Economic Impact of Severe Drought

by Joyce Beebe

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Economic Impacts of Severe Droughts

History and Background

Formal statewide water planning began around the late 1950s, after the "drought of record" left all except one of Texas' 254 counties classified as disaster areas. This 7-year dry period ended with massive rains that resulted in the flooding of every major river and tributary in the state. The drought of the 1950s cost the state hundreds of millions of dollars and was followed by floods that caused an additional $120 million in damages.[1]

In 1957, the Texas legislature created the Texas Water Development Board (TWDB) as a state agency to provide financial and logistical assistance concerning water-related resources. The agency began publishing the State Water Plan (SWP), Texas' most comprehensive water supply planning tool, in 1961. The plan uses the drought of record as a benchmark for future disaster planning, akin to a worst-case scenario consideration. The water planning process remained centralized until 1997, another year of severe drought.[2] After that year, the legislature established a regional water planning process, which shifted water planning to begin at the local level. The legislature also directed the SWP to be published every five years.

Today, the TWDB continues to function as the state's primary water supply planning and financing agency. With severe drought conditions continuing to threaten the Texas economy, water resources planning is more critical than ever. For instance, the recent period between 2010 and 2014 represents the second worst drought in Texas history, and the dry conditions in 2011 alone cost the state's agriculture sector an estimated $7.6 billion.[3]

An important goal of the SWP is to ensure adequate water supply for all Texans during future droughts. In general, every SWP begins with an overview of the state's current and prospective water use and identifies water supplies, projected water needs, and potential investment required. It then identifies water problems and planning opportunities, outlines significant environmental concerns, and offers policy and funding recommendations to the Texas legislature.[4]

The 2022 Texas State Water Plan[5]

The 2022 SWP, the most recent, is the fifth plan completed under the regional model, which includes 16 regional water plans and considers a 50-year planning horizon. From a demand

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[1] Texas Board of Water Engineers, Texas Water Resources Planning at the End of the Year 1958—A Progress Report to the Fifty-Sixth Legislature, 1958. From Texas Water Development Board, 2022 Texas State Water Plan, adopted by the Board on July 7, 2021, page A-160, https://www.twdb.texas.gov/waterplanning/swp/2022/index.asp

[2] Texas Water Development Board, 2022 Texas State Water Plan.

[3] Spencer Grubbs, Shannon Halbrook, Jessica Donald and Bruce Wright, Texas Water: Planning for More, Texas Comptroller Fiscal Notes, April 2019, https://comptroller.texas.gov/economy/fiscal-notes/2019/apr/tx-water-planning.php (This number potentially includes damages beyond income losses.)

[4] Texas Legislative Budget Board, Fiscal Size-up, 2020-21 Biennium, May 2020, https://www.lbb.state.tx.us/Documents/Publications/Fiscal_SizeUp/Fiscal_SizeUp_2020-21.pdf

[5] Unless otherwise indicated, this section references the 2022 Texas State Water Plan from the Texas Water Development Board.

perspective, population growth is a major factor behind the increased water demand. Texas' population has increased substantially over the last few decades, and the trend is expected to continue. Between 2020 and 2070, Texas' population is projected to increase by more than 70%, from 29.7 million to 51.5 million. Half of the growth is expected in the regions surrounding the Houston and Dallas-Fort Worth metropolitan areas.

Water demand is expected to increase by about 9% from 2020 to 2070, which is from 17.7 million acre-feet to 19.2 million acre-feet.[6] Among major water use groups (WUG),[7] municipal demand (generally, residential, institutional, and commercial uses) is expected to increase the most; agricultural irrigation and mining uses are expected to decrease. Livestock and manufacturing uses are also expected to increase, whereas the steam electric power uses will remain constant. Water needs—potential shortages in the event of severe drought—are projected to increase from 3.1 million acre-feet in 2020 to 6.9 million acre-feet in 2070.

The existing water supply, on the other hand, is expected to decrease over the planning horizon. In 2020, Texas' existing water supply of approximately 16.8 million acre-feet consisted roughly of half surface water and half groundwater, and reuse contributed to 4% of the water supply. The existing water supply is projected to decline by 18% between 2020 and 2070, from 16.8 million acre-feet to 13.8 million acre-feet. The total surface water supply largely remains stable, declining by about 2% over the 50-year period; however, the total groundwater supply is expected to decline by 32% during this period primarily due to the depletion of aquifers.[8] Even when considering water availability—the maximum volume of water that can be withdrawn annually from each source during droughts—groundwater availability is still expected to decline by 25%.[9] **Table 1** below summarizes the trends in population growth, water demand, water supply, and water needs over the planning horizon.

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[6] An acre foot is the volume of water needed to cover one acre to the depth of one foot. It equals 325,851 gallons and is roughly equivalent of the average annual water use by two families. Texas Legislative Budget Board, Fiscal Size-up, 2020-21 Biennium.

[7] Major WUGs include: municipal utilities, county-other rural areas, and non-municipal categories: irrigation, livestock, manufacturing, mining, and steam electric power. Municipal WUGs are primarily privately owned utilities or publicly water systems that provide more than 100 acre-feet per year for municipal use. See https://www.twdb.texas.gov/waterplanning/data/projections/FAQ/index.asp#title-01c

[8] Specifically, the reduction in supplies from the Ogallala Aquifer and mandatory pumping restrictions on the Gulf Coast Aquifer are the primary drivers for reduction.

[9] Water supply is available water that is connected to users from a legal and infrastructure perspective. Water availability, on the other hand, does not consider whether the water source is connected to users or is legally authorized for use. As such, water supply is a subset of water availability.

Table 1: Demographic and Key Water Trends, 2020-2050

Measure	2020	2030	2040	2050	2060	2070
Population	29,695,345	33,913,233	38,063,056	42,294,281	46,763,473	51,486,113
Growth Rate (from 2020)	0	14.20%	28.18%	42.43%	57.48%	73.38%
(In acre foot)						
Demand	17,680,444	18,426,781	18,326,558	18,394,477	18,647,792	19,230,876
Existing Supplies	16,763,586	15,461,714	14,683,204	14,209,494	13,901,890	13,817,572
Needs (Potential Shortages)	3,116,261	4,744,425	5,281,460	5,740,132	6,248,900	6,859,300

Data Sources: TWDB, 2022 Texas State Water Plan; author's summary.

To address the potential water shortage, the SWP recommends 5,800 water management strategies (WMS) that collectively would provide 1.7 million acre-feet per year in additional water supply in 2020 and 7.7 million acre-feet per year in 2070. In addition to the WMS, the SWP includes 2,400 water management strategy projects (WMSP). The difference between the WMS and WMSP is that the WMSP aim to increase the water supply through the building of new water infrastructure, while the WMS typically do not require new infrastructure. The construction of new water infrastructure projects not only requires long-term planning, but also the financing of capital costs. According to the TWDB, implementing the 2,400 WMSP before 2070 will cost approximately $80 billion in 2018 dollars.

On the other hand, if no action is taken, an insufficient water supply could have wide-ranging impacts. In addition to every Texan's daily routines, activities such as manufacturing, power generation, cattle feeding, timber, tourism, and agriculture will all be negatively affected. Public health and safety also depend on adequate water supplies for drinking, sanitation, and hygiene. Almost no one will be immune to the impacts of water shortage. Beyond direct economic losses, a perceived lack of water can prevent decision-makers from starting a new business, expanding an existing business, or relocating a business to Texas.

According to a recent Texas State Climatologist report, drought severity is affected by several factors, including precipitation variability, changes in water use efficiency, and temperature variations. [10] Although the variability of rainfall is projected to be constant until 2036, trends of the other two factors imply that when severe drought happens, there will be unprecedentedly severe impacts. [11] In other words, the extreme weather patterns will reduce the overall water availability and increase the intensity of future droughts.

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[10] John Nielsen-Gammon, Sara Holman, Austin Buley, Savannah Jorgensen, Jacob Escobedo, Catherine Ott, Jeramy Dedrick, and Ali Van Fleet, Assessment of Historic and Future Trends of Extreme Weather in Texas, 1900- 2036: 2021 Update. Document OSC-202101, Office of the State Climatologist, Texas A&M University, October 7, 2021.

[11] For instance, the extreme summer temperature days (number of 100-degree days) is expected to nearly double between 2001-2020 and 2036. See pages 16-17 of the report.

Economic Analysis I: Statewide Analysis

Unmet water needs will negatively affect existing businesses, impair future economic development, and harm public health and safety in Texas. The SWP includes estimated economic and social impacts of not meeting future water needs as part of the regional planning process. As such, the economic analysis of this section references TWDB's Socioeconomic Impact Analysis as a starting point to estimate the economic impacts on different sectors.[12]

Similar to the structure of the SWP, the Socioeconomic Impact Analysis takes a regional approach and forecasts the impacts of severe drought on the state's economy over a 50-year period.[13] To focus on immediate actions, this section highlights results over the next three decades, including 2036. Because statewide water needs will increase by more than 80% between 2020 and 2050, from 3.1 million acre-feet to 5.7 million acre-feet, the associated economic and social impacts will also rise significantly over this period.

For each region, the economic analysis measures the potential impacts of unmet water needs. Two major indicators are income losses and job losses. The former, income losses, represents an approximation of the gross domestic product (GDP) that would be lost if water needs are not met. The latter measures the number of job losses as a result of the water shortage. Both measures include direct, indirect, and induced monetary impacts on the region.[14]

A separate measure reports the tax losses on production and imports. This item shows a variety of taxes not collected because of the water shortage, which include sales and excise taxes, customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies.

From the social impact perspective, potential demographic effects are reported. These primarily include population losses and school enrollment losses as a result of insufficient water. Both statistics are derived from potential job loss estimates. Specifically, the SWP relies on the results of a recent study to derive a ratio of job to net population losses, which estimates that for every 100 job losses, 18 people will leave the area.[15] In terms of school enrollment losses, the SWP

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[12] The statewide impacts summarized in Table 6.3 of the SWP are slightly different from the impact results presented in the regional water plans (Appendix D). According to the SWP, this is primarily due to the difference in the quantity of water needs used to estimate the impacts. The results included in the regional water plans were compiled in September 2019 whereas the final regional water plans were prepared 14 months later, in November 2020. This analysis follows the regional water plans in Appendix D, because this data source provides more detailed breakdown to allow sector level calculation.

[13] Texas Water Development Board, Socioeconomic Impact Analysis, 2021 RWP Impact Reports, November 2019, https://www.twdb.texas.gov/waterplanning/data/analysis/index.asp

[14] According to SWP's definition, the direct impacts measure the initial change in the industry. The indirect impacts are changes in inter-industry transactions as supplying industries respond to reduced demand from the directly affected industries. The induced impacts reflect changes in local spending that result from reduced household income among employees in the directly and indirectly affected industry sectors. The SWP does not report each impact separately.

[15] According to the description in the SWP, the ratio of job to net population losses are calculated for the state as a whole. The 18% ratio is based on a study by Andrew Foote, Michel Grosz, and Ann Stevens, Locate Your Nearest

references public school enrollment data from the Texas Education Agency regarding the K-12-age population within the state. The study assumes population losses will lead to 19% of school enrollment losses. These analyses estimate how changes in a region's economy could affect patterns of migration from a region.

Another helpful measure from a social impact perspective is the loss of consumer surplus, defined as the lost value to consumers accompanying restricted water use. The consumer surplus does not represent out-of-pocket expenses; instead, it is a welfare measure that shows how much consumers would be willing to pay to have sufficient water supply when severe drought occurs.[16]

Table 2 below summarizes aggregated state-level economic and social impact measures. The key economic indicators include job losses, income losses, and tax revenue losses due to water shortage. From a social impact perspective, consumer surplus losses and demographic measures, specifically population and school enrollment losses, are presented. [17] The SWP states that because of data and methodological limitations, the actual economic impacts are likely significantly larger than those amounts presented. This is consistent with the conclusions from the Texas State Climatologist report: the higher intensity of future droughts imply that these economic impact estimates may be conservative measures.

Table 2: Socioeconomic Impact Summary, by Impact Measure, All Regions [18]

	Impact Measure	2020	2030	2036	2040	2050
Label	**Economic and Financial Transfer Impacts**					
A	Income losses (millions)	98,165	111,139	111,139	111,139	117,611
B	Job loss	598,210	756,637	812,937	850,470	988,056
C	Tax loss on production and import	9,926	10,522	10,037	9,713	9,540
Label	**Social Impacts**					
G	Consumer surplus losses (millions)	987	2,054	3,151	3,883	6,493
H = B*0.18	Population losses	109,829	138,919	149,255	156,146	181,405
I = H*0.19	School enrollment losses	21,008	26,572	28,549	29,867	34,697

Data Sources: TWDB, Socioeconomic Impact Analysis; author's calculation and summary.

Impact on Selected Sectors: Agriculture, Energy, Semiconductor, and Manufacturing

The Socioeconomic Impact Analysis reports economic impacts in each region by six water use categories (irrigation, livestock, manufacturing, mining, municipal, and steam-electric). The following table summarizes the aggregated results from all 16 regions by economic impact

Exit: Mass Layoffs and Local Labor Market Response, University of California, Davis, April 2015, http://paa2015.princeton.edu/papers/150194

[16] For the calculation of consumer surplus losses and limitations, see TWDB, Drought Management Costing Tool User Manual, September 2019, https://www.twdb.texas.gov/waterplanning/rwp/planningdocu/2021/doc/current_docs/project_docs/TWDB_Drought_Management_Costing_Tool_User_Manual_2019.pdf

[17] The Socioeconomic Impact Analysis reports other indicators, including water trucking losses, utility revenue losses, and utility tax revenue losses, which are not reported in this section.

[18] The original estimates were provided in ten year intervals. The results reported in Table 2 added year 2036, calculated proportionally using estimates between 2030 and 2040.

measure and water use category. Although each region's economic and demographic profile is different, this table provides a high-level overview regarding the magnitude of each measure in the event of a severe drought.

Table 3: Economic Impact Summary, by Impact Measure and Water Use Category, All Regions

Water Use Category	Label	Economic and Financial Transfer Impacts	2020	2030	2036	2040	2050
Irrigation	A	Income losses (millions)	844	1,356	1,334	1,320	1,289
	B	Job loss	13,108	19,486	19,140	18,910	18,442
Livestock	A	Income losses (millions)	2,195	2,415	2,575	2,681	3,032
	B	Job loss	46,400	49,843	52,179	53,736	58,536
	C	Tax loss on production and import	114	124	132	138	155
Manufacturing	A	Income losses (millions)	19,192	30,450	33,596	35,694	43,552
	B	Job loss	156,432	244,191	264,701	278,375	331,939
	C	Tax loss on production and import	1,330	2,120	2,291	2,405	2,859
Mining	A	Income losses (millions)	67,239	62,452	54,158	48,629	38,494
	B	Job loss	348,111	325,173	283,300	255,385	205,625
	C	Tax loss on production and import	8,307	7,651	6,581	5,867	4,526
Municipal	A	Income losses (millions)	1,816	7,167	11,979	15,187	23,347
	B	Job loss	34,159	117,944	193,616	244,064	373,514
	C	Tax loss on production and import	175	627	1,033	1,303	2,000
Steam-Electric	A	Income losses (millions)	6,879	7,299	7,496	7,628	7,897

Data Sources: TWDB, Socioeconomic Impact Analysis; author's calculation and summary.

The next step is to segregate the economic impact of each water use category by selected sectors: specifically agriculture, energy, semiconductor, and manufacturing. This section references the descriptions in the North American Industry Classification System (NAICS) to identify the relationship between water use categories and sectors.[19] The NAICS is commonly used by federal agencies to classify business establishments for data collection purposes related to the U.S. economy. It is a 2 through 6 digit hierarchical classification system, with each additional digit progressively narrowing the underlying business activities. In other words, the more digits in the code, the greater the classification details.[20] As discussed below, some adjustments are made to align water use categories with sectors using Texas sector-level GDP data from the Bureau of Economic Analysis (BEA).[21]

The irrigation and livestock water use categories roughly correspond to NAICS code 11: agriculture, forestry, fishing and hunting. The sector 11 code encompasses two sub-sectors: farms (NAICS: 111-112) and forestry, fishing, and related activities (NAICS: 113–115), which are generally consistent with the activities in the agriculture sector. As such, the irrigation and livestock water use categories are used as a proxy for the agriculture industry; the reported

[19] U.S. Census Bureau, North American Industry Classification System, last accessed: November 17, 2021, https://www.census.gov/naics/

[20] The first two digits designate the economic sector, the third digit designates the subsector, the fourth digit designates the industry group, the fifth digit designates the NAICS industry, and the sixth digit designates the national industry. See U.S. Census Bureau, FAQ #5, last accessed: November 17, 2021, https://www.census.gov/naics/#q5

[21] Bureau of Economic Analysis, GDP by Industry, last accessed: November 17, 2021, https://www.bea.gov/data/gdp/gdp-industry

economic impacts from these categories are used to represent the economic impacts of severe drought on the state's agriculture industry.

The manufacturing water use category corresponds to the description of NAICS codes 31–33: manufacturing. The manufacturing sector includes the following three-digit sub-sectors:[22]

Table 4: NAICS Group 31-33: Manufacturing

	NAICS Three Digit Groups for 31-33: Manufacturing
321,327-339	***Durable goods manufacturing***
321	Wood product manufacturing
327	Nonmetallic mineral product manufacturing
331	Primary metal manufacturing
332	Fabricated metal product manufacturing
333	Machinery manufacturing
334	Computer and electronic product manufacturing
335	Electrical equipment, appliance, and component manufacturing
336	Transportation equipment manufacturing
337	Furniture and related product manufacturing
339	Miscellaneous manufacturing
311-316,322-326	***Nondurable goods manufacturing***
311-312	Food and beverage and tobacco product manufacturing
313-314	Textile mills and textile product mills
315-316	Apparel, leather, and allied product manufacturing
322	Paper manufacturing
323	Printing and related support activities
324	Petroleum and coal products manufacturing
325	Chemical manufacturing
326	Plastics and rubber products manufacturing

Data Sources: U.S. Census Bureau, NAICS; BEA, Texas GDP by Sector.

The manufacturing sector includes a diverse group of sub-sectors; some require limited water, whereas others may need a substantial amount of water during the production process. Some may use water not only to produce goods, but also to dilute the waste products generated in their manufacturing processes. In certain cases, consumers may be unware of how water-intensive a product can be. For instance, an American Society of Civil Engineers (ASCE) publication documents that smartphones are made of many smaller components. Producing and assembling all these components requires roughly 3,000 gallons of water per phone.[23] Finally, construction

[22] The table does not include all three-digit NAICS codes because not all corresponding activities were present in the Texas economy. See Bureau of Economic Analysis, GDP by Industry, last accessed: November 17, 2021, https://www.bea.gov/data/gdp/gdp-industry

[23] American Society of Civil Engineers, The Economic Benefits of Investing in Water Infrastructure, August 2020, https://infrastructurereportcard.org/wp-content/uploads/2021/03/Failure-to-Act-Water-Wastewater-2020-Final.pdf

activities under NAICS code 23 is also included in the manufacturing water use category because these activities physically convert materials from lower to higher value.[24]

The manufacturing water use category encompasses many key manufacturing activities; however, it also includes semiconductor manufacturing and certain manufacturing activities related to the energy sector. Specifically, NAICS codes 333: machinery manufacturing and 334: computer and electronic product manufacturing are the sub-sectors that include semiconductor manufacturing activities. To approximate the economic impacts of semiconductor manufacturing, activities from these two NAICS codes need to be carved out from the overall manufacturing sector. Texas sector-level GDP data from the BEA are used to estimate the size of the semiconductor manufacturing activities.[25]

Because the NAICS includes up to six digits of industry classification, it would be more precise to investigate four-digit NAICS codes within the three-digit 333 and 334 codes to ascertain the specific activities of the semiconductor sector. However, the BEA only reports data for up to three digits of the NAICS under these codes. Therefore, we are unable to further separate semiconductor-specific activities within these three-digit NAICS codes.[26]

Another NAICS code, 324: petroleum and coal products manufacturing, potentially corresponds to activities in the energy sector. As such, activities under this NAICS code also need to be removed from the overall manufacturing sector and added to the energy sector. It is worth noting that activities under code 325: chemical manufacturing are not reallocated to the energy sector. Although this code includes petrochemical manufacturing, it also includes medicine-, pesticide-, and fertilizer-related manufacturing activities that are irrelevant to the energy sector; adding activities under code 325 to the energy sector may overstate the size of the activities.

Finally, the mining and steam-electric water use categories, together with NAICS code 324, are used as a proxy for the activities in the energy sector. The remaining water use category, municipal water use, primarily consists of residential (e.g., single and multi-family residential settings), institutional (e.g., schools, churches, hospitals, and government facilities), and commercial uses (e.g., hotels, restaurants, office buildings, or places of business). None of the activities in the municipal water use category directly corresponds to the industrial sectors referenced in this section.[27]

After establishing the general mapping between water use categories and NAICS codes, the next step is to properly allocate the economic impacts reported by each water use category to the identified sectors. BEA's Texas GDP data reports the following results for 2020:

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[24] TWDB, Water Use of Texas Water Utilities, 2020 Biannual Report, Appendix B – Sector Descriptions, January 1, 2021, https://www.twdb.texas.gov/publications/reports/special_legislative_reports/doc/2021_WaterUseofTexasWaterUtilities.pdf

[25] Bureau of Economic Analysis, GDP by Industry, last accessed: November 17, 2021, https://www.bea.gov/data/gdp/gdp-industry

[26] For instance, within the NAICS code 334, four-digit code 3344 (Semiconductor and Other Electronic Component Manufacturing) specifically reflects semiconductor related activities.

[27] TWDB, Water Use of Texas Water Utilities, 2020 Biannual Report, Appendix B – Sector Descriptions, January 1, 2021.

Table 5: 2020 Texas GDP by Sector and NAICS Codes

NAICS	Description	Amount (Millions)	Percent of State Total
11	Agriculture	7,615	0.4%
21	Mining, quarrying, and oil and gas extraction	74,495	4.2%
22	Utilities	31,569	1.8%
23	Construction	89,987	5.1%
31-33	Manufacturing	211,513	11.9%
42	Wholesale Trade	146,148	8.2%
44-45	Retail Trade	103,003	5.8%
48-49	Transportation and warehousing	58,487	3.3%
51	Information	70,278	4.0%
52-53	Finance, insurance, real estate, rental, and leasing	347,212	19.6%
54	Professional, scientific, and technical services	136,051	7.7%
55	Management of companies and enterprises	25,654	1.4%
56	Adm and support and waste management and remediation services	62,935	3.5%
61-62	Educational services, health care, and social assistance	121,451	6.8%
71-72	Art and entertainment; accommodation and food services	52,331	2.9%
81	Other Services	34,656	2.0%
NA	Government	202,205	11.4%
	Total State GDP	1,775,588	100%

Data Sources: BEA, Texas GDP by Sector; author's calculation.

This table provides a high-level summary regarding the size of each sector in the Texas economy. As described, BEA's NAICS codes 31–33, associated with "manufacturing," include certain three-digit codes that overlap with the semiconductor and energy sectors. As such, it will be prudent to reclassify these activities from manufacturing to corresponding sectors to obtain more precise economic impact estimates.

In order to accomplish this, activities related to semiconductors and the energy sector within the NAICS codes 31–33 are separately identified. The results are summarized in **Table 6** below:

Table 6: Manufacturing and Selected Sub-sectors from NAICS Codes 23, 31-33

NAICS	Description	Amount (Millions)	Percent of Manufacturing
23, 31-33	Manufacturing, Construction	301,499	100%
324	Petroleum and coal products manufacturing	26,524	9%
333	Machinery manufacturing	16,408	5%
334	Computer and electronic product manufacturing	27,728	9%
	Manufacturing (non-energy, non-semiconductor)	230,839	77%

Data Sources: BEA, Texas GDP by Sector; author's calculation.

Summary of Sector Impacts

Recall that **Table 3** reports income losses by water use category. **Tables 4 to 6** investigate the relationship between water use categories, NAICS codes, and their relative size in Texas' GDP in order to ascertain the relationship between water use categories and selected industry sectors.

Certain water use categories, such as irrigation and livestock, directly correspond to the agriculture sector. As such, the income losses from severe drought reported by each region from these two water use categories are added together to obtain aggregate impacts on the agriculture sector.

For the manufacturing water use category, 77% of the reported income losses are estimated to be associated with manufacturing activities outside of semiconductor manufacturing and the manufacturing of petroleum-related products. Therefore, approximately 77% of the income losses reported by the manufacturing water use category are attributable to non-semiconductor-, non-energy-related manufacturing.

Next, NAICS codes 333 and 334 approximate the semiconductor manufacturing activities, which respectively account for 5% and 9% of activities in the manufacturing sector, and 14% combined. As such, 14% of the income losses from the manufacturing water use category are apportioned to semiconductor manufacturing activities.

Finally, the economic impact on the energy sector is estimated as the sum of income losses from the mining and steam-electric water use categories, and 9% of the income losses from the manufacturing water use category. The last item is derived from the NAICS code 324 to account for the economic impact of energy-related manufacturing activities. **Table 7** summarizes the income losses of these sectors.

Table 7: Economic Losses during Severe Drought, Selected Sectors

Water Use Category	Income Losses (Billions USD)	2020	2030	2036	2040	2050
Irrigation & livestock	*Income losses - Agriculture sector*	3.04	3.77	3.91	4.00	4.32
Manufacturing	Income losses	19.19	30.45	33.60	35.69	43.55
	Percent non-semiconductor, non-energy	77%	77%	77%	77%	77%
	Income losses - Manufacturing sector	14.78	23.45	25.87	27.48	33.54
	Percent semiconductor manufacturing	14%	14%	14%	14%	14%
	Income losses - Semiconductor Manufacturing	2.69	4.26	4.70	5.00	6.10
	Percent energy-related manufacturing	9%	9%	9%	9%	9%
	Energy related manufacturing	1.73	2.74	3.02	3.21	3.92
Mining	Income Losses	67.24	62.45	54.16	48.63	38.49
Steam-Electric	Income Losses	6.88	7.30	7.50	7.63	7.90
	Income Losses - Energy sector	75.85	72.49	64.65	59.47	50.31

Based on the results in **Table 7**, a severe drought is expected to cause $3.04 billion in income losses to the agriculture sector if it occurs within this decade. The losses will increase over time:

in two decades, they are expected to reach $4 billion and further increase to $4.32 billion in 2050.

For the manufacturing sector, the losses will increase at a faster rate. An estimated $14.78 billion will be lost if a severe drought takes place now. Around 2036, the loss will increase by over 70%. The damage will roughly double in 20 years: by 2040, $27.48 billion will be lost in the case of severe drought; in another 10 years, the income losses will increase to $33.54 billion.

In addition, the increasingly important semiconductor manufacturing sector in Texas will witness similarly progressive income losses due to severe drought. If a drought happens during this decade, the semiconductor sector is expected to incur $2.69 billion in losses, which increases to over $4.70 billion in 2036. By the middle of the century, the income losses are expected to exceed $6.10 billion.

Finally, although the overall income losses due to severe drought are expected to decline over the next 30 years for the energy sector, the sector will experience the largest change in terms of dollar amounts. If a drought had taken place in 2020, the sector would have been expected to suffer $75.85 billion in income losses. The income losses will decline to $72.49 billion in 2030, $64.65 billion in 2036, $59.47 billion in 2040, and $50.31 billion in 2050. This constitutes a 34% reduction between 2020 and 2050, primarily driven by reduced losses from the mining water use category. However, certain sub-sectors, such as manufacturing and steam-electric related activities, may see a trend of growing income losses.

Economic Analysis II: Regional Analysis

This section of the economic analysis takes a slightly different perspective, starting at each individual planning region and examining the impacts of potential water shortage on selected industry sectors. The methodology and the results of the analyses are described below.

The TWDB provides detailed reports for each regional planning group (Regions A to P). Each report complements the Socioeconomic Impact Analysis and includes comprehensive description of the region's economic activities, population, employment, and key industries. As such, this section references both the Regional Water Plans and the Socioeconomic Impact Analysis to examine the potential impacts of water shortage on certain industry sectors: specifically manufacturing, energy, and agriculture industries.[28]

Each region's Socioeconomic Impact Analysis includes an overview that summarizes the region's economic activities by sector, ranked by a sector's contribution to the region's GDP. These sectors are grouped by two-digit NAICS codes.[29]

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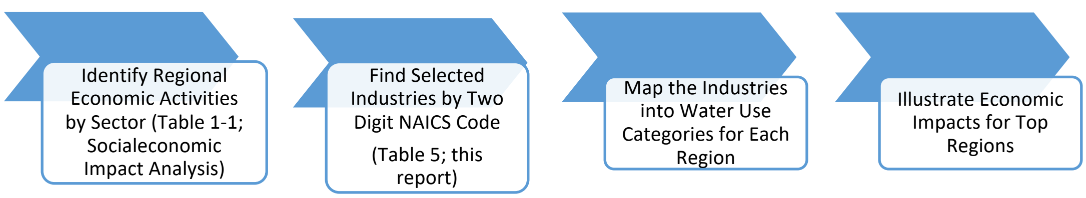
[28] These two reports for each region can be found at: Texas Water Development Board, 2021 Regional Water Plans, https://www.twdb.texas.gov/waterplanning/rwp/plans/2021/index.asp; the Socioeconomic Impact Analysis, https://www.twdb.texas.gov/waterplanning/data/analysis/index.asp

[29] The Regional Water Plan does not have a consistent summary of regional economies across all regions. As such, we use Table 1-1 in each Socioeconomic Impact Analysis as our regional benchmark measure. The most recent economic data summarized in the Socioeconomic Impact Analysis of each region is from 2016.

As described in the previous section (Statewide Analysis), BEA's industry data provides GDP information for up to three digits of NAICS codes. Thus, we reviewed statewide industry GDP information and allocated certain three-digit NAICS codes to specific sectors. This approach allowed us to more accurately reflect a portion of the manufacturing activities (NAICS 324, 333, 334, see **Table 6**) as activities attributable to the energy and semiconductor sectors.

However, because the Socioeconomic Impact Analysis from each region only provides information under two-digit NAICS codes, similar allocations are not applicable. For instance, if we allocate 14% of the regional manufacturing GDP to the semiconductor sector for Region O, it will not be a good proxy. Region O, the Llano Estacado region where Lubbock is located, is best known for its agricultural crops (especially cotton) and livestock operations. Manufacturing or semiconductor manufacturing is not mentioned as one of the region's key industries. In other words, the ratio used to bifurcate semiconductor manufacturing from overall manufacturing is accurate for the state as a whole, but may not be a good regional level approximation. Therefore, for the purpose of this section, "manufacturing" includes semiconductor-related manufacturing activities due to the NAICS limitation.

For each of the three industry sectors, we begin by reviewing the two-digit NAICS codes (**Table 5**) and examining industries associated with these codes for each water planning region. Then, we identify the top three to five regions with the highest concentration of these industry sectors. Finally, the potential income losses of these selected regions are presented. The process can be illustrated with the chart below:



Manufacturing

The manufacturing industry is a key economic sector for many regions. Manufacturing is covered under NAICS codes 31-33, which include durable and non-durable goods manufacturing. When we reference the six water use categories (irrigation, livestock, manufacturing, mining, municipal, and steam-electric power), the "manufacturing" water use category potentially include all industrial activities that physically convert materials from lower to higher value. As such, construction-related activities under NAICS code 23: Construction are also included. The following table summarizes the GDP and number of jobs in the manufacturing industry across all 16 regions.

Table 8: Manufacturing GDP and Number of Jobs - All 16 Regions

Region	A	B	C	D	E	F	G	H
Name / Geographic Feature	Panhandle	North Central TX	North Texas	North East TX	Far West Texas	West Texas	Brazos River Basin	Upper TX Coast
Manufacturing GDP (Million$)	$5,221	$971	$62,979	$5,447	$2,629	$3,091	$12,158	$77,055
Manufacturing Jobs	22,224	6,520	290,469	38,589	18,922	18,614	71,960	245,107
Construction GDP (Million$)	$1,293	$325	$27,064	$1,975	$1,183	$2,651	$5,874	$34,660
Construction Jobs	15,848	5,198	289,959	29,218	26,328	30,015	79,659	323,162
Mfg + Const GDP (Million$)	$6,514	$1,296	$90,043	$7,422	$3,812	$5,742	$18,032	$111,715
Mfg + Const Jobs	38,072	11,718	580,428	67,807	45,250	48,629	151,619	568,269

Region	I	J	K	L	M	N	O	P	TOTAL (A-P)
Name / Geographic Feature	East Texas	Plateau	Lower Colorado	South Central TX	Rio Grande	Costal Bend	Llano Eatacado	Lavaca	
Manufacturing GDP (Million$)	$16,153	$372	$9,623	$11,484	$1,570	$5,528	$1,506	$255	$216,042
Manufacturing Jobs	47,857	3,610	46,647	64,959	17,474	11,243	11,631	2,295	918,121
Construction GDP (Million$)	$3,471	$271	$6,056	$7,788	$1,593	$2,830	$1,126	$158	$98,318
Construction Jobs	44,007	5,093	70,072	110,766	36,849	31,549	16,701	1,552	1,115,976
Mfg + Const GDP (Million$)	$19,624	$643	$15,679	$19,272	$3,163	$8,358	$2,632	$413	$314,360
Mfg + Const Jobs	91,864	8,703	116,719	175,725	54,323	42,792	28,332	3,847	2,034,097

Data Sources: Socioeconomic Impact Analysis; author's calculation.

These can be expressed in percentage terms, as shares of total number of jobs and GDP across all regions. The results in percentage terms are presented in the following table:[30]

[30] Another benefit of referencing a percentage instead of an absolute number is that the BEA state wide industry GDP information and the estimates provided by TWDB (using IMPLAN) show a wedge in these industries. Generally, the IMPLAN GDP estimates are higher than the BEA data. Because TWDB's reports are the only data source that links economic sectors to water planning categories, this report uses the data from TWDB.

Table 9: Manufacturing GDP and Number of Jobs - All 16 Regions (in Percentage)

Region	A	B	C	D	E	F	G	H
Name / Geographic Feature	Panhandle	North Central TX	North Texas	North East TX	Far West Texas	West Texas	Brazos River Basin	Upper TX Coast
Manufacturing GDP	2.4%	0.4%	29.2%	2.5%	1.2%	1.4%	5.6%	35.7%
Manufacturing Jobs	2.4%	0.7%	31.6%	4.2%	2.1%	2.0%	7.8%	26.7%
Construction GDP	1.3%	0.3%	27.5%	2.0%	1.2%	2.7%	6.0%	35.3%
Construction Jobs	1.4%	0.5%	26.0%	2.6%	2.4%	2.7%	7.1%	29.0%
Mfg + Const GDP	2.1%	0.4%	28.6%	2.4%	1.2%	1.8%	5.7%	35.5%
Mfg + Const Jobs	1.9%	0.6%	28.5%	3.3%	2.2%	2.4%	7.5%	27.9%

Region	I	J	K	L	M	N	O	P
Name / Geographic Feature	East Texas	Plateau	Lower Colorado	South Central TX	Rio Grande	Costal Bend	Llano Eatacado	Lavaca
Manufacturing GDP	7.5%	0.2%	4.5%	5.3%	0.7%	2.6%	0.7%	0.1%
Manufacturing Jobs	5.2%	0.4%	5.1%	7.1%	1.9%	1.2%	1.3%	0.2%
Construction GDP	3.5%	0.3%	6.2%	7.9%	1.6%	2.9%	1.1%	0.2%
Construction Jobs	3.9%	0.5%	6.3%	9.9%	3.3%	2.8%	1.5%	0.1%
Mfg + Const GDP	6.2%	0.2%	5.0%	6.1%	1.0%	2.7%	0.8%	0.1%
Mfg + Const Jobs	4.5%	0.4%	5.7%	8.6%	2.7%	2.1%	1.4%	0.2%

Data Sources: Socioeconomic Impact Analysis; author's calculation.

The solid red outlines indicate that manufacturing activities are important for that region, and the industry is ranked as a top economic sector for the region in terms of both GDP and employment. The dotted lines are presented either because the GDP or the number of jobs (but not both) is top-ranked for the region, or several regions have similar percentages in terms of GDP or employment.

Specifically, Regions C and H clearly dominate the manufacturing activities in terms of both percentage of workers and GDP. Region I has slightly higher GDP than Regions L and G; however, the latter two regions employ more workers in the manufacturing sector. As such, we highlight all five regions to avoid arbitrary cut offs.

Examining the economic and population characteristics of all regions, the commonality is that all have large cities and rapidly growing populations in the regions. Regions C and H, the two regions with dominant manufacturing activities, are where Dallas-Fort Worth and Houston are located, respectively. The population of Region C was over 7.6 million in 2020, is expected to exceed 8.8 million in 2030, and will be over 10 million by 2040. In 2050, the region is projected to have over 11.5 million residents. Region H, where Houston is located, shows a similar trend of population growth: from 7.3 million in 2020, 8.2 million in 2030, 9 million in 2040, to almost 10 million in 2050. Region G has major cities such as College Station, Temple and Waco. Region I is where Beaumont, Tyler and Lufkin are located. Region L hosts cities such as San Antonio and Victoria.

Collectively, these five regions account for 82% of the state manufacturing GDP (an equivalent of $258 billion) and 77% of the manufacturing jobs (an equivalent of over 1.5 million jobs).

According to the estimates from TWDB, if no action is taken, the water shortages associated with a drought of record will have significant economic impacts in these five regions (C, H, G, I, and L). This means that if severe drought happens around 2036, **roughly $15 billion of the manufacturing GDP and up to 100,000 jobs could be lost in these five water planning regions**.[31]

Table 10: Economic Impact of Severe Drought – Manufacturing Sector, Top Five Regions

All Five Regions	2020	2030	2036	2040	2050
Income Losses (million$)	$6,428	$12,897	$14,730	$16,563	$21,622
Job loss	46,727	93,733	105,159	116,585	149,067

Data Sources: Socioeconomic Impact Analysis; author's calculation.

Energy

The energy industry is a key economic sector for a number of regions. The energy sector is covered under NAICS code 21: Mining, quarrying, and oil and gas extraction, and NAICS code 22: Utilities. In addition, this sector most directly corresponds to mining and steam-electric power water use categories. The following table summarizes the GDP and number of jobs in the energy industry across all 16 regions.

Table 11: Energy GDP and Number of Jobs - All 16 Regions

Region	A	B	C	D	E	F	G	H
Name / Geographic Feature	Panhandle	North Central TX	North Texas	North East TX	Far West Texas	West Texas	Brazos River Basin	Upper TX Coast
Mining GDP (Million$)	$3,694	$1,127	$22,397	$1,940	$65	$19,712	$3,917	$53,254
Mining Jobs	15,105	9,477	87,272	15,703	1,171	67,722	31,093	134,003
Utilities GDP (Million$)	$762	$274	$7,514	$1,424	$806	$1,350	$3,453	$14,460
Utilities Jobs	1,391	432	11,294	2,452	1,572	2,089	6,194	18,945
Mining + Utility GDP (Million$)	$4,456	$1,401	$29,911	$3,364	$871	$21,062	$7,370	$67,714
Mining + Utility jobs	16,496	9,909	98,566	18,155	2,743	69,811	37,287	152,948

Region	I	J	K	L	M	N	O	P	TOTAL (A-P)
Name / Geographic Feature	East Texas	Plateau	Lower Colorado	South Central TX	Rio Grande	Costal Bend	Llano Eatacado	Lavaca	
Mining GDP (Million$)	$4,789	$90	$5,018	$8,493	$1,206	$2,469	$1,332	$100	$129,603
Mining Jobs	16,819	1,334	17,303	32,890	7,204	14,661	10,766	1,060	463,583
Utilities GDP (Million$)	$1,654	$55	$2,816	$1,984	$731	$1,228	$850	$24	$39,385
Utilities Jobs	2,743	218	6,302	4,421	2,151	1,628	1,971	58	63,861
Mining + Utility GDP (Million$)	$6,443	$145	$7,834	$10,477	$1,937	$3,697	$2,182	$124	$168,988
Mining + Utility jobs	19,562	1,552	23,605	37,311	9,355	16,289	12,737	1,118	527,444

Data Sources: Socioeconomic Impact Analysis; author's calculation.

[31] We note that, using the economic industry importance of each region to identify estimated economic impact is a preferable approach to reviewing the economic impact of each region and finding the top regions with the biggest impact amounts. For example, region O's biggest sectors are public administration, agriculture, and real estate rental. However, its impact estimate shows an estimated GDP loss of $7,318 million in the event of drought in 2020, which is 2.5 times bigger than the region's GDP for that sector ($2,630 million).

Similar to the approach taken in the manufacturing sector, these results can be expressed as shares of total number of jobs and GDP across all regions. The table below shows the results in percentage terms.

Table 12: Energy GDP and Number of Jobs - All 16 Regions (in Percentage)

Region	A	B	C	D	E	F	G	H
Name / Geographic Feature	Panhandle	North Central TX	North Texas	North East TX	Far West Texas	West Texas	Brazos River Basin	Upper TX Coast
Mining GDP	2.9%	0.9%	17.3%	1.5%	0.1%	15.2%	3.0%	41.1%
Mining Jobs	3.3%	2.0%	18.8%	3.4%	0.3%	14.6%	6.7%	28.9%
Utilities GDP	1.9%	0.7%	19.1%	3.6%	2.0%	3.4%	8.8%	36.7%
Utilities Jobs	2.2%	0.7%	17.7%	3.8%	2.5%	3.3%	9.7%	29.7%
Mining + Utility GDP	2.6%	0.8%	17.7%	2.0%	0.5%	12.5%	4.4%	40.1%
Mining + Utility jobs	3.1%	1.9%	18.7%	3.4%	0.5%	13.2%	7.1%	29.0%

Region	I	J	K	L	M	N	O	P
Name / Geographic Feature	East Texas	Plateau	Lower Colorado	South Central TX	Rio Grande	Costal Bend	Llano Eatacado	Lavaca
Mining GDP	3.7%	0.1%	3.9%	6.6%	0.9%	1.9%	1.0%	0.1%
Mining Jobs	3.6%	0.3%	3.7%	7.1%	1.6%	3.2%	2.3%	0.2%
Utilities GDP	4.2%	0.1%	7.1%	5.0%	1.9%	3.1%	2.2%	0.1%
Utilities Jobs	4.3%	0.3%	9.9%	6.9%	3.4%	2.5%	3.1%	0.1%
Mining + Utility GDP	3.8%	0.1%	4.6%	6.2%	1.1%	2.2%	1.3%	0.1%
Mining + Utility jobs	3.7%	0.3%	4.5%	7.1%	1.8%	3.1%	2.4%	0.2%

Data Sources: Socioeconomic Impact Analysis; author's calculation.

Therefore, Regions C, F, and H are clearly the regions with energy as a major industry in terms of both percentage of workers and GDP. As discussed above, Regions C and H are the two biggest metropolitan areas in Texas, where Dallas-Fort Worth and Houston are located. Both regions list energy as a major economic sector in the Regional Water Plans. Region F, with major cities including Midland, Odessa, and San Angelo, is part of the Permian Basin. Oil and gas related activities are the key economic driver and the sector employs the largest number of workers as described in its Regional Water Plan.[32]

In addition, the Regional Water Plans of Region G (College Station, Temple and Waco) and Region L (San Antonio and Victoria) both describe mining and energy related activities as a major industry in the region. [33] Therefore, these ratios are directionally consistent with the descriptions in the Regional Water Plans; we highlight these five regions with energy as a key economic sector.[34]

[32] TWDB, Region F 2021 RWP (Section 1.1.1 Economic Activity in Region F, page 55/450), https://www.twdb.texas.gov/waterplanning/rwp/plans/2021/index.asp#region-a

[33] TWDB, Region G 2021 RWP (Section 1.3 Economic Activities, page 309/1064), and TWDB, Region L 2021 RWP (Section 1.4 Economy – Major Sectors and Industries, page 74/656).

[34] Region K, where Austin is located, has oil, gas, petrochemical processing, and mineral production around Wharton and Matagorda counties. However, its Regional Water Plan does not list mining or energy as a region-wide important industry. See TWDB, Region K 2021 RWP (Section 1.2.2.2 Primary Economic Activities, page 146/538) https://www.twdb.texas.gov/waterplanning/rwp/plans/2021/index.asp#region-a

In aggregate, these five regions account for over 80% of the state energy GDP (an equivalent of $137 billion) and 75% of the energy related jobs (an equivalent of 396,000 jobs).

According to the estimates from TWDB, if no action is taken, the water shortages associated with a drought of record will impose significant economic impacts in these five regions (C, F, G, H, and L). This means that if a severe drought happens around 2036**, over $46 billion of the energy sector GDP and 220,000 jobs could be lost in these five water planning regions**. Both the GDP reduction and job losses are more significant than the manufacturing sector.

Table 13: Economic Impact of Severe Drought – Energy Sector, Top Five Regions

All Five Regions	2020	2030	2036	2040	2050
Income Losses (million$)	$49,746	$50,072	$46,127	$42,181	$34,293
Job loss	241,831	240,697	219,616	198,535	157,638

Data Sources: Socioeconomic Impact Analysis; author's calculation.

Agriculture

Agriculture is covered under NAICS code 11: Agriculture, forestry, fishing and hunting. When we reference the water use categories, agriculture is associated with irrigation and livestock categories. The following table summarizes the GDP and number of jobs in the agriculture sector across all 16 regions.

Table 14: Agriculture GDP and Number of Jobs - All 16 Regions

Region	A	B	C	D	E	F	G	H
Name / Geographic Feature	Panhandle	North Central TX	North Texas	North East TX	Far West Texas	West Texas	Brazos River Basin	Upper TX Coast
Agriculture GDP (Million$)	$994	$147	$567	$540	$106	$413	$1,117	$661
Agriculture Jobs	13,087	6,216	38,719	24,728	2,929	16,847	56,319	29,892

Region	I	J	K	L	M	N	O	P	TOTAL (A-P)
Name / Geographic Feature	East Texas	Plateau	Lower Colorado	South Central TX	Rio Grande	Costal Bend	Llano Eatacado	Lavaca	
Agriculture GDP (Million$)	$710	$59	$530	$830	$784	$280	$2,253	$88	$10,079
Agriculture Jobs	22,427	3,769	21,738	33,150	18,398	10,630	27,250	3,990	330,089

Data Sources: Socioeconomic Impact Analysis; author's calculation.

These results can be expressed as shares of total jobs and GDP across all regions. The table below shows the results in percentage terms:

Table 15: Agriculture GDP and Number of Jobs - All 16 Regions (in Percentage)

Region	A	B	C	D	E	F	G	H
Name / Geographic Feature	Panhandle	North Central TX	North Texas	North East TX	Far West Texas	West Texas	Brazos River Basin	Upper TX Coast
Agriculture GDP (Million$)	9.9%	1.5%	5.6%	5.4%	1.1%	4.1%	11.1%	6.6%
Agriculture Jobs	4.0%	1.9%	11.7%	7.5%	0.9%	5.1%	17.1%	9.1%

Region	I	J	K	L	M	N	O	P
Name / Geographic Feature	East Texas	Plateau	Lower Colorado	South Central TX	Rio Grande	Costal Bend	Llano Eatacado	Lavaca
Agriculture GDP (Million$)	7.0%	0.6%	5.3%	8.2%	7.8%	2.8%	22.4%	0.9%
Agriculture Jobs	6.8%	1.1%	6.6%	10.0%	5.6%	3.2%	8.3%	1.2%

Data Sources: Socioeconomic Impact Analysis; author's calculation.

Regions G and O are the two noticeable regions with large agriculture operations, both in terms of GDP and number of employment. However, identifying secondary regions with large agriculture industries by reviewing the number of workers and GDP posts challenges. For instance, a region's agriculture GDP may be higher than another region, but has a small number of workers employed in the sector. In addition, a certain region's overall agriculture industry GDP could be small but it is the region's key economic activity. As a result, we review the descriptions in Regional Water Plans regarding each region's major economic activities as a more comprehensive approach.

Region D, the North East Texas region, has agribusiness as its major economic base. Its activities include a variety of crops, as well as cattle and poultry production. Region I is adjacent to Region D, and has major economic sectors such as petrochemical, timber, and agriculture. In addition, the Rio Grande region's (Region M) large economic sectors include agriculture, trade, services, manufacturing, and hydrocarbon production.

In aggregate, these five regions account for 54% of the state agriculture GDP (an equivalent of $5.4 billion) and 45% of agriculture related jobs (an equivalent of about 150,000 jobs).

According to the estimates from TWDB, if no action is taken, the water shortages associated with a drought of record will have significant economic impacts on these five regions (D, G, I, M, and O). This means that if a severe drought happens around 2036, **over $3.5 billion of the agriculture sector GDP and 62,000 jobs could be lost in these five water planning regions.** Although the GDP reduction is not as significant as that in the manufacturing or energy sector, the number of job losses is disproportionally high. For instance, agriculture sector's GDP loss is about 23% of the manufacturing sector GDP loss in an event of severe drought, but the number of job losses is estimated to be 62% of the manufacturing sector job losses.[35] Therefore, for regions that rely heavily on agriculture, this could have large impacts on the economy.

[35] The GDP loss of 23% is calculated as: $3.5 billion divided by $15 billion; the job loss of 62% is calculated as 62,000 divided by 100,000.

Table 16: Economic Impact of Severe Drought – Agriculture Sector, Top Five Regions

All Five Regions	2020	2030	2036	2040	2050
Income Losses (million$)	$2,782	$3,427	$3,512	$3,597	$3,929
Job loss	52,693	60,389	61,861	63,332	67,807

Data Sources: Socioeconomic Impact Analysis; author's calculation

Water Infrastructure Update

Overview and Background

The issue of weatherization gained awareness after Winter Storm Uri hit Texas in February 2021. The storm caused over 110 deaths and widespread damage to homes and businesses, and left millions without power and water for days. In the aftermath of the winter storm, many discussions centered on the weatherization of power plants, and the Texas legislature also required power generation companies and critical gas facilities to weatherize so electricity would not be disconnected during future emergencies. Water infrastructure has received relatively less attention.

This section first discusses recent damage estimates caused by the February winter storm, and reviews studies that analyze the costs and benefits of weatherizing power plants. Next, it illustrates the interconnectivity between power and water infrastructure. However, weatherizing power plants does not completely resolve water supply issues during extreme weather. Chronic underinvestment in the water system and the improvement of water infrastructure resiliency, for example, are issues unique to water infrastructure that need to be addressed separately. The section then summarizes recent federal and state measures that are relevant to water infrastructure weatherization.

Weatherizing Power Plants

Available studies provide a wide range of estimates for the damage caused by the February winter storm, and they often vary in methodologies and details. A study by the Federal Reserve Bank of Dallas indicates the value of electricity lost due to power outages was $4.3 billion.[36] An industry analysis shows the storm cost $80 billion to $130 billion in direct and indirect economic losses to the Texas economy.[37] This estimate includes approximately $35 billion that can be attributed to physical damage such as water bursting from broken or frozen pipes, and $45 billion

[36] Garrett Golding, Anil Kumar and Karel Mertens, Cost of Texas' 2021 Deep Freeze Justifies Weatherization, Federal Reserve Bank of Dallas, April 15, 2021, https://www.dallasfed.org/research/economics/2021/0415.aspx (The Federal Reserve study uses the value of lost load (VOLL) as their basis to come up with the economic value of power interruption during the storm. It measures the amount of revenue electricity providers could have made during the period if the power supply had not been interrupted.)

[37] Brian K. Sullivan, Texas Deep Freeze Could Cost $90 Billion in Losses, Modeler Says, Bloomberg, February 24, 2021, https://www.bloomberg.com/news/articles/2021-02-24/texas-deep-freeze-could-cost-90-billion-in-losses-modeler-says

in losses associated with supply chain disruptions. Only a small portion of the entire damage, roughly $10 to $20 billion, is covered by insurance. Finally, a University of Houston study puts the damage at $295 billion, which is nearly double the damage generated by Hurricane Harvey.[38]

After the catastrophic storm, calls for weatherizing Texas' power supply infrastructure intensified. The disaster also reminded many Texans of a similarly devastating winter storm that took place almost exactly a decade ago in 2011. Following the 2011 incident, a federal study regarding the power and water outages and associated recommendations was prepared.[39] However, no specific actions were taken to require power plants or other energy infrastructure to winterize.[40] After the 2021 winter storm, survey results showed that over 75% of Texans supported policies that would require electricity generators and natural gas companies to winterize.[41]

In simple terms, weatherization means to provide the heat and insulation to protect equipment and personnel against harsh winter conditions and freezing temperatures.[42] However, the cost estimates of weatherizing power plants also encompass a wide range, and the numbers are sometimes not readily comparable. For instance, some anecdotal estimates show a range of $5 billion and $20 billion to winterize all power plants,[43] whereas others show a price tag of $95 million for the winterization of all 162 gas plants.[44]

Despite the different estimates regarding the costs of weatherization, there are certain consistencies. First, practitioners agree it is much more expensive, and sometimes prohibitively so, to weatherize existing plants or equipment than to do so during the construction stage.[45] In other words, retrofitting these weatherizing features costs a lot more than incorporating them when plants or equipment are being built. Second, if certain types of facilities and plants need to be prioritized over others, many agree that the natural gas power delivery infrastructure would be a worthwhile investment. This is because natural gas provides more than half of the state's energy. In addition, according to the Electric Reliability Council of Texas (ERCOT), natural gas plant shutdowns during the Winter Storm Uri were the most significant cause of power outages.

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[38] University of Houston - Hobby School of Public Affairs, The Winter Storm of 2021, March 29, 2021, https://uh.edu/hobby/winter2021/storm.pdf

[39] Federal Energy Regulatory Commission and North American Electric Reliability Corporation, Report on Outrages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011, August 2011, https://www.ferc.gov/sites/default/files/2020-04/08-16-11-report.pdf

[40] After the 2011 winter storm, S.B. 1133 was signed into law on June 17, 2011 to require mandatory reporting of emergency operations procedures from power generators. However, no weatherization requirements was included as part of the law.

[41] University of Houston - Hobby School of Public Affairs, The Winter Storm of 2021.

[42] For technical description of the weatherization process, see Federal Energy Regulatory Commission and North American Electric Reliability Corporation, Report on Outrages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011, Appendix: Winterization for Generators.

[43] Charlotte Huffman and Jason Trahan, Here's How Much Winterizing the Texas Power Grid Could Impact Your Power Bill, WFAA, May 2, 2021, https://www.wfaa.com/article/news/local/investigates/texans-could-see-higher-electricity-bills-to-pay-for-power-plant-winterization-experts-say/287-5e7fd5ed-2c43-4fad-a786-a27308f9c234

[44] Garrett Golding, Anil Kumar and Karel Mertens, Cost of Texas' 2021 Deep Freeze Justifies Weatherization.

[45] For instance, winterizing wind turbines by installing blades with internal warming equipment at the factory can cost $400,000 per unit. Thus, retrofitting existing turbines for these features would be infeasible. Alternative measures, such as applying cold weather lubricants and de-icing drones, may mitigate ice formation at lower costs.

Many practitioners, researchers, and administrators agree preventive and proactive actions for weatherization are justified.[46] The Federal Reserve researchers—who estimate the damage was $4.3 billion, the lowest among available estimates—argue that because the extreme weather events occur once every decade, as long as weatherizing power facilities costs less than $430 million per year, it is justified from a cost-benefit perspective.

Weatherizing Water Infrastructure

Most studies focus on the costs and benefits of weatherizing electricity plants and equipment. In general, these studies support enhanced weatherization requirements even with high capital investments. As discussed further below, the Texas legislature also expressed their approval on weatherizing power and critical gas facilities. In comparison, weatherizing water infrastructure generated less discussion. However, it is by no means less important, or the cost of non-investment less devastating. In fact, power failures often lead to water supply issues.

During Winter Storm Uri, many households experienced power outages, followed by the loss of running water and boil water notices. A limited power supply often impacts the water system, because the water system requires energy for treatment and pumping. Sub-zero temperatures create a perfect storm for water infrastructure—a pump failure reduces the supply; burst pipes and millions of people dripping their faucets increase the demand. Both lead to reduced water pressure, which causes the growth of harmful bacteria in the water. In addition, power outages also prevent water treatment plants from properly treating water. When the pressure is below a certain level and water quality is compromised, operators need to wait for the power to return, allow sufficient time for pressurization, and then test water quality before state regulators can lift boil water notices.[47]

Although the water supply depends on electricity delivery, weatherizing electricity plants does not solve the water supply issue in its entirety. First, the underinvestment in water and wastewater infrastructure has been a chronic concern nationwide. The American Society of Civil Engineers (ASCE), citing several Environmental Protection Agency (EPA) studies, estimates that in 2019 the total capital investment needs on water infrastructure at the local, state, and federal levels were $129 billion, but actual spending was approximately $48 billion, which

[46] Erin Douglas, Gov. Greg Abbott Wants Power Companies to "Winterize." Texas Track Record Won't Make That Easy, The Texas Tribune, February 20, 2021, https://www.texastribune.org/2021/02/20/texas-power-grid-winterize/

[47] See (1) Reese Oxner, Texans Now Face a Water Crisis After Enduring Days Without Power, The Texas Tribune, February 19, 2021, https://www.texastribune.org/2021/02/19/texas-water-power-outages/ (2) Phil Helsel and Yuliya Talmazan, NBC News, February 17, 2021, https://www.nbcnews.com/news/us-news/texas-contending-water-nightmare-top-power-crisis-n1258208

generated an $81 billion gap.[48] Similar investment needs apply to Texas: as referenced, the SWP recommended investing $80 billion in new infrastructure to augment Texas' water supply.[49]

The ASCE gave the country's overall drinking water infrastructure system a C- rating in 2021, and indicated that the system is aging and underfunded.[50] Texas's water infrastructure rating, C-, is comparable to the national average, but slightly lags behind several large states including California and Florida (both have C ratings).

The ASCE cautions that the infrastructure deterioration is progressive, and the economic impact will significantly escalate over time if no action is taken. These costs will rise as the systems continue to age, placing smaller or less affluent communities at a relative disadvantage.[51] Businesses will incur higher costs when water services become less efficient and less reliable, which will also lead to reduced productivity, lower employment, and ultimately a lower GDP. Households will pay more for water services and have lower income. Consumers will need to reprioritize their expenditures and reduce their discretionary spending.

Although the economic consequences from failing infrastructure are devastating, a large portion of them can be prevented by making investments that address documented inefficiencies. An ASCE study shows that if the U.S. invests sufficiently in its water infrastructure to make it more reliable, the nation can prevent $250 billion in increased costs to businesses by 2039.[52]

Second, water infrastructure resiliency has become increasingly important in recent years. Although the U.S.' water infrastructure is old and needs to be improved, many have started to realize that simply replacing it with the same structure is not adequate. First and foremost, population growth is pressuring the scale and functionality of the existing water system. In addition, water infrastructure faces a variety of challenges that were not anticipated or were nonexistent when it was designed and built. For instance, changing weather conditions, such as sea-level rise, drought, wildfires, extreme temperatures, and flooding, all pose challenges to the reliability of today's water infrastructure.

At the implementation level, water infrastructure resiliency generally means that water systems should improve their capacity to respond to negative incidents or irregularities. The

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[48] American Society of Civil Engineers, The Economic Benefits of Investing in Water Infrastructure, 2020, https://infrastructurereportcard.org/wp-content/uploads/2021/03/Failure-to-Act-Water-Wastewater-2020-Final.pdf The two studies referenced in the ASCE study are: (1) Office of Water, Drinking Water Infrastructure Needs Survey and Assessment: Sixth Report to Congress, Environmental Protection Agency (EPA), March 2018, https://www.epa.gov/sites/production/files/2018-10/documents/corrected_sixth_drinking_water_infrastructure_needs_survey_and_assessment.pdf and (2) EPA, Clean Watersheds Needs Survey 2012: Report to Congress, January 2016, https://www.epa.gov/sites/default/files/2015-12/documents/cwns_2012_report_to_congress-508-opt.pdf

[49] Texas Water Development Board, 2022 Texas State Water Plan.

[50] American Society of Civil Engineers, 2021 Report Card for America's Infrastructure: Drinking Water, last visited: November 17, 2021, https://infrastructurereportcard.org/cat-item/drinking-water/

[51] American Society of Civil Engineers, FAILURE TO ACT: Economic Impacts of Status Quo Investment Across Infrastructure System, February 2021, https://infrastructurereportcard.org/wp-content/uploads/2021/02/FTA_Econ_Impacts_Status_Quo-1.pdf

[52] American Society of Civil Engineers, The Economic Benefits of Investing in Water Infrastructure, 2020.

weatherization of water infrastructure is often discussed in the context of improving water system resiliency. This may include developing and updating risk assessments and emergency response plans, protecting water infrastructure from extreme weather conditions, deploying innovative water technologies like sensors and smart water quality monitoring, or other similar measures.

Recent State and Federal Measures

Texas State Legislature

In response to the fallout after the 2021 storm, state legislators reacted quickly and passed S.B. 3 in May 2021.[53] This demonstrates the state's efforts to safeguard the reliability and resiliency of Texas' critical infrastructure, and to prepare for future extreme weather events. The bill requires power generators to weatherize and be prepared for extreme weather. It also mandates critical gas facilities to be identified, registered with power utilities, and weatherized so that electricity will not be disconnected during an emergency.

In connection with water infrastructure, S.B. 3 requires water utilities to develop and implement emergency preparedness plans (EPPs) to keep their services operating during an extended power outage. Specifically, the EPPS need to be submitted to the Texas Commission on Environmental Quality (TCEQ) before March 2022, and water utilities must start implementing these plans by July 2022. Operators can use backup generators, alternative power sources, or other water demand management strategies to meet the requirements.

However, a provision that aimed to create a Water Infrastructure Resiliency Fund (WIRF), which would have provided grants to entities for weatherizing and hardening water and wastewater systems, was not included in the final bill.[54]

Federal Measures

Some believe the prolonged underinvestment in water infrastructure requires more federal financial participation. Despite the growing need for funds, the federal government has been investing a smaller percentage of funds in water infrastructure over time. A Congressional Budget Office (CBO) study shows that between 1977 and 2014, the federal government's spending on capital water infrastructure declined from 63% to less than 10% of the total capital spending. In 2017, the federal government spent $4 billion on water utilities (including water supply and wastewater treatment facilities) whereas state and local governments collectively spent $109 billion.[55] The decline in federal investment means more responsibilities have been shifted to the state and local governments to finance water infrastructure needs.

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[53] Texas Legislature, 87th Regular Session, S.B. 3, effective June 8, 2021, https://capitol.texas.gov/billlookup/BillStages.aspx?LegSess=87R&Bill=SB3

[54] Legislative Budget Board, Fiscal Notes to H.B. 2275, April 13, 2021, https://capitol.texas.gov/tlodocs/87R/fiscalnotes/pdf/HB02275I.pdf#navpanes=0

[55] (1) American Society of Civil Engineers, The Economic Benefits of Investing in Water Infrastructure, and (2) Congressional Budget Office, Public Spending on Transportation and Water Infrastructure, 1956 to 2017, October 2018, https://www.cbo.gov/system/files/2018-10/54539-Infrastructure.pdf

Some observers have called for additional federal spending to help states with their water infrastructure investments. In 2018, Congress passed America's Water Infrastructure Act (AWIA)[56] to improve water quality, deepen infrastructure investment, and enhance public health. The provisions of the AWIA were remarked upon as the most far-reaching changes to water policies since the 1996 amendment to the Safe Drinking Water Act (SDWA).[57]

The AWIA created a few new initiatives targeting priorities like drinking water, climate resilience, and emergency preparedness. After the Texas winter storm, several advocacy groups urged Congress to expand these programs to specifically support weatherization efforts.[58]

The Drinking Water System Infrastructure Resilience and Sustainability Program is the EPA's first program dedicated to helping community water systems adapt their infrastructure to withstand the effects of climate change and extreme weather.[59] This program offers grants to increase the resiliency of community water systems against natural hazards, including winter storms. However, the scope is limited to drinking water systems serving fewer than 10,000 people or serving disadvantaged communities. In addition, Congress only appropriated $7 million to this program.

The second relevant initiative is the Drinking Water Infrastructure Risk and Resilience Program,[60] which is intended to help community water systems respond to risks identified in the system's emergency response plan, including equipment necessary to support emergency water and power supplies.

However, practitioners caution that although the weatherization efforts will benefit from more federal funds, these efforts do not need more federal regulations.[61] A TCEQ report corroborates this view, indicating that compliance is especially burdensome for small water systems that serve less than 3,300 users. [62]

This issue is prominent for Texas, as 84% of Texas' 7,053 public water systems serve a population of less than 3,300.[63] In the last few decades, the number and complexity of EPA drinking water regulations have significantly increased for systems of all sizes. However, smaller

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[56] America's Water Infrastructure Act of 2018, Pub. L. No. 115-270, October 23, 2018, https://www.congress.gov/115/bills/s3021/BILLS-115s3021enr.pdf

[57] Environmental Protection Agency, America's Water Infrastructure Act of 2018 Overview, last visited: November 17, 2021, https://www.epa.gov/ground-water-and-drinking-water/americas-water-infrastructure-act-2018-awia

[58] Association of Metropolitan Water Agencies, Comments to Hearing on "Examining the Challenges Facing Drinking Water and Waste Water Infrastructure Projects," March 17, 2021, https://www.amwa.net/system/files/linked-files/AMWA_EPW_RecordStatement3-17-21.pdf

[59] This program is authorized by AWIA through Section 1459A (l) of the SDWA.

[60] This program is authorized by AWIA through Section 1433(g) of the SDWA.

[61] Bobby Magill, Climate-Proofing Water System Needs Billions, Advocates Say, Bloomberg, February 25, 2021, https://news.bloomberglaw.com/environment-and-energy/climate-proofing-water-systems-needs-billions-after-deep-freeze

[62] Texas Commission on Environmental Quality, 2021 Sunset Self-evaluation Report, IX. Major Issues, September 2021, https://www.tceq.texas.gov/downloads/publications/sfr/123/123-21.pdf

[63] A public water system provides potable water for public use. Examples include cities, residential subdivisions, private businesses, and governmental entities.

water systems have less capability and fewer resources to comply with them from financial, managerial, and technical perspectives.

The Path Forward

Water infrastructure often operates "out of sight and out of mind" and only gets attention when major failure surfaces. Most water pipes are underground, and treatment facilities are far from central business areas, which removes the sense of urgency for updates and maintenance. [64]

Water infrastructure resiliency has been gaining traction, but has stopped short of formal and full financial support from the federal and state governments. For instance, S.B. 3 requires water utilities to develop and implement EPPs but does not authorize the Water Infrastructure Resiliency Fund (WIRF), which would provide funds for weatherizing water facilities.

Although weatherization has generated strong public support since February, comprehensive analyses that are dedicated to the weatherizing of water facilities and backup power are limited. More in-depth, objective studies will strengthen the support for resiliency. Moreover, requirements for on-site backup power, weatherization, and associated emergency response vary across states and even localities. Although these measures require greater capital investment as well as investment in operations and maintenance, preliminary evidence indicates that Texas cities with greater preparedness did fare better during the February storm.[65] This is consistent with findings from the federal study after the 2011 storm.

The long-term underinvestment in water systems and the coming waves of required upgrades and capital expenditures provide a good opportunity to modernize our water infrastructure. Given the substantial projected population growth and potential demand increase, Texas should invest in a water system that is resilient, is sufficient for safeguarding public health, and facilitates sustainable economic growth. Although state and local governments are at the front and center of designing and implementing water-related policies, federal funds will definitely help enable and expedite the process of ensuring access to safe and quality water for all state residents.

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[64] Senate Committee on Environment and Public Works and the Fisheries, Water and Wildlife Subcommittee, Examining the Challenges Facing Drinking Water and Waste Water Infrastructure Projects, March 17, 2021, https://www.epw.senate.gov/public/index.cfm/2021/3/examining-the-challenges-facing-drinking-water-and-waste-water-infrastructure-projects

[65] Emily Foxhall and Dylan McGuinness, Texas Water Systems Failed During February Cold Storm. Now, The Challenge Is Making Them Stronger, Houston Chronicle, April 15, 2021, https://www.houstonchronicle.com/news/houston-texas/environment/article/Texas-water-systems-failed-during-February-cold-16101869.php