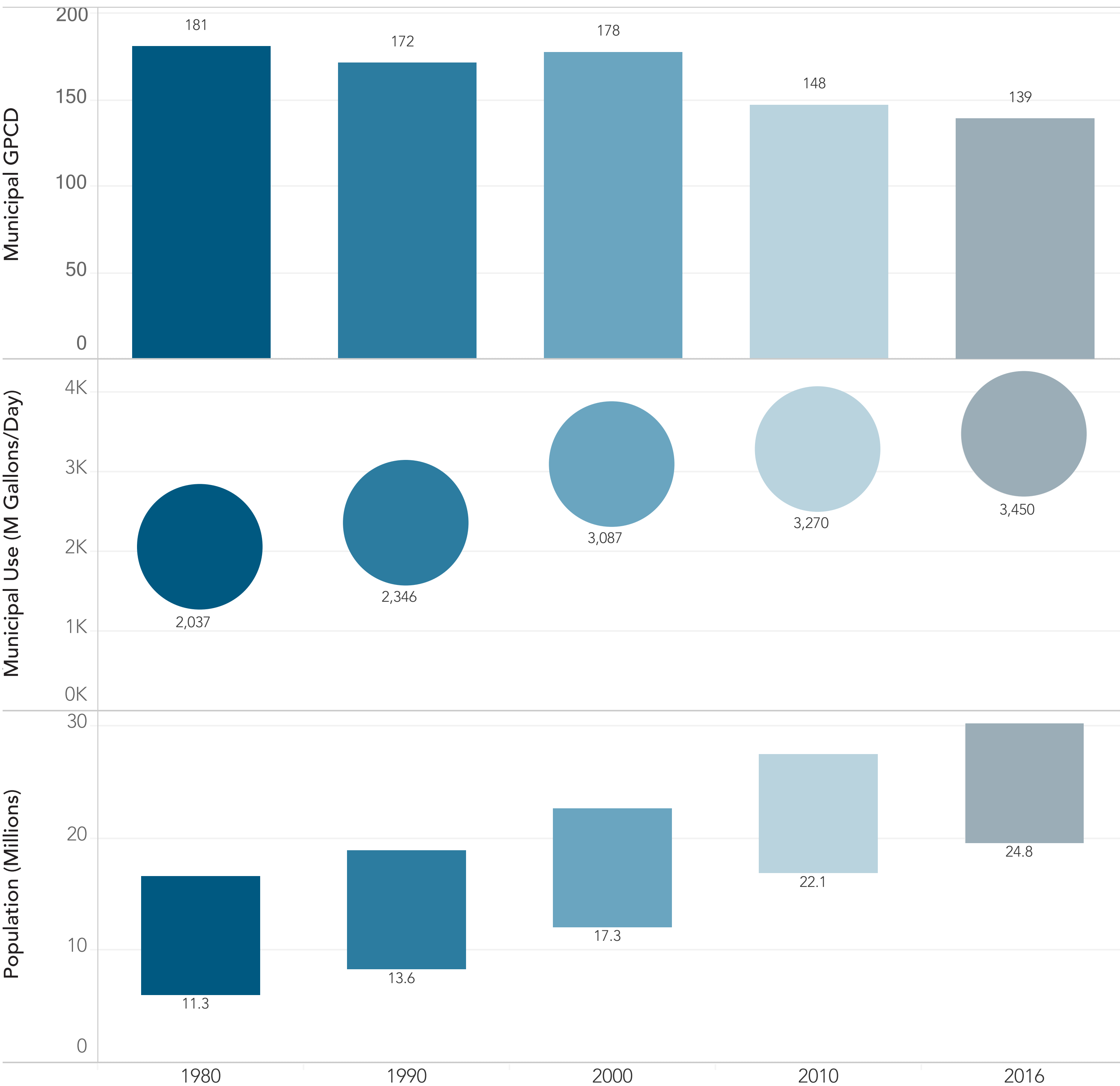
Household water use is often measured in the "Gallons per Capita per Day" (GPCD) metric. Part of the complexity of comparing GPCD across metropolitan areas stems from the diversity of water use within a metro area. Different utilities can include a variety of municipal water uses (household, commercial, industrial) when releasing GPCD data. GPCD look considerably different when they reflect residential use (per capita household use) versus per capita municipal use which can include commercial use, industrial use, and leaks, in addition to household use. A lack of consistent GPCD reporting methods also makes comparison difficult. For example, it is not always clear if water loss is included in the calculation, which can significantly alter GPCD values. Another complicating factor is that Texas is a diverse state demographically, culturally, ecologically, and hydrologically; GPCD varies significantly across the state because of these different characteristics.

In addition to water directly used by Texas metro residents at the household scale, Texas metro residents also depend on water to produce food through irrigation of crops and watering of livestock, on water that is used for manufacturing, mining, and steam electric production, and on water that supports the broader ecosystems dependent on environmental flows that provide Texans with food, recreation, and economic development through tourism, recreation, and fishing industries. For this report, metro water use is considered to be the total amount of water used within a metro area for municipal use, as well as irrigation, livestock, steam electric, mining, and manufacturing use within the metro boundaries. So, if water was used outside a metro boundary to produce food, energy, or industrial materials that benefit a metro resident, this non-metro water use is not considered in this analysis, due to the complexity of calculating full lifecycle water budgets for each metro resident. In addition, since environmental flows are not yet quantified at the metro scale, this report does not focus on environmental flows, despite their critical role in human health, well-being, and economic development.

Metro areas in Texas generally rely on surface water for water supply, with surface water providing about 2/3 of metropolitan water use. In contrast, some metro areas, such as San Antonio, depend primarily on groundwater; Houston, El Paso, and Amarillo also use groundwater to some degree. In addition, many rural residents outside metro areas, and outside utility service areas, depend on groundwater as a residential water source. Despite the historic tendency for most metros to rely heavily on surface water, expansion of metropolitan groundwater consumption seems likely, both because metros will expand into areas where groundwater is the most readily available source and also because additional surface water rights will be extremely difficult to procure. For example, San Antonio is in the process of building a 140-mile pipeline, called the Vista Ridge Pipeline, that will import 50,000 acre-ft of groundwater from non-metropolitan Burleson County to San Antonio.[8]

Despite Texas' largely metropolitan residential population, water use outside metro areas remains roughly equivalent to metro water use (see Figure 24). Historically, non-metro water use exceeded metro water use in the state, predominantly because of the volume of water used for irrigation. For example, in 1974 non-metro water use (11.9M acre-ft) was more than double that in metro areas (5.3M acre-ft). Metro and non-metro water use converged over the next few decades. The first year in which metro use exceeded non-metro was 2006, when metros used 7.7M acre-ft versus 7.4M acre-ft of non-metro use. The two have since remained close in overall use, with metro use exceeding non-metro only two more times during wet years (2015 and 2016). Overall, metro use is growing slowly while non-metro use is declining, albeit more sporadically. Part of that

Figure 25: Municipal Gallons per Capita per Day Metro Summary



Source: Texas Water Development Board, 2017. Water Use Survey. Historic Water Use Estimates

Figure 26: Percent Change in Municipal Gallons per Capita per Day (GPCD) (1980-2016)

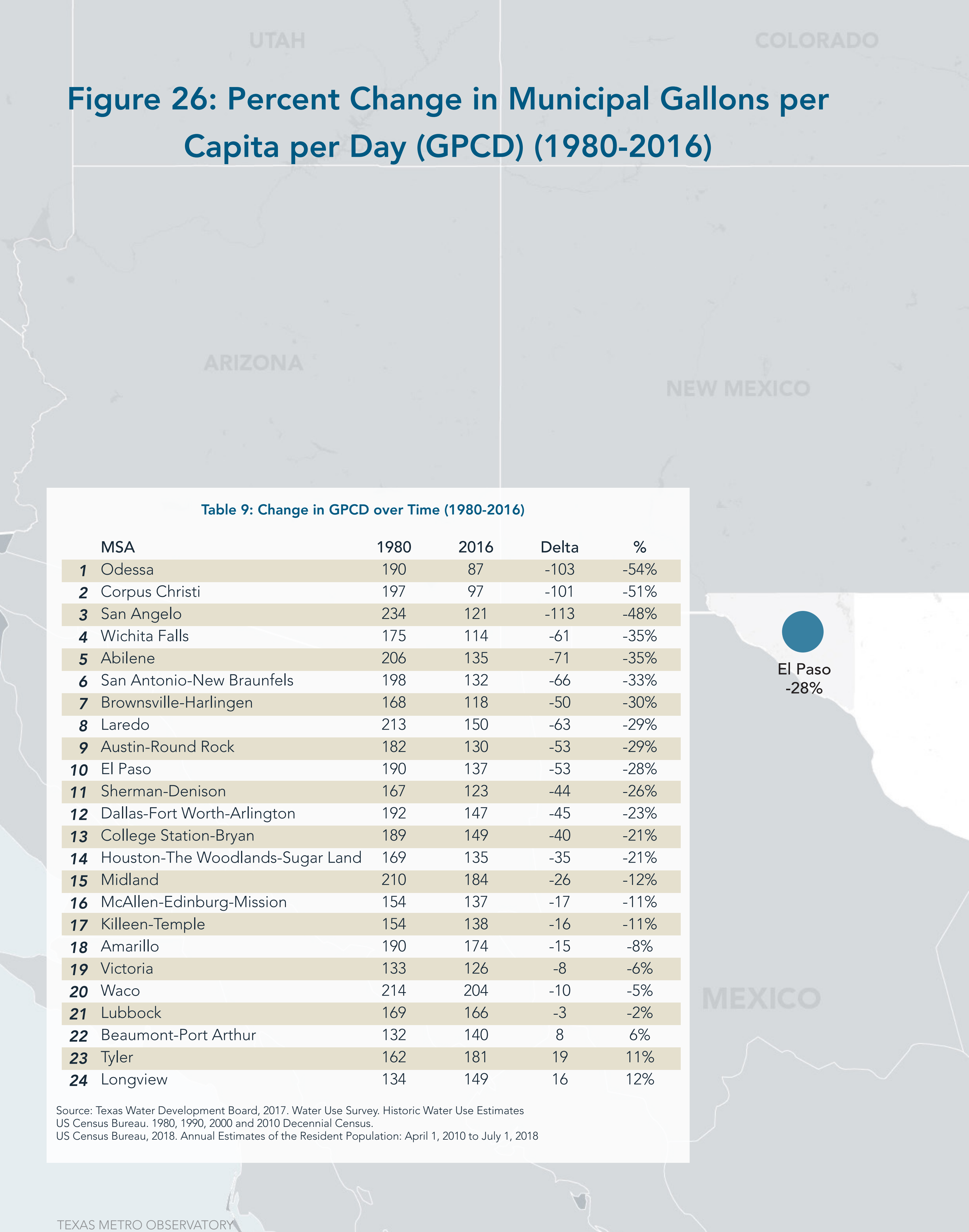


Table 9: Change in GPCD over Time (1980-2016)

	MSA	1980	2016	Delta	%
1	Odessa	190	87	-103	-54%
2	Corpus Christi	197	97	-101	-51%
3	San Angelo	234	121	-113	-48%
4	Wichita Falls	175	114	-61	-35%
5	Abilene	206	135	-71	-35%
6	San Antonio-New Braunfels	198	132	-66	-33%
7	Brownsville-Harlingen	168	118	-50	-30%
8	Laredo	213	150	-63	-29%
9	Austin-Round Rock	182	130	-53	-29%
10	El Paso	190	137	-53	-28%
11	Sherman-Denison	167	123	-44	-26%
12	Dallas-Fort Worth-Arlington	192	147	-45	-23%
13	College Station-Bryan	189	149	-40	-21%
14	Houston-The Woodlands-Sugar Land	169	135	-35	-21%
15	Midland	210	184	-26	-12%
16	McAllen-Edinburg-Mission	154	137	-17	-11%
17	Killeen-Temple	154	138	-16	-11%
18	Amarillo	190	174	-15	-8%
19	Victoria	133	126	-8	-6%
20	Waco	214	204	-10	-5%
21	Lubbock	169	166	-3	-2%
22	Beaumont-Port Arthur	132	140	8	6%
23	Tyler	162	181	19	11%
24	Longview	134	149	16	12%

Source: Texas Water Development Board, 2017. Water Use Survey. Historic Water Use Estimates
US Census Bureau. 1980, 1990, 2000 and 2010 Decennial Census.
US Census Bureau, 2018. Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2018


KANSAS
MISSOURI
OKLAHOMA
ARKANSAS
LOUISIANA
Amarillo
-8%
Wichita Falls
-35%
Sherman-Denison
-26%
Lubbock
-2%
Longview
12%
Dallas-Fort Worth-Arlington
-23%
Midland
-12%
Abilene
-35%
Tyler
11%
Waco
-5%
Killeen-Temple
-11%
Odessa
-54%
Beaumont-Port Arthur
6%
San Angelo
-48%
College Station-Bryan
-21%
Austin-Round Rock
-29%
Houston-The Woodlands-Sugar Land
-21%
San Antonio-New Braunfels
-33%
Victoria
-6%
Corpus Christi
-51%
Laredo
-29%
McAllen-Edinburg-Mission
-11%
Brownsville-Harlingen
-30%

decline is due to increasing water conservation due to growing adoption and efficiencies of agricultural irrigation.[9]
While water use has generally risen across Texas metros, Figure 25, Figure26, and Table 9 show a different, perhaps encouraging pattern – statewide reductions in municipal water use per person (measured in GPCD).[10] Since 1980, statewide municipal GPCD has dropped approximately 23% from 181 GPCD to 139 GPCD. Although it is difficult to compare GPCD across broad geographic and cultural regions, due to the reasons discussed above, it is useful to put Texas' municipal GPCD in context. Average US domestic per capita water use in 2015 was 82 GPCD (note: this calculation is different from the TWDB's municipal water use per person calculation; this does not include water used for office uses, commercial uses, light industrial uses, institutional, or public uses such as firefighting, etc.).[11] Domestic water use ranged from 35 GPCD in Connecticut to 186 GPCD in Idaho; Texas' domestic water use, at just over 80 GPCD, was about average for US states.

Figure 26 and Table 9 show 1980 and 2016 GPCDs data for each metro, illustrating the distribution of GPCD change. Nearly all regions other than far east Texas have seen reductions in GPCD, with significant reductions found in Central, South, West, and North Texas.

BREAKDOWN OF METRO WATER USE BY SECTOR

Given the increasing share of metro water use, it is important to further examine how metro water has been and may be used moving forward (Figure 27). In 1980, more water was used, even within metro areas, for irrigation than it was for municipalities. This irrigation was not associated with residential lawns, which can be significant, but with agriculture within metropolitan boundaries.[12] Municipal use became dominant as a use within metro areas by the mid-1980s and has increased in its share ever since (to 51% in 2016). Metro groundwater transitioned towards municipal dominance two decades earlier (1974) than did surface water (1995). Municipal groundwater grew most (350k acre-ft) from 1974 to 1985, almost half of which took place in Houston and one quarter in San Antonio. Though it cannot be gleaned from these water use data, the relative ease of groundwater access may have played a role in the location and type of development that took place at that time.

After municipal and irrigation, manufacturing represents the next largest use; however, since 1974 it has declined both in absolute (from 1.20 acre-ft to .85 acre-ft) and relative (from 22% to 11%) terms. The decline in manufacturing water almost entirely comes from groundwater reductions including more than 220k acre-ft in Houston alone (where groundwater use has been restricted because of subsidence). Power generation is beginning to grow, although it only constitutes 3% of total water use (water consumption, not withdraw) in Texas. Tracking water associated with power consumptions in metro areas is difficult as power plants may be and often are located outside of metro areas, with transmission lines distributing power to end-users in metros. Clearly, such water is an extension of metropolitan demand, though tracking it as such is challenging. Both manufacturing and power generation rely heavily on surface water.

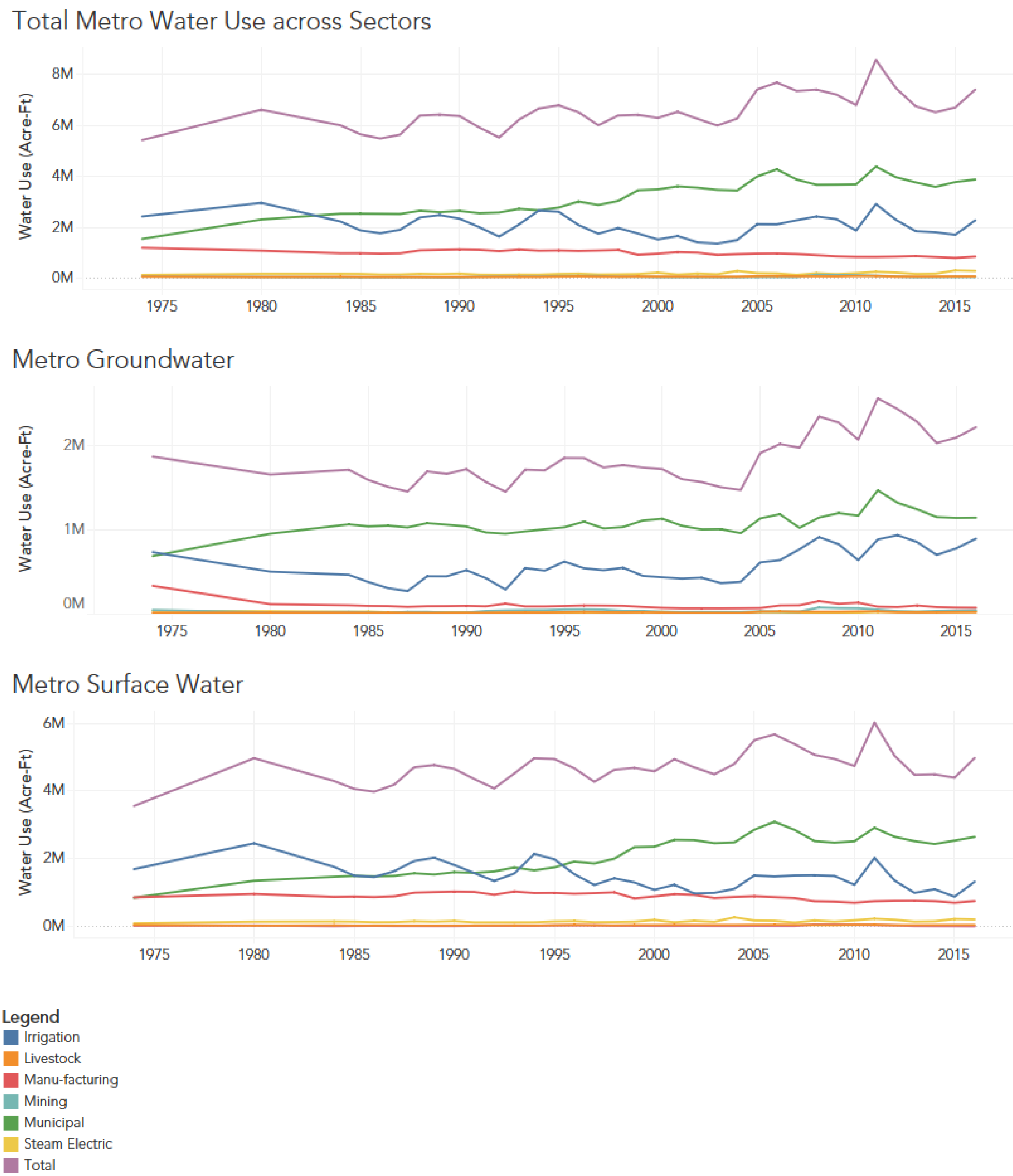
GEOGRAPHIC PATTERNS OF METRO WATER USE

Examination of geographic patterns across Texas provides necessary spatial differentiation beyond just analysis of sources and uses. Just as hydrogeology differs sharply across the state, so too does the use of groundwater within metros. Figure 28 shows the distribution of metro reliance on groundwater in 1974 and 2016.

In 1974, metros in the Texas Panhandle along with San Antonio and College Station were the most reliant on groundwater. Houston and Victoria were the only metros that used roughly the same quantity of groundwater and surface water, while the rest of the metros were received more than 60% of their water from surface water. Since then, a few metros have transitioned from groundwater to surface water, notably Houston, Odessa, and Sheman-Denison while only San Angelo switched towards groundwater use. The rest of metros only shifted slightly, primarily in the direction of less reliance on groundwater.

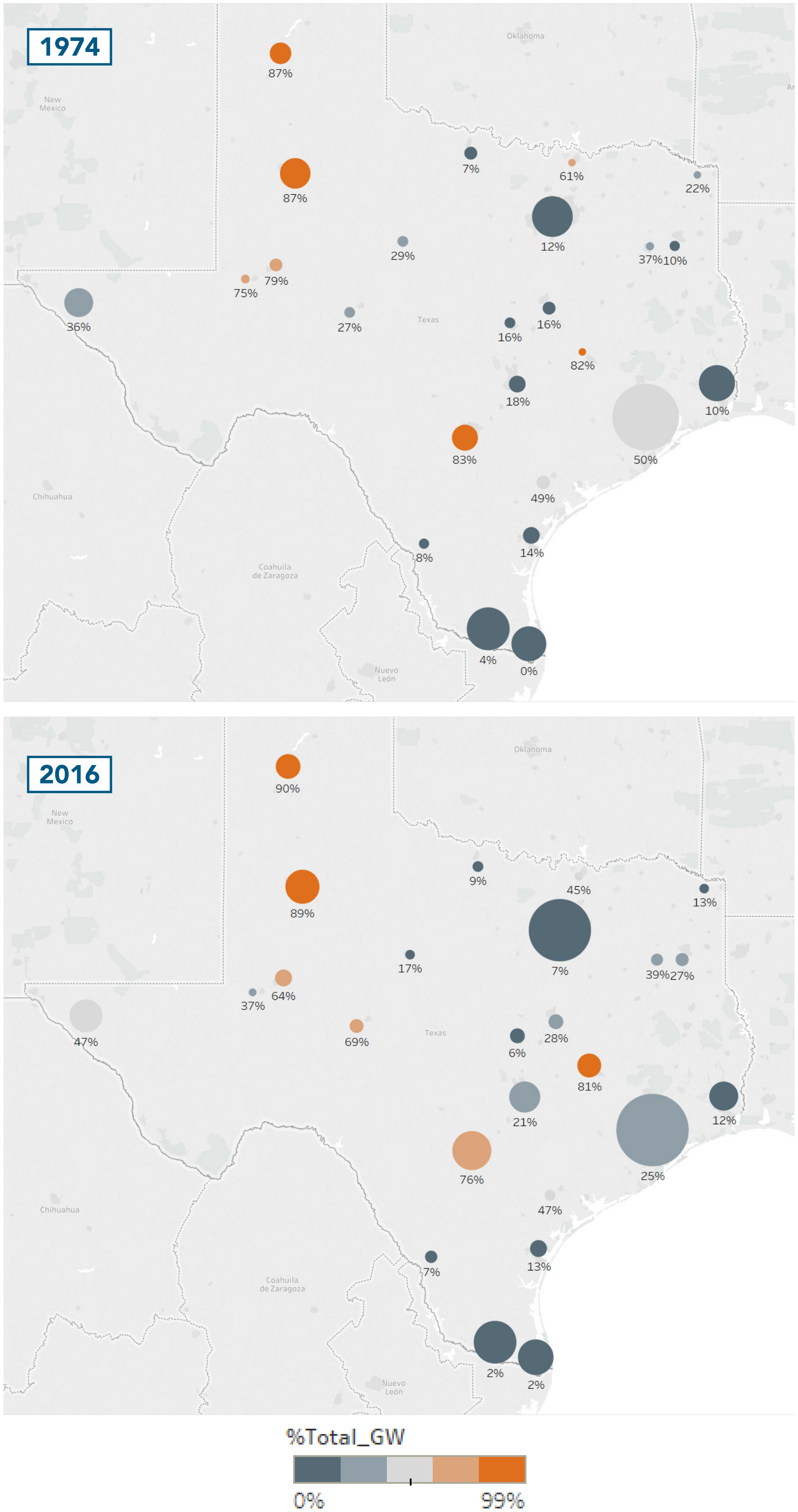
Though their metros rely on groundwater, the Panhandle region and College Station still use most of that water for irrigating crops and not municipalities. This speaks both to the centrality of agriculture to their regional economies and also perhaps to the relatively weak extension of urban influence out from the core cities in those metros. Interestingly, groundwater in Houston has seen a sharp transition towards municipal use, with both manufacturing and irrigation seeing steep declines (see Figure 29). The TMO online dashboards, which can be found at https://bridgingbarriers.utexas.edu/planet-texas-2050/, allow users to toggle between all years and metro areas, which include more variation and patterns than was

Figure 27: Sectoral Breakdown of Metropolitan Total and Groundwater Use



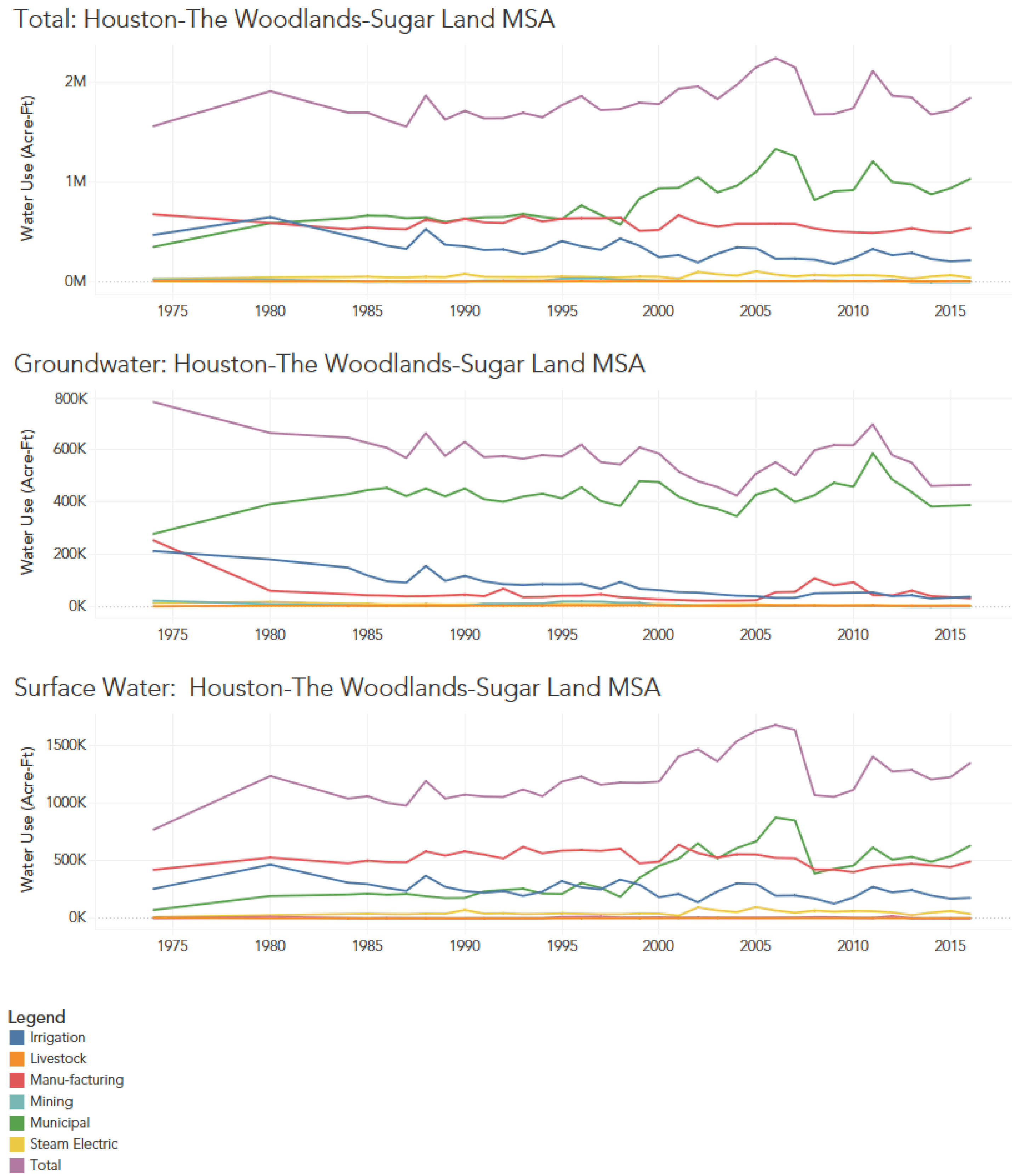
Source: Texas Water Development Board, 2017. Water Use Survey. Historic Water Use Estimates

Figure 28: Reliance on Surface vs Groundwater (1974 vs 2016)



Source: Texas Water Development Board, 2017. Water Use Survey. Historic Water Use Estimates

Figure 29: Sectoral Breakdown of Houston MSA Use



Source: Texas Water Development Board, 2017. Water Use Survey. Historic Water Use Estimates

METROPOLITAN WATER NEEDS AND PLAN

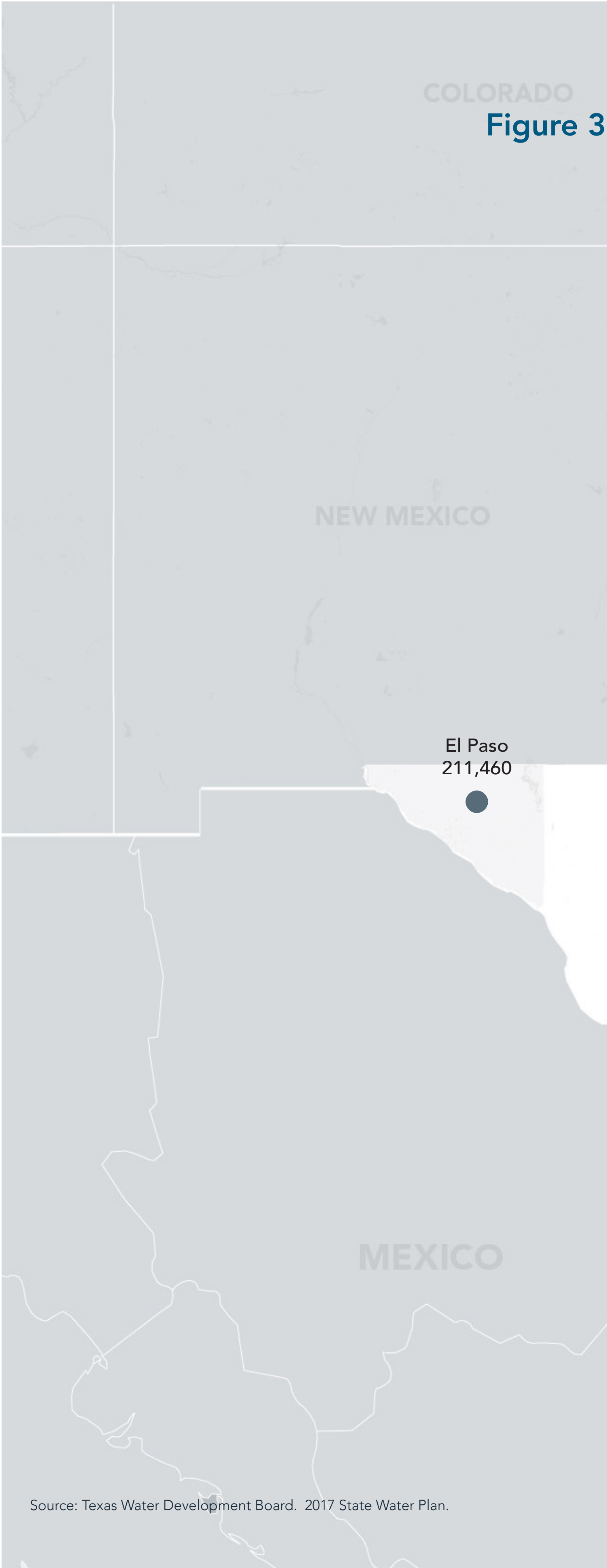
In addition to the construction of water infrastructure, Texas' response to the 1950s Drought of Record included the creation of new institutions for water planning. Today, the Texas Water Development Board, whose Water Use Survey provided the data for this report's earlier analysis, updates the State Water Plan every five years. The most recent version was published in 2017, though the regional plans that form the basis for the state plan come from 2016. The plan includes forecasts of future demand and supply through 2070, with the difference between the two being classified as a "need." The 2070 needs of metros (Figure 30) largely correspond with their population growth.[13]

The 2017 State Water Plan includes more than 7,200 individual water strategies that seek to fill the needs identified in the plan. Strategies include 15 different technologies, programs, and infrastructures, ranging from irrigation and municipal conservation to new reservoir development to desalination. Of those, the largest sources are surface water (48%), followed by demand reduction (conservation) (22%), reuse (17%), groundwater (11%), and seawater (2%); however, the future sources of water vary greatly throughout the state (Figure 32).

Surface water is the top source for 11 metros while demand reduction leads for seven, and groundwater for five metros. Some metros will rely heavily on a single source to meet future needs. The six metros most dependent on a single source all heavily plan on expanding surface water use. Most are these lie in wetter East Texas, but Abilene, Dallas, and Sherman-Denison fall in drier climates. Two metros will rely on groundwater to meet most of their needs (Amarillo and El Paso), and two more will rely heavily on demand reduction (Brownsville and McAllen). There is a general reduction of reliance on groundwater from west to east, with College Station being a minor exception at 43% of 2070 strategies.

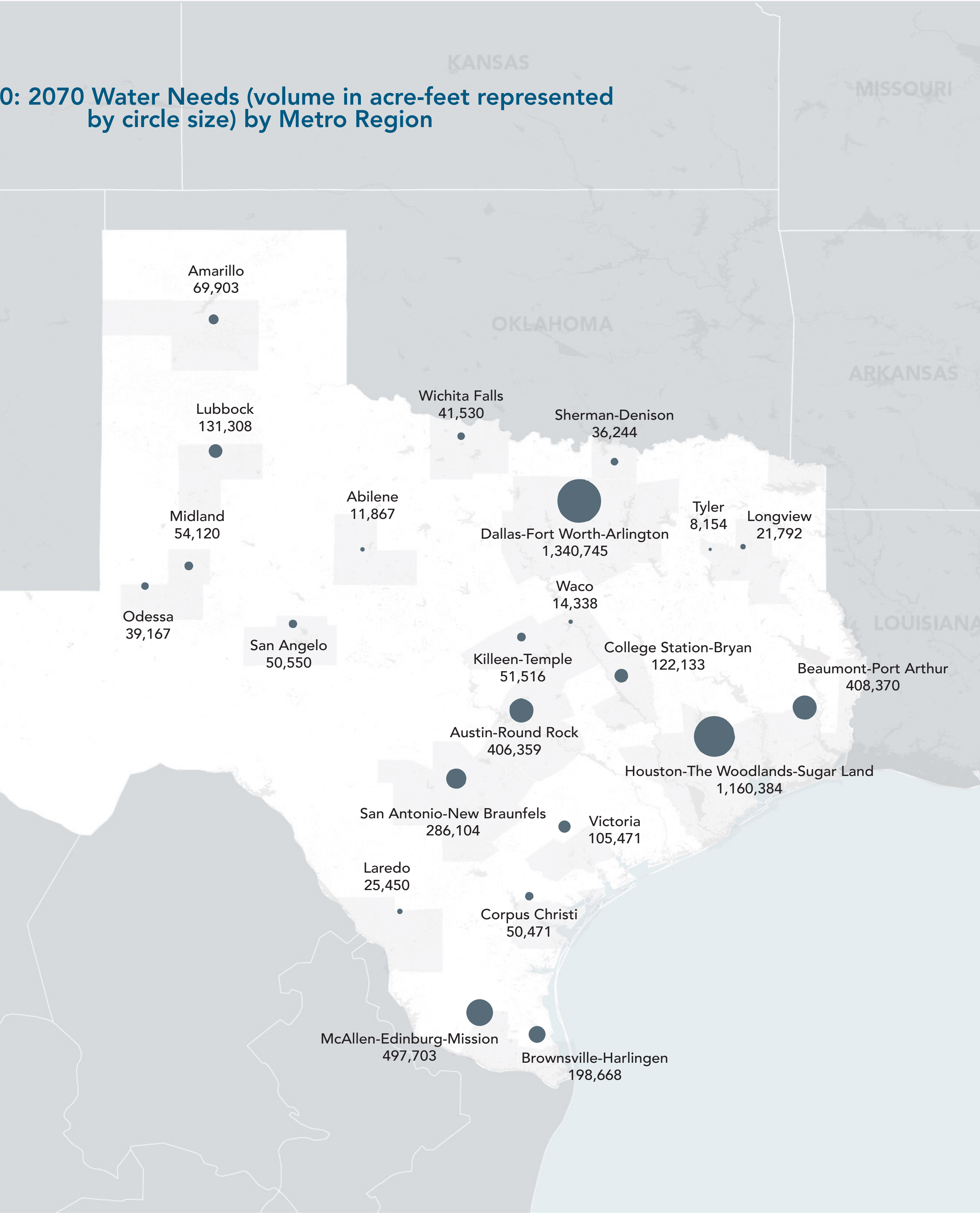
Given the risk posed by population growth and climate change, conservation (demand reduction) and reuse represent a crucial strategy. Fortunately, both are commonly used across the state and combine for 39% of total strategies. Nearly all metros have some, and in many cases, significant plans to reduce water demand or reuse existing supply. Only five metros have a combined reuse and demand reduction share under 10%, and they are mostly found in wetter East Texas (Sherman-Denison being the exception). The three metros with the highest combined demand reduction and

Figure 3



Source: Texas Water Development Board. 2017 State Water Plan.

0: 2070 Water Needs (volume in acre-feet represented by circle size) by Metro Region



reuse share are all along the border, with Laredo's combined share at an astounding 94%.

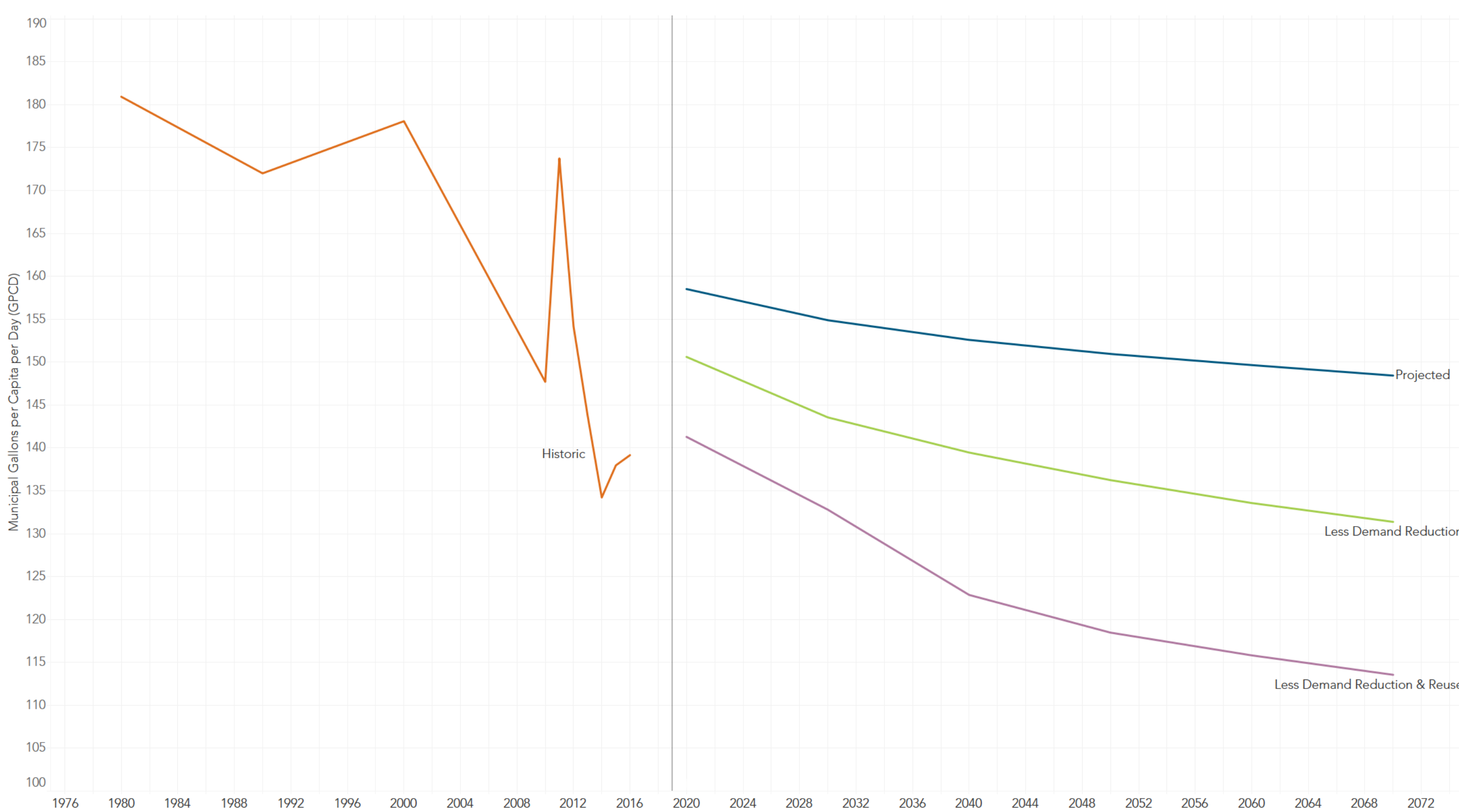
Projecting future municipal GPCD using data from the 2017 State Water Plan (Figure 31) provides a useful perspective on the impacts of planned conservation and reuse. In 2020, municipal demand is forecast to be just over 158 GPCD, slightly higher than the actual GPCD in 2010. This reflects the impact of drought in 2011 that led to a GPCD nearly equal to the high in 1980. Factoring in demand reduction and reuse drops the 2020 GPCD by 11% to a GPCD of 141. Both sources grow over time, and so do their impacts on overall water use. Municipal GPCD is projected to be 148 in 2070. It is slightly lower than in 2020 due to the incorporation of "passive conservation" that comes with updated building codes and improvements in building stock. Factoring in demand reduction and reuse drops the GPCD to 114, well below the recent low of 134 in 2014. Even with current plans for conservation and reuse, population growth will lead to a 17% increase in total municipal demand from the 2011 high of 3,916 million gallons per day to 4,587 million gallons per day.

It can be hard to imagine where, during a major drought like that of 2011, another 17% of total water supply might be found. Figure 32 provides a breakdown of TWDB's projections for water supply strategies in 2070, based on the regional water plans and presented at the MSA scale. Changes in the adoption of innovative water strategies, such as reuse and aquifer storage and recovery, may change these projected portfolios.

TEXAS' WATER FUTURES

Given water use history from 1980 to 2016, we can expect that metro water use will continue to exceed non-metro water use in the state. Although increased total water use in metro areas due to population growth has driven this shift in part, decreasing rates of water use growth in non-metro areas due to increases in irrigation conservation have also contributed to

Figure 31: Historic and Project Municipal GPCD including Demand Reduction and Reuse



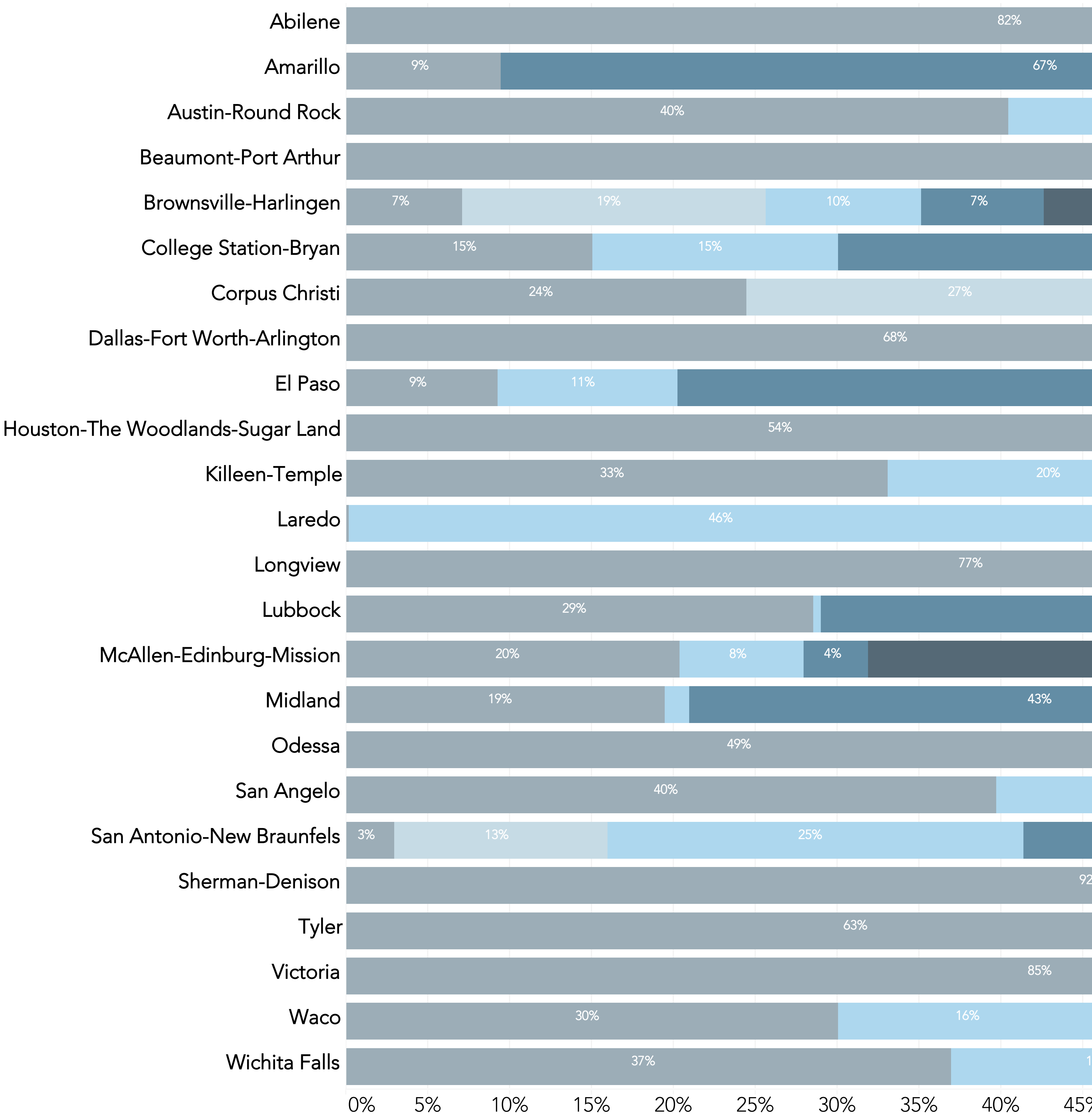
Source: Texas Water Development Board, 2017. Water Use Survey. Historic Water Use Estimates
US Census Bureau. 1980, 1990, 2000 and 2010 Decennial Census.
US Census Bureau, 2018. Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2018.
Texas Water Development Board. 2017 State Water Plan.

this change.[14] The relative success story of irrigation conservation in Texas gives hope that municipal conservation in metro areas will become an increasingly important water "supply" in areas of Texas experiencing fast population growth. Indeed, metro areas across the state have seen decreasing gallons per capita per day (GPCD) use in the period from 1980-2016, providing an encouraging trendline for future GPCD water use reductions in metro areas between now and 2050.

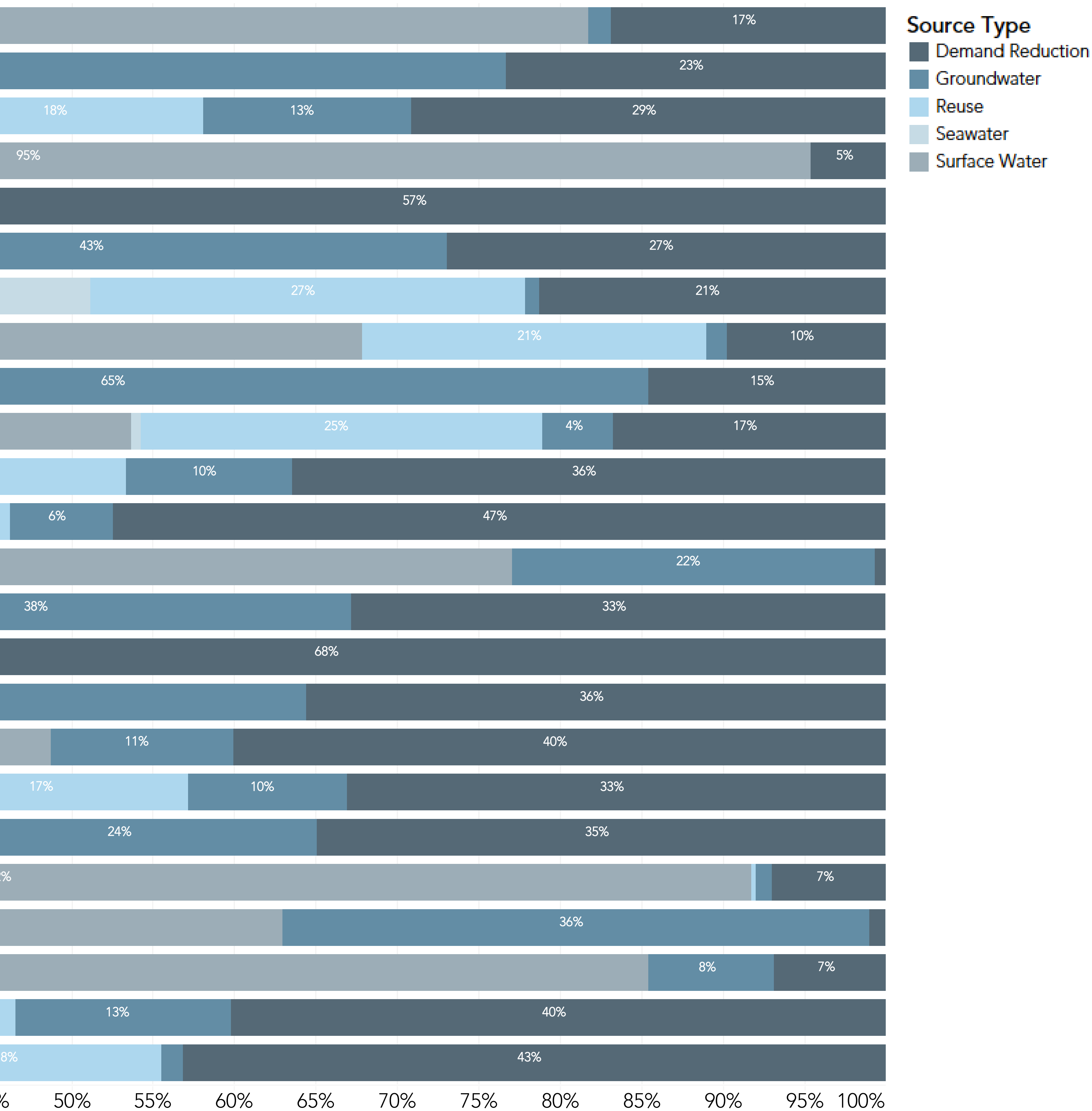
Despite positive news about less water being used per metro resident over time, we can expect overall water use in metro areas to continue to increase due to Texas' expected population growth. In response, nearly all metro areas have plans to continue to reduce demand over the next several decades. Innovative strategies, such as expanded use of reclaimed water or rainwater, have promise but are still unproven strategies at scale, although significant exploration and research into innovative strategies – brackish desalination and aquifer storage and recharge in particular– has occurred since the 2017 plan.[15] However, at least for the foreseeable future, most metro areas are projected to continue to depend on surface water. But even though groundwater likely will make up a relatively small portion of metro future water strategies, groundwater development may play an increased role in times of drought, when over-allocated surface water supplies experience additional demand. In conclusion, while metro areas appear to be dependent upon scarce—and growing scarcer due to climate change—surface water into the immediate future, water conservation will play a key part in most metros' future water portfolios, metro GPDC water use will likely continue to decline, groundwater may provide a cushion in many metros during drought years, and adoption of innovative water strategies will be an area to watch.

Austin, Texas
Source: https://www.10best.com/awards/travel/best-city-park/

Figure 32: Breakdown of 2070



) Strategies by Source and Type



ENDNOTES

[1] Page, G. E. G. W., & Susskind, L. (2007). Five Important Themes in the Special Issue on Planning for Water. Journal of the American Planning Association, 73(2), 141–145. https://doi.org/10.1080/01944360708976147

[2] See TWDB's Conservation Annual Report data available at http://www.twdb.texas.gov/conservation/municipal/waterloss/historical-annual-report.asp

[3] See TWDB 2017. Statewide Water Conservation Quantification Project. http://www.twdb.texas.gov/conservation/doc/StatewideWaterConservationQuantificationProject.pdf

[4] Water is used to produce electricity through steam electric processes, in which energy is used to produce steam from water, which then turns a generator and creates electricity. Although steam electric production is the largest overall water use both in the US and Texas, very little water that is withdrawn for use in steam electric plants is "consumed" or "used up" (e.g., lost to evaporation); most water used for steam electric plants is returned to a surface water source, where it can later be used for other purposes. The TWDB tracks data about water consumed for steam electric production (i.e., lost to evaporation), not the larger volume of water that is withdrawn (and then returned) for steam electric production.

[5] Declaration, Brisbane. "The Brisbane Declaration: environmental flows are essential for freshwater ecosystem health and human well-being." 10th International River Symposium, Brisbane, Australia. 2007.

[6] Hermitte, S., & Mace, R. (2012). The Grass Is Always Greener… Outdoor Residential Water Use in Texas (Technical Note No. 12–01). Texas Water Development Board.

[7] Center for Neighborhood Technology. 2013. The case for fixing the leaks: Protecting people and saving water while supporting economic growth in the Great Lakes region. https://www.cnt.org/publications/the-case-for-fixing-the-leaks-protecting-people-and-saving-water-while-supporting

[8] An acre foot is a term of measurement for the volume of a sheet of water one acre in area and one foot in depth, which is equivalent to 43,560 cubic feet (1233.5 cu m).

[9] Texas Water Development board. 2017 State Water Plan. https://www.twdb.texas.gov/waterplanning/swp/2017/doc/SWP17-Water-for-Texas.pdf?d=5768

[10] TWDB Municipal uses include: City-owned utilities, water districts, water supply corporations, or private utilities supplying residential, commercial (non-goods-producing businesses), and institutional (schools, governmental operations). Municipal includes smaller manufacturing operations that rely on city utilities (or other water providers). See https://www.twdb.texas.gov/waterplanning/waterusesurvey/faq.asp.

[11] Dieter, Cheryl A., and Molly A. Maupin. Public supply and domestic water use in the United States, 2015. No. 2017-1131. US Geological Survey, 2017.

[12] Hermitte, S., & Mace, R. (2012). The Grass Is Always Greener… Outdoor Residential Water Use in Texas (Technical Note No. 12–01). Texas Water Development Board.

[13] Two exceptions are Beaumont and Victoria, which are projected to require much more water per person than their population growth merits, perhaps because of high industrial use.

[14] TWBD 2017

[15] TWDB defines Brackish Desalination as "groundwater with a total dissolved solids content of between 1,000 and 10,000 parts per million. Desalination is a widely used process that makes brackish water drinkable. Factors that affect the implementation of desalination include local conditions, permitting, treatment, and concentrate disposal." (http://www.twdb.texas.gov/publications/shells/Desal_Brackish.pdf) It defines Aquifer Storage and Recharge as "the practice of storing water in a suitable aquifer through a well when water is available and recovering the water from the same aquifer when it is needed. Typically, the same well is used for both injection and recovery." (http://www.twdb.texas.gov/innovativewater/asr/faq.asp#title-01)

Buchanan Dam and Lake Buchanan
Source: https://www.lcra.org/water/dams-and-lakes/Pages/default.aspx

TEXAS

METRO

FUTURE WORK

OBSERV

63 Future Work

63 Sustainable Residential Development

63 Urban Densification and Housing Retrofit for Climate Change Mitigation

65 Metropolitan Governance Indicators

68 Endnotes

VATORY

FUTURE WORK

The Texas Metro Observatory team also conducted three pilot research projects during its first year (June 2018 - May 2019). Future reports may focus on expansion of some of these projects to the metro scale across the state, in addition to shorter reports focused on the pilot studies themselves. These projects include:

SUSTAINABLE RESIDENTIAL DEVELOPMENT

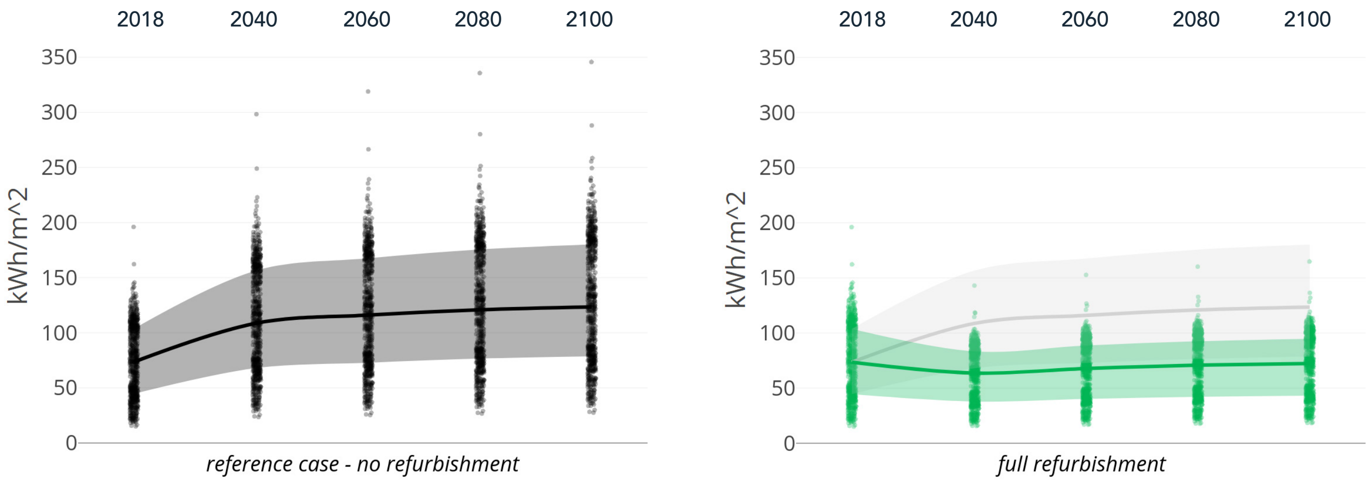
This project focuses on using the City of Austin as a case study. The City of Austin's population is expected to double within the next 25 years, approximately two-thirds of Austin's built environment consists of residential construction, and available land for residential infill development under current zoning and land-use ordinances is almost exhausted. This situation presents significant challenges as the metropolitan area will need to accommodate twice as many people, straining its resources and functions in unprecedented ways. Decreases in average household size and increases in average house size have doubled the per capita residential square footage demand over the last 50 years, and currently 11% of global carbon emissions are due to embodied carbon in the building sector.

This research project concerns itself with the sustainability of our built environment. To build our metropolitan areas we consume resources such as land and construction materials that have direct and indirect effects on greenhouse gas emissions. Even though 90% of residential construction in the United States has a wood structural system, it consumes land and concrete as well. By classifying residential construction according to its height and density, we can extract resource demand information that can be analyzed and integrated into useful indicators of embodied carbon per development density type. These indicators can provide timely guidance to individual residential projects, or they can contribute to a holistic assessment of housing development through parametric scenario modeling. While not every city is experiencing rapid population growth like the City of Austin, there are many that are, and the observations and conclusions reached in this study can serve as a useful reference for other cities in Texas and elsewhere.

URBAN DENSIFICATION AND HOUSING RETROFIT FOR CLIMATE CHANGE MITIGATION

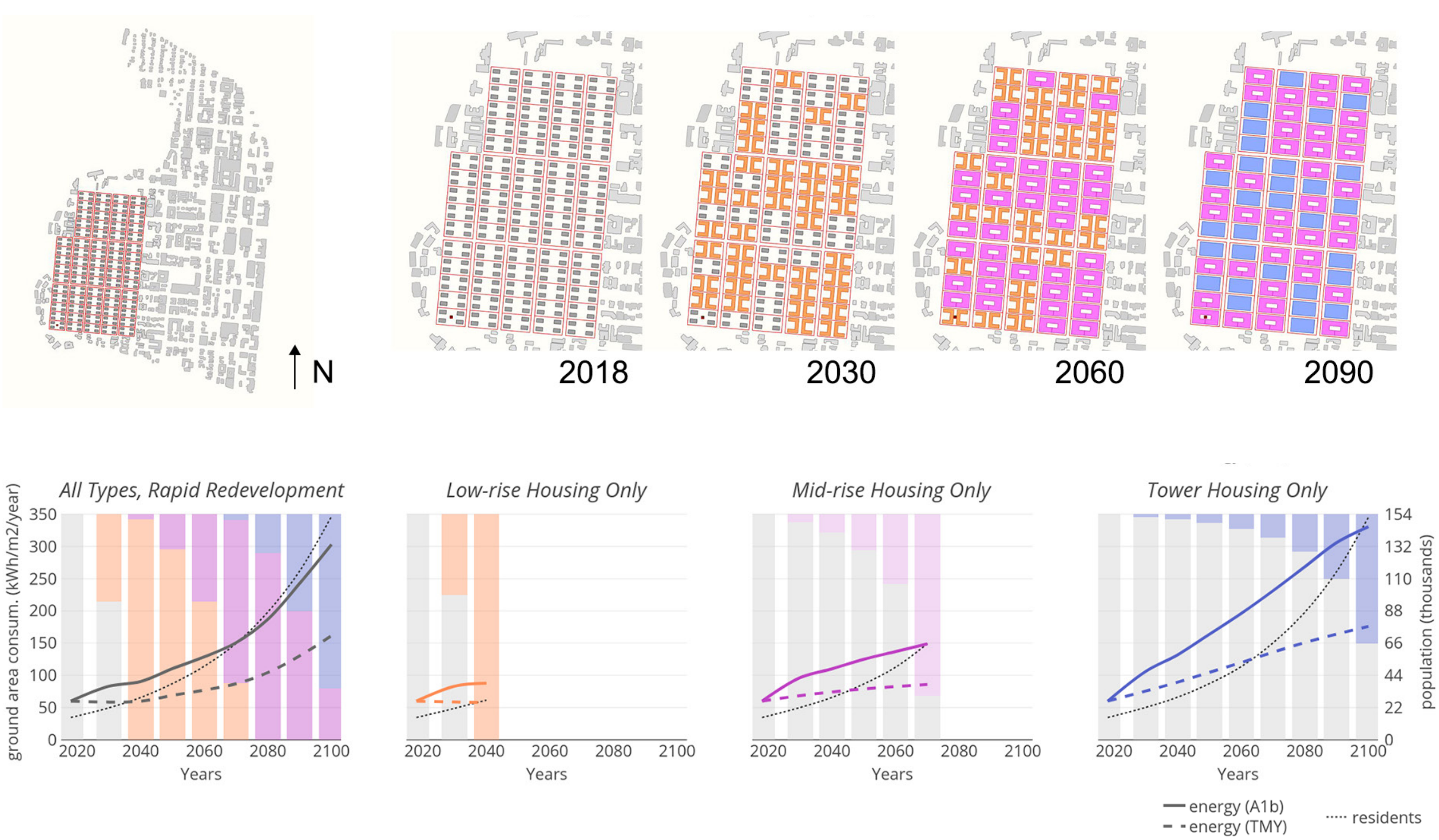
Additionally, a pair of case studies were performed on Austin aiming to examine the effects of climate change on metropolitan areas. These projects analyze a residential area, West Campus, under Intergovernmental Panel on Climate Change scenarios to determine several intriguing relationships. A simulation was developed to conduct experiments that allowed for parametric design and analysis of neighborhoods with varying morphologies and building types. Our simulation first uses a GIS database to reconstruct the area of interest in Grasshopper, attaching all relevant information to each building, then pushes the model to CitySim to estimate energy consumption. The first of these studies concerns itself primarily with the effects of retrofit and building typology on energy consumption; finding notable disparities between the performance of buildings depending on their use (Figure 33). The second study examines the relationships between urban densification, housing typology, and energy demands. Four building types are explored in the second study as a replacement to single-family housing in a residential area: low-rise, midrise, tower, and a combination of the former three options. This study found all housing types perform comparably in terms of energy savings but differ greatly with respect to occupancy (Figure 34). This shows that half of the energy consumption increase is due to population, and the other half is due to climate change. While this study is a more involved examination of a subsection of Austin, the methodology is to be applied to other metro areas across Texas, to better predict which areas will be most vulnerable and at risk for overheating and population stress, and what strategies could mitigate these effects.

Figure 33: Energy Use Impact Of Building Refurbishments



Source: Juliana Felkner1, Julien D. Brown1, José R. Vázquez-Canteli2, Rachel L. Schutte2, Nicolás C. Castejón2, Zoltán Nagy2 1School of Architecture, The University of Texas at Austin, TX, USA 2Intelligent Environments Laboratory, Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, TX, USA

Figure 34: Urban Densification and Housing Typology for Climate Change Mitigation



Character of Housing Growth Scenarios: Building Stock (Bar Charts), Neighborhood Population, and Built Area Energy Consumption

Source: Juliana Felkner, Julien D. Brown, Jose R. Vazquez-Canteli, and Zoltan Nagy. School of Architecture, The University of Texas at Austin. Cockrell School of Engineering, The University of Texas at Austin

METROPOLITAN GOVERNANCE INDICATORS

Governance is increasingly used to describe the process by which collective decisions are made. How are collective decisions made in metropolitan areas? Historically, two scenarios exist: a single or small group of leaders make policy that affects the larger community or a process in which all community members have a say in their own governance.[1] Research on urban governance, which has seen a resurgence of interest in the context of smart cities and sustainability, emphasizes collaboration and open governance processes.

Indicators of urban governance typically include metrics of effectiveness, efficiency, equity, participation, and accountability.[2,3] Attempting to compare the performance of metropolitan government entities might be overly ambitious, since they are highly complex and interdependent structures. Nonetheless, we suggest developing a metropolitan governance indicator that can be developed and reported on annually (Table 10 suggests some of those potential indicators).

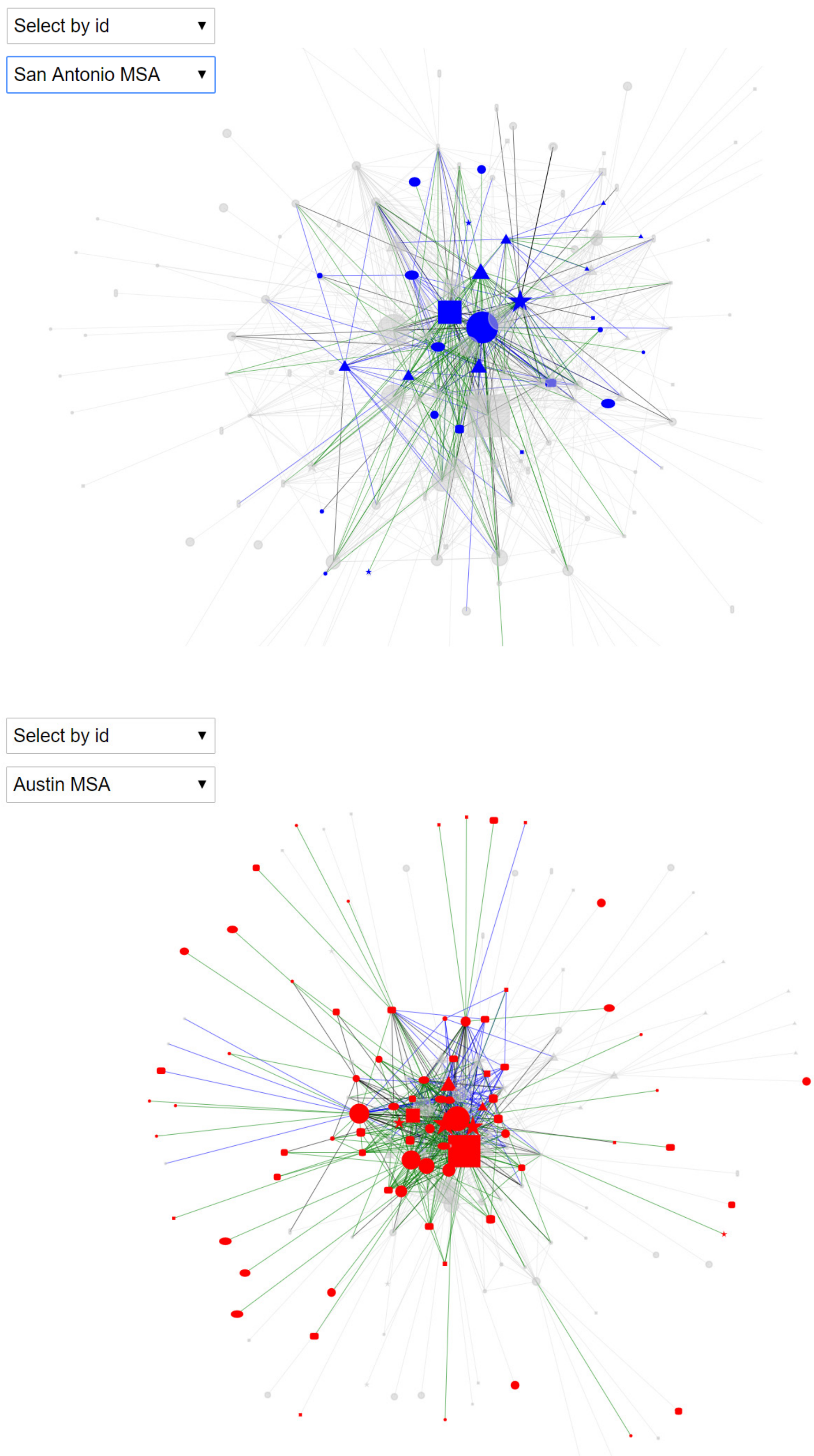
The vision for TMO is develop a set of governance indicators across effectiveness, equity, participation, and accountability in FY20. One aspect that is currently in progress is understanding civic association participation in governance networks. We develop these indicators through researching the public-civic networks involved in environmental governance across each MSA. Figure 35 (Austin MSA and San Antonio MSA) serve as pilot case for this approach to providing indicators of civic association participation in governance networks.

The Texas Metro Observatory will publish these future reports, as well as other research products, to the TMO site, which can be accessed through https://bridgingbarriers.utexas.edu/planet-texas-2050/. Like the information about people, land, and water presented in this report, future reports will focus on trends, resources, and patterns that will influence the future of Texas. The data and visualizations shared above tell a story of a state that, over the past few decades, has experienced rapid population growth and significant community change. These trends permit us a window into life in the state today, a chance to compare how our communities have changed, and an idea of where Texas may be headed.

Table 10: Proposed Metropolitan Governance Indicators

Effectiveness
Published performance metrics
Citizen satisfaction surveys
Updated municipal vision statement
Smart city policy
Cross-departmental collaboration/integrated management
Equity
Percentage of women city council
Percentage minority city council
Affordable housing policies
Participation
Voter turnout
Active citizenry
Civic associations per 10,000 residents
Civic association participation in governance networks and centrality of nonprofits in networks (example provided below)
Accountability
Open data policy
Response to 311 calls
Transparency

Figure 35: Civic Association Participation in Governance Networks



Source: Texas Metro Observatory https://bridgingbarriers.utexas.edu/planet-texas-2050/

Dallas Fort-Worth, Texas
Source: https://parksfordowntowndallas.org/historic-places-downtown-dallas/

ENDNOTES

[1]Dahl, R. A. (1989). Democracy and its critics. New Haven: Yale University Press.

[2]Cruz, N. F. da, & Marques, R. C. (2014). Scorecards for sustainable local governments. Cities, 39, 165–170. https://doi.org/10.1016/j.cities.2014.01.001

[3]Stewart, K. (2006). Designing good urban governance indicators: The importance of citizen participation and its evaluation in Greater Vancouver. Cities, 23(3), 196–204. https://doi.org/10.1016/j.cities.2006.03.003