Explanatory Report for Proposed Desired Future Conditions of the Trinity Aquifer in Groundwater Management Area 10

Table of Contents

List of Appendices

FIGURES

TABLES

Abbreviations

DFC	Desired Future Conditions
GCD	Groundwater Conservation District
GMA	Groundwater Management Area
RWPG	Regional Water Planning Group
MAG	Modeled Available Groundwater
TERS	Total Estimated Recoverable Storage
TWDB	Texas Water Development Board

1. Description of Groundwater Management Area 10

Groundwater Conservation Districts (GCDs, or districts) were created, typically by legislative action, to provide for the conservation, preservation, protection, recharging, and prevention of waste of the groundwater, and of groundwater reservoirs or their subdivisions, and to control subsidence caused by withdrawal of water from those groundwater reservoirs or their subdivisions. The individual GCDs overlying each of the major aquifers or, for some aquifers, their geographic subdivisions were aggregated by the Texas Water Development Board (TWDB) acting under legislative mandate to form Groundwater Management Areas (GMAs). Each GMA is charged with facilitating joint planning efforts for all aquifers wholly or partially within its GMA boundaries that are considered relevant to joint regional planning.

GMA 10 was delineated based primarily on the extents of the San Antonio and Barton Springs segments of the Fresh Edwards (Balcones Fault Zone) Aquifer, but it also includes the underlying down-dip Trinity Aquifer. Other aquifers in GMA 10 include the Leona Gravel, Buda Limestone, Austin Chalk, and the Saline Edwards (Balcones Fault Zone) aquifers. The planning area of GMA 10 includes all or parts of Bexar, Caldwell, Comal, Guadalupe, Hays, Kinney, Medina, Travis, and Uvalde counties (Figure 1). GCDs in Groundwater Management Area 10 include Barton Springs/Edwards Aquifer Conservation District (BSEACD), Comal Trinity GCD, Edwards Aquifer Authority, Kinney County GCD, Medina County GCD, Plum Creek Conservation District, Uvalde County Underground Water Conservation District, and Southwestern Travis County Groundwater Conservation District SWTCGCD (Figure 1).

As mandated in Texas Water Code § 36.108, districts in a GMA are required to submit Desired Future Conditions (DFCs) of the groundwater resources in their GMA to the executive administrator of the TWDB, unless that aquifer is deemed to be non-relevant for the purposes of joint planning. According to Texas Water Code § 36.108 (d-3), the district representatives shall produce a Desired Future Conditions Explanatory Report for the management area and submit to the TWDB a copy of the Explanatory Report.

GMA 10 has designated the Trinity Aquifer as a relevant aquifer (excluding Plum Greek Conservation District) for purposes of joint planning. This document is the preliminary Explanatory Report for this aquifer.

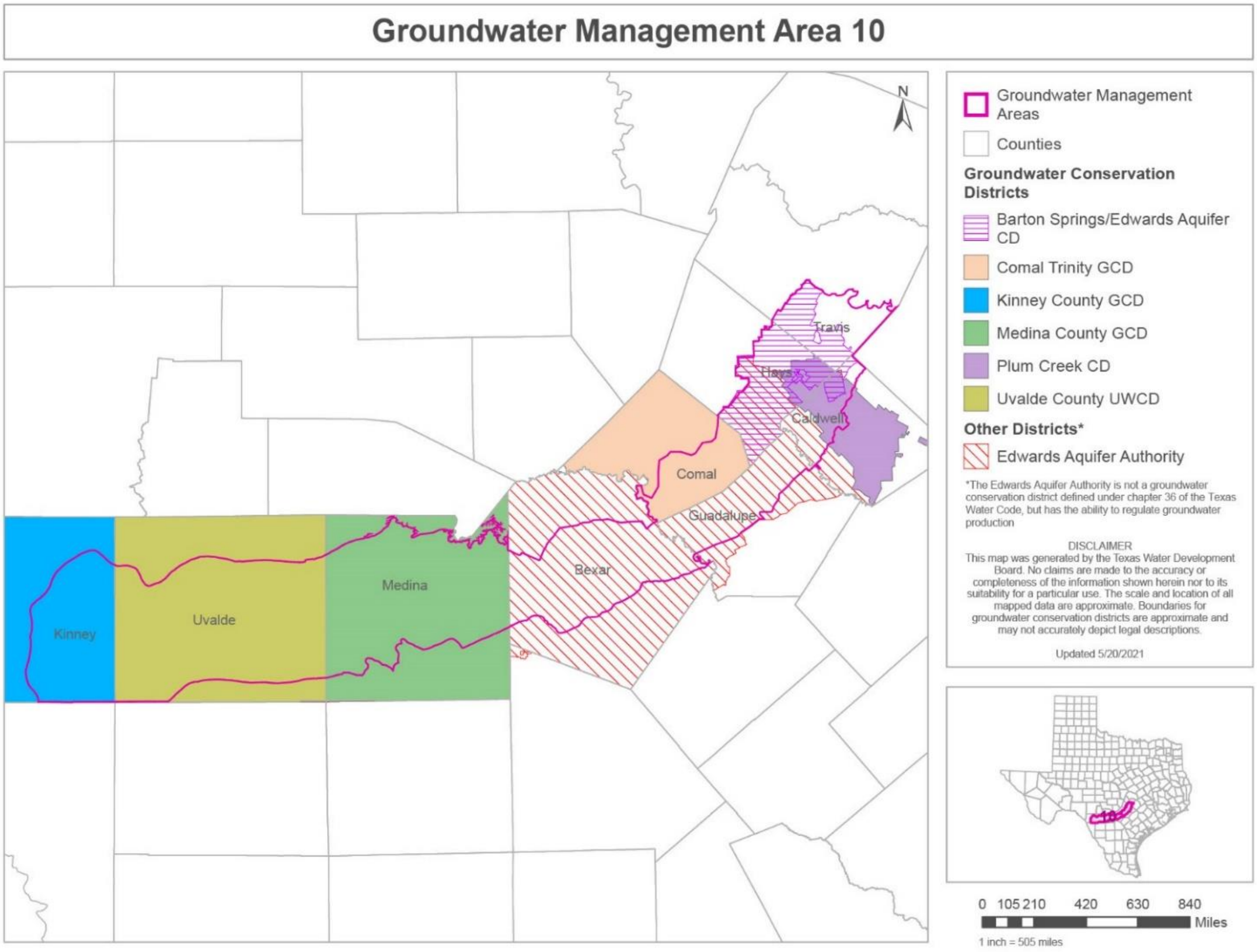
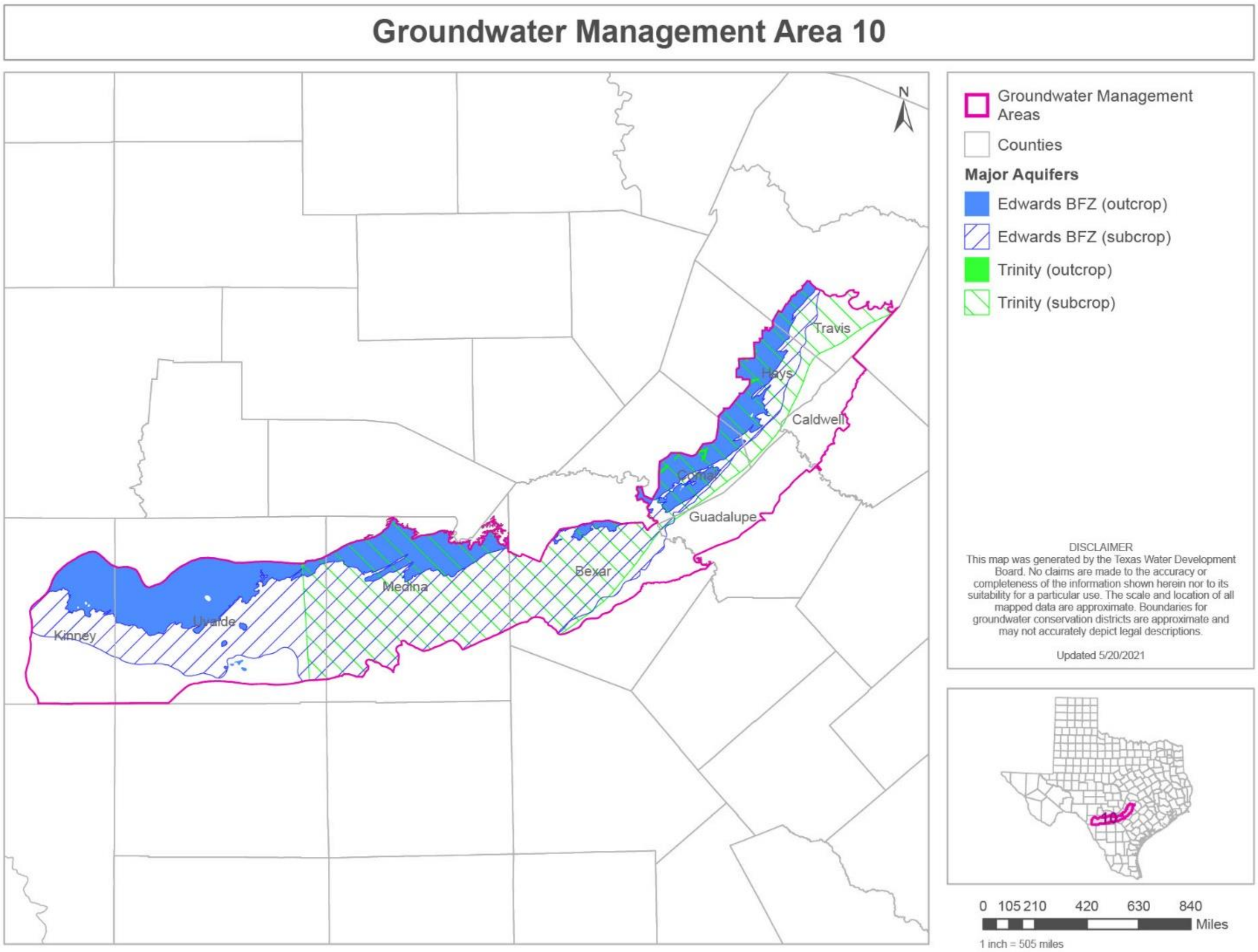


Figure 1. Map of the administrative boundaries of GMA 10 designated for joint-planning purposes and the GCDs in the GMA (From Texas Water Development Board website).

2. Aquifer Description

The Trinity Aquifer consists of Cretaceous-age formations of varying viability as water sources. The Upper Trinity Aquifer (comprising the upper Glen Rose Limestone) generally has low yields and poor water quality due to its evaporite beds; but in some localities domestic and public water supply wells have produced better yields and water quality. In some localities the upper most zones of the Upper Trinity Aquifer appear to be vertically connected with the Edwards Aquifer (Smith and Hunt, 2011). However, the Upper Trinity and Edwards Aquifer are generally hydraulically distinct over most of GMA 10. The Middle Trinity Aquifer (comprising the lower Glen Rose Limestone, the Hensel Sand, and Cow Creek Limestone) is the most widely used portion ofthe aquifer. The Lower Trinity Aquifer (comprising the Hosston Sand and Sligo Limestone) is not as widely used due to its depth and water quality (SCTRWPG, 2010). The Trinity Aquifer outcrops very little within GMA 10 and exists as a confined aquifer underlying the Edwards (Balcones Fault Zone) Aquifer. It is currently used as a minor source of groundwater in Uvalde, Medina, Bexar, Comal, Guadalupe, Hays, and Travis counties, but is increasingly becoming a major source due to rapid development and increased water demands.



DISCLAIMER
This map was generated by the Texas Water Development Board. No claims are made to the accuracy or completeness of the information shown herein nor to its suitability for a particular use. The scale and location of all mapped data are approximate. Boundaries for groundwater conservation districts are approximate and may not accurately depict legal descriptions.

Updated 5/20/2021

Figure 2. Map showing the extent of the Trinity Aquifer in GMA 10 (From Texas Water Development Board website)

3. Desired Future Conditions

The desired future conditions (DFC) adopted on 6/26/2017 for the Trinity Aquifer are as follows: Outside of Uvalde and Bexar Counties: Average regional well drawdown not exceeding 25 feet during average recharge conditions (including exempt and non-exempt use); within Uvalde County: No (zero) regional well drawdown (including exempt and non-exempt use).

GMA 10 has proposed to maintain the same DFCs in the third round as in the first round for this aquifer, with the exception of Hays-Trinity GCD, which is no longer in GMA 10. This third round of proposed DFCs was approved at the GMA 10 meeting on April 20, 2021 to be available for consideration during the 90-day public comment period and a public hearing held by each GCD. After the comment period and public hearings, the proposed DFCs were adopted at the GMA 10 meeting on October 26, 2021.

4. Policy Justification

The DFCs in the Trinity Aquifer within GMA 10 were adopted after considering the following factors specified in Texas Water Code §36.108 (d):

1. Aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another;
   a. for each aquifer, subdivision of an aquifer, or geologic strata; and
   b. for each geographic area overlying an aquifer
2. The water supply needs and water management strategies included in the state waterplan;
3. Hydrological conditions, including for each aquifer in the management area the TERS as provided by the executive administrator, and the average annual recharge, inflows, and discharge;
4. Other environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water;
5. The impact on subsidence;
6. Socioeconomic impacts reasonably expected to occur;
7. The impact on the interests and rights in private property, including ownership and the rights of management area landowners and their lessees and assigns in groundwater asrecognized under Section 36.002;
8. The feasibility of achieving the DFC; and
9. Any other information relevant to the specific DFCs.

These factors and their relevance to establishing the DFCs are discussed in detail in corresponding sections and subsections of this Explanatory Report.

5. Technical Justification

The TWDB developed a method described in GTA Aquifer Assessment 10-06 (Thorkildsen and Backhouse, 2010) that uses an analytical solution to estimate modeled available groundwater for various drawdown scenarios. The same methods used by Thorkildsen and Backhouse (2010) were later used by Bradley and Radu (2018) in GAM Run 16-033 to recalculate modeled available groundwater for the Trinity Aquifer to reflect boundary changes in GMA 10 and groundwater conservation districts.

The proposed DFC is an expression of average drawdown of the potentiometric surface. Table 1 is anestimate of modeled available groundwater using the analytical approach used by TWDB. As described in Thorkildsen and Backhouse (2010), the modeled available groundwater (MAG) is estimated by multiplying the average drawdown by the storage coefficient and the area and then adding in estimated lateral inflow. As other inflows and outflows are considered to be negligible (described later in this report), this approach treats the aquifer as a closed system.

Table 1. Estimation of Modeled Available Groundwater (MAG) by County and GCD values are in acre-ft per year (Trinity).

Groundwater Conservation District	County	MAG
BSEACD	Hays	3,854
	Travis	341
Comal Trinity GCD	Comal	33,554
Medina County GCD	Medina	6,661
Uvalde County UWCD	Uvalde	40
Plum Creek Conservation District	Hays	276
Kinney County GCD**	Kinney	70,341
Non-District Areas	Caldwell	10
	Guadalupe	660
	Travis	239
Total		115,976

Estimated amounts from TWDB Report GAM Run 16-033
** Kinney County MAG number is based on information from GMA 7 and the undifferentiated Edwards-Trinity Plateau. This number is for the whole county and not specific for the GMA 10 Area. There is no MAG specifically for the Trinity within Kinney County.

6. Consideration of Designated Factors

In accordance with Texas Water Code § 36.108 (d-3), the district representatives shall produce a Desired Future Condition Explanatory Report. The report must include documentation of how nine factors identified in Texas Water Code §36.108(d) were considered and how the proposed DFC impacts each factor. The following sections of the Explanatory Report summarize the information that the GCDs used in their deliberations and discussions.

6.1 Aquifer Uses or Conditions

6.1.1 Description of Factors for the Trinity Aquifer in GMA 10

The Trinity Aquifer does not serve as the primary source of water for counties in GMA 10. However, given restrictions on groundwater withdrawals from the Edwards Aquifer, withdrawals from the Trinity Aquifer have been growing. The aquifer is stressed due to increasing numbers of wells to supply rapidly developing areas of central Texas. In addition, wells that were poorly cased through evaporite beds in the Upper Trinity formation have diminished the water quality in parts of the Middle Trinity Aquifer (SCTRWPG, 2010). Another concern is potential movement of the "bad water line" (where total dissolved solids concentrations exceed 1,000 milligrams per liter) due to increased groundwater withdrawal. Water quality becomes progressively poorer in the downdip sections of the Trinity Aquifer, with the "bad water line" stretching east-west through southern Uvalde and Medina counties, and then southeast-northwest through central Bexar, and along the southeastern edge of Comal and Hays counties (SCTRWPG, 2010).

The TWDB provides historical groundwater pumpage values by county and aquifer. Table 3 provides the estimated actual amount of groundwater in acre-feet supplied by the Trinity Aquifer for the period 2000-2018. Values reported by TWDB are county-based. In cases where a GCD only covers a portion of one or more counties, such as BSEACD and Plum Creek Conservation District, the data values are modified using a multiplier that more accurately represent the GCD. The multiplier is based on land area of GCD in county divided by the land area of county. BSEACD annexed additional portions of Hays County in 2015, prior to 2016 the percentage in Hays or appropriating multiplier was 15.5%.

Table 2 Areal Distribution of BSEACD and Plum Creek Conservation District by County.

County	BSEACD Total Acres in County	BSEACD Acres in District	Plum Creek Conservation District Acres in District	Percent in BSEACD prior to 2015	Percent in Plum Creek	Total percent or apportioning multiplier
Travis	656,348	74,311	NA	11.5%	NA	11.5%
Hays	433,248	184,513	39,425	42.5%	9.1%	51.6%
Caldwell	350,498	16,777	180,611	4.5%	51.53%	56.03%

The Trinity Aquifer does not provide the majority of groundwater in any county, although the Trinity Aquifer share has increased from 2000 in all counties. Variability in annual pumpage values could be attributed to factors such as climate conditions and precipitation. The TWDB does not report any pumping from the Trinity Aquifer in Caldwell or Kinney counties.

Table 3. Total groundwater pumpage values by county from the Trinity Aquifer in acre-ft/yr.Note that pumping estimates for Hays and Travis Counties are modified using a multiplier from Table 2. Prior to 2016 the BSEACD multiplier was (15.5%) and Plum Creek Conservation District was (9.1%) therefore a total of 24.6% was used.

County	**Bexar**	**Comal**	**Guadalupe**	**Hays***	**Medina**	**Travis***	**Uvalde**
2000	7,974	2,895	0	550	42	215	49
2001	8,761	2,422	0	600	33	226	46
2002	9,425	2,229	0	544	35	224	45
2003	8,681	2,169	0	520	36	224	43
2004	9,301	5,642	0	498	35	202	40
2005	11,579	5,404	0	553	186	222	61
2006	11,353	6,916	4	860	248	413	96
2007	8,698	6,896	4	939	242	326	91
2008	10,020	4,270	4	903	220	398	170
2009	11,675	4,166	6	1,048	248	528	163
2010	15,475	2,456	9	1,226	356	1,012	246
2011	18,530	4,678	6	1,503	479	1,192	257
2012	17,854	7,119	8	1,300	338	878	195

2013	14,763	4,180	7	1,245	332	1,013	180
2014	12,558	7,844	9	809	298	718	191
2015	26,309	6,964	9	685	308	737	201
2016	36,146	5,683	7	1,472	305	837	134
2017	27,344	6,503	5	1,550	323	742	110
2018	21,527	8,695	3	1,499	880	618	119

Values from https://www.twdb.texas.gov/waterplanning/waterusesurvey/historical-pumpage.asp

District-level water use numbers compiled by two GCDs in the GMA 10 area are also available, dating back to 2007,. Uvalde County UWCD values are sourced from their annual water usereport database and provided in Table 4. Although these numbers were higher than the county-wide values provided by the TWDB, pre-2011, in recent years the districts reporting is below the county-wide values.

Table 4. Total groundwater pumpage values for the Trinity Aquifer in Uvalde County, according to the UCUWCD (2021)in acre-ft/yr.

Aquifer	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Trinity	228	267	1,667	908	117	108	120	120	140	138	106	114	106

The Barton Springs Edwards Aquifer Conservation District (BSEACD) values are based on meter readings from non-exempt district wells and include the Middle Trinity and Lower Trinity within a portion of Hays County and Travis and are provided in Table 4. The numbers are smaller than the county-wide numbers given by TWDB because the BSEACD only covers a portion of Travis County and Hays County. However, Trinity Aquifer permitted and actual pumpage values have significantly increased since 2007 within BSEACD. Furthermore, in 2015, BSEACD's jurisdictional area was expanded to include the portion of Hays County located within the boundaries of the Edwards Aquifer Authority (EAA) that excludes the Edwards Aquifer but includes the underlying Trinity and values from 2016 to 2019 reflect that expansion.

Table 5. Total actual groundwater pumpage values for the TrinityAquifer in Travis and Hays County within BSEACD (acre-ft/yr). Values from BSEACD.

Aquifer	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Trinity	10.7	27.9	17.8	19.7	49.1	165.9	149.2	185.4	160.6	405.7	651.5	671.6	614.7

6.1.2 DFC Considerations

The Trinity Aquifer in GMA 10 is not the primary water source for much of the area. However, pressure on the freshwater Edwards (Balcones Fault Zone) Aquifer and population growth has led to the need for all viable water supplies. The current DFCs allow for a modeled available groundwater that is above the current use of the aquifer and allows room for development of the aquifer as a supply while protecting existing groundwater supplies. However rapid population growth along, particularly along the I-35 corridor, will increase demand for the Trinity Aquifer.

Table 6. MAG vs Permitted and Actual Pumpage

GCD	County	MAG	2019 Permitted Pumpage	2019 Actual Pumpage	2019 Exempt Pumpage Estimate
BSEACD	Hays and Travis	4,195	1,892	614.7	369.4
Uvalde County UWCD	Uvalde	795	30	106	20
Medina County GCD	Medina	6,661	11,763	1,129	N/A
Plum Creek Conservation District	Hays	276	0	0	0
Comal Trinity GCD	Comal	29,284	N/A	7,580	N/A
Kinney GCD	Kinney**	N/A	N/A	N/A	N/A

** Please see ** in table 1 for Kinney County GCD explanation

6.2 Water-Supply Needs

6.2.1 Description of Factors for the Trinity Aquifer in GMA 10

For estimating projected water-supply needs (i.e., water demand vs. supply), the districts used data extracted from the 2022 State Water Plan and provided by the TWDB. The TWDB provides water-supply needs estimates by decade as well as by county. A summary of the projected water-supply needs is provided in Table 7 by decade in acre-ft/yr. Also shown in Table 7 are demands, existing supplies, and water-supply strategies. Note that these are county totals, not just the portions of each county in GMA 10.

As in prior plans, some of the water-demand deficits in the area in the out-years (the later years in the planning period) include numerous contractual shortages.

These contractual shortages will be addressed on an *ad-hoc* basis, through the renewal and expansion of contracts with wholesale water suppliers and the contractual reallocation of existing supplies in order to address the projected water demands for these and other area water-user groups. But even so, it is projected that there will be unmet needs under drought-of-record conditions and in the out-years.

6.2.2 DFC Considerations

Population growth throughout GMA 10 is creating demand for additional water supplies from all sources. The DFCs allow for drawdown of the Trinity Aquifer to allow for its use in the future as water supply of growing importance to the region.

Table 7. 2022 State Water Plan information for counties in GMA 10 containing the Trinity Aquifer. All values are in acre-ft/yr. Note that these are county totals and are not limited to the portion of each county in GMA 10.

County	Category	2020	2030	2040	2050	2060	2070
Bexar	Demands	344,503	270,868	395,122	420,879	446,877`	471,297
	Existing Supplies	350,128	352,726	356,461	360,814	364,601	366,478
	Needs	12,387	27,016	47,872	68,266	90,218	112,499
	Strategy Supplies	47,631	186,674	265,999	294,951	371,856	404,066
Caldwell	Demands	7,719	8,765	9,862	10,998	12,205	13,415
	Existing Supplies	12,791	12,800	12,770	12,737	12,692	12,655
	Needs	140	290	588	1,367	2,215	3,060
	Strategy Supplies	3,651	4,421	4,981	5,772	6,259	7,055
Comal	Demands	42,052	51,191	59,458	67,595	76,204	84,763
	Existing Supplies	44,176	44,353	44,611	44,792	45,014	46,603
	Needs	8,307	15,421	21,459	27,434	33,874	39,952
	Strategy Supplies	36,887	48,133	53,873	57,496	61,001	63,748
Guadalupe	Demands	40,989	47,698	52,552	57,475	62,659	67,827
	Existing Supplies	56,481	57,901	59,203	59,251	59,315	59,482
	Needs	43	480	2,379	6,552	10,906	14,765
	Strategy Supplies	13,806	24,193	33,761	34,397	36,464	37,631
Hays	Demands	40,729	50,453	61,476	72,555	89,124	107,760
	Existing Supplies	54,630	54,727	56,157	57,587	61,082	62,497
	Needs	626	4,079	10,390	18,751	31,337	48,349
	Strategy Supplies	19,698	35,543	55,564	65,714	78,368	90,058
Medina	Demands	70826,	71,745	72,527	73,276	74,069	74,822
	Existing Supplies	37,751	37,814	38,202	38,181	38,353	37,643
	Needs	36,808	37,544	37,831	38,489	39,053	40,481
	Strategy Supplies	1,779	2,126	2,519	2,918	3,293	3,726
Travis	Demands	267,501	308,104	348,116	377,848	402,586	430,760
	Existing Supplies	419,733	417,640	417,290	414,772	411,540	407,170
	Needs	3,102	6,867	20,254	25,866	31,463	43,787
	Strategy Supplies	31,385	63,916	121,452	153,681	183,330	241,184
Uvalde	Demands	73,467	74,152	74,647	75,323	76,062	76,818
	Existing Supplies	30,700	30,749	30,813	30,867	30,928	30,988
	Needs	43,173	43,773	44,193	44,779	45,420	46,079
	Strategy Supplies	2,881	3,257	3,613	3,992	4,376	4,738
Total	**Demands**	**887,786**	**882,976**	**1,073,760**	**1,155,949**	**1,239,786**	**1,327,462**
	Existing Supplies	**1,006,390**	**1,008,710**	**1,015,507**	**1,019,001**	1,023,525	**1,023,516**
	Needs	**104,586**	**135,470**	**184,988**	**231,504**	**284,486**	**348,972**
	Strategy Supplies	**157,718**	**368,263**	**541,762**	**618,921**	**744,947**	**852,206**

6.3 Water-Management Strategies

6.3.1 Description of Factors for the Trinity Aquifer in GMA 10

Both Regional Water Planning Groups K and L plan to further develop the Trinity Aquifer as part of their water management strategies to cover future water needs. Table 8-provides the proposed Trinity Aquifer Groundwater Wells and Other Water Management Strategies (WMS) developed by Regional Water Planning Groups K and L for the 2022 State Water Plan (in units of acre-feet per year). Groundwater WMSs values listed in Tables 8came from the 2022 Texas State Water

Plan. The apportioning multipliers shown in Table 2 were used for Hays and Travis Counties. No WMS values for the Trinity Aquifer were listed to be sourced from Caldwell, or Kinney counties.

Table 8. Proposed Trinity Aquifer Water Management Strategy Values

Groundwater Wells and Other Water Management Strategy for Trinity Aquifer (acre/ft)								
County	**Regional Planning**		**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Comal	L	Existing Supplies	16,577	16,602	16,639	16,662	16,864	18,468
		Strategy Supplies	6,118	10,997	13,191	14,907	16,468	17,169
		Total	**22,695**	**27,599**	**29,830**	**31,569**	**33,332**	**35,637**
Hays	K and L	Existing Supplies	5,367	5,367	5,367	5,371	5,373	5,375
		Strategy Supplies	0	94	346	604	728	831
		Total	**5,367**	**5,461**	**5,713**	**5,975**	**6,101**	**6,206**
Travis	K	Existing Supplies	1,333	1,333	1,332	1,331	1,330	1,329
		Strategy Supplies	0	28	74	75	78	544
		Total	**1,333**	**1,362**	**1,407**	**1,407**	**1,408**	**1,873**
Medina	L	Existing Supplies	7,030	6,828	7,028	6,828	6,778	5,828
		Strategy Supplies	0	0	0	0	0	0
		Total	**7,030**	**6,828**	**7,028**	**6,828**	**6,778**	**5,828**
Uvalde	L	Existing Supplies	795	795	795	795	795	795
		Strategy Supplies	0	0	0	0	0	0
		Total	**795**	**795**	**795**	**795**	**795**	**795**
		Total for Decades	**37,220**	**42,045**	**44,772**	**46,574**	**48,415**	**50,339**

WMSs for Comal County from 2020 to 2070.

6.3.2 DFC Considerations

The proposed DFCs allow for development of the Trinity Aquifer in GMA 10 as contemplated in the water management strategies in the 2022 State Water Plan.

6.4. Hydrological Conditions

6.4.1 Description of Factors for the Trinity Aquifer in GMA 10

6.4.1.1 Total Estimated Recoverable Storage

Texas statute requires that the TERS of relevant aquifers be determined (Texas Water Code § 36.108) by the TWDB. Texas Administrative Code Rule §356.10 (Texas Administrative Code, 2011) defines the TERS as the estimated amount of groundwater within an aquifer that accounts for hypothetical recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume.

TERS values may include a mixture of water-quality types, including fresh, brackish, and saline groundwater, because the available data and the existing Groundwater Availability Models do not permit the differentiation between different water- quality types. The TERS values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface- water/groundwater interaction that may occur due to pumping.

Table 9 provides the TERS values for the Trinity Aquifer in GMA 10. The percentage values for the 25 percent of total storage and 75 percent total storage shown here were rounded within one percent of the total.

Table 9. Total estimate of recoverable storage by county for the Trinity Aquifer within the GMA 10 jurisdiction (Values in acre-ft)(Jones et al., 2013)

County	Total Storage	25 percent of Total Storage	75 percent of Total Storage
Bexar	5,500,000	1,375,000	4,125,000
Caldwell	24,000	6,000	18,000
Comal	2,300,000	575,000	1,725,000
Guadalupe	43,000	10,750	32,250
Hays	2,400,000	600,000	1,800,000
Medina	11,000,000	2,750,000	8,250,000
Travis	690,000	172,500	517,500
Uvalde	1,100,000	275,000	825,000
Total	**23,057,000**	**5,764,250**	**17,292,750**

6.4.1.2 Average Annual Recharge

The Trinity Aquifer is confined throughout most of the extent of GMA 10; therefore, it does not receive direct recharge in this area. Rather the aquifer is recharged in the Trinity Aquifer outcrop area located in GMA 9 where the aquifer is not confined. The GMA 10 area is located south and east of GMA 9. Recharge estimates from previous studies varied from 1.5 to 11 percent of the annual rainfall falling on Trinity Aquifer outcrop areas. Recharge also occurs from losing streams crossing the aquifer outcrop (Jones et al., 2009). Table 11 includes recharge values calculated for the Medina County Groundwater Conservation District. Note that this district includes some Trinity Aquifer outcrop area that falls outside the GMA 10 boundary and this recharge occurs in that area, rather than within the GMA 10 extent. As shown in TWDB AquiferAssessment 10-06 (Thorkildsen and Backhouse, 2010), there are small outcrop areas within GMA 10. In this assessment, TWDB estimates recharge to the aquifer to be approximately 4 percent of precipitation.

6.4.1.3 Inflows

Lateral Inflow Table 12 provides the estimated annual volume of flow into the Trinity Aquifer inGMA 10 from the Hill Country portion of the Trinity Aquifer across the Balcones Fault Zone (from Thorkildsen and Backhouse, 2010).

6.4.1.4 Discharge

Cross-formational flow: There is some evidence of vertical leakage from the Edwards Aquifer into the Trinity Aquifer in some locations, but this input is likely limited to the top 100 feet of the Upper Trinity Aquifer, as the bottom portion of the Upper Trinity Aquifer acts as an aquitard and prevents leakage from reaching the Middle Trinity Aquifer (BSEACD, 2013; Smith and Hunt, 2011). While this vertical leakage may be classified as cross-formational flow in a geologic sense, the upper portion of the Upper Trinity Aquifer appears to be hydraulically connected to and thus part of the Edwards Aquifer where vertical leakage was observed. In general, cross- formational flow is out of, not into, the Trinity Aquifer in GMA 10. Jones et al. (2011) estimated that cross-formational discharge from the Hill Country portion of the Trinity Aquifer to the Barton Springs and San Antonio segments of the Edwards Aquifer were 660 acre-ft/yr per mile of aquifer boundary in Uvalde and Medina counties; 2,400 in Bexar and Comal counties; and 350 in Hays and Travis counties. Table 13 provides estimated cross-formational flow from the Trinity Aquifer to the Edwards Aquifer within the Edwards Aquifer Authority (EAA).

Table 10. Recharge values for the Trinity Aquifer provided by the Medina County Groundwater Conservation District (acre-ft) and TWDB Aquifer Assessment 10-06. Note MCGCD recharge estimate reflects large amount of area occurring in the contributing zone outside of GMA 10 while the other estimates presented in this table only reflect estimated recharge within GMA 10 boundaries.

Area	Source	Aquifer	Estimated annual amount of recharge from precipitation to the district
MCGCD	GAM Run 20-003	Trinity Aquifer	6,918
Uvalde Co. UWCD	TWDB Aquifer Assessment 10-06	Trinity Aquifer	36
Comal County	TWDB Aquifer Assessment 10-06	Trinity Aquifer	206
Hays County	TWDB Aquifer Assessment 10-06	Trinity Aquifer	107

Natural Discharge: Since the Trinity Aquifer is confined in the GMA 10 study area, no direct discharge from the aquifer to surface springs is expected. Trinity Aquifer spring discharge occurs in the outcrop areas, north and northwest of GMA 10, where springs flow from the Trinity Aquifer and streams are net gaining from Trinity Aquifer discharge (Jones et al., 2009). No major springs issue from the Trinity Aquifer itself within GMA 10. However, it is possible that pumping from the Middle Trinity Aquifer within GMA 10 could impact flow to upgradient springs outside of GMA 10. The Blanco River Aquifer Assessment Tool is a numerical model currently in development designed to simulate some of these potential impacts (Martin et al., 2019). BSEACD (2013) does mention that some Upper Trinity Aquifer water may flow laterally or vertically into the Edwards Aquifer and thus, indirectly, feed Edwards Aquifer springs, such as Barton Springs. However, Middle Trinity Aquifer does not appear to discharge in the Balcones Fault Zone.

6.4.1.5 Other Environmental Impacts Including Springflow and Groundwater/Surface Water Interaction

As described in previous sections relating to inflows and discharges, the Trinity Aquifer in GMA 10 is confined and largely separated from surficial processes and the overlying Edwards Aquifer except the upper portion of the Upper Trinity Aquifer. While the current conceptualization of the aquifer includes flow from the Hill Country portion of the Trinity Aquifer (GMA 9) into the Trinity Aquifer in GMA 10, it is possible that large-scale development in GMA 10 could impact up-dip areas outside the GMA. There is not currently a groundwater availability model to evaluate the extent to which these impacts could occur.

Table 11. Lateral inflow to the Trinity Aquifer in GMA 10 (all values in acre-ft).

Aquifer	County	Lateral Inflow from Hill Country Trinity
Upper Trinity	Bexar	8,530
Upper Trinity	Caldwell	0
Upper Trinity	Comal	15,346
Upper Trinity	Guadalupe	0
Upper Trinity	Hays	2,512
Upper Trinity	Medina	1,576
Upper Trinity	Travis	267
Upper Trinity	Uvalde	176
Middle Trinity	Bexar	11,560
Middle Trinity	Caldwell	0
Middle Trinity	Comal	13,678
Middle Trinity	Guadalupe	0
Middle Trinity	Hays	913
Middle Trinity	Medina	3,751
Middle Trinity	Travis	374
Middle Trinity	Uvalde	417
Total		**59,100**

Table 12. Estimated value of cross-formational flow from the Trinity Aquifer to the Edwards Aquifer (acre-ft).

District	Source	Aquifer	Estimated net annual volume of flow between each aquifer in the district
EAA	GAM Run 15-009	from Trinity Aquifer to Edwards and associated limestones	13,658

6.4.2 DFC Considerations

Analysis of the hydrological conditions of the Trinity Aquifer in GMA 10 indicates that the aquifer can continue to serve as an alternative water supply to the freshwater Edwards (Balcones Fault Zone) Aquifer. However, since it has not seen large development historically in many areas of GMA 10, there is limited information on how the aquifer will respond to significant pumping. Two BSEACD permit applicants in Hays County provide recent examples of the potential impacts of large-scale pumping in the confined portion of the Trinity Aquifer within GMA 10: Electro Purification and Needmore Water LLC (See appendix C). In both cases, modeled drawdown based on aquifer test data analysis significantly exceeded the proposed DFC in less than 10 years at a distance of two miles from the high-capacity pumping wells.

7. Subsidence Impacts

Subsidence has historically not been an issue with the Trinity Aquifer in GMA 10. The aquifer matrix in the northern subdivision is well-indurated and the amount of pumping does not create compaction of the host rock and/or subsidence of the land surface. Hence, the proposed DFCs are not affected by and do not affect land-surface subsidence or compaction of the aquifer.

Additionally, LRE Water LLC hydrologists have built a Subsidence Prediction Tool (SPT) that takes individual well characteristics and calculates a potential subsidence risk in a localized area.

GMA 10 recognizes that the general reports from the SPT indicate that subsidence is not a concern for GMA 10 at this time.

8. Socioeconomic Impacts Reasonably Expected to Occur

8.1 Description of Factors for the Trinity Aquifer in GMA 10

Administrative rules require that regional water planning groups evaluate the impacts of not meeting water needs as part of the regional water planning process. The executive administrator shall provide available technical assistance to the regional water planning groups, upon request, on water supply and demand analysis, including methods to evaluate the social and economic impacts of not meeting needs [§357.7 (4)]. Staff of the TWDB's Water Resources Planning Division designed and conducted a report in support of the South Central Texas Regional Water Planning Group (Region L) and also the Lower Colorado Regional Water Planning Group (Region K). The report "Socioeconomic Impacts of Projected Water Shortages for the South Central Texas Regional Water Planning Area (Region L)" was prepared by the TWDB in support of the 2021

South Central Texas Regional Water Plan and is illustrative of these types of analyses.

The report on socioeconomic impacts summarizes the results of the TWDB analysis and discusses the methodology used to generate the results for Regions L. The socioeconomic impact reports for Water Planning Group J, K, and L are included in Appendix A. These reports are supportive of a cost-benefit assessment of the water management strategies and the socioeconomic impact of not promulgating those strategies.

8.2 DFC Considerations

The proposed DFC allows for development of the Trinity Aquifer above what is called for in the water-management strategies in the 2022 State Water Plan. For this reason, the proposed DFC will not have a socioeconomic impact associated with an unmet water need.

9. Private Property Impacts

9.1 Description of Factors for the Trinity Aquifer in GMA 10

The interests and rights in private property, including ownership and the rights of GMA 10 landowners and their lessees and assigns in groundwater, are recognized under Texas Water Code Section 36.002. The legislature affirmed that a landowner owns the groundwater below the surface of the landowner's land as real property. Joint planning must take into account the impacts on those rights in the process of establishing DFCs, including the property rights of both existing and future groundwater users. Nothing should be construed as granting the authority to deprive or divest a landowner, including a landowner's lessees, heirs, or assigns, of the groundwater ownership and rights described by this section. At the same time, the law holds that no landowner is guaranteed a certain amount of such groundwater below the surface of his/her land.

Texas Water Code Section 36.002 does not: (1) prohibit a district from limiting or prohibiting the drilling of a well by a landowner for failure or inability to comply with minimum well spacing or tract size requirements adopted by the district; (2) affect the ability of a district to regulate groundwater production as authorized under Section 36.113, 36.116, or 36.122 or otherwise under this chapter or a special law governing a district; or (3) require that a rule adopted by a district allocate to each landowner a proportionate share of available groundwater for production from the aquifer based on the number of acres owned by the landowner.

9.2 DFC Considerations

The DFC is designed to allow for additional development of the Trinity Aquifer as an alternative water supply in a manner that does not harm other property owners. The DFC does not prevent use of the groundwater by landowners either now or in the future, although ultimately total use of the groundwater in the aquifer is restricted by the aquifer condition, and that may affect the amount of water that any one landowner could use, either at particular times or all of the time.

10. Feasibility of Achieving the DFCs

The feasibility of achieving a DFC directly relates to the ability of the GCDs to manage the Trinity Aquifer to achieve the DFC, including promulgating and enforcing rules and other board actions that support the DFC. The feasibility of achieving this goal is limited by (1) the finite nature of the resource and how it responds to drought; and (2) the pressures placed on this resource by the high level of economic and population growth within the area served by this resource.

Texas state law provides Groundwater Conservation Districts with the responsibility and authority to conserve, preserve, and protect these resources and to ensure the recharge and prevention of waste of groundwater and control of subsidence in the management area. State law also provides that GMAs assist in that endeavor by joint regional planning that balances aquifer protection and highest practicable production of groundwater. The feasibility of achieving these goals could be altered if state law is revised or interpreted differently than is currently the case.

The caveats above notwithstanding, there are no current hydrological or regulatory conditions that call into question the feasibility of achieving the DFC.

11. Discussion of Other DFCs Considered

No other expression of DFC of the Trinity Aquifer in GMA 10 was considered. GMA 10 evaluated alternative amounts of drawdown for the DFC expression, including larger amounts of drawdown. The proposed DFC specifies an amount of drawdown that is not unreasonably large or small, and that should be readily achieved based on currently known information about the aquifer.

12. Discussion of Other Recommendations

12.1 Advisory Committees

An Advisory Committee for GMA10 has not been established.

12.2 Public Comments

GMA 10 approved its proposed DFCs on April 20, 2021. In accordance with requirements in Chapter 36.108(d-2), each GCD then had 90 days to hold a public meeting at which stakeholder input was documented. This input was submitted by the GCD to the GMA within this 90-day period. The dates on which each GCD held its public meeting is summarized in Table 14. Public comments for GMA 10 are included in Appendix B.

Table 13. Dates on which each GCD held a public meeting allowing for stakeholder input on the DFCs.

GCD	Date
Barton Springs/Edwards Aquifer Conservation District	June 10, 2021
Comal Trinity GCD	May 17, 2021
Kinney County GCD	June 10, 2021
Medina County GCD	June 16, 2021
Plum Creek Conservation District	June 30, 2021
Uvalde County UWCD	May 19, 2021

Under Texas Water Code, Ch. 36.108(d-3)(5), GMA 10 is required to “discuss reasons why recommendations made by advisory committees and relevant public comments were or were not incorporated into the desired future conditions” in each DFC Explanatory Report.

- The Trinity Aquifer is a confined aquifer in GMA 10 and its use does not appreciably affect the surface water systems there, including springs, seeps, and base flow of streams,which has been identified as a benefit of zero-drawdown approaches elsewhere, in other GMAs.
- Zero-drawdown is inconsistent with achieving the required balance between aquifer protection and maximum feasible groundwater production.
- Zero-drawdown does not protect private property rights and property values.
- Zero-drawdown is inimical to future municipal, commercial, and other economic interests.

13. Any Other Information Relevant to the Specific DFCs

During the process of DFC development, the GCDs in GMA 10 reviewed and evaluated the potential impacts of a planned development of the Cow Creek formation of the Middle Trinity Aquifer in central Hays County. The evaluation focused on 1) the potential for drawdown impacts within the Cow Creek to propagate to other portions of the Trinity and Edwards aquifers,and 2) the viability of production over the 50-year planning period at a wide range of pumping rates. This evaluation is documented in Appendix C.

14. Provide a Balance Between the Highest Practicable Level of Groundwater Production and the Conservation, Preservation, Protection, Recharging, and Prevention ofWaste of Groundwater and Control of Subsidence in the Management Area

The “DFC Considerations” discussed in previous sections (especially 6.x.2, 8.2, 9.2, 10, and 11) provide the context in which the balancing factor is being addressed. But the TWDB has not developed guidance on how to approach this factor. It is up to the GCDs to determine how to approach it for each relevant aquifer, whether in a qualitative, quantitative, or combination manner. In addition, the GCDs need to include stakeholder input so that this factor can be more confidently addressed. GCD management plans will also be used to complete this requirement.

This DFC is designed to balance the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater and control of subsidence in the management area. This balance is demonstrated in (a) how GMA 10 has assessed and incorporated each of the nine factors used to establish the DFC, as described in Chapter 6 of this Explanatory Report, and (b) how GMA 10 responded to certain public comments and concerns expressed in timely public meetings that followed proposing the DFC, as described more specifically in Appendix B of this Explanatory Report. Further, this approved DFC will enable current and future Management Plans and regulations of those GMA 10 GCDs charged with achieving this DFC to balance specific local risks arising from protecting theaquifer while maximizing groundwater production.

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APPENDIX A

Socioeconomic Impacts of Projected Water Shortages for the Plateau (Region J) Regional Water Planning Area

Prepared in Support of the 2021 Region J Regional Water Plan

Texas Water
Development Board

Dr. John R. Ellis
Water Use, Projections, & Planning Division
Texas Water Development Board

November 2021

Table of Contents

Executive Summary

Evaluating the social and economic impacts of not meeting identified water needs is a required analysis in the regional water planning process. The Texas Water Development Board (TWDB) estimates these impacts for regional water planning groups (RWPGs) and summarizes the impacts in the state water plan. The analysis presented is for the Plateau Regional Water Planning Group (Region J).

Based on projected water demands and existing water supplies, Region J identified water needs (potential shortages) that could occur within its region under a repeat of the drought of record for six water use categories (irrigation, livestock, manufacturing, mining, municipal and steam-electric power). The TWDB then estimated the annual socioeconomic impacts of those needs—if they are not met—for each water use category and as an aggregate for the region.

This analysis was performed using an economic impact modeling software package, IMPLAN (Impact for Planning Analysis), as well as other economic analysis techniques, and represents a snapshot of socioeconomic impacts that may occur during a single year repeat of the drought of record with the further caveat that no mitigation strategies are implemented. Decade specific impact estimates assume that growth occurs, and future shocks are imposed on an economy at 10-year intervals. The estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

For regional economic impacts, income losses and job losses are estimated within each planning decade (2020 through 2070). The income losses represent an approximation of gross domestic product (GDP) that would be foregone if water needs are not met.

The analysis also provides estimates of financial transfer impacts, which include tax losses (state, local, and utility tax collections); water trucking costs; and utility revenue losses. In addition, social impacts are estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses.

IMPLAN data reported that the Region J generated more than $4.5 billion in gross domestic product (GDP) (2018 dollars) and supported roughly 68,000 jobs in 2016. The Region J estimated total population was approximately 131,000 in 2016.

It is estimated that not meeting the identified water needs in Region J would result in an annually combined lost income impact of approximately $233 million in 2020, increasing to $257 million in 2070 (Table ES-1). In 2020, the region would lose approximately 2,300 jobs, and by 2070 job losses would increase to approximately 3,000 if anticipated needs are not mitigated.

All impact estimates are in year 2018 dollars and were calculated using a variety of data sources and tools including the use of a region-specific IMPLAN model, data from TWDB annual water use

estimates, the U.S. Census Bureau, Texas Agricultural Statistics Service, and the Texas Municipal League.

Table ES-1 Region J socioeconomic impact summary

Regional Economic Impacts	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$233	$298	$316	$289	$268	$257
Job losses	2,272	2,597	2,780	2,850	2,935	3,064
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$26	$33	$35	$32	$29	$28
Water trucking costs ($ millions)*	$1	$1	$1	$1	$1	$1
Utility revenue losses ($ millions)*	$14	$15	$17	$18	$20	$22
Utility tax revenue losses ($ millions)*	$0	$0	$0	$0	$0	$0
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$5	$7	$8	$10	$12	$15
Population losses	417	477	510	523	539	563
School enrollment losses	80	91	98	100	103	108

* Year 2018 dollars, rounded**.** Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

1 Introduction

Water shortages during a repeat of the drought of record would likely curtail or eliminate certain economic activity in businesses and industries that rely heavily on water. Insufficient water supplies could not only have an immediate and real impact on the regional economy in the short term, but they could also adversely and chronically affect economic development in Texas. From a social perspective, water supply reliability is critical as well. Shortages could disrupt activity in homes, schools and government, and could adversely affect public health and safety. For these reasons, it is important to evaluate and understand how water supply shortages during drought could impact communities throughout the state.

As part of the regional water planning process, RWPGs must evaluate the social and economic impacts of not meeting water needs (31 Texas Administrative Code §357.33 (c)). Due to the complexity of the analysis and limited resources of the planning groups, the TWDB has historically performed this analysis for the RWPGs upon their request. Staff of the TWDB's Water Use, Projections, & Planning Division designed and conducted this analysis in support of Region J, and those efforts for this region as well as the other 15 regions allow consistency and a degree of comparability in the approach.

This document summarizes the results of the analysis and discusses the methodology used to generate the results. Section 1 provides a snapshot of the region's economy and summarizes the identified water needs in each water use category, which were calculated based on the RWPG's water supply and demand established during the regional water planning process. Section 2 defines each of ten impact assessment measures used in this analysis. Section 3 describes the methodology for the impact assessment and the approaches and assumptions specific to each water use category (i.e., irrigation, livestock, manufacturing, mining, municipal, and steam-electric power). Section 4 presents the impact estimates for each water use category with results summarized for the region as a whole. Appendix A presents a further breakdown of the socioeconomic impacts by county.

1.1 Regional Economic Summary

The Region J Regional Water Planning Area generated more than $4.5 billion in gross domestic product (2018 dollars) and supported roughly 68,000 jobs in 2016, according to the IMPLAN dataset utilized in this socioeconomic analysis. This activity accounted for 0.3 percent of the state's total gross domestic product of 1.73 trillion dollars for the year based on IMPLAN. Table 1-1 lists all economic sectors ranked by the total value-added to the economy in Region J. The real estate and retail trade sectors generated close to 20 percent of the region's total value-added and were also significant sources of tax revenue. The top employers in the region were in the public administration, retail trade, and health care sectors. Region J's estimated total population was roughly 131,000 in 2016, approximately 0.5 percent of the state's total.

This represents a snapshot of the regional economy as a whole, and it is important to note that not all economic sectors were included in the TWDB socioeconomic impact analysis. Data considerations prompted use of only the more water-intensive sectors within the economy because damage estimates could only be calculated for those economic sectors which had both reliable income and water use estimates.

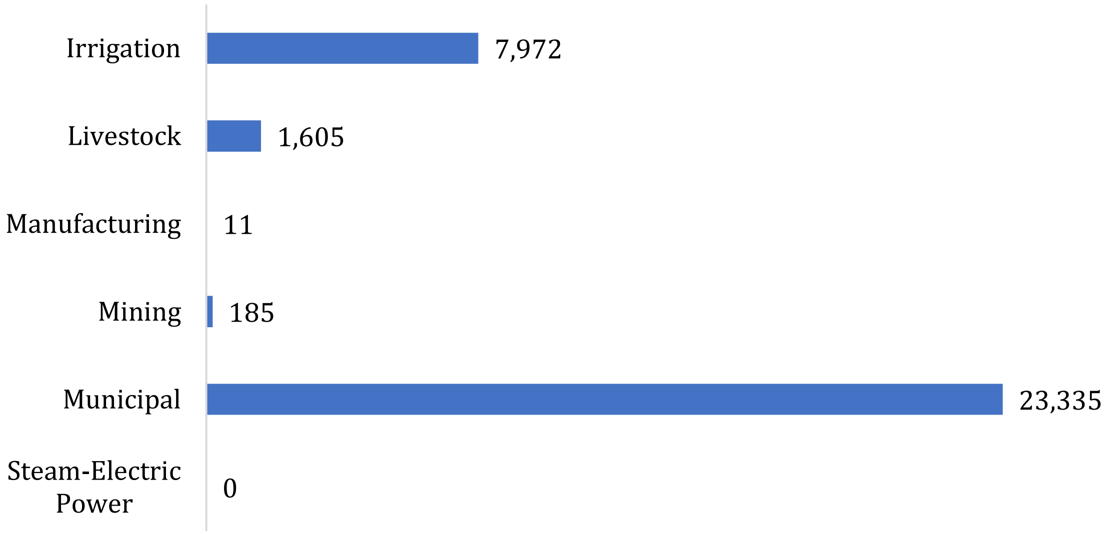
Table 1-1 Region J regional economy by economic sector*

Economic sector	Value-added ($ millions)	Tax ($ millions)	Jobs
Public Administration	$1,098.8	$(7.7)	10,835
Real Estate and Rental and Leasing	$511.9	$91.5	3,031
Retail Trade	$383.5	$100.4	7,154
Manufacturing	$372.0	$14.1	3,610
Health Care and Social Assistance	$364.4	$5.9	7,151
Construction	$270.8	$5.6	5,093
Accommodation and Food Services	$230.2	$33.8	5,358
Professional, Scientific, and Technical Services	$189.9	$6.4	3,150
Other Services (except Public Administration)	$184.0	$19.9	4,987
Wholesale Trade	$171.9	$65.4	2,211
Administrative and Support and Waste Management and Remediation Services	$137.6	$3.4	2,744
Transportation and Warehousing	$135.8	$4.2	1,756
Finance and Insurance	$128.8	$8.2	2,828
Information	$91.9	$32.3	662
Mining, Quarrying, and Oil and Gas Extraction	$89.9	$49.8	1,334
Agriculture, Forestry, Fishing and Hunting	$59.4	$2.5	3,769
Utilities	$54.7	$14.7	218
Arts, Entertainment, and Recreation	$35.1	$6.5	1,075
Educational Services	$28.4	$1.9	1,025
Management of Companies and Enterprises	$6.7	$0.7	251
Grand Total	$4,545.8	$459.6	68,241

*Source: 2016 IMPLAN for 536 sectors aggregated by 2-digit NAICS (North American Industry Classification System)

Figure 1-1 illustrates Region J's breakdown of the 2016 water use estimates by TWDB water use category. The categories with the highest use in Region J in 2016 were municipal (70 percent) and irrigation (24 percent).

Figure 1-1 Region J 2016 water use estimates by water use category (in acre-feet)



Source: TWDB Annual Water Use Estimates (all values in acre-feet)

1.2 Identified Regional Water Needs (Potential Shortages)

As part of the regional water planning process, the TWDB adopted water demand projections for water user groups (WUG) in Region J with input from the planning group. WUG-level demand projections were established for utilities that provide more than 100 acre-feet of annual water supply, combined rural areas (designated as county-other), and county-wide water demand projections for five non-municipal categories (irrigation, livestock, manufacturing, mining and steam-electric power). The RWPG then compared demands to the existing water supplies of each WUG to determine potential shortages, or needs, by decade.

Table 1-2 summarizes the region's identified water needs in the event of a repeat of the drought of record. Demand management, such as conservation, or the development of new infrastructure to increase supplies, are water management strategies that may be recommended by the planning group to address those needs. This analysis assumes that no strategies are implemented, and that the identified needs correspond to future water shortages. Note that projected water needs generally increase over time, primarily due to anticipated population growth, economic growth, or declining supplies. To provide a general sense of proportion, total projected needs as an overall percentage of total demand by water use category are also presented in aggregate in Table 1-2. Projected needs for individual water user groups within the aggregate can vary greatly and may reach 100% for a given WUG and water use category. A detailed summary of water needs by WUG and county appears in Chapter 4 of the 2021 Region J Regional Water Plan.

Table 1-2 Regional water needs summary by water use category*

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	water needs (acre-feet per year)	75	75	75	75	75	75
	% of the category's total water demand	1%	1%	1%	1%	1%	1%
Livestock	water needs (acre-feet per year)	357	357	357	357	357	357
	% of the category's total water demand	16%	16%	16%	16%	16%	16%
Manufacturing	water needs (acre-feet per year)	-	-	-	-	-	-
	% of the category's total water demand	0%	0%	0%	0%	0%	0%
Mining	water needs (acre-feet per year)	221	281	294	259	229	210
	% of the category's total water demand	62%	67%	66%	63%	58%	55%
Municipal**	water needs (acre-feet per year)	5,956	6,685	7,336	8,143	9,198	10,223
	% of the category's total water demand	23%	24%	26%	28%	30%	32%
Steam-electric power	water needs (acre-feet per year)	-	-	-	-	-	-
	% of the category's total water demand	0%	0%	0%	0%	0%	0%
Total water needs (acre-feet per year)		**6,609**	**7,398**	**8,062**	**8,834**	**9,859**	**10,865**

*Entries denoted by a dash (-) indicate no identified water need for a given water use category.
** Municipal category consists of residential and non-residential (commercial and institutional) subcategories.

2 Impact Assessment Measures

A required component of the regional and state water plans is to estimate the potential economic and social impacts of potential water shortages during a repeat of the drought of record. Consistent with previous water plans, ten impact measures were estimated and are described in Table 2-1.

Table 2-1 Socioeconomic impact analysis measures

Regional economic impacts	Description
Income losses - value-added	The value of output less the value of intermediate consumption; it is a measure of the contribution to gross domestic product (GDP) made by an individual producer, industry, sector, or group of sectors within a year. Value-added measures used in this report have been adjusted to include the direct, indirect, and induced monetary impacts on the region.
Income losses - electrical power purchase costs	Proxy for income loss in the form of additional costs of power as a result of impacts of water shortages.
Job losses	Number of part-time and full-time jobs lost due to the shortage. These values have been adjusted to include the direct, indirect, and induced employment impacts on the region.
Financial transfer impacts	**Description**
Tax losses on production and imports	Sales and excise taxes not collected due to the shortage, in addition to customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies. These values have been adjusted to include the direct, indirect and induced tax impacts on the region.
Water trucking costs	Estimated cost of shipping potable water.
Utility revenue losses	Foregone utility income due to not selling as much water.
Utility tax revenue losses	Foregone miscellaneous gross receipts tax collections.
Social impacts	**Description**
Consumer surplus losses	A welfare measure of the lost value to consumers accompanying restricted water use.
Population losses	Population losses accompanying job losses.
School enrollment losses	School enrollment losses (K-12) accompanying job losses.

2.1 Regional Economic Impacts

The two key measures used to assess regional economic impacts are income losses and job losses. The income losses presented consist of the sum of value-added losses and the additional purchase costs of electrical power.

Income Losses - Value-added Losses

Value-added is the value of total output less the value of the intermediate inputs also used in the production of the final product. Value-added is similar to GDP, a familiar measure of the productivity of an economy. The loss of value-added due to water shortages is estimated by input-output analysis using the IMPLAN software package, and includes the direct, indirect, and induced monetary impacts on the region. The indirect and induced effects are measures of reduced income as well as reduced employee spending for those input sectors which provide resources to the water shortage impacted production sectors.

Income Losses - Electric Power Purchase Costs

The electrical power grid and market within the state is a complex interconnected system. The industry response to water shortages, and the resulting impact on the region, are not easily modeled using traditional input/output impact analysis and the IMPLAN model. Adverse impacts on the region will occur and are represented in this analysis by estimated additional costs associated with power purchases from other generating plants within the region or state. Consequently, the analysis employs additional power purchase costs as a proxy for the value-added impacts for the steam-electric power water use category, and these are included as a portion of the overall income impact for completeness.

For the purpose of this analysis, it is assumed that power companies with insufficient water will be forced to purchase power on the electrical market at a projected higher rate of 5.60 cents per kilowatt hour. This rate is based upon the average day-ahead market purchase price of electricity in Texas that occurred during the recent drought period in 2011. This price is assumed to be comparable to those prices which would prevail in the event of another drought of record.

Job Losses

The number of jobs lost due to the economic impact is estimated using IMPLAN output associated with each TWDB water use category. Because of the difficulty in predicting outcomes and a lack of relevant data, job loss estimates are not calculated for the steam-electric power category.

2.2 Financial Transfer Impacts

Several impact measures evaluated in this analysis are presented to provide additional detail concerning potential impacts on a portion of the economy or government. These financial transfer impact measures include lost tax collections (on production and imports), trucking costs for

imported water, declines in utility revenues, and declines in utility tax revenue collected by the state. These measures are not solely adverse, with some having both positive and negative impacts. For example, cities and residents would suffer if forced to pay large costs for trucking in potable water. Trucking firms, conversely, would benefit from the transaction. Additional detail for each of these measures follows.

Tax Losses on Production and Imports

Reduced production of goods and services accompanying water shortages adversely impacts the collection of taxes by state and local government. The regional IMPLAN model is used to estimate reduced tax collections associated with the reduced output in the economy. Impact estimates for this measure include the direct, indirect, and induced impacts for the affected sectors.

Water Trucking Costs

In instances where water shortages for a municipal water user group are estimated by RWPGs to exceed 80 percent of water demands, it is assumed that water would need to be trucked in to support basic consumption and sanitation needs. For water shortages of 80 percent or greater, a fixed, maximum of $35,000[1] per acre-foot of water applied as an economic cost. This water trucking cost was utilized for both the residential and non-residential portions of municipal water needs.

Utility Revenue Losses

Lost utility income is calculated as the price of water service multiplied by the quantity of water not sold during a drought shortage. Such estimates are obtained from utility-specific pricing data provided by the Texas Municipal League, where available, for both water and wastewater. These water rates are applied to the potential water shortage to estimate forgone utility revenue as water providers sold less water during the drought due to restricted supplies.

Utility Tax Losses

Foregone utility tax losses include estimates of forgone miscellaneous gross receipts taxes. Reduced water sales reduce the amount of utility tax that would be collected by the State of Texas for water and wastewater service sales.

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[1] Based on staff survey of water hauling firms and historical data concerning transport costs for potable water in the recent drought in California for this estimate. There are many factors and variables that would determine actual water trucking costs including distance to, cost of water, and length of that drought.

2.3 Social Impacts

Consumer Surplus Losses for Municipal Water Users

Consumer surplus loss is a measure of impact to the wellbeing of municipal water users when their water use is restricted. Consumer surplus is the difference between how much a consumer is willing and able to pay for a commodity (i.e., water) and how much they actually have to pay. The difference is a benefit to the consumer's wellbeing since they do not have to pay as much for the commodity as they would be willing to pay. Consumer surplus may also be viewed as an estimate of how much consumers would be willing to pay to keep the original quantity of water which they used prior to the drought. Lost consumer surplus estimates within this analysis only apply to the residential portion of municipal demand, with estimates being made for reduced outdoor and indoor residential use. Lost consumer surplus estimates varied widely by location and degree of water shortage.

Population and School Enrollment Losses

Population loss due to water shortages, as well as the associated decline in school enrollment, are based upon the job loss estimates discussed in Section 2.1. A simplified ratio of job and net population losses are calculated for the state as a whole based on a recent study of how job layoffs impact the labor market population.[2] For every 100 jobs lost, 18 people were assumed to move out of the area. School enrollment losses are estimated as a proportion of the population lost based upon public school enrollment data from the Texas Education Agency concerning the age K-12 population within the state (approximately 19%).

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[2] Foote, Andrew, Grosz, Michel, Stevens, Ann. "Locate Your Nearest Exit: Mass Layoffs and Local Labor Market Response." University of California, Davis. April 2015, http://paa2015.princeton.edu/papers/150194. The study utilized Bureau of Labor Statistics data regarding layoffs between 1996 and 2013, as well as Internal Revenue Service data regarding migration, to model the change in the population as the result of a job layoff event. The study found that layoffs impact both out-migration and in-migration into a region, and that a majority of those who did move following a layoff moved to another labor market rather than an adjacent county.

3 Socioeconomic Impact Assessment Methodology

This portion of the report provides a summary of the methodology used to estimate the potential economic impacts of future water shortages. The general approach employed in the analysis was to obtain estimates for income and job losses on the smallest geographic level that the available data would support, tie those values to their accompanying historic water use estimate, and thereby determine a maximum impact per acre-foot of shortage for each of the socioeconomic measures. The calculations of economic impacts are based on the overall composition of the economy divided into many underlying economic sectors. Sectors in this analysis refer to one or more of the 536 specific production sectors of the economy designated within IMPLAN, the economic impact modeling software used for this assessment. Economic impacts within this report are estimated for approximately 330 of these sectors, with the focus on the more water-intensive production sectors. The economic impacts for a single water use category consist of an aggregation of impacts to multiple, related IMPLAN economic sectors.

3.1 Analysis Context

The context of this socioeconomic impact analysis involves situations where there are physical shortages of groundwater or surface water due to a recurrence of drought of record conditions. Anticipated shortages for specific water users may be nonexistent in earlier decades of the planning horizon, yet population growth or greater industrial, agricultural or other sector demands in later decades may result in greater overall demand, exceeding the existing supplies. Estimated socioeconomic impacts measure what would happen if water user groups experience water shortages for a period of one year. Actual socioeconomic impacts would likely become larger as drought of record conditions persist for periods greater than a single year.

3.2 IMPLAN Model and Data

Input-Output analysis using the IMPLAN software package was the primary means of estimating the value-added, jobs, and tax related impact measures. This analysis employed regional level models to determine key economic impacts. IMPLAN is an economic impact model, originally developed by the U.S. Forestry Service in the 1970's to model economic activity at varying geographic levels. The model is currently maintained by the Minnesota IMPLAN Group (MIG Inc.) which collects and sells county and state specific data and software. The year 2016 version of IMPLAN, employing data for all 254 Texas counties, was used to provide estimates of value-added, jobs, and taxes on production for the economic sectors associated with the water user groups examined in the study. IMPLAN uses 536 sector-specific Industry Codes, and those that rely on water as a primary input were assigned to their appropriate planning water user categories (irrigation, livestock, manufacturing, mining, and municipal). Estimates of value-added for a water use category were obtained by summing value-added estimates across the relevant IMPLAN sectors associated with that water use category. These calculations were also performed for job losses as well as tax losses on production and imports.

The adjusted value-added estimates used as an income measure in this analysis, as well as the job and tax estimates from IMPLAN, include three components:

- ***Direct effects*** representing the initial change in the industry analyzed;
- ***Indirect effects*** that are changes in inter-industry transactions as supplying industries respond to reduced demands from the directly affected industries; and,
- ***Induced effects*** that reflect changes in local spending that result from reduced household income among employees in the directly and indirectly affected industry sectors.

Input-output models such as IMPLAN only capture backward linkages and do not include forward linkages in the economy.

3.3 Elasticity of Economic Impacts

The economic impact of a water need is based on the size of the water need relative to the total water demand for each water user group. Smaller water shortages, for example, less than 5 percent, are generally anticipated to result in no initial negative economic impact because water users are assumed to have a certain amount of flexibility in dealing with small shortages. As a water shortage intensifies, however, such flexibility lessens and results in actual and increasing economic losses, eventually reaching a representative maximum impact estimate per unit volume of water. To account for these characteristics, an elasticity adjustment function is used to estimate impacts for the income, tax and job loss measures. Figure 3-1 illustrates this general relationship for the adjustment functions. Negative impacts are assumed to begin accruing when the shortage reaches the lower bound 'b1' (5 percent in Figure 3-1), with impacts then increasing linearly up to the 100 percent impact level (per unit volume) once the upper bound reaches the 'b2' level shortage (40 percent in Figure 3-1).

To illustrate this, if the total annual value-added for manufacturing in the region was $2 million and the reported annual volume of water used in that industry is 10,000 acre-feet, the estimated economic measure of the water shortage would be $200 per acre-foot. The economic impact of the shortage would then be estimated using this value-added amount as the maximum impact estimate ($200 per acre-foot) applied to the anticipated shortage volume and then adjusted by the elasticity function. Using the sample elasticity function shown in Figure 3-1, an approximately 22 percent shortage in the livestock category would indicate an economic impact estimate of 50% of the original $200 per acre-foot impact value (i.e., $100 per acre-foot).

Such adjustments are not required in estimating consumer surplus, utility revenue losses, or utility tax losses. Estimates of lost consumer surplus rely on utility-specific demand curves with the lost consumer surplus estimate calculated based on the relative percentage of the utility's water shortage. Estimated changes in population and school enrollment are indirectly related to the elasticity of job losses.

Assumed values for the lower and upper bounds 'b1' and 'b2' vary by water use category and are presented in Table 3-1.

Figure 3-1 Example economic impact elasticity function (as applied to a single water user's

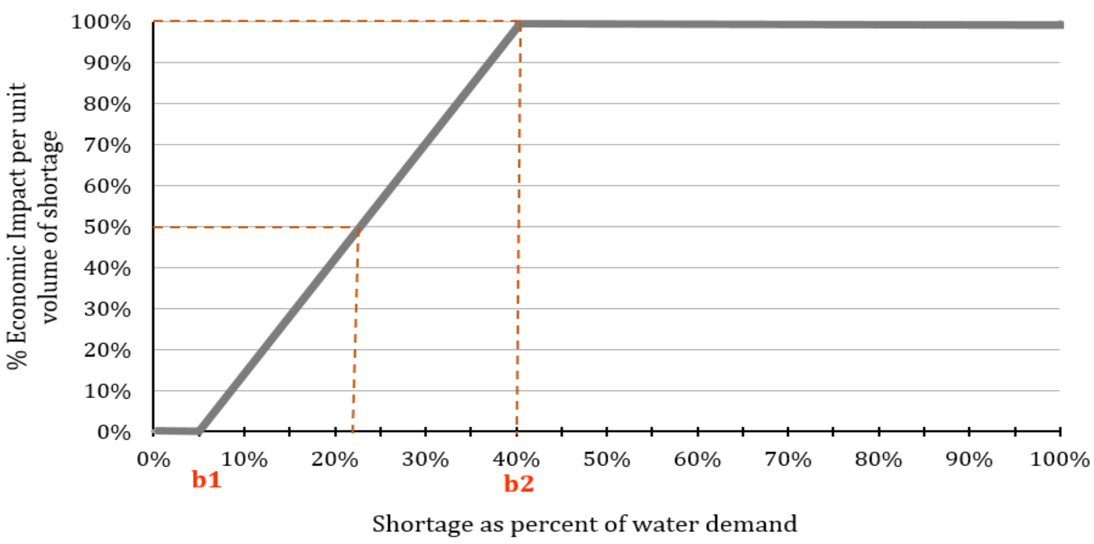

Table 3-1 Economic impact elasticity function lower and upper bounds

Water use category	Lower bound (b1)	Upper bound (b2)
Irrigation	**5%**	**40%**
Livestock	**5%**	**10%**
Manufacturing	**5%**	**40%**
Mining	**5%**	**40%**
Municipal (non-residential water intensive subcategory)	**5%**	**40%**
Steam-electric power	**N/A**	**N/A**

3.4 Analysis Assumptions and Limitations

The modeling of complex systems requires making many assumptions and acknowledging the model's uncertainty and limitations. This is particularly true when attempting to estimate a wide range of socioeconomic impacts over a large geographic area and into future decades. Some of the key assumptions and limitations of this methodology include:

1. The foundation for estimating the socioeconomic impacts of water shortages resulting from a drought are the water needs (potential shortages) that were identified by RWPGs as part of the

regional water planning process. These needs have some uncertainty associated with them but serve as a reasonable basis for evaluating the potential impacts of a drought of record event.

2. All estimated socioeconomic impacts are snapshots for years in which water needs were identified (i.e., 2020, 2030, 2040, 2050, 2060, and 2070). The estimates are independent and distinct "what if" scenarios for each particular year, and water shortages are assumed to be temporary events resulting from a single year recurrence of drought of record conditions. The evaluation assumed that no recommended water management strategies are implemented. In other words, growth occurs and future shocks are imposed on an economy at 10-year intervals, and the resulting impacts are estimated. Note that the estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

3. Input-output models such as IMPLAN rely on a static profile of the structure of the economy as it appears today. This presumes that the relative contributions of all sectors of the economy would remain the same, regardless of changes in technology, availability of limited resources, and other structural changes to the economy that may occur in the future. Changes in water use efficiency will undoubtedly take place in the future as supplies become more stressed. Use of the static IMPLAN structure was a significant assumption and simplification considering the 50-year time period examined in this analysis. To presume an alternative future economic makeup, however, would entail positing many other major assumptions that would very likely generate as much or more error.

4. This is not a form of cost-benefit analysis. That approach to evaluating the economic feasibility of a specific policy or project employs discounting future benefits and costs to their present value dollars using some assumed discount rate. The methodology employed in this effort to estimate the economic impacts of future water shortages did not use any discounting methods to weigh future costs differently through time.

5. All monetary values originally based upon year 2016 IMPLAN and other sources are reported in constant year 2018 dollars to be consistent with the water management strategy requirements in the State Water Plan.

6. IMPLAN based loss estimates (income-value-added, jobs, and taxes on production and imports) are calculated only for those IMPLAN sectors for which the TWDB's Water Use Survey (WUS) data was available and deemed reliable. Every effort is made in the annual WUS effort to capture all relevant firms who are significant water users. Lack of response to the WUS, or omission of relevant firms, impacts the loss estimates.

7. Impacts are annual estimates. The socioeconomic analysis does not reflect the full extent of impacts that might occur as a result of persistent water shortages occurring over an extended duration. The drought of record in most regions of Texas lasted several years.

8. Value-added estimates are the primary estimate of the economic impacts within this report. One may be tempted to add consumer surplus impacts to obtain an estimate of total adverse economic impacts to the region, but the consumer surplus measure represents the change to the wellbeing of households (and other water users), not an actual change in the flow of dollars through the economy. The two measures (value-added and consumer surplus) are both valid impacts but ideally should not be summed.

9. The value-added, jobs, and taxes on production and import impacts include the direct, indirect and induced effects to capture backward linkages in the economy described in Section 2.1. Population and school enrollment losses also indirectly include such effects as they are based on the associated losses in employment. The remaining measures (consumer surplus, utility revenue, utility taxes, additional electrical power purchase costs, and potable water trucking costs), however, do not include any induced or indirect effects.

10. The majority of impacts estimated in this analysis may be more conservative (i.e., smaller) than those that might actually occur under drought of record conditions due to not including impacts in the forward linkages in the economy. Input-output models such as IMPLAN only capture backward linkages on suppliers (including households that supply labor to directly affected industries). While this is a common limitation in this type of economic modeling effort, it is important to note that forward linkages on the industries that use the outputs of the directly affected industries can also be very important. A good example is impacts on livestock operators. Livestock producers tend to suffer substantially during droughts, not because there is not enough water for their stock, but because reductions in available pasture and higher prices for purchased hay have significant economic effects on their operations. Food processors could be in a similar situation if they cannot get the grains or other inputs that they need. These effects are not captured in IMPLAN, resulting in conservative impact estimates.

11. The model does not reflect dynamic economic responses to water shortages as they might occur, nor does the model reflect economic impacts associated with a recovery from a drought of record including:
    a. The likely significant economic rebound to some industries immediately following a drought, such as landscaping;
    b. The cost and time to rebuild liquidated livestock herds (a major capital investment in that industry);
    c. Direct impacts on recreational sectors (i.e., stranded docks and reduced tourism); or,
    d. Impacts of negative publicity on Texas' ability to attract population and business in the event that it was not able to provide adequate water supplies for the existing economy.

12. Estimates for job losses and the associated population and school enrollment changes may exceed what would actually occur. In practice, firms may be hesitant to lay off employees, even in difficult economic times. Estimates of population and school enrollment changes are based on regional evaluations and therefore do not necessarily reflect what might occur on a statewide basis.

13. **The results must be interpreted carefully. It is the general and relative magnitudes of impacts as well as the changes of these impacts over time that should be the focus rather than the absolute numbers.** Analyses of this type are much better at predicting relative percent differences brought about by a shock to a complex system (i.e., a water shortage) than the precise size of an impact. To illustrate, assuming that the estimated economic impacts of a drought of record on the manufacturing and mining water user categories are $2 and $1 million, respectively, one should be more confident that the economic impacts on manufacturing are twice as large as those on mining and that these impacts will likely be in the millions of dollars. But one should have less confidence that the actual total economic impact experienced would be $3 million.

14. The methodology does not capture "spillover" effects between regions – or the secondary impacts that occur outside of the region where the water shortage is projected to occur.

15. The methodology that the TWDB has developed for estimating the economic impacts of unmet water needs, and the assumptions and models used in the analysis, are specifically designed to estimate potential economic effects at the regional and county levels. Although it may be tempting to add the regional impacts together in an effort to produce a statewide result, the TWDB cautions against that approach for a number of reasons. The IMPLAN modeling (and corresponding economic multipliers) are all derived from regional models – a statewide model of Texas would produce somewhat different multipliers. As noted in point 14 within this section, the regional modeling used by TWDB does not capture spillover losses that could result in other regions from unmet needs in the region analyzed, or potential spillover gains if decreased production in one region leads to increases in production elsewhere. The assumed drought of record may also not occur in every region of Texas at the same time, or to the same degree.

4 Analysis Results

This section presents estimates of potential economic impacts that could reasonably be expected in the event of water shortages associated with a drought of record and if no recommended water management strategies were implemented. Projected economic impacts for the six water use categories (irrigation, livestock, manufacturing, mining, municipal, and steam-electric power) are reported by decade.

4.1 Impacts for Irrigation Water Shortages

One of the six counties in the region are projected to experience water shortages in the irrigated agriculture water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-1. Note that tax collection impacts were not estimated for this water use category. IMPLAN data indicates a negative tax impact (i.e., increased tax collections) for the associated production sectors, primarily due to past subsidies from the federal government. However, it was not considered realistic to report increasing tax revenues during a drought of record.

Table 4-1 Impacts of water shortages on irrigation in Region J

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$0	$0	$0	$0	$0	$0
Job losses	0	0	0	0	0	0

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.2 Impacts for Livestock Water Shortages

Three of the six counties in the region are projected to experience water shortages in the livestock water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-2.

Table 4-2 Impacts of water shortages on livestock in Region J

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$11	$11	$11	$11	$11	$11
Jobs losses	573	573	573	573	573	573
Tax losses on production and imports ($ millions)*	$1	$1	$1	$1	$1	$1

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.3 Impacts of Manufacturing Water Shortages

None of the six counties in the region are projected to experience water shortages in the manufacturing water use category. Estimated impacts to this water use category appear in Table 4-3.

Table 4-3 Impacts of water shortages on manufacturing in Region J

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$-	$-	$-	$-	$-	$-
Job losses	-	-	-	-	-	-
Tax losses on production and Imports ($ millions)*	$-	$-	$-	$-	$-	$-

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.4 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in three of the six counties in the region one or more decades within the planning horizon. Estimated impacts to this water use type appear in Table 4-4.

Table 4-4 Impacts of water shortages on mining in Region J

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$162	$220	$230	$195	$164	$144
Job losses	495	666	696	592	502	441
Tax losses on production and Imports ($ millions)*	$19	$26	$27	$23	$19	$17

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.5 Impacts for Municipal Water Shortages

Five of the six counties in the region are projected to experience water shortages in the municipal water use category for one or more decades within the planning horizon.

Impact estimates were made for two sub-categories within municipal water use: residential, and non-residential. Non-residential municipal water use includes commercial and institutional users, which are further divided into non-water-intensive and water-intensive subsectors including car wash, laundry, hospitality, health care, recreation, and education. Lost consumer surplus estimates were made only for needs in the residential portion of municipal water use. Available IMPLAN and TWDB Water Use Survey data for the non-residential, water-intensive portion of municipal demand allowed these sectors to be included in income, jobs, and tax loss impact estimate.

Trucking cost estimates, calculated for shortages exceeding 80 percent, assumed a fixed, maximum cost of $35,000 per acre-foot to transport water for municipal use. The estimated impacts to this water use category appear in Table 4-5.

Table 4-5 Impacts of water shortages on municipal water users in Region J

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses[1] ($ millions)*	$59	$67	$75	$83	$92	$101
Job losses[1]	1,204	1,358	1,511	1,686	1,860	2,050
Tax losses on production and imports[1] ($ millions)*	$6	$7	$8	$9	$10	$11
Trucking costs ($ millions)*	$1	$1	$1	$1	$1	$1
Utility revenue losses ($ millions)*	$14	$15	$17	$18	$20	$22
Utility tax revenue losses ($ millions)*	$0	$0	$0	$0	$0	$0

[1] Estimates apply to the water-intensive portion of non-residential municipal water use.
* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.6 Impacts of Steam-Electric Water Shortages

None of the six counties in the region are projected to experience water shortages in the steam-electric water use category. Estimated impacts to this water use category appear in Table 4-6.

Note that estimated economic impacts to steam-electric water users:

- Are reflected as an income loss proxy in the form of estimated additional purchasing costs for power from the electrical grid to replace power that could not be generated due to a shortage;
- Do not include estimates of impacts on jobs. Because of the unique conditions of power generators during drought conditions and lack of relevant data, it was assumed that the industry would retain, perhaps relocating or repurposing, their existing staff in order to manage their ongoing operations through a severe drought.
- Do not presume a decline in tax collections. Associated tax collections, in fact, would likely increase under drought conditions since, historically, the demand for electricity increases during times of drought, thereby increasing taxes collected on the additional sales of power.

Table 4-6 Impacts of water shortages on steam-electric power in Region J

Impacts measure	2020	2030	2040	2050	2060	2070
Income Losses ($ millions)*	$-	$-	$-	$-	$-	$-

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.7 Regional Social Impacts

Projected changes in population, based upon several factors (household size, population, and job loss estimates), as well as the accompanying change in school enrollment, were also estimated and are summarized in Table 4-7.

Table 4-7 Region-wide social impacts of water shortages in Region J

Impacts measure	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$5	$7	$8	$10	$12	$15
Population losses	417	477	510	523	539	563
School enrollment losses	80	91	98	100	103	108

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

Appendix A - County Level Summary of Estimated Economic Impacts for Region J

County level summary of estimated economic impacts of not meeting identified water needs by water use category and decade (in 2018 dollars, rounded). Values are presented only for counties with projected economic impacts for at least one decade.
(* Entries denoted by a dash (-) indicate no estimated economic impact)

		Income losses (Million $)*						**Job losses**					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
BANDERA	IRRIGATION	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0	0	0	0	0	0
BANDERA	MUNICIPAL	$0.71	$0.90	$1.00	$1.05	$1.08	$1.09	14	18	20	21	22	22
BANDERA Total		**$0.71**	**$0.91**	**$1.01**	**$1.05**	**$1.08**	**$1.10**	**15**	**18**	**21**	**21**	**22**	**22**
EDWARDS	MINING	$14.69	$14.69	$14.69	$14.69	$14.69	$14.69	55	55	55	55	55	55
EDWARDS	MUNICIPAL	$0.31	$0.30	$0.29	$0.29	$0.29	$0.29	6	6	6	6	6	6
EDWARDS Total		**$15.00**	**$14.99**	**$14.98**	**$14.98**	**$14.98**	**$14.98**	**62**	**61**	**61**	**61**	**61**	**61**
KERR	LIVESTOCK	$10.90	$10.90	$10.90	$10.90	$10.90	$10.90	527	527	527	527	527	527
KERR	MINING	$0.36	$0.41	$0.52	$0.59	$0.60	$0.71	1	2	2	2	2	3
KERR	MUNICIPAL	$4.45	$5.32	$5.56	$6.29	$7.17	$7.98	90	108	113	127	145	162
KERR Total		**$15.71**	**$16.63**	**$16.97**	**$17.78**	**$18.68**	**$19.59**	**618**	**636**	**641**	**656**	**674**	**691**
KINNEY	LIVESTOCK	$0.54	$0.54	$0.54	$0.54	$0.54	$0.54	46	46	46	46	46	46
KINNEY Total		**$0.54**	**$0.54**	**$0.54**	**$0.54**	**$0.54**	**$0.54**	**46**	**46**	**46**	**46**	**46**	**46**
REAL	MUNICIPAL	$2.35	$2.28	$2.23	$2.22	$2.22	$2.22	48	46	45	45	45	45
REAL Total		**$2.35**	**$2.28**	**$2.23**	**$2.22**	**$2.22**	**$2.22**	**48**	**46**	**45**	**45**	**45**	**45**
VAL VERDE	MINING	$147.22	$204.75	$214.50	$179.40	$149.17	$128.70	438	609	638	534	444	383
VAL VERDE	MUNICIPAL	$51.61	$58.21	$65.51	$73.36	$81.04	$89.62	1,046	1,179	1,327	1,486	1,642	1,816
VAL VERDE Total		**$198.84**	**$262.96**	**$280.01**	**$252.75**	**$230.22**	**$218.32**	**1,484**	**1,789**	**1,966**	**2,020**	**2,086**	**2,199**
REGION J Total		**$233.14**	**$298.31**	**$315.75**	**$289.32**	**$267.72**	**$256.74**	**2,272**	**2,597**	**2,780**	**2,850**	**2,935**	**3,064**

Socioeconomic Impacts of Projected Water Shortages for the Lower Colorado (Region K) Regional Water Planning Area

Prepared in Support of the 2021 Region K Regional Water Plan

Texas Water Development Board

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Texas Water Development Board

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Table of Contents

Executive Summary

Evaluating the social and economic impacts of not meeting identified water needs is a required analysis in the regional water planning process. The Texas Water Development Board (TWDB) estimates these impacts for regional water planning groups (RWPGs) and summarizes the impacts in the state water plan. The analysis presented is for the Lower Colorado Regional Water Planning Group (Region K).

Based on projected water demands and existing water supplies, Region K identified water needs (potential shortages) that could occur within its region under a repeat of the drought of record for six water use categories (irrigation, livestock, manufacturing, mining, municipal and steam-electric power). The TWDB then estimated the annual socioeconomic impacts of those needs—if they are not met—for each water use category and as an aggregate for the region.

This analysis was performed using an economic impact modeling software package, IMPLAN (Impact for Planning Analysis), as well as other economic analysis techniques, and represents a snapshot of socioeconomic impacts that may occur during a single year repeat of the drought of record with the further caveat that no mitigation strategies are implemented. Decade specific impact estimates assume that growth occurs, and future shocks are imposed on an economy at 10-year intervals. The estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

For regional economic impacts, income losses and job losses are estimated within each planning decade (2020 through 2070). The income losses represent an approximation of gross domestic product (GDP) that would be foregone if water needs are not met.

The analysis also provides estimates of financial transfer impacts, which include tax losses (state, local, and utility tax collections); water trucking costs; and utility revenue losses. In addition, social impacts are estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses.

IMPLAN data reported that Region K generated more than $120 billion in GDP (2018 dollars) and supported roughly 1.2 million jobs in 2016. The Region K estimated total population was approximately 1.6 million in 2016.

It is estimated that not meeting the identified water needs in Region K would result in an annually combined lost income impact of approximately $1.3 billion in 2020, increasing to $2.6 billion in 2070 (Table ES-1). In 2020, the region would lose approximately 5,000 jobs, and by 2070 job losses would increase to approximately 27,000 if anticipated needs are not mitigated.

All impact estimates are in year 2018 dollars and were calculated using a variety of data sources and tools including the use of a region-specific IMPLAN model, data from TWDB annual water use

estimates, the U.S. Census Bureau, Texas Agricultural Statistics Service, and the Texas Municipal League.

Table ES-1 Region K socioeconomic impact summary

Regional Economic Impacts	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$1,282	$1,363	$1,702	$1,986	$2,168	$2,609
Job losses	5,018	6,859	12,154	16,898	21,398	27,413
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$73	$49	$67	$93	$117	$151
Water trucking costs ($ millions)*	$-	$-	$58	$62	$65	$69
Utility revenue losses ($ millions)*	$16	$49	$125	$187	$272	$419
Utility tax revenue losses ($ millions)*	$0	$1	$2	$3	$4	$7
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$6	$20	$181	$244	$396	$704
Population losses	921	1,259	2,231	3,102	3,929	5,033
School enrollment losses	176	241	427	593	752	963

* Year 2018 dollars, rounded**.** Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

1 Introduction

Water shortages during a repeat of the drought of record would likely curtail or eliminate certain economic activity in businesses and industries that rely heavily on water. Insufficient water supplies could not only have an immediate and real impact on the regional economy in the short term, but they could also adversely and chronically affect economic development in Texas. From a social perspective, water supply reliability is critical as well. Shortages could disrupt activity in homes, schools and government, and could adversely affect public health and safety. For these reasons, it is important to evaluate and understand how water supply shortages during drought could impact communities throughout the state.

As part of the regional water planning process, RWPGs must evaluate the social and economic impacts of not meeting water needs (31 Texas Administrative Code §357.33 (c)). Due to the complexity of the analysis and limited resources of the planning groups, the TWDB has historically performed this analysis for the RWPGs upon their request. Staff of the TWDB's Water Use, Projections, & Planning Division designed and conducted this analysis in support of Region K, and those efforts for this region as well as the other 15 regions allow consistency and a degree of comparability in the approach.

This document summarizes the results of the analysis and discusses the methodology used to generate the results. Section 1 provides a snapshot of the region's economy and summarizes the identified water needs in each water use category, which were calculated based on the RWPG's water supply and demand established during the regional water planning process. Section 2 defines each of ten impact assessment measures used in this analysis. Section 3 describes the methodology for the impact assessment and the approaches and assumptions specific to each water use category (i.e., irrigation, livestock, manufacturing, mining, municipal, and steam-electric power). Section 4 presents the impact estimates for each water use category with results summarized for the region as a whole. Appendix A presents a further breakdown of the socioeconomic impacts by county.

1.1 Regional Economic Summary

The Region K Regional Water Planning Area generated more than $120 billion in gross domestic product (2018 dollars) and supported roughly 1.2 million jobs in 2016, according to the IMPLAN dataset utilized in this socioeconomic analysis. This activity accounted for 7 percent of the state's total gross domestic product of 1.73 trillion dollars for the year based on IMPLAN. Table 1-1 lists all economic sectors ranked by the total value-added to the economy in Region K. The professional services and real estate sectors generated close to 25 percent of the region's total value-added and were also significant sources of tax revenue. The top employers in the region were in the public administration, professional services, and accommodation and food services sectors. Region K's estimated total population was roughly 1.6 million in 2016, approximately 6 percent of the state's total.

This represents a snapshot of the regional economy as a whole, and it is important to note that not all economic sectors were included in the TWDB socioeconomic impact analysis. Data considerations prompted use of only the more water-intensive sectors within the economy because damage estimates could only be calculated for those economic sectors which had both reliable income and water use estimates.

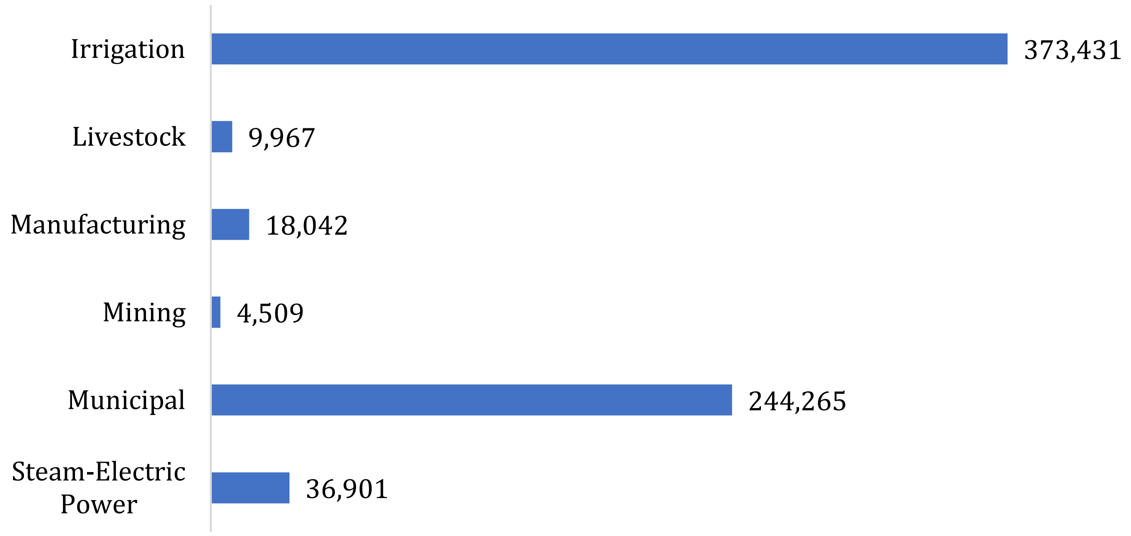
Table 1-1 Region K regional economy by economic sector*

Economic sector	Value-added ($ millions)	Tax ($ millions)	Jobs
Professional, Scientific, and Technical Services	$16,213.9	$434.6	134,238
Real Estate and Rental and Leasing	$13,217.6	$1,630.3	60,139
Public Administration	$12,751.8	$(45.7)	136,355
Manufacturing	$9,623.3	$415.1	46,647
Wholesale Trade	$9,526.2	$1,234.9	42,012
Information	$7,384.4	$1,264.7	33,536
Finance and Insurance	$6,913.1	$326.0	64,221
Health Care and Social Assistance	$6,662.0	$77.9	92,984
Retail Trade	$6,396.3	$1,199.5	90,468
Construction	$6,056.0	$77.8	70,072
Mining, Quarrying, and Oil and Gas Extraction	$5,017.9	$706.9	17,303
Administrative and Support and Waste Management and Remediation Services	$4,672.4	$72.9	71,876
Other Services (except Public Administration)	$4,517.9	$314.1	83,965
Accommodation and Food Services	$4,484.6	$596.7	102,377
Utilities	$2,816.0	$260.4	6,302
Transportation and Warehousing	$1,710.7	$83.2	25,190
Arts, Entertainment, and Recreation	$964.9	$146.7	28,762
Educational Services	$710.1	$23.8	19,443
Management of Companies and Enterprises	$604.2	$29.5	10,456
Agriculture, Forestry, Fishing and Hunting	$529.6	$16.5	21,738
Grand Total	$120,773.2	$8,865.8	1,158,084

*Source: 2016 IMPLAN for 536 sectors aggregated by 2-digit NAICS (North American Industry Classification System)

While municipal and manufacturing sectors led the region in economic output, the majority (54 percent) of water use in 2016 occurred in irrigated agriculture. More than 5 percent of the state's municipal water use occurred within Region K. Figure 1-1 illustrates Region K's breakdown of the 2016 water use estimates by TWDB water use category.

Figure 1-1 Region K 2016 water use estimates by water use category (in acre-feet)



Source: TWDB Annual Water Use Estimates (all values in acre-feet)

1.2 Identified Regional Water Needs (Potential Shortages)

As part of the regional water planning process, the TWDB adopted water demand projections for water user groups (WUG) in Region K with input from the planning group. WUG-level demand projections were established for utilities that provide more than 100 acre-feet of annual water supply, combined rural areas (designated as county-other), and county-wide water demand projections for five non-municipal categories (irrigation, livestock, manufacturing, mining and steam-electric power). The RWPG then compared demands to the existing water supplies of each WUG to determine potential shortages, or needs, by decade.

Table 1-2 summarizes the region's identified water needs in the event of a repeat of the drought of record. Demand management, such as conservation, or the development of new infrastructure to increase supplies, are water management strategies that may be recommended by the planning group to address those needs. This analysis assumes that no strategies are implemented, and that the identified needs correspond to future water shortages. Note that projected water needs generally increase over time, primarily due to anticipated population growth, economic growth, or declining supplies. To provide a general sense of proportion, total projected needs as an overall percentage of total demand by water use category are also presented in aggregate in Table 1-2. Projected needs for individual water user groups within the aggregate can vary greatly and may reach 100% for a given WUG and water use category. A detailed summary of water needs by WUG and county appears in Chapter 4 of the 2021 Region K Regional Water Plan.

Table 1-2 Regional water needs summary by water use category*

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	water needs (acre-feet per year)	254,364	239,922	225,869	212,193	198,886	185,938
	% of the category's total water demand	44%	42%	41%	39%	38%	36%
Livestock	water needs (acre-feet per year)	-	-	-	-	-	-
	% of the category's total water demand	0%	0%	0%	0%	0%	0%
Manufacturing	water needs (acre-feet per year)	-	40	40	40	40	40
	% of the category's total water demand	0%	0%	0%	0%	0%	0%
Mining	water needs (acre-feet per year)	2,677	6,937	8,264	7,708	5,472	6,860
	% of the category's total water demand	13%	27%	30%	28%	24%	27%
Municipal**	water needs (acre-feet per year)	4,726	13,182	33,806	50,010	72,394	107,425
	% of the category's total water demand	1%	4%	8%	11%	14%	19%
Steam-electric power	water needs (acre-feet per year)	8,669	8,669	8,669	8,669	8,669	8,669
	% of the category's total water demand	5%	5%	5%	5%	5%	5%
Total water needs (acre-feet per year)		**270,436**	**268,750**	**276,648**	**278,620**	**285,461**	**308,932**

*Entries denoted by a dash (-) indicate no identified water need for a given water use category.

** Municipal category consists of residential and non-residential (commercial and institutional) subcategories.

2 Impact Assessment Measures

A required component of the regional and state water plans is to estimate the potential economic and social impacts of potential water shortages during a repeat of the drought of record. Consistent with previous water plans, ten impact measures were estimated and are described in Table 2-1.

Table 2-1 Socioeconomic impact analysis measures

Regional economic impacts	Description
Income losses - value-added	The value of output less the value of intermediate consumption; it is a measure of the contribution to gross domestic product (GDP) made by an individual producer, industry, sector, or group of sectors within a year. Value-added measures used in this report have been adjusted to include the direct, indirect, and induced monetary impacts on the region.
Income losses - electrical power purchase costs	Proxy for income loss in the form of additional costs of power as a result of impacts of water shortages.
Job losses	Number of part-time and full-time jobs lost due to the shortage. These values have been adjusted to include the direct, indirect, and induced employment impacts on the region.
Financial transfer impacts	**Description**
Tax losses on production and imports	Sales and excise taxes not collected due to the shortage, in addition to customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies. These values have been adjusted to include the direct, indirect and induced tax impacts on the region.
Water trucking costs	Estimated cost of shipping potable water.
Utility revenue losses	Foregone utility income due to not selling as much water.
Utility tax revenue losses	Foregone miscellaneous gross receipts tax collections.
Social impacts	**Description**
Consumer surplus losses	A welfare measure of the lost value to consumers accompanying restricted water use.
Population losses	Population losses accompanying job losses.
School enrollment losses	School enrollment losses (K-12) accompanying job losses.

2.1 Regional Economic Impacts

The two key measures used to assess regional economic impacts are income losses and job losses. The income losses presented consist of the sum of value-added losses and the additional purchase costs of electrical power.

Income Losses - Value-added Losses

Value-added is the value of total output less the value of the intermediate inputs also used in the production of the final product. Value-added is similar to GDP, a familiar measure of the productivity of an economy. The loss of value-added due to water shortages is estimated by input-output analysis using the IMPLAN software package, and includes the direct, indirect, and induced monetary impacts on the region. The indirect and induced effects are measures of reduced income as well as reduced employee spending for those input sectors which provide resources to the water shortage impacted production sectors.

Income Losses - Electric Power Purchase Costs

The electrical power grid and market within the state is a complex interconnected system. The industry response to water shortages, and the resulting impact on the region, are not easily modeled using traditional input/output impact analysis and the IMPLAN model. Adverse impacts on the region will occur and are represented in this analysis by estimated additional costs associated with power purchases from other generating plants within the region or state. Consequently, the analysis employs additional power purchase costs as a proxy for the value-added impacts for the steam-electric power water use category, and these are included as a portion of the overall income impact for completeness.

For the purpose of this analysis, it is assumed that power companies with insufficient water will be forced to purchase power on the electrical market at a projected higher rate of 5.60 cents per kilowatt hour. This rate is based upon the average day-ahead market purchase price of electricity in Texas that occurred during the recent drought period in 2011. This price is assumed to be comparable to those prices which would prevail in the event of another drought of record.

Job Losses

The number of jobs lost due to the economic impact is estimated using IMPLAN output associated with each TWDB water use category. Because of the difficulty in predicting outcomes and a lack of relevant data, job loss estimates are not calculated for the steam-electric power category.

2.2 Financial Transfer Impacts

Several impact measures evaluated in this analysis are presented to provide additional detail concerning potential impacts on a portion of the economy or government. These financial transfer impact measures include lost tax collections (on production and imports), trucking costs for

imported water, declines in utility revenues, and declines in utility tax revenue collected by the state. These measures are not solely adverse, with some having both positive and negative impacts. For example, cities and residents would suffer if forced to pay large costs for trucking in potable water. Trucking firms, conversely, would benefit from the transaction. Additional detail for each of these measures follows.

Tax Losses on Production and Imports

Reduced production of goods and services accompanying water shortages adversely impacts the collection of taxes by state and local government. The regional IMPLAN model is used to estimate reduced tax collections associated with the reduced output in the economy. Impact estimates for this measure include the direct, indirect, and induced impacts for the affected sectors.

Water Trucking Costs

In instances where water shortages for a municipal water user group are estimated by RWPGs to exceed 80 percent of water demands, it is assumed that water would need to be trucked in to support basic consumption and sanitation needs. For water shortages of 80 percent or greater, a fixed, maximum of $35,000[1] per acre-foot of water applied as an economic cost. This water trucking cost was utilized for both the residential and non-residential portions of municipal water needs.

Utility Revenue Losses

Lost utility income is calculated as the price of water service multiplied by the quantity of water not sold during a drought shortage. Such estimates are obtained from utility-specific pricing data provided by the Texas Municipal League, where available, for both water and wastewater. These water rates are applied to the potential water shortage to estimate forgone utility revenue as water providers sold less water during the drought due to restricted supplies.

Utility Tax Losses

Foregone utility tax losses include estimates of forgone miscellaneous gross receipts taxes. Reduced water sales reduce the amount of utility tax that would be collected by the State of Texas for water and wastewater service sales.

[1] Based on staff survey of water hauling firms and historical data concerning transport costs for potable water in the recent drought in California for this estimate. There are many factors and variables that would determine actual water trucking costs including distance to, cost of water, and length of that drought.

2.3 Social Impacts

Consumer Surplus Losses for Municipal Water Users

Consumer surplus loss is a measure of impact to the wellbeing of municipal water users when their water use is restricted. Consumer surplus is the difference between how much a consumer is willing and able to pay for a commodity (i.e., water) and how much they actually have to pay. The difference is a benefit to the consumer's wellbeing since they do not have to pay as much for the commodity as they would be willing to pay. Consumer surplus may also be viewed as an estimate of how much consumers would be willing to pay to keep the original quantity of water which they used prior to the drought. Lost consumer surplus estimates within this analysis only apply to the residential portion of municipal demand, with estimates being made for reduced outdoor and indoor residential use. Lost consumer surplus estimates varied widely by location and degree of water shortage.

Population and School Enrollment Losses

Population loss due to water shortages, as well as the associated decline in school enrollment, are based upon the job loss estimates discussed in Section 2.1. A simplified ratio of job and net population losses are calculated for the state as a whole based on a recent study of how job layoffs impact the labor market population.[2] For every 100 jobs lost, 18 people were assumed to move out of the area. School enrollment losses are estimated as a proportion of the population lost based upon public school enrollment data from the Texas Education Agency concerning the age K-12 population within the state (approximately 19%).

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[2] Foote, Andrew, Grosz, Michel, Stevens, Ann. "Locate Your Nearest Exit: Mass Layoffs and Local Labor Market Response." University of California, Davis. April 2015, http://paa2015.princeton.edu/papers/150194. The study utilized Bureau of Labor Statistics data regarding layoffs between 1996 and 2013, as well as Internal Revenue Service data regarding migration, to model the change in the population as the result of a job layoff event. The study found that layoffs impact both out-migration and in-migration into a region, and that a majority of those who did move following a layoff moved to another labor market rather than an adjacent county.

3 Socioeconomic Impact Assessment Methodology

This portion of the report provides a summary of the methodology used to estimate the potential economic impacts of future water shortages. The general approach employed in the analysis was to obtain estimates for income and job losses on the smallest geographic level that the available data would support, tie those values to their accompanying historic water use estimate, and thereby determine a maximum impact per acre-foot of shortage for each of the socioeconomic measures. The calculations of economic impacts are based on the overall composition of the economy divided into many underlying economic sectors. Sectors in this analysis refer to one or more of the 536 specific production sectors of the economy designated within IMPLAN, the economic impact modeling software used for this assessment. Economic impacts within this report are estimated for approximately 330 of these sectors, with the focus on the more water-intensive production sectors. The economic impacts for a single water use category consist of an aggregation of impacts to multiple, related IMPLAN economic sectors.

3.1 Analysis Context

The context of this socioeconomic impact analysis involves situations where there are physical shortages of groundwater or surface water due to a recurrence of drought of record conditions. Anticipated shortages for specific water users may be nonexistent in earlier decades of the planning horizon, yet population growth or greater industrial, agricultural or other sector demands in later decades may result in greater overall demand, exceeding the existing supplies. Estimated socioeconomic impacts measure what would happen if water user groups experience water shortages for a period of one year. Actual socioeconomic impacts would likely become larger as drought of record conditions persist for periods greater than a single year.

3.2 IMPLAN Model and Data

Input-Output analysis using the IMPLAN software package was the primary means of estimating the value-added, jobs, and tax related impact measures. This analysis employed regional level models to determine key economic impacts. IMPLAN is an economic impact model, originally developed by the U.S. Forestry Service in the 1970's to model economic activity at varying geographic levels. The model is currently maintained by the Minnesota IMPLAN Group (MIG Inc.) which collects and sells county and state specific data and software. The year 2016 version of IMPLAN, employing data for all 254 Texas counties, was used to provide estimates of value-added, jobs, and taxes on production for the economic sectors associated with the water user groups examined in the study. IMPLAN uses 536 sector-specific Industry Codes, and those that rely on water as a primary input were assigned to their appropriate planning water user categories (irrigation, livestock, manufacturing, mining, and municipal). Estimates of value-added for a water use category were obtained by summing value-added estimates across the relevant IMPLAN sectors associated with that water use category. These calculations were also performed for job losses as well as tax losses on production and imports.

The adjusted value-added estimates used as an income measure in this analysis, as well as the job and tax estimates from IMPLAN, include three components:

- ***Direct effects*** representing the initial change in the industry analyzed;
- ***Indirect effects*** that are changes in inter-industry transactions as supplying industries respond to reduced demands from the directly affected industries; and,
- ***Induced effects*** that reflect changes in local spending that result from reduced household income among employees in the directly and indirectly affected industry sectors.

Input-output models such as IMPLAN only capture backward linkages and do not include forward linkages in the economy.

3.3 Elasticity of Economic Impacts

The economic impact of a water need is based on the size of the water need relative to the total water demand for each water user group. Smaller water shortages, for example, less than 5 percent, are generally anticipated to result in no initial negative economic impact because water users are assumed to have a certain amount of flexibility in dealing with small shortages. As a water shortage intensifies, however, such flexibility lessens and results in actual and increasing economic losses, eventually reaching a representative maximum impact estimate per unit volume of water. To account for these characteristics, an elasticity adjustment function is used to estimate impacts for the income, tax and job loss measures. Figure 3-1 illustrates this general relationship for the adjustment functions. Negative impacts are assumed to begin accruing when the shortage reaches the lower bound 'b1' (5 percent in Figure 3-1), with impacts then increasing linearly up to the 100 percent impact level (per unit volume) once the upper bound reaches the 'b2' level shortage (40 percent in Figure 3-1).

To illustrate this, if the total annual value-added for manufacturing in the region was $2 million and the reported annual volume of water used in that industry is 10,000 acre-feet, the estimated economic measure of the water shortage would be $200 per acre-foot. The economic impact of the shortage would then be estimated using this value-added amount as the maximum impact estimate ($200 per acre-foot) applied to the anticipated shortage volume and then adjusted by the elasticity function. Using the sample elasticity function shown in Figure 3-1, an approximately 22 percent shortage in the livestock category would indicate an economic impact estimate of 50% of the original $200 per acre-foot impact value (i.e., $100 per acre-foot).

Such adjustments are not required in estimating consumer surplus, utility revenue losses, or utility tax losses. Estimates of lost consumer surplus rely on utility-specific demand curves with the lost consumer surplus estimate calculated based on the relative percentage of the utility's water shortage. Estimated changes in population and school enrollment are indirectly related to the elasticity of job losses.

Assumed values for the lower and upper bounds 'b1' and 'b2' vary by water use category and are presented in Table 3-1.

Figure 3-1 Example economic impact elasticity function (as applied to a single water user's shortage)

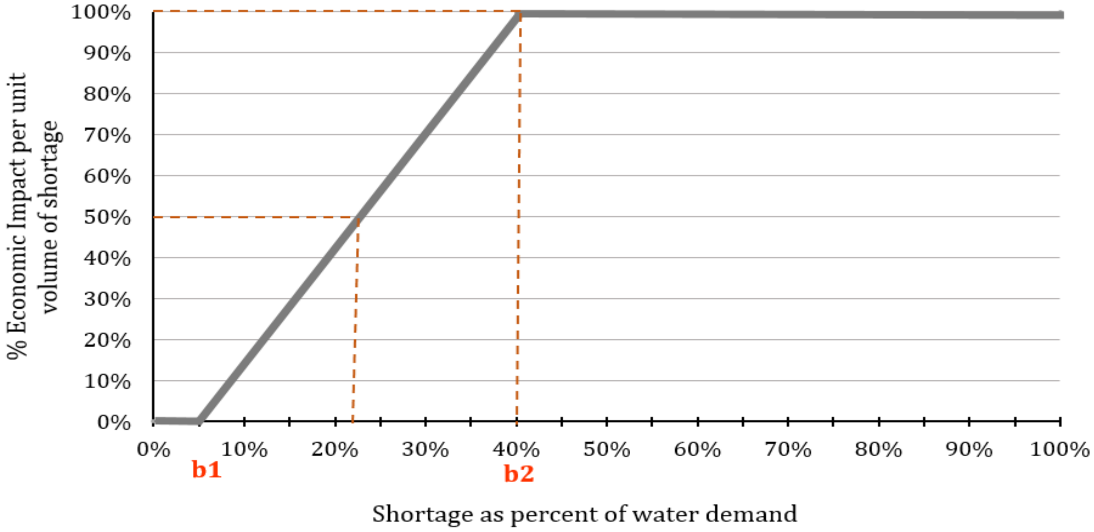

Table 3-1 Economic impact elasticity function lower and upper bounds

Water use category	Lower bound (b1)	Upper bound (b2)
Irrigation	**5%**	**40%**
Livestock	**5%**	**10%**
Manufacturing	**5%**	**40%**
Mining	**5%**	**40%**
Municipal (non-residential water intensive subcategory)	**5%**	**40%**
Steam-electric power	**N/A**	**N/A**

3.4 Analysis Assumptions and Limitations

The modeling of complex systems requires making many assumptions and acknowledging the model's uncertainty and limitations. This is particularly true when attempting to estimate a wide range of socioeconomic impacts over a large geographic area and into future decades. Some of the key assumptions and limitations of this methodology include:

1. The foundation for estimating the socioeconomic impacts of water shortages resulting from a drought are the water needs (potential shortages) that were identified by RWPGs as part of the

regional water planning process. These needs have some uncertainty associated with them but serve as a reasonable basis for evaluating the potential impacts of a drought of record event.

2. All estimated socioeconomic impacts are snapshots for years in which water needs were identified (i.e., 2020, 2030, 2040, 2050, 2060, and 2070). The estimates are independent and distinct “what if” scenarios for each particular year, and water shortages are assumed to be temporary events resulting from a single year recurrence of drought of record conditions. The evaluation assumed that no recommended water management strategies are implemented. In other words, growth occurs and future shocks are imposed on an economy at 10-year intervals, and the resulting impacts are estimated. Note that the estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

3. Input-output models such as IMPLAN rely on a static profile of the structure of the economy as it appears today. This presumes that the relative contributions of all sectors of the economy would remain the same, regardless of changes in technology, availability of limited resources, and other structural changes to the economy that may occur in the future. Changes in water use efficiency will undoubtedly take place in the future as supplies become more stressed. Use of the static IMPLAN structure was a significant assumption and simplification considering the 50-year time period examined in this analysis. To presume an alternative future economic makeup, however, would entail positing many other major assumptions that would very likely generate as much or more error.

4. This is not a form of cost-benefit analysis. That approach to evaluating the economic feasibility of a specific policy or project employs discounting future benefits and costs to their present value dollars using some assumed discount rate. The methodology employed in this effort to estimate the economic impacts of future water shortages did not use any discounting methods to weigh future costs differently through time.

5. All monetary values originally based upon year 2016 IMPLAN and other sources are reported in constant year 2018 dollars to be consistent with the water management strategy requirements in the State Water Plan.

6. IMPLAN based loss estimates (income-value-added, jobs, and taxes on production and imports) are calculated only for those IMPLAN sectors for which the TWDB’s Water Use Survey (WUS) data was available and deemed reliable. Every effort is made in the annual WUS effort to capture all relevant firms who are significant water users. Lack of response to the WUS, or omission of relevant firms, impacts the loss estimates.

7. Impacts are annual estimates. The socioeconomic analysis does not reflect the full extent of impacts that might occur as a result of persistent water shortages occurring over an extended duration. The drought of record in most regions of Texas lasted several years.

8. Value-added estimates are the primary estimate of the economic impacts within this report. One may be tempted to add consumer surplus impacts to obtain an estimate of total adverse economic impacts to the region, but the consumer surplus measure represents the change to the wellbeing of households (and other water users), not an actual change in the flow of dollars through the economy. The two measures (value-added and consumer surplus) are both valid impacts but ideally should not be summed.

9. The value-added, jobs, and taxes on production and import impacts include the direct, indirect and induced effects to capture backward linkages in the economy described in Section 2.1. Population and school enrollment losses also indirectly include such effects as they are based on the associated losses in employment. The remaining measures (consumer surplus, utility revenue, utility taxes, additional electrical power purchase costs, and potable water trucking costs), however, do not include any induced or indirect effects.

10. The majority of impacts estimated in this analysis may be more conservative (i.e., smaller) than those that might actually occur under drought of record conditions due to not including impacts in the forward linkages in the economy. Input-output models such as IMPLAN only capture backward linkages on suppliers (including households that supply labor to directly affected industries). While this is a common limitation in this type of economic modeling effort, it is important to note that forward linkages on the industries that use the outputs of the directly affected industries can also be very important. A good example is impacts on livestock operators. Livestock producers tend to suffer substantially during droughts, not because there is not enough water for their stock, but because reductions in available pasture and higher prices for purchased hay have significant economic effects on their operations. Food processors could be in a similar situation if they cannot get the grains or other inputs that they need. These effects are not captured in IMPLAN, resulting in conservative impact estimates.

11. The model does not reflect dynamic economic responses to water shortages as they might occur, nor does the model reflect economic impacts associated with a recovery from a drought of record including:
    a. The likely significant economic rebound to some industries immediately following a drought, such as landscaping;
    b. The cost and time to rebuild liquidated livestock herds (a major capital investment in that industry);
    c. Direct impacts on recreational sectors (i.e., stranded docks and reduced tourism); or,
    d. Impacts of negative publicity on Texas' ability to attract population and business in the event that it was not able to provide adequate water supplies for the existing economy.

12. Estimates for job losses and the associated population and school enrollment changes may exceed what would actually occur. In practice, firms may be hesitant to lay off employees, even in difficult economic times. Estimates of population and school enrollment changes are based on regional evaluations and therefore do not necessarily reflect what might occur on a statewide basis.

13. **The results must be interpreted carefully. It is the general and relative magnitudes of impacts as well as the changes of these impacts over time that should be the focus rather than the absolute numbers.** Analyses of this type are much better at predicting relative percent differences brought about by a shock to a complex system (i.e., a water shortage) than the precise size of an impact. To illustrate, assuming that the estimated economic impacts of a drought of record on the manufacturing and mining water user categories are $2 and $1 million, respectively, one should be more confident that the economic impacts on manufacturing are twice as large as those on mining and that these impacts will likely be in the millions of dollars. But one should have less confidence that the actual total economic impact experienced would be $3 million.

14. The methodology does not capture “spillover” effects between regions – or the secondary impacts that occur outside of the region where the water shortage is projected to occur.

15. The methodology that the TWDB has developed for estimating the economic impacts of unmet water needs, and the assumptions and models used in the analysis, are specifically designed to estimate potential economic effects at the regional and county levels. Although it may be tempting to add the regional impacts together in an effort to produce a statewide result, the TWDB cautions against that approach for a number of reasons. The IMPLAN modeling (and corresponding economic multipliers) are all derived from regional models – a statewide model of Texas would produce somewhat different multipliers. As noted in point 14 within this section, the regional modeling used by TWDB does not capture spillover losses that could result in other regions from unmet needs in the region analyzed, or potential spillover gains if decreased production in one region leads to increases in production elsewhere. The assumed drought of record may also not occur in every region of Texas at the same time, or to the same degree.

4 Analysis Results

This section presents estimates of potential economic impacts that could reasonably be expected in the event of water shortages associated with a drought of record and if no recommended water management strategies were implemented. Projected economic impacts for the six water use categories (irrigation, livestock, manufacturing, mining, municipal, and steam-electric power) are reported by decade.

4.1 Impacts for Irrigation Water Shortages

Four of the 14 counties in the region are projected to experience water shortages in the irrigated agriculture water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-1. Note that tax collection impacts were not estimated for this water use category. IMPLAN data indicates a negative tax impact (i.e., increased tax collections) for the associated production sectors, primarily due to past subsidies from the federal government. However, it was not considered realistic to report increasing tax revenues during a drought of record.

Table 4-1 Impacts of water shortages on irrigation in Region K

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$50	$46	$42	$38	$35	$31
Job losses	1,109	1,017	931	850	775	705

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.2 Impacts for Livestock Water Shortages

None of the 14 counties in the region are projected to experience water shortages in the livestock water use category. Estimated impacts to this water use category appear in Table 4-2.

Table 4-2 Impacts of water shortages on livestock in Region K

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$-	$-	$-	$-	$-	$-
Jobs losses	-	-	-	-	-	-
Tax losses on production and imports ($ millions)*	$-	$-	$-	$-	$-	$-

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.3 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in one of the 14 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use category appear in Table 4-3.

Table 4-3 Impacts of water shortages on manufacturing in Region K

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$-	$1	$1	$1	$1	$1
Job losses	-	8	8	8	8	8
Tax losses on production and Imports ($ millions)*	$-	$0	$0	$0	$0	$0

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.4 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in four of the 14 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use type appear in Table 4-4.

Table 4-4 Impacts of water shortages on mining in Region K

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$594	$633	$674	$645	$456	$572
Job losses	3,320	4,474	5,077	4,872	3,512	4,393
Tax losses on production and Imports ($ millions)*	$69	$41	$34	$33	$24	$30

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.5 Impacts for Municipal Water Shortages

Twelve of the 14 counties in the region are projected to experience water shortages in the municipal water use category for one or more decades within the planning horizon.

Impact estimates were made for two sub-categories within municipal water use: residential and non-residential. Non-residential municipal water use includes commercial and institutional users, which are further divided into non-water-intensive and water-intensive subsectors including car wash, laundry, hospitality, health care, recreation, and education. Lost consumer surplus estimates were made only for needs in the residential portion of municipal water use. Available IMPLAN and TWDB Water Use Survey data for the non-residential, water-intensive portion of municipal demand allowed these sectors to be included in income, jobs, and tax loss impact estimate.

Trucking cost estimates, calculated for shortages exceeding 80 percent, assumed a fixed, maximum cost of $35,000 per acre-foot to transport water for municipal use. The estimated impacts to this water use category appear in Table 4-5.

Table 4-5 Impacts of water shortages on municipal water users in Region K

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses[1] ($ millions)*	$37	$83	$384	$701	$1,076	$1,404
Job losses[1]	590	1,360	6,138	11,168	17,104	22,307
Tax losses on production and imports[1] ($ millions)*	$3	$7	$33	$61	$93	$121
Trucking costs ($ millions)*	$-	$-	$58	$62	$65	$69
Utility revenue losses ($ millions)*	$16	$49	$125	$187	$272	$419
Utility tax revenue losses ($ millions)*	$0	$1	$2	$3	$4	$7

[1] Estimates apply to the water-intensive portion of non-residential municipal water use.
* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.6 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in two of the 14 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-6.

Note that estimated economic impacts to steam-electric water users:

- Are reflected as an income loss proxy in the form of estimated additional purchasing costs for power from the electrical grid to replace power that could not be generated due to a shortage;
- Do not include estimates of impacts on jobs. Because of the unique conditions of power generators during drought conditions and lack of relevant data, it was assumed that the industry would retain, perhaps relocating or repurposing, their existing staff in order to manage their ongoing operations through a severe drought.
- Do not presume a decline in tax collections. Associated tax collections, in fact, would likely increase under drought conditions since, historically, the demand for electricity increases during times of drought, thereby increasing taxes collected on the additional sales of power.

Table 4-6 Impacts of water shortages on steam-electric power in Region K

Impacts measure	2020	2030	2040	2050	2060	2070
Income Losses ($ millions)*	$601	$601	$601	$601	$601	$601

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.7 Regional Social Impacts

Projected changes in population, based upon several factors (household size, population, and job loss estimates), as well as the accompanying change in school enrollment, were also estimated and are summarized in Table 4-7.

Table 4-7 Region-wide social impacts of water shortages in Region K

Impacts measure	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$6	$20	$181	$244	$396	$704
Population losses	921	1,259	2,231	3,102	3,929	5,033
School enrollment losses	176	241	427	593	752	963

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

Appendix A - County Level Summary of Estimated Economic Impacts for Region K

County level summary of estimated economic impacts of not meeting identified water needs by water use category and decade (in 2018 dollars, rounded). Values are presented only for counties with projected economic impacts for at least one decade.

(* Entries denoted by a dash (-) indicate no estimated economic impact)

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
BASTROP	MINING	$11.53	$352.50	$409.28	$290.49	-	-	85	2,587	3,004	2,132	-	-
BASTROP	MUNICIPAL	-	$5.09	$37.98	$132.34	$261.58	$442.48	-	80	601	2,094	4,138	7,000
BASTROP Total		**$11.53**	**$357.58**	**$447.26**	**$422.84**	**$261.58**	**$442.48**	**85**	**2,668**	**3,605**	**4,226**	**4,138**	**7,000**
BLANCO	MUNICIPAL	-	-	$0.47	$1.25	$1.94	$2.49	-	-	8	21	32	42
BLANCO Total		**-**	**-**	**$0.47**	**$1.25**	**$1.94**	**$2.49**	**-**	**-**	**8**	**21**	**32**	**42**
BURNET	MINING	$35.56	$97.88	$180.18	$262.82	$347.62	$444.28	261	718	1,322	1,929	2,551	3,261
BURNET	MUNICIPAL	$1.65	$2.48	$3.81	$21.44	$45.38	$62.26	26	39	60	339	718	985
BURNET Total		**$37.21**	**$100.36**	**$183.99**	**$284.25**	**$393.00**	**$506.54**	**287**	**758**	**1,383**	**2,268**	**3,269**	**4,246**
COLORADO	IRRIGATION	$10.44	$8.86	$7.41	$6.09	$4.90	$3.84	221	188	157	129	104	81
COLORADO	MUNICIPAL	$0.04	$0.05	$0.06	$0.12	$0.22	$0.35	1	1	1	2	4	6
COLORADO	STEAM ELECTRIC POWER	$344.66	$344.66	$344.66	$344.66	$344.66	$344.66	-	-	-	-	-	-
COLORADO Total		**$355.14**	**$353.57**	**$352.13**	**$350.88**	**$349.79**	**$348.86**	**222**	**188**	**158**	**131**	**107**	**87**
FAYETTE	MANUFACTURING	-	$0.71	$0.71	$0.71	$0.71	$0.71	-	8	8	8	8	8
FAYETTE	MINING	$504.09	$121.04	-	-	-	-	2,593	623	-	-	-	-
FAYETTE	MUNICIPAL	$9.48	$14.22	$16.01	$17.61	$19.13	$20.33	150	225	253	279	303	322
FAYETTE	STEAM ELECTRIC POWER	$256.40	$256.40	$256.40	$256.40	$256.40	$256.40	-	-	-	-	-	-
FAYETTE Total		**$769.97**	**$392.36**	**$273.12**	**$274.72**	**$276.24**	**$277.44**	**2,743**	**855**	**261**	**286**	**310**	**329**
HAYS	MINING	$42.90	$61.48	$84.58	$91.36	$108.25	$127.56	381	546	751	811	961	1,132
HAYS	MUNICIPAL	-	$11.95	$66.24	$172.99	$295.05	$390.11	-	189	1,048	2,738	4,671	6,179
HAYS Total		**$42.90**	**$73.42**	**$150.82**	**$264.36**	**$403.30**	**$517.66**	**381**	**735**	**1,799**	**3,549**	**5,632**	**7,311**
LLANO	MUNICIPAL	$18.99	$19.92	$19.47	$18.77	$19.67	$20.63	300	315	308	297	311	326
LLANO Total		**$18.99**	**$19.92**	**$19.47**	**$18.77**	**$19.67**	**$20.63**	**300**	**315**	**308**	**297**	**311**	**326**
MATAGORDA	IRRIGATION	$20.75	$19.88	$19.04	$18.21	$17.41	$16.64	503	482	461	441	422	403
MATAGORDA	MUNICIPAL	-	-	-	-	$0.03	$0.16	-	-	-	-	0	3
MATAGORDA Total		**$20.75**	**$19.88**	**$19.04**	**$18.21**	**$17.44**	**$16.80**	**503**	**482**	**461**	**441**	**422**	**406**

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
MILLS	IRRIGATION	$1.35	$1.35	$1.35	$1.35	$1.35	$1.35	25	25	25	25	25	25
MILLS Total		**$1.35**	**$1.35**	**$1.35**	**$1.35**	**$1.35**	**$1.35**	**25**	**25**	**25**	**25**	**25**	**25**
TRAVIS	MUNICIPAL	$6.65	$29.01	$222.41	$319.14	$415.33	$447.71	113	510	3,574	5,119	6,647	7,166
TRAVIS Total		**$6.65**	**$29.01**	**$222.41**	**$319.14**	**$415.33**	**$447.71**	**113**	**510**	**3,574**	**5,119**	**6,647**	**7,166**
WHARTON	IRRIGATION	$17.51	$15.68	$13.96	$12.37	$10.88	$9.51	360	323	287	255	224	196
WHARTON	MUNICIPAL	-	-	-	-	-	$0.02	-	-	-	-	-	0
WHARTON Total		**$17.51**	**$15.68**	**$13.96**	**$12.37**	**$10.88**	**$9.53**	**360**	**323**	**287**	**255**	**224**	**196**
WILLIAMSON	MUNICIPAL	-	-	$18.05	$17.75	$17.67	$17.67	-	-	285	281	280	280
WILLIAMSON Total		**-**	**-**	**$18.05**	**$17.75**	**$17.67**	**$17.67**	**-**	**-**	**285**	**281**	**280**	**280**
REGION K Total		**$1,282.00**	**$1,363.15**	**$1,702.07**	**$1,985.88**	**$2,168.18**	**$2,609.15**	**5,018**	**6,859**	**12,154**	**16,898**	**21,398**	**27,413**

Socioeconomic Impacts of Projected Water Shortages for the South Central Texas (Region L) Regional Water Planning Area

Prepared in Support of the 2021 Region L Regional Water Plan

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Table of Contents

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Executive Summary

Evaluating the social and economic impacts of not meeting identified water needs is a required analysis in the regional water planning process. The Texas Water Development Board (TWDB) estimates these impacts for regional water planning groups (RWPGs) and summarizes the impacts in the state water plan. The analysis presented is for the South Central Texas Regional Water Planning Group (Region L).

Based on projected water demands and existing water supplies, Region L identified water needs (potential shortages) that could occur within its region under a repeat of the drought of record for six water use categories (irrigation, livestock, manufacturing, mining, municipal and steam-electric power). The TWDB then estimated the annual socioeconomic impacts of those needs—if they are not met—for each water use category and as an aggregate for the region.

This analysis was performed using an economic impact modeling software package, IMPLAN (Impact for Planning Analysis), as well as other economic analysis techniques, and represents a snapshot of socioeconomic impacts that may occur during a single year repeat of the drought of record with the further caveat that no mitigation strategies are implemented. Decade specific impact estimates assume that growth occurs, and future shocks are imposed on an economy at 10-year intervals. The estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

For regional economic impacts, income losses and job losses are estimated within each planning decade (2020 through 2070). The income losses represent an approximation of gross domestic product (GDP) that would be foregone if water needs are not met.

The analysis also provides estimates of financial transfer impacts, which include tax losses (state, local, and utility tax collections); water trucking costs; and utility revenue losses. In addition, social impacts are estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses.

IMPLAN data reported that Region L generated close to $148 billion in GDP (2018 dollars) and supported roughly 1.6 million jobs in 2016. The Region L estimated total population was approximately 2.9 million in 2016.

It is estimated that not meeting the identified water needs in Region L would result in an annually combined lost income impact of approximately $16.6 billion in 2020, and $9.3 billion in 2070 (Table ES-1). It is also estimated that the region would lose approximately 100,500 jobs in 2020, and 95,000 in 2070.

All impact estimates are in year 2018 dollars and were calculated using a variety of data sources and tools including the use of a region-specific IMPLAN model, data from TWDB annual water use

estimates, the U.S. Census Bureau, Texas Agricultural Statistics Service, and the Texas Municipal League.

Table ES-1 Region L socioeconomic impact summary

Regional Economic Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Income losses ($ millions)*	$16,571	$17,246	$14,600	$11,679	$9,674	$9,384
Job losses	100,514	107,453	96,710	86,976	85,393	94,978
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$1,775	$1,794	$1,433	$1,032	$740	$663
Water trucking costs ($ millions)*	$3	$4	$6	$8	$9	$13
Utility revenue losses ($ millions)*	$70	$146	$268	$400	$560	$723
Utility tax revenue losses ($ millions)*	$1	$3	$5	$7	$10	$14
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$67	$80	$118	$184	$342	$651
Population losses	18,454	19,728	17,756	15,969	15,678	17,438
School enrollment losses	3,530	3,773	3,396	3,054	2,999	3,335

* Year 2018 dollars, rounded**.** Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

1 Introduction

Water shortages during a repeat of the drought of record would likely curtail or eliminate certain economic activity in businesses and industries that rely heavily on water. Insufficient water supplies could not only have an immediate and real impact on the regional economy in the short term, but they could also adversely and chronically affect economic development in Texas. From a social perspective, water supply reliability is critical as well. Shortages could disrupt activity in homes, schools and government, and could adversely affect public health and safety. For these reasons, it is important to evaluate and understand how water supply shortages during drought could impact communities throughout the state.

As part of the regional water planning process, RWPGs must evaluate the social and economic impacts of not meeting water needs (31 Texas Administrative Code §357.33 (c)). Due to the complexity of the analysis and limited resources of the planning groups, the TWDB has historically performed this analysis for the RWPGs upon their request. Staff of the TWDB's Water Use, Projections, & Planning Division designed and conducted this analysis in support of Region L, and those efforts for this region as well as the other 15 regions allow consistency and a degree of comparability in the approach.

This document summarizes the results of the analysis and discusses the methodology used to generate the results. Section 1 provides a snapshot of the region's economy and summarizes the identified water needs in each water use category, which were calculated based on the RWPG's water supply and demand established during the regional water planning process. Section 2 defines each of ten impact assessment measures used in this analysis. Section 3 describes the methodology for the impact assessment and the approaches and assumptions specific to each water use category (i.e., irrigation, livestock, manufacturing, mining, municipal, and steam-electric power). Section 4 presents the impact estimates for each water use category with results summarized for the region as a whole. Appendix A presents a further breakdown of the socioeconomic impacts by county.

1.1 Regional Economic Summary

The Region L Regional Water Planning Area generated close to $148 billion in gross domestic product (2018 dollars) and supported roughly 1.6 million jobs in 2016, according to the IMPLAN dataset utilized in this socioeconomic analysis. This activity accounted for 8.6 percent of the state's total gross domestic product of 1.73 trillion dollars for the year based on IMPLAN. Table 1-1 lists all economic sectors ranked by the total value-added to the economy in Region L. The real estate, finance, and manufacturing sectors generated more than 27 percent of the region's total value-added and were also significant sources of tax revenue. The top employers in the region were in the public administration, health care, and retail trade sectors. Region L's estimated total population was roughly 2.9 million in 2016, approximately 10 percent of the state's total.

This represents a snapshot of the regional economy as a whole, and it is important to note that not all economic sectors were included in the TWDB socioeconomic impact analysis. Data considerations prompted use of only the more water-intensive sectors within the economy because damage estimates could only be calculated for those economic sectors which had both reliable income and water use estimates.

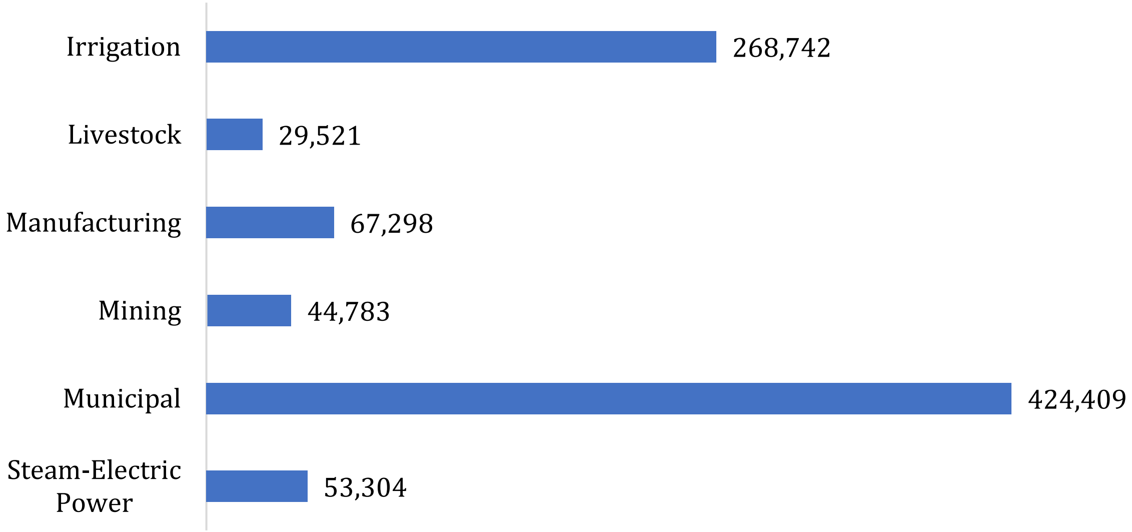
Table 1-1 Region L regional economy by economic sector*

Economic sector	Value-added ($ millions)	Tax ($ millions)	Jobs
Public Administration	$23,573.9	$(202.2)	233,720
Real Estate and Rental and Leasing	$15,515.7	$2,278.1	67,656
Finance and Insurance	$13,382.4	$1,120.4	109,447
Manufacturing	$11,484.3	$399.0	64,959
Health Care and Social Assistance	$10,396.6	$133.1	171,474
Retail Trade	$9,296.3	$2,156.9	158,939
Mining, Quarrying, and Oil and Gas Extraction	$8,492.5	$1,188.7	32,890
Professional, Scientific, and Technical Services	$8,348.1	$242.7	98,810
Wholesale Trade	$8,182.9	$1,400.0	47,605
Construction	$7,788.3	$122.6	110,766
Accommodation and Food Services	$6,028.2	$903.0	149,509
Transportation and Warehousing	$5,605.6	$194.9	52,917
Administrative and Support and Waste Management and Remediation Services	$5,103.9	$129.3	108,945
Information	$4,281.1	$953.1	25,718
Other Services (except Public Administration)	$4,150.0	$423.9	87,960
Utilities	$1,984.1	$247.7	4,421
Arts, Entertainment, and Recreation	$1,276.1	$264.1	29,315
Management of Companies and Enterprises	$1,259.6	$43.0	15,266
Educational Services	$991.2	$43.6	27,800
Agriculture, Forestry, Fishing and Hunting	$830.2	$29.7	33,150
Grand Total	$147,971.1	$12,071.5	1,631,267

*Source: 2016 IMPLAN for 536 sectors aggregated by 2-digit NAICS (North American Industry Classification System)

Figure 1-1 illustrates Region L's breakdown of the 2016 water use estimates by TWDB water use category. The categories with the highest use in Region L in 2016 were municipal (48 percent) and irrigation (30 percent). Notably, more than 26 percent of the state's mining water use occurred within Region L.

Figure 1-1 Region L 2016 water use estimates by water use category (in acre-feet)



Source: TWDB Annual Water Use Estimates (all values in acre-feet)

1.2 Identified Regional Water Needs (Potential Shortages)

As part of the regional water planning process, the TWDB adopted water demand projections for water user groups (WUG) in Region L with input from the planning group. WUG-level demand projections were established for utilities that provide more than 100 acre-feet of annual water supply, combined rural areas (designated as county-other), and county-wide water demand projections for five non-municipal categories (irrigation, livestock, manufacturing, mining and steam-electric power). The RWPG then compared demands to the existing water supplies of each WUG to determine potential shortages, or needs, by decade.

Table 1-2 summarizes the region's identified water needs in the event of a repeat of the drought of record. Demand management, such as conservation, or the development of new infrastructure to increase supplies, are water management strategies that may be recommended by the planning group to address those needs. This analysis assumes that no strategies are implemented, and that the identified needs correspond to future water shortages. Note that projected water needs generally increase over time, primarily due to anticipated population growth, economic growth, or declining supplies. To provide a general sense of proportion, total projected needs as an overall percentage of total demand by water use category are also presented in aggregate in Table 1-2. Projected needs for individual water user groups within the aggregate can vary greatly and may reach 100% for a given WUG and water use category. A detailed summary of water needs by WUG and county appears in Chapter 4 of the 2021 Region L Regional Water Plan.

Table 1-2 Regional water needs summary by water use category

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	water needs (acre-feet per year)	131,184	131,915	134,104	136,099	137,596	140,812
	% of the category's total water demand	37%	37%	37%	38%	38%	39%
Livestock	water needs (acre-feet per year)	1,674	1,668	1,757	1,852	1,930	1,930
	% of the category's total water demand	5%	5%	6%	6%	6%	6%
Manufacturing	water needs (acre-feet per year)	10,429	12,939	13,040	13,072	13,072	13,072
	% of the category's total water demand	14%	16%	16%	16%	16%	16%
Mining	water needs (acre-feet per year)	16,147	17,125	15,491	12,786	11,170	11,578
	% of the category's total water demand	33%	34%	32%	29%	27%	28%
Municipal*	water needs (acre-feet per year)	26,557	51,105	88,889	129,728	179,452	229,740
	% of the category's total water demand	6%	11%	17%	22%	28%	33%
Steam-electric power	water needs (acre-feet per year)	21,707	21,707	21,707	21,707	21,707	21,707
	% of the category's total water demand	20%	20%	20%	20%	20%	20%
Total water needs (acre-feet per year)		**207,698**	**236,459**	**274,988**	**315,244**	**364,927**	**418,839**

* Municipal category consists of residential and non-residential (commercial and institutional) subcategories.

2 Impact Assessment Measures

A required component of the regional and state water plans is to estimate the potential economic and social impacts of potential water shortages during a repeat of the drought of record. Consistent with previous water plans, ten impact measures were estimated and are described in Table 2-1.

Table 2-1 Socioeconomic impact analysis measures

Regional economic impacts	**Description**
Income losses - value-added	The value of output less the value of intermediate consumption; it is a measure of the contribution to gross domestic product (GDP) made by an individual producer, industry, sector, or group of sectors within a year. Value-added measures used in this report have been adjusted to include the direct, indirect, and induced monetary impacts on the region.
Income losses - electrical power purchase costs	Proxy for income loss in the form of additional costs of power as a result of impacts of water shortages.
Job losses	Number of part-time and full-time jobs lost due to the shortage. These values have been adjusted to include the direct, indirect, and induced employment impacts on the region.
Financial transfer impacts	**Description**
Tax losses on production and imports	Sales and excise taxes not collected due to the shortage, in addition to customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies. These values have been adjusted to include the direct, indirect and induced tax impacts on the region.
Water trucking costs	Estimated cost of shipping potable water.
Utility revenue losses	Foregone utility income due to not selling as much water.
Utility tax revenue losses	Foregone miscellaneous gross receipts tax collections.
Social impacts	**Description**
Consumer surplus losses	A welfare measure of the lost value to consumers accompanying restricted water use.
Population losses	Population losses accompanying job losses.
School enrollment losses	School enrollment losses (K-12) accompanying job losses.

2.1 Regional Economic Impacts

The two key measures used to assess regional economic impacts are income losses and job losses. The income losses presented consist of the sum of value-added losses and the additional purchase costs of electrical power.

Income Losses - Value-added Losses

Value-added is the value of total output less the value of the intermediate inputs also used in the production of the final product. Value-added is similar to GDP, a familiar measure of the productivity of an economy. The loss of value-added due to water shortages is estimated by input-output analysis using the IMPLAN software package, and includes the direct, indirect, and induced monetary impacts on the region. The indirect and induced effects are measures of reduced income as well as reduced employee spending for those input sectors which provide resources to the water shortage impacted production sectors.

Income Losses - Electric Power Purchase Costs

The electrical power grid and market within the state is a complex interconnected system. The industry response to water shortages, and the resulting impact on the region, are not easily modeled using traditional input/output impact analysis and the IMPLAN model. Adverse impacts on the region will occur and are represented in this analysis by estimated additional costs associated with power purchases from other generating plants within the region or state. Consequently, the analysis employs additional power purchase costs as a proxy for the value-added impacts for the steam-electric power water use category, and these are included as a portion of the overall income impact for completeness.

For the purpose of this analysis, it is assumed that power companies with insufficient water will be forced to purchase power on the electrical market at a projected higher rate of 5.60 cents per kilowatt hour. This rate is based upon the average day-ahead market purchase price of electricity in Texas that occurred during the recent drought period in 2011. This price is assumed to be comparable to those prices which would prevail in the event of another drought of record.

Job Losses

The number of jobs lost due to the economic impact is estimated using IMPLAN output associated with each TWDB water use category. Because of the difficulty in predicting outcomes and a lack of relevant data, job loss estimates are not calculated for the steam-electric power category.

2.2 Financial Transfer Impacts

Several impact measures evaluated in this analysis are presented to provide additional detail concerning potential impacts on a portion of the economy or government. These financial transfer impact measures include lost tax collections (on production and imports), trucking costs for

imported water, declines in utility revenues, and declines in utility tax revenue collected by the state. These measures are not solely adverse, with some having both positive and negative impacts. For example, cities and residents would suffer if forced to pay large costs for trucking in potable water. Trucking firms, conversely, would benefit from the transaction. Additional detail for each of these measures follows.

Tax Losses on Production and Imports

Reduced production of goods and services accompanying water shortages adversely impacts the collection of taxes by state and local government. The regional IMPLAN model is used to estimate reduced tax collections associated with the reduced output in the economy. Impact estimates for this measure include the direct, indirect, and induced impacts for the affected sectors.

Water Trucking Costs

In instances where water shortages for a municipal water user group are estimated by RWPGs to exceed 80 percent of water demands, it is assumed that water would need to be trucked in to support basic consumption and sanitation needs. For water shortages of 80 percent or greater, a fixed, maximum of $35,000[1] per acre-foot of water applied as an economic cost. This water trucking cost was utilized for both the residential and non-residential portions of municipal water needs.

Utility Revenue Losses

Lost utility income is calculated as the price of water service multiplied by the quantity of water not sold during a drought shortage. Such estimates are obtained from utility-specific pricing data provided by the Texas Municipal League, where available, for both water and wastewater. These water rates are applied to the potential water shortage to estimate forgone utility revenue as water providers sold less water during the drought due to restricted supplies.

Utility Tax Losses

Foregone utility tax losses include estimates of forgone miscellaneous gross receipts taxes. Reduced water sales reduce the amount of utility tax that would be collected by the State of Texas for water and wastewater service sales.

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[1] Based on staff survey of water hauling firms and historical data concerning transport costs for potable water in the recent drought in California for this estimate. There are many factors and variables that would determine actual water trucking costs including distance to, cost of water, and length of that drought.

2.3 Social Impacts

Consumer Surplus Losses for Municipal Water Users

Consumer surplus loss is a measure of impact to the wellbeing of municipal water users when their water use is restricted. Consumer surplus is the difference between how much a consumer is willing and able to pay for a commodity (i.e., water) and how much they actually have to pay. The difference is a benefit to the consumer's wellbeing since they do not have to pay as much for the commodity as they would be willing to pay. Consumer surplus may also be viewed as an estimate of how much consumers would be willing to pay to keep the original quantity of water which they used prior to the drought. Lost consumer surplus estimates within this analysis only apply to the residential portion of municipal demand, with estimates being made for reduced outdoor and indoor residential use. Lost consumer surplus estimates varied widely by location and degree of water shortage.

Population and School Enrollment Losses

Population loss due to water shortages, as well as the associated decline in school enrollment, are based upon the job loss estimates discussed in Section 2.1. A simplified ratio of job and net population losses are calculated for the state as a whole based on a recent study of how job layoffs impact the labor market population.[2] For every 100 jobs lost, 18 people were assumed to move out of the area. School enrollment losses are estimated as a proportion of the population lost based upon public school enrollment data from the Texas Education Agency concerning the age K-12 population within the state (approximately 19%).

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[2] Foote, Andrew, Grosz, Michel, Stevens, Ann. "Locate Your Nearest Exit: Mass Layoffs and Local Labor Market Response." University of California, Davis. April 2015, http://paa2015.princeton.edu/papers/150194. The study utilized Bureau of Labor Statistics data regarding layoffs between 1996 and 2013, as well as Internal Revenue Service data regarding migration, to model the change in the population as the result of a job layoff event. The study found that layoffs impact both out-migration and in-migration into a region, and that a majority of those who did move following a layoff moved to another labor market rather than an adjacent county.

3 Socioeconomic Impact Assessment Methodology

This portion of the report provides a summary of the methodology used to estimate the potential economic impacts of future water shortages. The general approach employed in the analysis was to obtain estimates for income and job losses on the smallest geographic level that the available data would support, tie those values to their accompanying historic water use estimate, and thereby determine a maximum impact per acre-foot of shortage for each of the socioeconomic measures. The calculations of economic impacts are based on the overall composition of the economy divided into many underlying economic sectors. Sectors in this analysis refer to one or more of the 536 specific production sectors of the economy designated within IMPLAN, the economic impact modeling software used for this assessment. Economic impacts within this report are estimated for approximately 330 of these sectors, with the focus on the more water-intensive production sectors. The economic impacts for a single water use category consist of an aggregation of impacts to multiple, related IMPLAN economic sectors.

3.1 Analysis Context

The context of this socioeconomic impact analysis involves situations where there are physical shortages of groundwater or surface water due to a recurrence of drought of record conditions. Anticipated shortages for specific water users may be nonexistent in earlier decades of the planning horizon, yet population growth or greater industrial, agricultural or other sector demands in later decades may result in greater overall demand, exceeding the existing supplies. Estimated socioeconomic impacts measure what would happen if water user groups experience water shortages for a period of one year. Actual socioeconomic impacts would likely become larger as drought of record conditions persist for periods greater than a single year.

3.2 IMPLAN Model and Data

Input-Output analysis using the IMPLAN software package was the primary means of estimating the value-added, jobs, and tax related impact measures. This analysis employed regional level models to determine key economic impacts. IMPLAN is an economic impact model, originally developed by the U.S. Forestry Service in the 1970's to model economic activity at varying geographic levels. The model is currently maintained by the Minnesota IMPLAN Group (MIG Inc.) which collects and sells county and state specific data and software. The year 2016 version of IMPLAN, employing data for all 254 Texas counties, was used to provide estimates of value-added, jobs, and taxes on production for the economic sectors associated with the water user groups examined in the study. IMPLAN uses 536 sector-specific Industry Codes, and those that rely on water as a primary input were assigned to their appropriate planning water user categories (irrigation, livestock, manufacturing, mining, and municipal). Estimates of value-added for a water use category were obtained by summing value-added estimates across the relevant IMPLAN sectors associated with that water use category. These calculations were also performed for job losses as well as tax losses on production and imports.

The adjusted value-added estimates used as an income measure in this analysis, as well as the job and tax estimates from IMPLAN, include three components:

- ***Direct effects*** representing the initial change in the industry analyzed;
- ***Indirect effects*** that are changes in inter-industry transactions as supplying industries respond to reduced demands from the directly affected industries; and,
- ***Induced effects*** that reflect changes in local spending that result from reduced household income among employees in the directly and indirectly affected industry sectors.

Input-output models such as IMPLAN only capture backward linkages and do not include forward linkages in the economy.

3.3 Elasticity of Economic Impacts

The economic impact of a water need is based on the size of the water need relative to the total water demand for each water user group. Smaller water shortages, for example, less than 5 percent, are generally anticipated to result in no initial negative economic impact because water users are assumed to have a certain amount of flexibility in dealing with small shortages. As a water shortage intensifies, however, such flexibility lessens and results in actual and increasing economic losses, eventually reaching a representative maximum impact estimate per unit volume of water. To account for these characteristics, an elasticity adjustment function is used to estimate impacts for the income, tax and job loss measures. Figure 3-1 illustrates this general relationship for the adjustment functions. Negative impacts are assumed to begin accruing when the shortage reaches the lower bound ‘b1’ (5 percent in Figure 3-1), with impacts then increasing linearly up to the 100 percent impact level (per unit volume) once the upper bound reaches the ‘b2’ level shortage (40 percent in Figure 3-1).

To illustrate this, if the total annual value-added for manufacturing in the region was $2 million and the reported annual volume of water used in that industry is 10,000 acre-feet, the estimated economic measure of the water shortage would be $200 per acre-foot. The economic impact of the shortage would then be estimated using this value-added amount as the maximum impact estimate ($200 per acre-foot) applied to the anticipated shortage volume and then adjusted by the elasticity function. Using the sample elasticity function shown in Figure 3-1, an approximately 22 percent shortage in the livestock category would indicate an economic impact estimate of 50% of the original $200 per acre-foot impact value (i.e., $100 per acre-foot).

Such adjustments are not required in estimating consumer surplus, utility revenue losses, or utility tax losses. Estimates of lost consumer surplus rely on utility-specific demand curves with the lost consumer surplus estimate calculated based on the relative percentage of the utility’s water shortage. Estimated changes in population and school enrollment are indirectly related to the elasticity of job losses.

Assumed values for the lower and upper bounds ‘b1’ and ‘b2’ vary by water use category and are presented in Table 3-1.

Figure 3-1 Example economic impact elasticity function (as applied to a single water user's shortage)

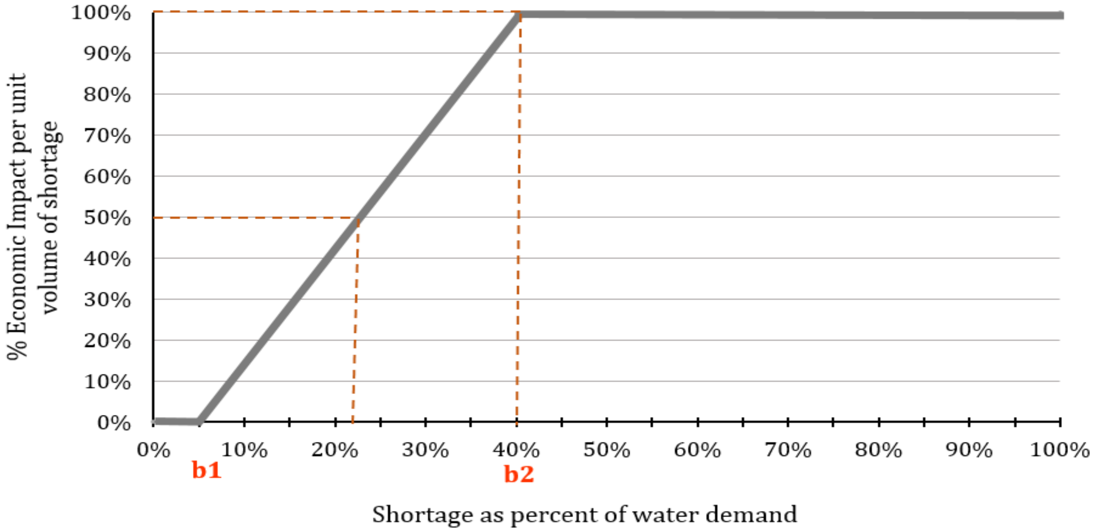


Table 3-1 Economic impact elasticity function lower and upper bounds

Water use category	Lower bound (b1)	Upper bound (b2)
Irrigation	**5%**	**40%**
Livestock	**5%**	**10%**
Manufacturing	**5%**	**40%**
Mining	**5%**	**40%**
Municipal (non-residential water intensive subcategory)	**5%**	**40%**
Steam-electric power	**N/A**	**N/A**

3.4 Analysis Assumptions and Limitations

The modeling of complex systems requires making many assumptions and acknowledging the model's uncertainty and limitations. This is particularly true when attempting to estimate a wide range of socioeconomic impacts over a large geographic area and into future decades. Some of the key assumptions and limitations of this methodology include:

1. The foundation for estimating the socioeconomic impacts of water shortages resulting from a drought are the water needs (potential shortages) that were identified by RWPGs as part of the

regional water planning process. These needs have some uncertainty associated with them but serve as a reasonable basis for evaluating the potential impacts of a drought of record event.

2. All estimated socioeconomic impacts are snapshots for years in which water needs were identified (i.e., 2020, 2030, 2040, 2050, 2060, and 2070). The estimates are independent and distinct "what if" scenarios for each particular year, and water shortages are assumed to be temporary events resulting from a single year recurrence of drought of record conditions. The evaluation assumed that no recommended water management strategies are implemented. In other words, growth occurs and future shocks are imposed on an economy at 10-year intervals, and the resulting impacts are estimated. Note that the estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

3. Input-output models such as IMPLAN rely on a static profile of the structure of the economy as it appears today. This presumes that the relative contributions of all sectors of the economy would remain the same, regardless of changes in technology, availability of limited resources, and other structural changes to the economy that may occur in the future. Changes in water use efficiency will undoubtedly take place in the future as supplies become more stressed. Use of the static IMPLAN structure was a significant assumption and simplification considering the 50-year time period examined in this analysis. To presume an alternative future economic makeup, however, would entail positing many other major assumptions that would very likely generate as much or more error.

4. This is not a form of cost-benefit analysis. That approach to evaluating the economic feasibility of a specific policy or project employs discounting future benefits and costs to their present value dollars using some assumed discount rate. The methodology employed in this effort to estimate the economic impacts of future water shortages did not use any discounting methods to weigh future costs differently through time.

5. All monetary values originally based upon year 2016 IMPLAN and other sources are reported in constant year 2018 dollars to be consistent with the water management strategy requirements in the State Water Plan.

6. IMPLAN based loss estimates (income-value-added, jobs, and taxes on production and imports) are calculated only for those IMPLAN sectors for which the TWDB's Water Use Survey (WUS) data was available and deemed reliable. Every effort is made in the annual WUS effort to capture all relevant firms who are significant water users. Lack of response to the WUS, or omission of relevant firms, impacts the loss estimates.

7. Impacts are annual estimates. The socioeconomic analysis does not reflect the full extent of impacts that might occur as a result of persistent water shortages occurring over an extended duration. The drought of record in most regions of Texas lasted several years.

8. Value-added estimates are the primary estimate of the economic impacts within this report. One may be tempted to add consumer surplus impacts to obtain an estimate of total adverse economic impacts to the region, but the consumer surplus measure represents the change to the wellbeing of households (and other water users), not an actual change in the flow of dollars through the economy. The two measures (value-added and consumer surplus) are both valid impacts but ideally should not be summed.

9. The value-added, jobs, and taxes on production and import impacts include the direct, indirect and induced effects to capture backward linkages in the economy described in Section 2.1. Population and school enrollment losses also indirectly include such effects as they are based on the associated losses in employment. The remaining measures (consumer surplus, utility revenue, utility taxes, additional electrical power purchase costs, and potable water trucking costs), however, do not include any induced or indirect effects.

10. The majority of impacts estimated in this analysis may be more conservative (i.e., smaller) than those that might actually occur under drought of record conditions due to not including impacts in the forward linkages in the economy. Input-output models such as IMPLAN only capture backward linkages on suppliers (including households that supply labor to directly affected industries). While this is a common limitation in this type of economic modeling effort, it is important to note that forward linkages on the industries that use the outputs of the directly affected industries can also be very important. A good example is impacts on livestock operators. Livestock producers tend to suffer substantially during droughts, not because there is not enough water for their stock, but because reductions in available pasture and higher prices for purchased hay have significant economic effects on their operations. Food processors could be in a similar situation if they cannot get the grains or other inputs that they need. These effects are not captured in IMPLAN, resulting in conservative impact estimates.

11. The model does not reflect dynamic economic responses to water shortages as they might occur, nor does the model reflect economic impacts associated with a recovery from a drought of record including:
    a. The likely significant economic rebound to some industries immediately following a drought, such as landscaping;
    b. The cost and time to rebuild liquidated livestock herds (a major capital investment in that industry);
    c. Direct impacts on recreational sectors (i.e., stranded docks and reduced tourism); or,
    d. Impacts of negative publicity on Texas' ability to attract population and business in the event that it was not able to provide adequate water supplies for the existing economy.

12. Estimates for job losses and the associated population and school enrollment changes may exceed what would actually occur. In practice, firms may be hesitant to lay off employees, even in difficult economic times. Estimates of population and school enrollment changes are based on regional evaluations and therefore do not necessarily reflect what might occur on a statewide basis.

13. **The results must be interpreted carefully. It is the general and relative magnitudes of impacts as well as the changes of these impacts over time that should be the focus rather than the absolute numbers.** Analyses of this type are much better at predicting relative percent differences brought about by a shock to a complex system (i.e., a water shortage) than the precise size of an impact. To illustrate, assuming that the estimated economic impacts of a drought of record on the manufacturing and mining water user categories are $2 and $1 million, respectively, one should be more confident that the economic impacts on manufacturing are twice as large as those on mining and that these impacts will likely be in the millions of dollars. But one should have less confidence that the actual total economic impact experienced would be $3 million.

14. The methodology does not capture "spillover" effects between regions – or the secondary impacts that occur outside of the region where the water shortage is projected to occur.

15. The methodology that the TWDB has developed for estimating the economic impacts of unmet water needs, and the assumptions and models used in the analysis, are specifically designed to estimate potential economic effects at the regional and county levels. Although it may be tempting to add the regional impacts together in an effort to produce a statewide result, the TWDB cautions against that approach for a number of reasons. The IMPLAN modeling (and corresponding economic multipliers) are all derived from regional models – a statewide model of Texas would produce somewhat different multipliers. As noted in point 14 within this section, the regional modeling used by TWDB does not capture spillover losses that could result in other regions from unmet needs in the region analyzed, or potential spillover gains if decreased production in one region leads to increases in production elsewhere. The assumed drought of record may also not occur in every region of Texas at the same time, or to the same degree.

4 Analysis Results

This section presents estimates of potential economic impacts that could reasonably be expected in the event of water shortages associated with a drought of record and if no recommended water management strategies were implemented. Projected economic impacts for the six water use categories (irrigation, livestock, manufacturing, mining, municipal, and steam-electric power) are reported by decade.

4.1 Impacts for Irrigation Water Shortages

Fifteen of the 21 counties in the region are projected to experience water shortages in the irrigated agriculture water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-1. Note that tax collection impacts were not estimated for this water use category. IMPLAN data indicates a negative tax impact (i.e., increased tax collections) for the associated production sectors, primarily due to past subsidies from the federal government. However, it was not considered realistic to report increasing tax revenues during a drought of record.

Table 4-1 Impacts of water shortages on irrigation in Region L

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$66	$66	$67	$67	$67	$68
Job losses	1,217	1,225	1,232	1,234	1,238	1,267

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.2 Impacts for Livestock Water Shortages

Eleven of the 21 counties in the region are projected to experience water shortages in the livestock water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-2.

Table 4-2 Impacts of water shortages on livestock in Region L

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$18	$18	$20	$21	$23	$23
Jobs losses	664	660	731	772	820	820
Tax losses on production and imports ($ millions)*	$1	$1	$1	$1	$1	$1

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.3 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in five of the 21 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use category appear in Table 4-3.

Table 4-3 Impacts of water shortages on manufacturing in Region L

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$3,349	$4,250	$4,283	$4,296	$4,296	$4,296
Job losses	21,100	27,846	28,069	28,155	28,155	28,155
Tax losses on production and Imports ($ millions)*	$221	$279	$281	$282	$282	$282

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.4 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in 12 of the 21 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use type appear in Table 4-4.

Table 4-4 Impacts of water shortages on mining in Region L

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$11,992	$11,666	$8,617	$5,081	$2,229	$985
Job losses	70,538	68,993	51,650	31,445	15,269	8,466
Tax losses on production and Imports ($ millions)*	$1,514	$1,465	$1,067	$608	$235	$67

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.5 Impacts for Municipal Water Shortages

Sixteen of the 21 counties in the region are projected to experience water shortages in the municipal water use category for one or more decades within the planning horizon.

Impact estimates were made for two sub-categories within municipal water use: residential and non-residential. Non-residential municipal water use includes commercial and institutional users, which are further divided into non-water-intensive and water-intensive subsectors including car wash, laundry, hospitality, health care, recreation, and education. Lost consumer surplus estimates were made only for needs in the residential portion of municipal water use. Available IMPLAN and TWDB Water Use Survey data for the non-residential, water-intensive portion of municipal demand allowed these sectors to be included in income, jobs, and tax loss impact estimate.

Trucking cost estimates, calculated for shortages exceeding 80 percent, assumed a fixed, maximum cost of $35,000 per acre-foot to transport water for municipal use. The estimated impacts to this water use category appear in Table 4-5.

Table 4-5 Impacts of water shortages on municipal water users in Region L

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses[1] ($ millions)*	$407	$507	$873	$1,474	$2,321	$3,273
Job losses[1]	6,995	8,729	15,028	25,370	39,911	56,270
Tax losses on production and imports[1] ($ millions)*	$39	$49	$84	$142	$223	$314
Trucking costs ($ millions)*	$3	$4	$6	$8	$9	$13
Utility revenue losses ($ millions)*	$70	$146	$268	$400	$560	$723
Utility tax revenue losses ($ millions)*	$1	$3	$5	$7	$10	$14

[1] Estimates apply to the water-intensive portion of non-residential municipal water use.
* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.6 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in two of the 21 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-6.

Note that estimated economic impacts to steam-electric water users:

- Are reflected as an income loss proxy in the form of estimated additional purchasing costs for power from the electrical grid to replace power that could not be generated due to a shortage;
- Do not include estimates of impacts on jobs. Because of the unique conditions of power generators during drought conditions and lack of relevant data, it was assumed that the industry would retain, perhaps relocating or repurposing, their existing staff in order to manage their ongoing operations through a severe drought.
- Do not presume a decline in tax collections. Associated tax collections, in fact, would likely increase under drought conditions since, historically, the demand for electricity increases during times of drought, thereby increasing taxes collected on the additional sales of power.

Table 4-6 Impacts of water shortages on steam-electric power in Region L

Impacts measure	2020	2030	2040	2050	2060	2070
Income Losses ($ millions)*	$740	$740	$740	$740	$740	$740

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.7 Regional Social Impacts

Projected changes in population, based upon several factors (household size, population, and job loss estimates), as well as the accompanying change in school enrollment, were also estimated and are summarized in Table 4-7.

Table 4-7 Region-wide social impacts of water shortages in Region L

Impacts measure	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$67	$80	$118	$184	$342	$651
Population losses	18,454	19,728	17,756	15,969	15,678	17,438
School enrollment losses	3,530	3,773	3,396	3,054	2,999	3,335

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

Appendix A - County Level Summary of Estimated Economic Impacts for Region L

County level summary of estimated economic impacts of not meeting identified water needs by water use category and decade (in 2018 dollars, rounded). Values are presented only for counties with projected economic impacts for at least one decade.
(* Entries denoted by a dash (-) indicate no estimated economic impact)

		Income losses (Million $)*						**Job losses**					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
ATASCOSA	MUNICIPAL	$6.52	$8.70	$12.68	$16.54	$20.57	$24.16	112	150	218	285	354	416
ATASCOSA Total		**$6.52**	**$8.70**	**$12.68**	**$16.54**	**$20.57**	**$24.16**	**112**	**150**	**218**	**285**	**354**	**416**
BEXAR	IRRIGATION	$0.92	$0.92	$0.92	$0.92	$0.92	$0.92	19	19	19	19	19	19
BEXAR	MUNICIPAL	$102.48	$113.74	$254.91	$517.90	$907.12	$1,401.82	1,765	1,958	4,389	8,918	15,620	24,139
BEXAR	STEAM ELECTRIC POWER	$94.79	$94.79	$94.79	$94.79	$94.79	$94.79	-	-	-	-	-	-
BEXAR Total		**$198.18**	**$209.44**	**$350.62**	**$613.61**	**$1,002.83**	**$1,497.53**	**1,784**	**1,978**	**4,409**	**8,937**	**15,640**	**24,158**
CALDWELL	MUNICIPAL	$1.21	$1.61	$4.71	$10.35	$22.89	$38.76	20	26	77	174	389	662
CALDWELL Total		**$1.21**	**$1.61**	**$4.71**	**$10.35**	**$22.89**	**$38.76**	**20**	**26**	**77**	**174**	**389**	**662**
CALHOUN	IRRIGATION	$2.32	$2.32	$2.32	$2.32	$2.32	$2.32	54	54	54	54	54	54
CALHOUN	LIVESTOCK	$3.26	$3.26	$3.26	$3.26	$3.26	$3.26	147	147	147	147	147	147
CALHOUN	MINING	$13.51	$14.10	$10.57	$7.05	$2.68	$1.01	96	100	75	50	19	7
CALHOUN	MUNICIPAL	-	-	$0.00	$0.06	$0.15	$0.29	-	-	0	1	3	5
CALHOUN Total		**$19.09**	**$19.68**	**$16.15**	**$12.68**	**$8.41**	**$6.87**	**297**	**301**	**276**	**252**	**223**	**213**
COMAL	IRRIGATION	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	0	0	0	0	0	0
COMAL	MANUFACTURING	$1,900.96	$2,571.00	$2,571.00	$2,571.00	$2,571.00	$2,571.00	16,829	22,761	22,761	22,761	22,761	22,761
COMAL	MINING	$327.57	$440.34	$548.92	$643.67	$762.34	$895.31	2,907	3,908	4,872	5,713	6,766	7,946
COMAL	MUNICIPAL	$35.17	$74.22	$189.22	$350.61	$472.41	$587.96	606	1,278	3,258	6,037	8,135	10,125
COMAL Total		**$2,263.71**	**$3,085.57**	**$3,309.15**	**$3,565.30**	**$3,805.77**	**$4,054.28**	**20,342**	**27,947**	**30,891**	**34,511**	**37,662**	**40,832**
DEWITT	IRRIGATION	$0.26	$0.26	$0.19	$0.19	-	-	6	6	4	4	-	-
DEWITT	MANUFACTURING	-	$0.65	-	-	-	-	-	9	-	-	-	-
DEWITT	MINING	$1,674.17	$1,554.31	$115.83	-	-	-	9,704	9,010	671	-	-	-
DEWITT Total		**$1,674.44**	**$1,555.23**	**$116.02**	**$0.19**	**-**	**-**	**9,710**	**9,024**	**675**	**4**	**-**	**-**
DIMMIT	IRRIGATION	$3.97	$3.97	$3.97	$3.97	$3.97	$3.97	65	65	65	65	65	65
DIMMIT	MINING	$4,116.25	$4,202.00	$3,558.84	$2,089.31	$622.70	$18.57	23,860	24,357	20,629	12,111	3,609	108
DIMMIT Total		**$4,120.22**	**$4,205.97**	**$3,562.81**	**$2,093.27**	**$626.67**	**$22.54**	**23,925**	**24,422**	**20,694**	**12,176**	**3,674**	**173**

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
FRIO	IRRIGATION	-	-	-	-	$0.30	$0.91	-	-	-	-	7	20
FRIO	MUNICIPAL	$10.81	$16.41	$21.97	$26.05	$29.61	$32.90	186	283	378	449	510	567
FRIO Total		**$10.81**	**$16.41**	**$21.97**	**$26.05**	**$29.91**	**$33.81**	**186**	**283**	**378**	**449**	**516**	**586**
GOLIAD	IRRIGATION	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	1	1	1	1	1	1
GOLIAD	MUNICIPAL	$0.18	$0.14	$0.11	$0.11	$0.10	$0.10	3	2	2	2	2	2
GOLIAD Total		**$0.21**	**$0.17**	**$0.15**	**$0.14**	**$0.13**	**$0.13**	**4**	**3**	**3**	**3**	**3**	**3**
GUADALUPE	MANUFACTURING	-	$17.48	$17.48	$17.48	$17.48	$17.48	-	179	179	179	179	179
GUADALUPE	MUNICIPAL	$0.03	$0.05	$8.19	$58.02	$144.05	$205.33	1	1	141	999	2,480	3,536
GUADALUPE Total		**$0.03**	**$17.53**	**$25.67**	**$75.50**	**$161.53**	**$222.81**	**1**	**179**	**320**	**1,178**	**2,659**	**3,714**
HAYS	LIVESTOCK	$8.58	$8.58	$8.58	$8.58	$8.58	$8.58	261	261	261	261	261	261
HAYS	MUNICIPAL	$2.56	$12.63	$73.92	$152.60	$322.83	$505.05	40	217	1,267	2,616	5,510	8,606
HAYS Total		**$11.14**	**$21.22**	**$82.51**	**$161.19**	**$331.41**	**$513.63**	**301**	**478**	**1,528**	**2,876**	**5,771**	**8,867**
KARNES	IRRIGATION	$0.13	$0.13	$0.68	$0.68	$0.68	$0.68	2	2	12	12	12	12
KARNES	MANUFACTURING	-	-	$34.37	$47.14	$47.14	$47.14	-	-	232	319	319	319
KARNES	MINING	$1,876.79	$1,319.99	$743.71	$109.72	$11.62	$0.97	10,879	7,651	4,311	636	67	6
KARNES	MUNICIPAL	$5.16	$5.08	$4.66	$4.57	$6.57	$6.40	89	88	80	79	113	110
KARNES Total		**$1,882.09**	**$1,325.20**	**$783.41**	**$162.10**	**$66.00**	**$55.19**	**10,970**	**7,741**	**4,635**	**1,045**	**511**	**446**
KENDALL	MUNICIPAL	-	$2.14	$4.91	$8.12	$31.23	$75.35	-	37	85	140	538	1,297
KENDALL Total		**-**	**$2.14**	**$4.91**	**$8.12**	**$31.23**	**$75.35**	**-**	**37**	**85**	**140**	**538**	**1,297**
LA SALLE	IRRIGATION	$0.19	$0.19	$0.20	$0.21	$0.22	$0.23	6	6	6	7	7	7
LA SALLE	MINING	$3,983.72	$4,134.76	$3,638.75	$2,231.58	$829.29	$68.54	23,092	23,967	21,092	12,935	4,807	397
LA SALLE Total		**$3,983.91**	**$4,134.96**	**$3,638.95**	**$2,231.80**	**$829.51**	**$68.77**	**23,098**	**23,973**	**21,099**	**12,942**	**4,814**	**405**
MEDINA	IRRIGATION	$18.46	$18.63	$18.60	$18.76	$18.85	$19.40	353	356	355	359	360	371
MEDINA	MINING	-	-	-	-	-	$0.25	-	-	-	-	-	2
MEDINA	MUNICIPAL	$16.32	$20.84	$25.35	$30.35	$34.73	$38.37	281	359	437	523	598	661
MEDINA Total		**$34.78**	**$39.48**	**$43.95**	**$49.11**	**$53.58**	**$58.02**	**634**	**715**	**792**	**881**	**958**	**1,034**
UVALDE	IRRIGATION	$25.48	$25.64	$25.72	$25.87	$26.05	$26.25	455	458	460	462	466	469
UVALDE	LIVESTOCK	$5.38	$5.28	$6.53	$8.19	$9.42	$9.42	207	203	251	315	362	362
UVALDE	MUNICIPAL	$60.80	$68.72	$75.60	$83.44	$91.59	$99.55	1,047	1,183	1,302	1,437	1,577	1,714
UVALDE Total		**$91.66**	**$99.65**	**$107.85**	**$117.51**	**$127.06**	**$135.23**	**1,709**	**1,845**	**2,013**	**2,214**	**2,405**	**2,546**
VICTORIA	IRRIGATION	$1.44	$1.44	$1.44	$1.44	$1.44	$1.44	33	33	33	33	33	33
VICTORIA	MANUFACTURING	$1,447.95	$1,660.38	$1,660.38	$1,660.38	$1,660.38	$1,660.38	4,270	4,897	4,897	4,897	4,897	4,897
VICTORIA	MUNICIPAL	$164.14	$179.88	$192.09	$204.46	$216.14	$226.15	2,826	3,097	3,308	3,521	3,722	3,894
VICTORIA	STEAM ELECTRIC POWER	$644.82	$644.82	$644.82	$644.82	$644.82	$644.82	-	-	-	-	-	-

County	Water Use Category	Income losses (Million $)* 2020	2030	2040	2050	2060	2070	Job losses 2020	2030	2040	2050	2060	2070
VICTORIA Total		**$2,258.36**	**$2,486.52**	**$2,498.74**	**$2,511.10**	**$2,522.79**	**$2,532.80**	**7,130**	**8,027**	**8,237**	**8,450**	**8,651**	**8,824**
WILSON	IRRIGATION	$0.82	$0.83	$0.84	$0.85	$0.93	$1.12	18	18	18	18	20	24
WILSON	LIVESTOCK	$1.25	$1.25	$1.80	$1.25	$1.25	$1.25	50	50	72	50	50	50
WILSON	MUNICIPAL	$1.13	$2.85	$4.96	$11.07	$20.87	$31.14	19	49	85	191	359	536
WILSON Total		**$3.20**	**$4.93**	**$7.60**	**$13.16**	**$23.06**	**$33.51**	**87**	**117**	**176**	**259**	**429**	**610**
ZAVALA	IRRIGATION	$11.74	$11.80	$11.67	$11.46	$11.14	$10.98	205	206	204	200	195	192
ZAVALA Total		**$11.74**	**$11.80**	**$11.67**	**$11.46**	**$11.14**	**$10.98**	**205**	**206**	**204**	**200**	**195**	**192**
REGION L Total		**$16,571.30**	**$17,246.20**	**$14,599.51**	**$11,679.18**	**$9,674.50**	**$9,384.38**	**100,514**	**107,453**	**96,710**	**86,976**	**85,393**	**94,978**

APPENDIX B

Summarization of Public Comments Received and Groundwater Management Area 10 Responses

Aquifer: Northern Fresh Edwards

Summary of Comment: 6.5 cfs is not adequate to sustain Salamander habitat and needs to be changed to 10 cfs

GMA 10 Response: As part of its approved Habitat Conservation Plan (HCP), BSEACD has spent considerable time, effort, and money over the past decade in analyzing the relationships between pumping of the aquifer, springflows within the aquifer and at Barton Springs, dissolved oxygen levels and regimes, and effects and impacts on the two endangered salamander species. In fact, much of the “best science available” that the Commenter refers to derives from BSEACD initiatives. In BSEACD’s view, it is infeasible to achieve a DOR springflow of 11 cfs on the basis of what is now known. That would be tantamount to complete cessation of pumping by all BSEACD permittees during a DOR. The District’s permittees have had to justify their normal pumpage levels as reasonable, non-speculative, and appropriate for the permitted use, and they are required to participate in a very stringent drought management program administered by BSEACD. The best they can currently and reasonably achieve is a DOR pumpage of 4.7 cfs. Using a well-documented water balance, that pumpage translates to 6.5 cfs of springflow during a DOR, which is the Extreme Drought DFC. This is a lower springflow than has been measured in recorded history, but it is very likely not the lowest springflow that ever existed at Barton Springs, considering the historical drought indices (e.g. dendrochronological record) of prolonged, more extreme droughts over the centuries. And yet the salamander populations persisted during those times. On the basis of the best science and other information available, the BSEACD Board considers a DOR springflow of 6.5 cfs as a reasonable balance of protection of private property rights and protection of the aquifer and salamander populations, and the US Fish and Wildlife Service - Austin Field Office has concurred with that determination.

Aquifer: Northern Fresh Edwards and Trinity

Summary of Comment: Increasing pumping in the Trinity threatens to decrease the flow in the Blanco River which in return could cause effects on recharge to the Northern Edwards

GMA 10 Response: GMA 10 agrees that the Blanco River is a critical resource which provides recharge to the northern segment of the Edwards Aquifer, especially during times of drought. However, it is still poorly understood to what extent pumping from the Trinity Aquifer in GMA 10 will affect upgradient springs which contribute to Blanco River flow, such as Pleasant Valley Spring and Jacobs Well Spring. This is why a consortium of GCDs, government agencies, and private firms are currently undertaking efforts to produce the Blanco River Aquifer Assessment Tool, a numerical groundwater model which, among other things, will be able to simulate potential impacts of pumping from the Trinity on these springs. Martin et al., 2019 presents the conceptual model, the first phase in creating the Blanco River Aquifer Assessment Tool numerical model. The second phase, creation of the numerical model, has been funded and is planned to begin in 2021 and be completed in 2022 or early 2023. Once the completed numerical groundwater model is available, we will be able to more accurately simulate pumping impacts on Blanco River flow to inform the DFC process.

Aquifer: Northern Fresh Edwards

Summary of Comment: Effects of Climate Change

GMA 10 Response: Climate modeling provides important high-level, long-term predictions for water planners. However, global climate models are less reliable at local scales, and have high level of uncertainty. Thus, they are less useful as a quantitative benchmark for DFC planning than historic droughts from which we have directly observed data, including springflow measurements at Barton Springs. Currently, the Texas 1950s drought of record (DOR) is the worst drought within the historical observation period; and is still widely accepted across the state as the benchmark for drought planning.

Furthermore, according to the best available groundwater models, achieving a DFC of 10 CFS at Barton Springs during a recurrence of the DOR event would require complete cessation of pumping within the northern segment of the Edwards Aquifer. Achieving a DFC of 10 CFS at Barton Springs during a drought worse than the DOR may be impossible, as spring flow may still drop below 10 CFS even with complete cessation of pumping. Enforcing a complete cessation of pumping would not be in accordance with the District’s mandate to balance beneficial use with conservation.

Aquifer: Trinity

Summary of Comment: Zero Region Well Drawdown

GMA 10 Response: The Trinity Aquifer condition is a confined aquifer that is isolated from the surface in GMA 10. It can produce fairly substantial amounts of groundwater, especially a mile or two downdip of the Trinity outcrop area (which coincides generally with the western boundary of GMA 10), without affecting other water supplies and without dewatering the aquifer. The demand for Trinity water in the area is growing, and there is little in the way of other alternative supplies to meet that demand. Zero-drawdown technically connotes no groundwater use, as drawdown is required to withdraw water from an individual well and from all wells in a given area. Sustainability, which is a more rational concept for management of groundwater in an area that depends on it for water supplies, connotes that total groundwater discharge, both natural (springs and seeps) and man-made (water wells), is balanced over the long term by the amount of recharge that may exist naturally or be induced by groundwater withdrawals, taking into consideration a time period required for achieving such a balance. The proposed DFCs are intended to provide such a balance, but a DFC based on zero-drawdown doesn’t pass that balancing test for any of its aquifers, in the judgment of GMA-10.

Aquifer: Trinity

Summary of Comment: Differentiating the Middle and Lower Trinity Aquifers and measuring methods

GMA 10 Response: GMA 10 has visited this concept and will continue to discuss during the next planning cycle on how to separate the Trinity and what would be the best way to measure DFC compliance. Currently, BSEACD is exploring the feasibility of a sustainable yield project that would allow the District to potentially establish a DFC for the Middle and a DFC for the Lower Trinity.

Aquifer: Trinity

Summary of Comment: Pumping in the Trinity would have effects to ecological and socioeconomic impacts and private property rights

GMA 10 Response: GMA 10 understands that maintaining a balance between needs, ecological and socioeconomic impacts, and private property rights is important to all users. However, adjusting the DFC would cause the balance test to start tipping in one favor or the other. For example, if the DFC was moved to a more conservative DFC, it would effect the socioeconomic and ecological impacts in a positive way, but, would cause the needs and private property rights to be impacted in a negative way. GMA 10 has determined that the DFCs provide the best balance to accomplish the balance test. GMA 10 will revisit comment next cycle once more data is obtained from current models being developed.

Aquifer: Undesignated/Multiple

Summary of Comment: DFC established around spring flow where necessary and DFC established for managed depletion where necessary

GMA 10 Response: Commenter do not provide guidance or additional information on what ***"is appropriate***" means or involves to them. So even if GMA 10 did know the specific aquifer(s) involved, it still would not know under what circumstances or rules to which ***"around spring flow"*** of these aquifers refer or apply.
The term "managed depletion" has not been defined within Chapter 36 of the Texas Water Code. Groundwater depletion has been described by the U.S. Geological Survey in concept as similar to money kept in a bank account:

> "If you withdraw money at a faster rate than you deposit new money you will eventually start having account-supply problems. Pumping water out of the ground faster than it is replenished over the long-term causes similar problems. The volume of groundwater in storage is decreasing in many areas of the United States in response to pumping. Groundwater depletion is primarily caused by sustained groundwater pumping." *Groundwater depletion*, USGS, https://water.usgs.gov/edu/gwdepletion.html

Such a condition is not a permanent condition within GMA 10. In GMA 10, there is substantial recharge, from both surface and subsurface sources, and the aquifers are able to induce additional recharge with additional drawdown until stability is reached.

Aquifer: Undesignated/Multiple

Summary of Comment: DFC Does not consider Subsidence

GMA 10 Response: Commenter does not assert nor provide evidence that there has been actual subsidence in GMA 10 caused by groundwater withdrawals. The Groundwater Conservation District representatives of GMA 10 are not aware of any subsidence, and would not expect any on the basis of all these aquifers' lithologic characteristics (dominantly competent carbonate formations), regardless of the DFC approved.

Aquifer: Trinity

Summary of Comment: Adopt a more conservative DFC even if Water Management Strategies (WMS) are affected

GMA 10 Response: GMA 10 complies with all laws governing joint groundwater planning, with its being included in the regional planning for all water resources in Texas, which coordinates groundwater and surface water supplies, needs, and water management strategies. GMA 10 does not have the authority to change this approach. A DFC has a statutory requirement to balance aquifer protection and the maximum groundwater production feasible. This means that GMA 10 has to consider all 9 Factors which includes WMS

Aquifer: General Comment

Summary of Comment: BSEACD should work with Hays Trinity GCD to establish a DFC based on spring flow from Jacobs Well

GMA 10 Response: Jacobs Well is not located in GMA 10 and the DFC should be established by GMA 9. However, GMA 10 is not opposed to local GCDs that benefit from Jacobs Well to work together across GMA boundaries to establish management tools for the future of Jacobs Well.

Aquifer: General Comment

Summary of Comment: Public comment/involvement process for DFCs

GMA 10 Response: GMA 10 understands the amount of information to be digested by the public in this process can be daunting. However, to a considerable extent, the deadlines for various actions are not controllable by the GMA, and GMA 10 has adhered to the required schedule for developing, proposing, and seeking public comment before adopting DFCs.

There have been several public meetings and hearings by both the GMA and individual GCDs where both written and oral comments were solicited and received. At this point, the GMA sees no reason to further delay considering the proposed DFC for adoption and completing this round. It should be noted that this is a recurring process on a five-year cycle, and the GMA and the public will be able to consider new information and use any new tools that might become available in the next five years.

Aquifer: General Comment

Summary of Comment: Release of an Explanatory Report before the 90 day public comment period begins

GMA 10 Response: The Explanatory Report is one of the last steps in the DFC process. The report has several components that have to be completed before the report can be viewed and finalized by GMA 10 for public dispersal, such as, public hearing meetings held by individual GCDs and public comment.

Aquifer: General Comment

Summary of Comment: Requiring less technical comments from the public

GMA 10 Response: State Law requires the use of scientific data to determine the DFC for each aquifer. Any public comment input that provides data will more likely have an affect on the DFC process.

Aquifer: General Comment

Summary of Comment: More funding for the DFC process

GMA 10 Response: Currently, there is no funding mechanism to provide funds to GCDs to complete the DFC process. Each GCD has to provide funds its own funds to complete the DFC process.

APPENDIX C

INTERA Incorporated
1812 Centre Creek Drive, Suite 300
Austin, Texas, USA 78754
512.425.2000

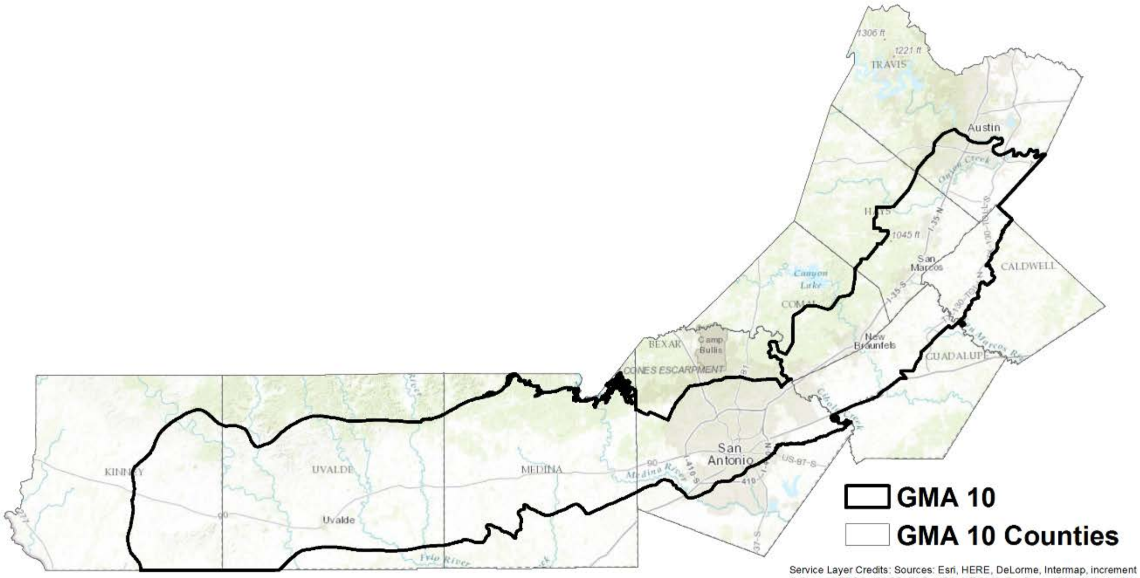
DRAFT TECHNICAL MEMORANDUM

To:	Groundwater Conservation Districts in Groundwater Management Area 10
From:	Wade Oliver, P.G., INTERA James Pinkard, INTERA Neil Deeds, PhD, PE, INTERA
Date:	May 19, 2016
RE:	**Development of an Analytic Element Tool to Evaluate the Trinity Aquifer in Hays County, Texas**

INTRODUCTION:

The Trinity Aquifer in Groundwater Management Area 10 (GMA 10) has become a target for significant groundwater development in recent years. While there has been increased interest in the Trinity Aquifer, there does not yet exist a groundwater availability model for groundwater conservation districts (GCDs) to use for the development of desired future conditions (DFCs). During the initial round of joint planning in 2010, the Texas Water Development Board used a simple spreadsheet-based approach for estimating modeled available groundwater based on the desired future conditions established by GMA 10. Due to the increased emphasis on the aquifer as a resource, and additional information that has become available, the GCDs in GMA 10 commissioned this study to better understand the relationship between pumping and aquifer impacts and help guide the development of desired future conditions. Figure 1 shows the extent of GMA 10.

The purpose of this technical memorandum is to document the evaluation of potential hydrogeologic impacts to the upper and middle sections of the Trinity Aquifer and their component units (upper and lower Glen Rose, Hensel, and Cow Creek). Our analysis primarily relies on the results of recent pumping tests completed at the Electro Purification (EP) well field in central Hays County (Figure 2). For this analysis we have used the modeling code TTIM. TTIM is useful for evaluating impacts at the well-scale, though it does contain simplifications from the level of detail that is included in a typical MODFLOW-based groundwater availability model. Additional information about TTIM and the approach used in this study are presented below. This includes development of the conceptual model of groundwater flow, development and calibration of the analytic element numerical model for the aquifer in Hays County, and several predictive simulations showing potential impacts to the aquifer from proposed groundwater production at the EP well field.



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 1. Groundwater Management Area 10 in Central Texas

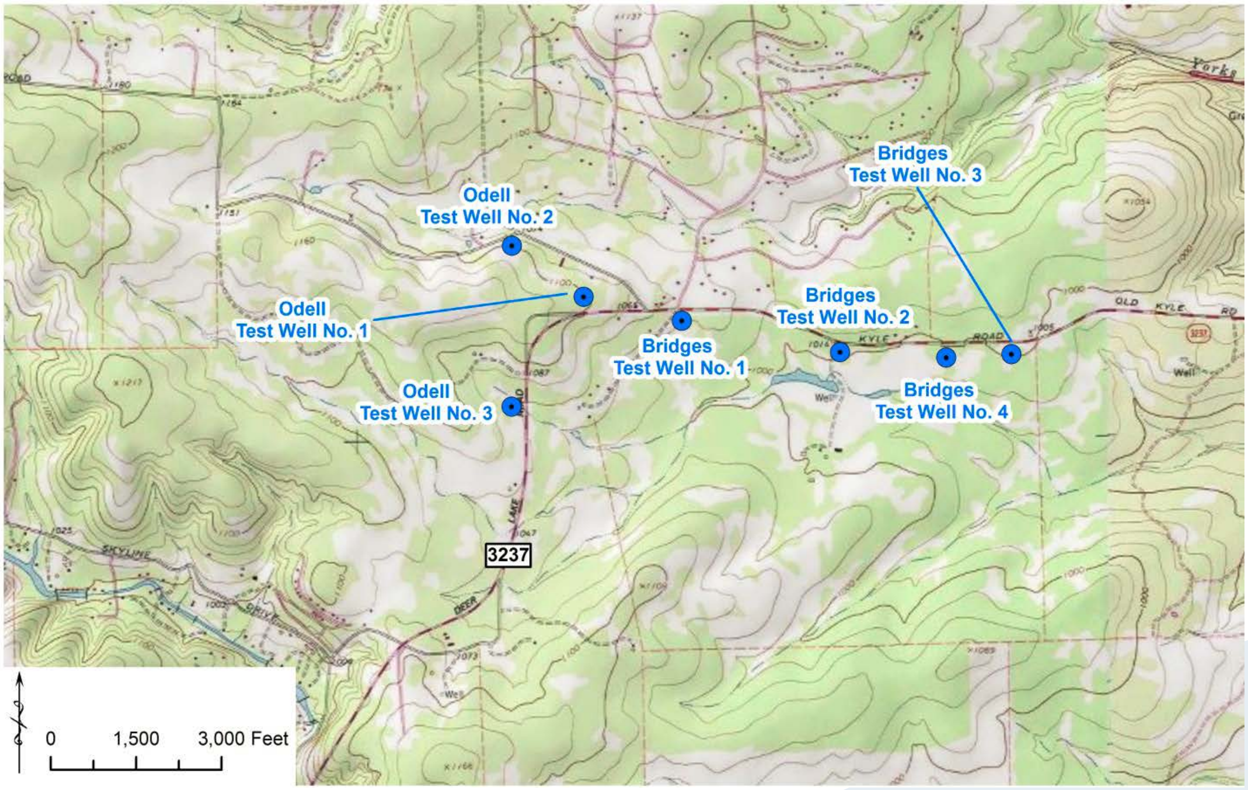


Figure 2. Electro Purification Well Field Layout (from WRGS, 2015)

APPROACH:

Groundwater model development typically includes definition of the conceptual model of groundwater flow prior to designing and calibrating the model for use in predictive simulations. The conceptual model of flow describes the current understanding of aquifer hydrogeology given available information and the purpose of the project. For this evaluation, we sought to better understand the hydraulic properties such as hydraulic conductivity and storativity and the degree of hydraulic connection between the various units within the Trinity Aquifer as well as the overlying Edwards (Balcones Fault Zone) Aquifer. The numerical model is the representation of this conceptual model of the aquifer in the computer code. All models, by definition, are simplifications of reality. When developed and applied appropriately, however, they can be very useful in increasing the level of understanding about how the aquifer works, defining those characteristics of the aquifer that most determine how it responds to pumping and assisting decision-makers tasked with developing groundwater management policies.

CONCEPTUAL MODEL:

The Trinity Aquifer in GMA 10 underlies the Edwards (Balcones Fault Zone) Aquifer. The Trinity Aquifer includes the upper and lower Glen Rose units, the Hensel, the Cow Creek, and the Sligo and Hosston formations of the Lower Trinity. The Hammett Shale is a confining unit that separates the Middle Trinity from the Lower Trinity. These units is shown in the stratigraphic chart in Figure 3. Large scale development at the EP well field is planned for the Cow Creek portion of the aquifer. One of the key purposes of this analysis is to better understand the potential impact that pumping of the Cow Creek could have on the overlying Lower Glen Rose and Edwards (Balcones Fault Zone) Aquifer.

To assist in the development of the conceptual model for the Trinity Aquifer, Barton Springs/Edwards Aquifer Conservation District (BSEACD) provided INTERA with pumping test information and estimated aquifer thicknesses for the EP well field. As these pumping tests were performed on many different wells, they represent a valuable source of information for understanding the aquifer in the area. Details of these pumping tests are documented in WRGS (2015). Additional information on the Trinity Aquifer nearby was also provided by BSEACD, including pumping test results at the Ruby Ranch and Needmore properties. These are documented in Mikels (2010) and WRGS (2016), respectively.

The primary aquifer in GMA 10 is the Edwards (Balcones Fault Zone) Aquifer. The Balcones Fault Zone is an area of extensive southeast to northeast trending faulting that extends through the Edwards and Trinity Aquifers. These faults can enhance dissolution and creation of karst features, create pathways for flow between aquifer units, or in some cases restrict flow across fault boundaries. Figure 4 shows a cross-section along the Blanco River in Hays County from Hunt and others (2015). Most relevant to the current study, the occurrence of faulting can inhibit the flow of groundwater down-dip. For a detailed description of the hydrogeology of the Trinity Aquifer in the study area, see Wierman and others (2010).

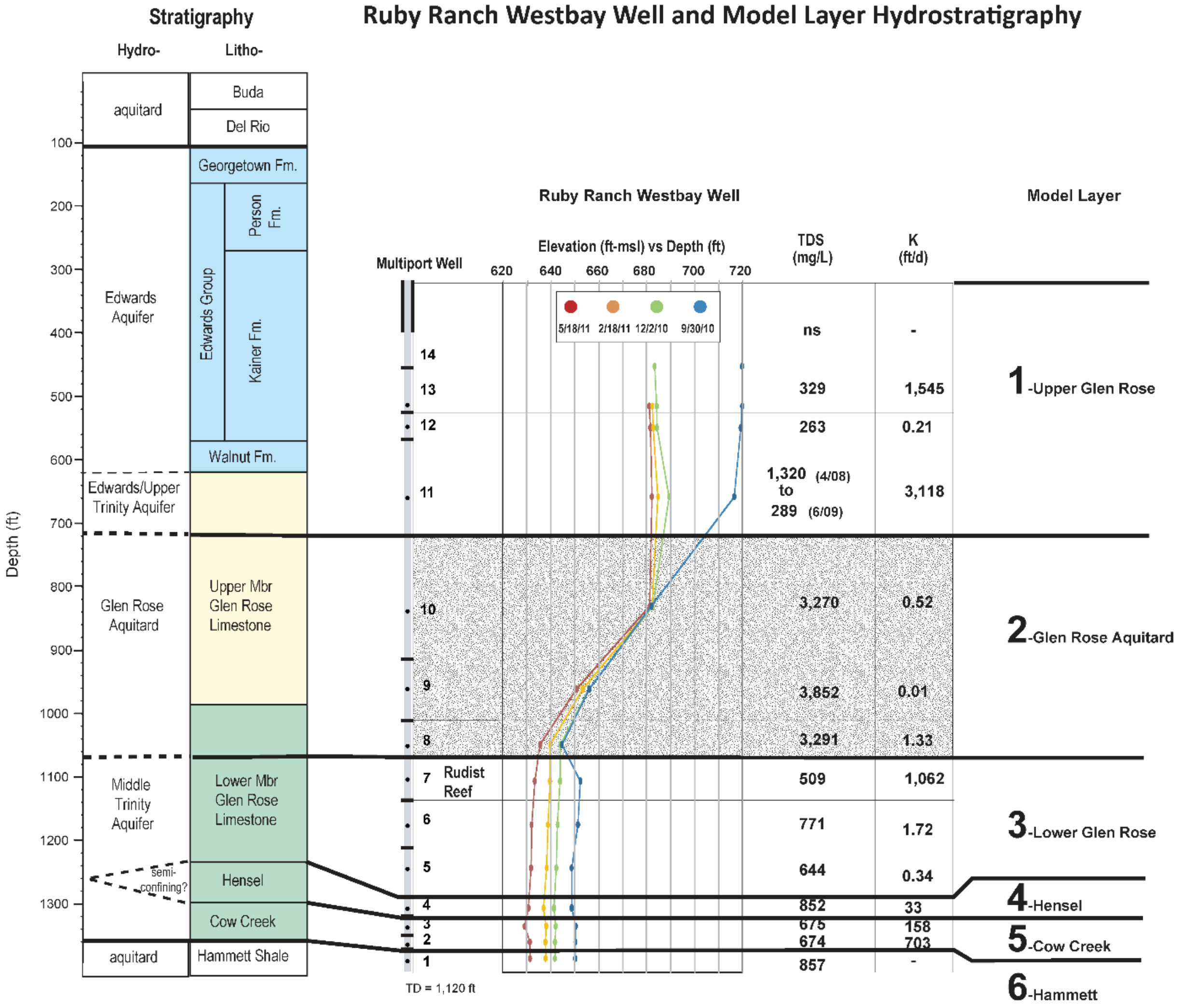


Figure 3. Stratigraphic chart, Ruby Ranch Westbay well, and model layer hydrostratigraphy

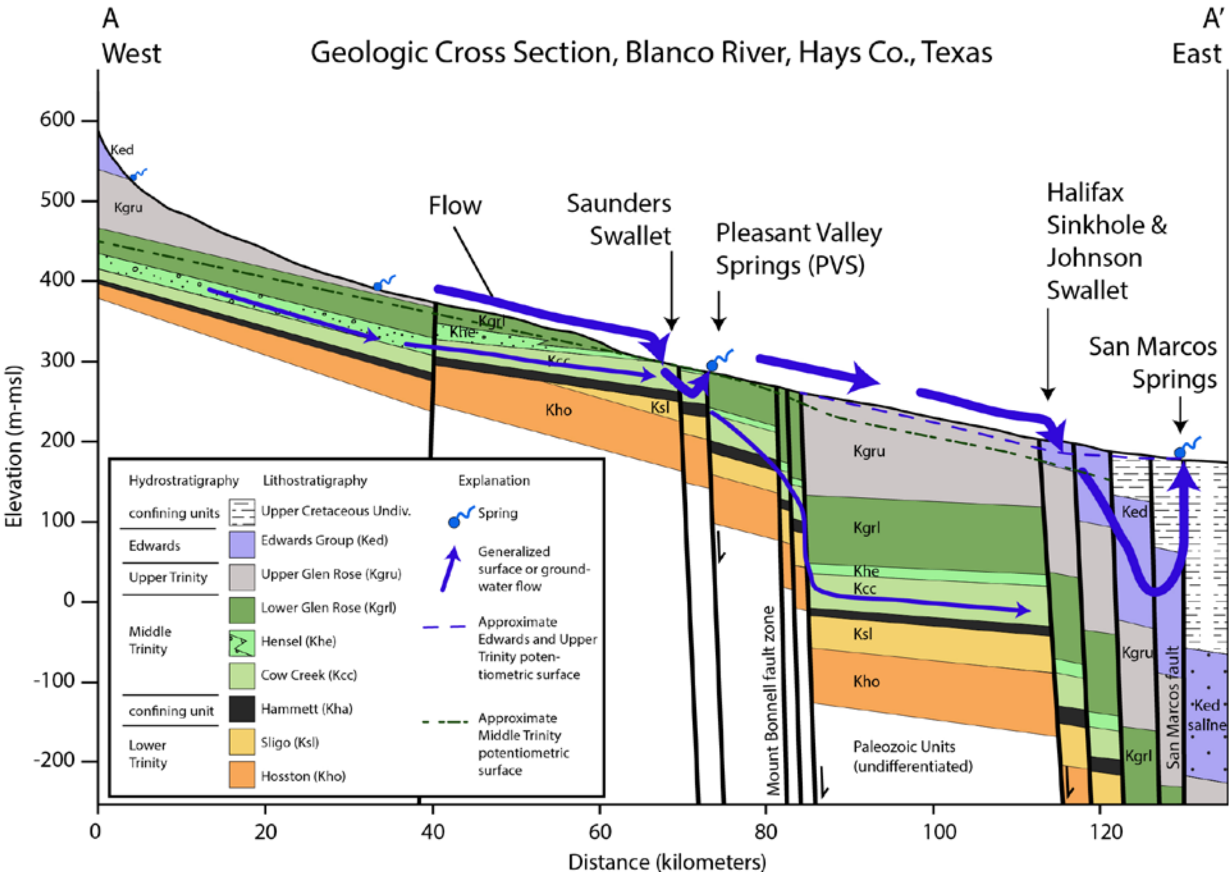


Figure 4. Geologic cross-section along the Blanco River in Hays County (from Wierman and others, 2010).

NUMERICAL MODEL:

Model Code:

The code chosen for this analysis is the transient analytic element groundwater modeling code known as TTIM (Bakker, 2015). TTIM was selected because it contains many characteristics that are key to this analysis including the ability to calibrate to pumping tests and evaluate drawdowns at a local scale for aquifers overlying and underlying the pumping unit (Cow Creek). A TTIM analytic element model can be developed much more cost effectively than a MODFLOW groundwater availability model. However, there are characteristics of the aquifer that are not simulated as part of the TTIM analysis. For instance, a MODFLOW groundwater availability model has aquifer properties that can vary spatially. A TTIM model assumes uniform aquifer properties horizontally within a particular unit. Similarly, a MODFLOW model can incorporate spatially varying aquifer structure and thickness. A TTIM model assumes uniform aquifer thickness. MODFLOW groundwater models have user-defined cell sizes. For the Texas Water Development Board's groundwater availability models, this is typically 1 mile x 1 mile. By contrast, a TTIM model is not limited by a user-defined cell size. Instead, the water level change (drawdown) is calculated at user-defined locations. That is, it can calculate drawdown at individual wells.

Given these differences in the assumptions and limitations of each of the modeling codes, MODFLOW is typically better suited for large, regional-scale groundwater resource evaluations. With its ability to evaluate impacts at individual well sites, TTIM is typically better suited for more local scale evaluations. For this reason, the results shown in this study are limited to the portion of Hays County in Groundwater Management Area 10.

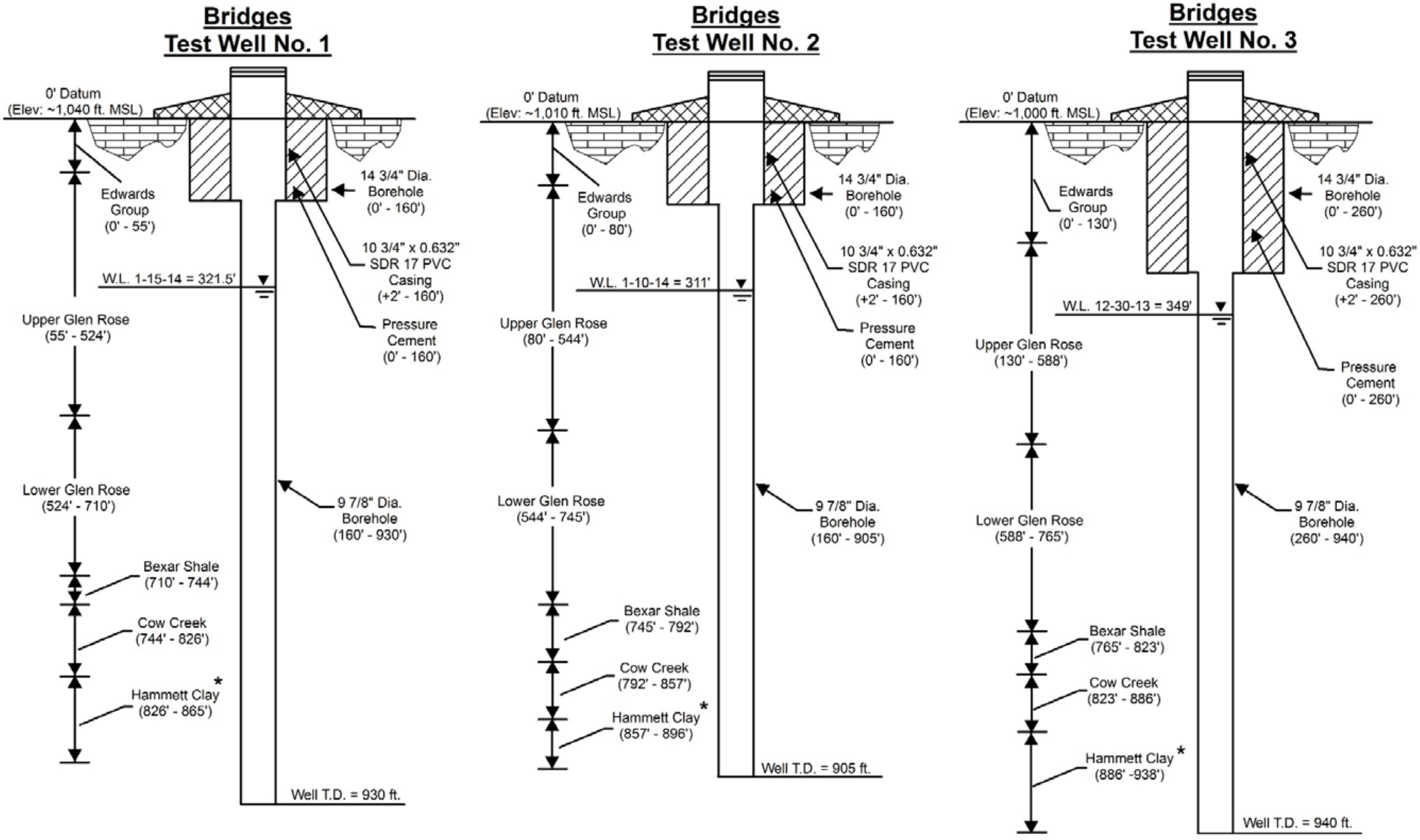
Model Calibration:

The model calibration focused on matching the aquifer test results at the EP well field in central Hays County near the boundary between Groundwater Management Area 9 (GMA 9) and GMA 10. We used the parameter estimation code PEST (Watermark, 2004) to aid in the matching of drawdowns in the pumping tests during model calibration. When using PEST, each of the model parameters are adjusted within a reasonable range to better match observed drawdowns. The model set up including layer thicknesses and aquifer properties is shown in Table 1. During calibration, the specific storage and horizontal and vertical hydraulic conductivities were adjusted.

Table 1. Model layering setup and mid-point calibrated hydraulic properties

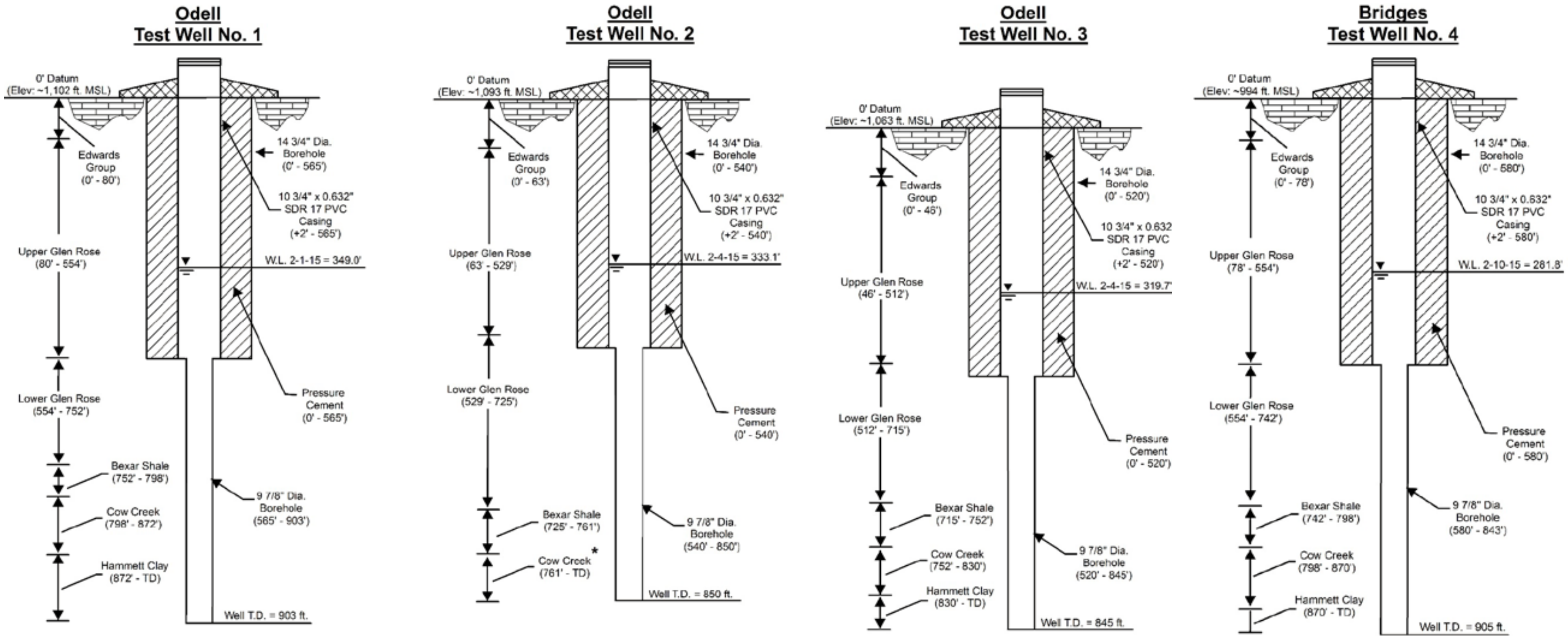
Unit	Thickness (ft)	Horizontal K (ft/d)	Transmissivity (ft^2/d)	Vertical Anisotropy	Specific Storage
Edwards	65	1.00E+01		5.00E-01	7.94E-07
Upper Glen Rose	470	1.74E-03		1.68E-02	1.50E-05
Lower Glen Rose	195	2.33E-01	45.5	4.91E-01	3.29E-07
Hensel	45	1.00E-04	0.0	1.00E-02	1.52E-04
Cow Creek	75	6.06E+00	454.3	6.58E-02	1.00E-07
Hammett	50	5.00E-07		1.00E-02	1.00E-04

The current well completions for the EP well field are open hole. During the pumping tests it was assumed that a majority of the pumping was sourced from the Cow Creek with a small amount from the Lower Glen Rose. As shown in Figure 5, the Bridges 1, Bridges 2 and Bridges 3 wells have some completion into and below the Hammett Clay. After discussions with BSEACD staff, we conclude it is reasonable to assume that the Hammett Clay and underlying Lower Trinity do not contribute significantly to water produced from the Bridges wells in the EP well field. For predictive simulations, it is our understanding that the wells will be completed to only produce from the Cow Creek.



Notes:
- Well profiles created with information from downhole geophysical surveys.
- Figure for schematic purposes; not drawn to scale.
* = Borehole filled in to a shallower depth than T.D. due to sloughing from the Hammet Clay

Figure 5. EP well field well completion diagrams (from WRGS, 2015).



Notes:
- Well profiles created with information from downhole geophysical surveys.
- Figure for schematic purposes; not drawn to scale.
* = Borehole filled in to a shallower depth than T.D. due to sloughing from the Hammett Clay

Figure 5. Continued.

The goal of the calibration was to match aquifer test results – to the extent possible – acknowledging that mismatches will occur due to heterogeneity in the aquifer. In order to better reflect aquifer impacts of an active pumping well, we normalized the drawdown targets so shorter periods with high drawdown carried as much weight as longer periods with little to no drawdown.

The test and observation well setup for the EP well field are shown in Table 2 (WRGS, 2015). We have removed all aquifer test results associated with the Bridges 3 well. This well does not appear to have a significant hydraulic connection to the other wells completed in the Cow Creek in the EP well field. As shown in Table 2, the Bridges 3 well had the lowest well yield (48 gallons per minute). The well also exhibited very little drawdown when used as an observation well during the pumping tests for Bridges 1 and Bridges 2. During the Bridges 1 test, no drawdown was observed in Bridges 3 which was 1.1 miles away. During the Bridges 2 test, only 2.6 feet of drawdown was observed at a distance of just over half a mile. Bridges 1 was also observed during the Bridges 2 pumping test at approximately the same distance (half mile). Bridges 1 showed 23.5 feet of drawdown during this test, approximately 10 times as much as was observed in Bridges 3.

Table 2. EP test and observation well pumping rates and drawdowns (from WRGS, 2015). All test and observation well results associated with Bridges 3 were omitted from the current analysis.

Pumping Well	Pumping Rate gpm (MGD)	Observation Well 1 (Distance from Pumping Well)	Observation Well 1 Drawdown	Observation Well 2 (Distance from Pumping Well)	Observation Well 2 Drawdown in feet
Bridges Test Well No. 1 (B-1)	435 (0.63)	B-3 (1.1 miles)	0 feet		
Bridges Test Well No. 2 (B-2)	333 (0.48)	B-1 (0.54 miles)	23.5 feet	B-3 (0.57 miles)	2.6 feet
Bridges Test Well No. 3 (B-3)	48 (0.07)				
Bridges Test Well No. 4 (B-4)	66 (0.09)	B-2 (0.35 miles)	4.7 feet	B-1 (0.64 miles)	0 feet
Odell Test Well No. 1 (O-1)	95 (0.14)	O-3 (0.44 miles)	8.7 feet	B-1 (0.33 miles)	7.5 feet
Odell Test Well No. 2 (O-2)	300 (0.43)	O-1 (0.29 miles)	22.7 feet	O-3 (0.54 miles)	14.3 feet
Odell Test Well No. 3 (O-3)	175 (0.25)	O-1 (0.44 miles)	9.9 feet	B-1 (0.64 miles)	20.4 feet

The calibrated hydraulic parameters are also shown in Table 1. The calibrated hydraulic conductivity of the Cow Creek is approximately 6 feet per day. The horizontal hydraulic conductivity of the Hensel is that of a confining unit at 10^{-4} feet per day. Because water levels in wells only completed in units shallower than the Cow Creek were not observed during these tests, the calibrated hydraulic parameters in the lower and upper Glen Rose units are not well constrained. For the lower Glen Rose and Cow Creek, the mid-point calibration results indicate approximately 90 percent of the transmissivity of the Middle Trinity is in the Cow Creek (454.3 ft^2/d for the Cow Creek, compared to 45.5 ft^2/d for the Lower Glen Rose). This is in-line with the conceptual model of flow for the aquifer in which the Cow Creek is the primary source of water produced.

Vertical anisotropy of the Hensel is a key parameter in this analysis as it strongly influences the degree to which pumping in the Cow Creek affects water levels in the overlying lower Glen Rose. A discussion of the sensitivity of the results to changes in the vertical anisotropy of the Hensel is included later in this memorandum.

Figure 6 through Figure 11 show a comparison of the model-predicted drawdowns to the measured drawdowns for the Bridges and Odell wells during calibration. Due to horizontal anisotropy in the aquifer and other heterogeneities, the model predicted drawdowns have significant variations from the observed drawdowns for several of the wells. For example, Bridges 1 has a model predicted drawdown greater than the observed drawdown during the aquifer test. However, Bridges 2 has a model-predicted drawdown less than the observed drawdown during its aquifer test. As shown for Bridges 1, the modeled drawdowns when Bridges 1 was used as an observation well more closely match observed drawdowns.

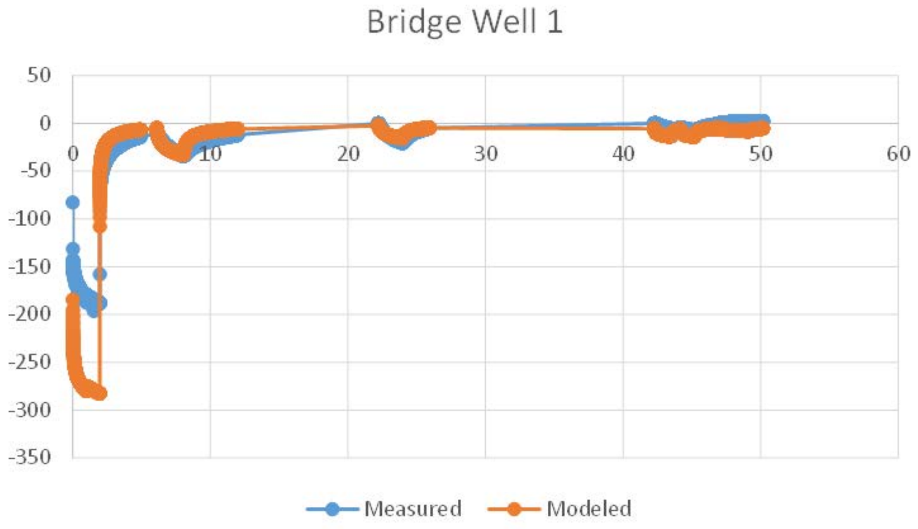


Figure 6. Comparison of measured to modeled drawdowns (in feet) for the Bridges 1 well.

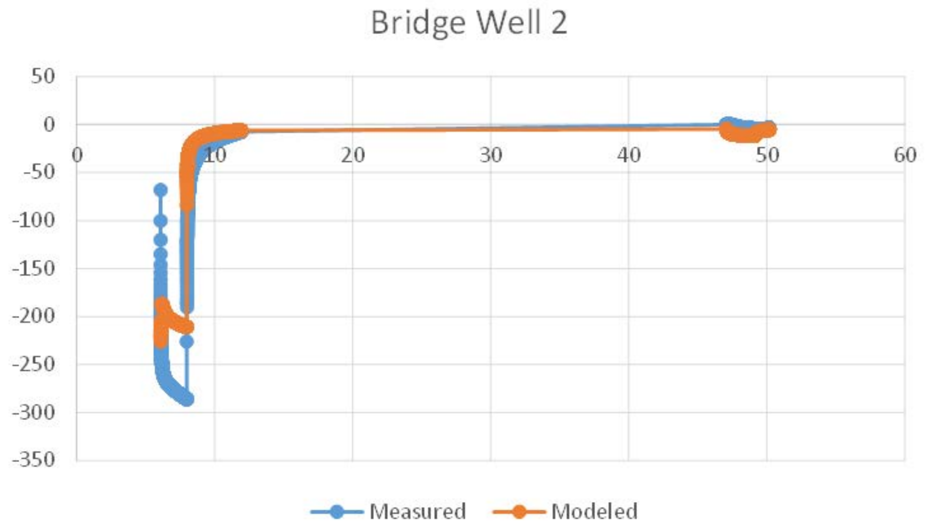


Figure 7. Comparison of measured to modeled drawdowns (in feet) for the Bridges 2 well.

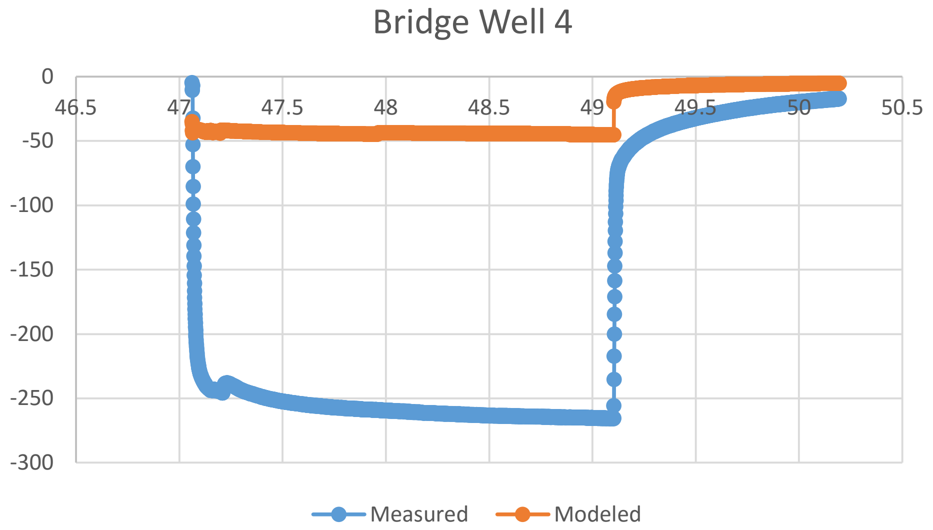


Figure 8. Comparison of measured to modeled drawdowns (in feet) for the Bridges 4 well.

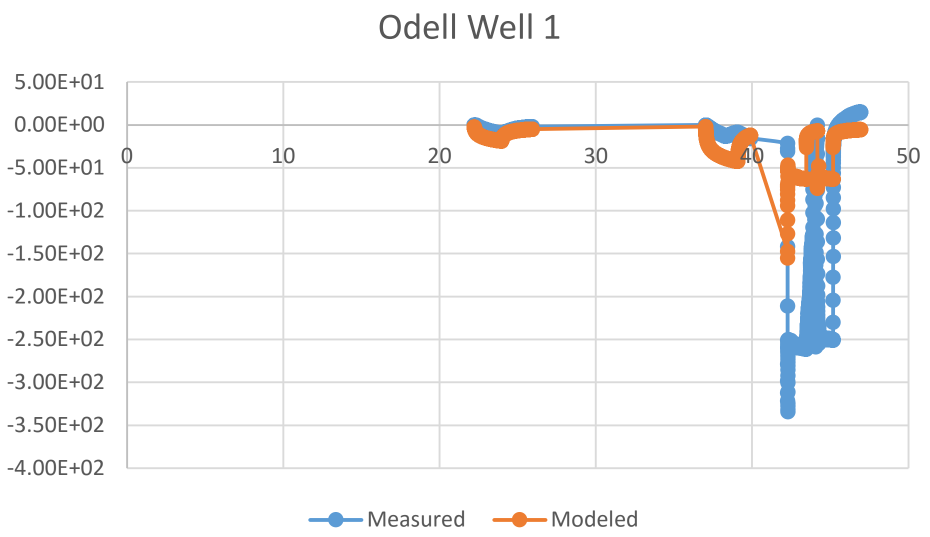


Figure 9. Comparison of measured to modeled drawdowns (in feet) for the Odell 1 well.

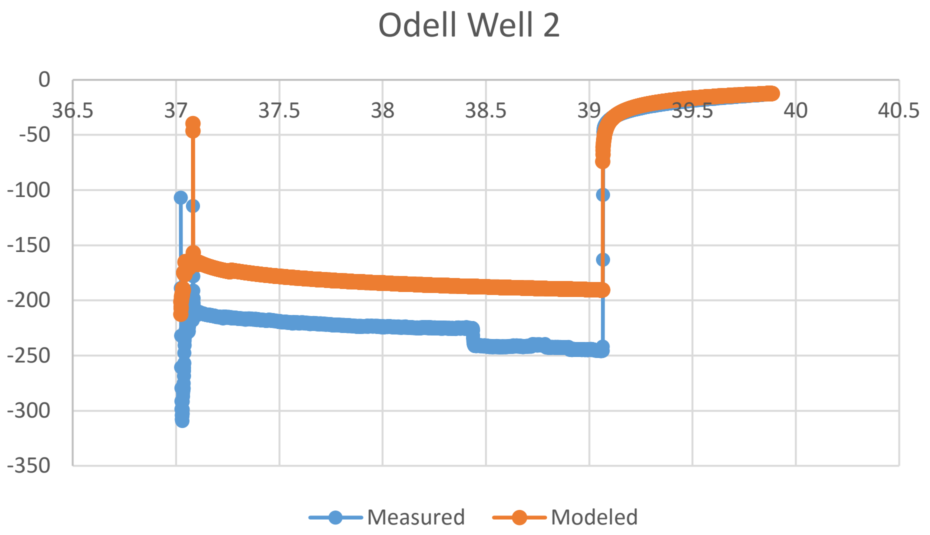


Figure 10. Comparison of measured to modeled drawdowns (in feet) for the Odell 2 well.

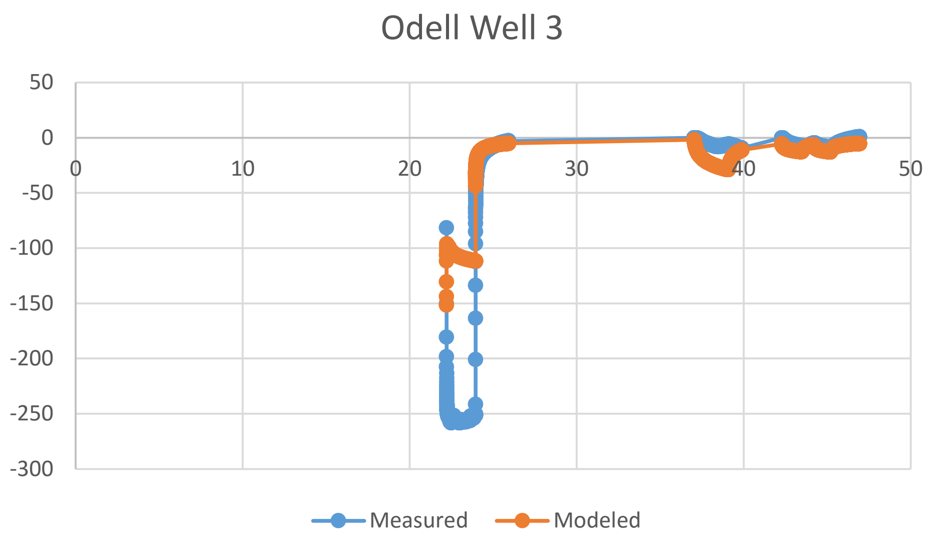


Figure 11. Comparison of measured to modeled drawdowns (in feet) for the Odell 3 well.

PREDICTIVE SIMULATIONS:

With the model calibrated to aquifer test results at the EP well field, the model was then used to evaluate the potential impacts to the units of the Trinity and overlying Edwards (Balcones Fault Zone) aquifers under a range of pumping scenarios. The predictive scenarios were chosen in coordination with the groundwater conservation districts in GMA 10. The results of these predictive scenarios are shown in Table 3 and Table 4. Cross-sections of drawdown in the Cow Creek, lower Glen Rose, and Edwards aquifers are shown in the Appendix.

Scenario Parameters:

Each of the scenarios described below use the same hydraulic properties and contain pumping from the same wells at the EP well field. The time period for each of the simulations is 50 years, consistent with the time period for the joint planning and regional water planning processes. The primary differences between the scenarios relate to the goal of the scenario – whether it is a specified pumping scenario or whether the scenario aims to achieve a specific drawdown at the well field or in GMA 10 in Hays County. The Bridges 1 well was chosen to represent drawdowns in the EP well field because of its location at the center of the field and because it had the highest pumping rate among the EP wells.

For the vertical anisotropy of the Hensel, scenarios 1 through 5 reflect the mid-point calibration with a vertical anisotropy of 0.01. Because of the sensitivity of the model results to the vertical hydraulic conductivity of the Hensel, scenarios 6 through 10 reflect the same five pumping/drawdown scenarios for a case in which the vertical anisotropy is 1.0. While this represents an anisotropy 100 times higher than the mid-point calibration, it is still a fairly restrictive unit because the horizontal hydraulic conductivity of the Hensel is 10^{-4}.

Scenario 1: Pumping of 2.47 Million Gallons Per Day

WRGS (2015) indicates that the expected productivity of the EP well field after the Bridges 3 well is plugged will be approximately 2.47 million gallons per day (1,717 gallons per minute). This conclusion comes from the well yields from the aquifer tests, a stated desire to keep the water level 60 feet above the top of the Cow Creek, and a "safety factor" of 25 percent. In this pumping scenario we applied the 2.47 million gallons per day to the well field by assigning pumping proportionally to the well yield established during the aquifer test. As shown in Table 3, the drawdown that occurs in the Cow Creek with this level of pumping is 805 feet after 50 years. Given the water level in the Cow Creek and the depth of the formation, this level of drawdown could not be achieved as the water level would be below the bottom of the aquifer.

Due to the restrictive nature of the Hensel in the mid-point calibration results, the impacts to the overlying lower Glen Rose in this scenario are relatively small. As shown in Table 3, the drawdown for the lower Glen rose is estimated to be only 6 feet after 50 years. Similarly, no drawdown is observed in this scenario in the Edwards (Balcones Fault Zone) Aquifer.

Scenario 2: Drawdown to 60 Feet Above the Cow Creek Top

For the second scenario we adjusted the pumping for the EP well field so that the resulting drawdown in the Cow Creek matches the stated goal in (WRGS, 2015) of keeping the water level 60 feet above the top of the Cow Creek unit. This condition results in a pumping rate for the field of 773 gallons per minute and a drawdown of 362 feet in the Cow Creek. As in Scenario 1, the drawdown impact to overlying units is limited. While this pumping achieves the stated goals for the well field in terms of drawdown, it is 55 percent less pumping than is estimated in WRGS (2015).

Scenario 3: Drawdown to the Cow Creek Top

Scenario 3 is similar to Scenario 2 except that the drawdown goal is set at the top of the Cow Creek. This 60 feet of additional drawdown compared to Scenario 2 is associated with 128 gallons per minute of additional pumping – totaling 901 gallons per minute for the field with 422 feet of drawdown in the Cow Creek.

Scenario 4: Drawdown to the Top of the Lower Glen Rose

For Scenario 4 the drawdown goal was set at the top of the lower Glen Rose. This represents the level of drawdown in the Cow Creek that could significantly affect water availability in the lower Glen Rose if there is significant communication between the two formations. The pumping that achieves this 182 feet of drawdown in the Cow Creek is 389 gallons per minute. As with the higher pumping scenarios, drawdown impacts to shallower formations are limited.

Scenario 5: Drawdown of 25 Feet for GMA 10 Portion of Hays County

Scenario 5 differs from scenarios 1 through 4 in that drawdown is calculated not at the center of the EP well field (Bridges 1), but as an average over the portion of Hays County in GMA 10. The drawdown was calculated not just for the Cow Creek portion of the Trinity Aquifer, but for the Trinity Aquifer as a whole consistent with desired future conditions being considered by the groundwater conservation districts in GMA 10. To calculate the Trinity Aquifer average drawdown the water level declines in each unit of the Trinity Aquifer (upper Glen Rose, lower Glen Rose, Hensel and Cow Creek) were weighted by the transmissivity of each unit (i.e. the product of the hydraulic conductivity and the aquifer thickness).

The aerial drawdown was calculated using TTIM by dividing the portion of GMA 10 in Hays County into one square mile blocks. Pumping was then adjusted iteratively until the Trinity Aquifer average drawdown inside the 298 square mile area matched the proposed desired future condition of an average drawdown of 25 feet. The pumping associated with this scenario was slightly more than Scenario 4 – 400 gallons per minute.

As described above, one limitation of TTIM is that it assumes constant horizontal hydraulic conductivity throughout a particular unit. Though it could not be incorporated into the model, one of the components of the conceptual model for the Trinity Aquifer is that, due to faulting and other heterogeneities, the horizontal hydraulic conductivity is greater along the strike of the Balcones Fault Zone (southwest to northeast) than along the dip of the aquifer (northwest to southeast). This horizontal anisotropy would lead to greater drawdowns along strike and lesser drawdowns along dip than the model predicts. A comparison of the modeled drawdowns to a conceptual representation of how anisotropy could affect drawdown contours is shown in Figure 12.

Table 3. Predictive simulation drawdowns (in feet) for scenarios 1 through 5 with a vertical anisotropy ratio for the Hensel of 0.01.

Hensel Vertical Hydraulic Conductivity Scenario	Hensel Vertical Hydraulic Conductivity = 10^{-6} feet/day				
Aquifer Impact Scenario	Scenario 1: 2.47 MGD	Scenario 2: 60 ft Above Cow Creek Top	Scenario 3: Cow Creek Top	Scenario 4: Lower Glen Rose Top	Scenario 5: GMA 10 Hays DFC 25 ft
EP Well Field Cow Creek Pumping Rate	1717 gpm	773 gpm	901 gpm	389 gpm	400 gpm
Drawdown Location	**Center of Proposed EP Well Field (Bridges 4 Well)**				
Edwards	0	0	0	0	0
Upper Glen Rose	-1	0	0	0	0
Lower Glen Rose	-6	-3	-3	-1	-2
Hensel	-60	-27	-32	-14	-14
CowCreek	-805	-362	-422	-182	-188
Trinity Average	*-731*	*-329*	*-384*	*-166*	*-170*
Drawdown Location	**Average for GMA 10 in Hays County**				
Edwards	0	0	0	0	0
Upper Glen Rose	0	0	0	0	0
Lower Glen Rose	-3	-1	-2	-1	-1
Hensel	-12	-6	-6	-3	-3
CowCreek	-118	-53	-62	-27	-28
Trinity Average	*-108*	*-49*	*-57*	*-24*	*-25*

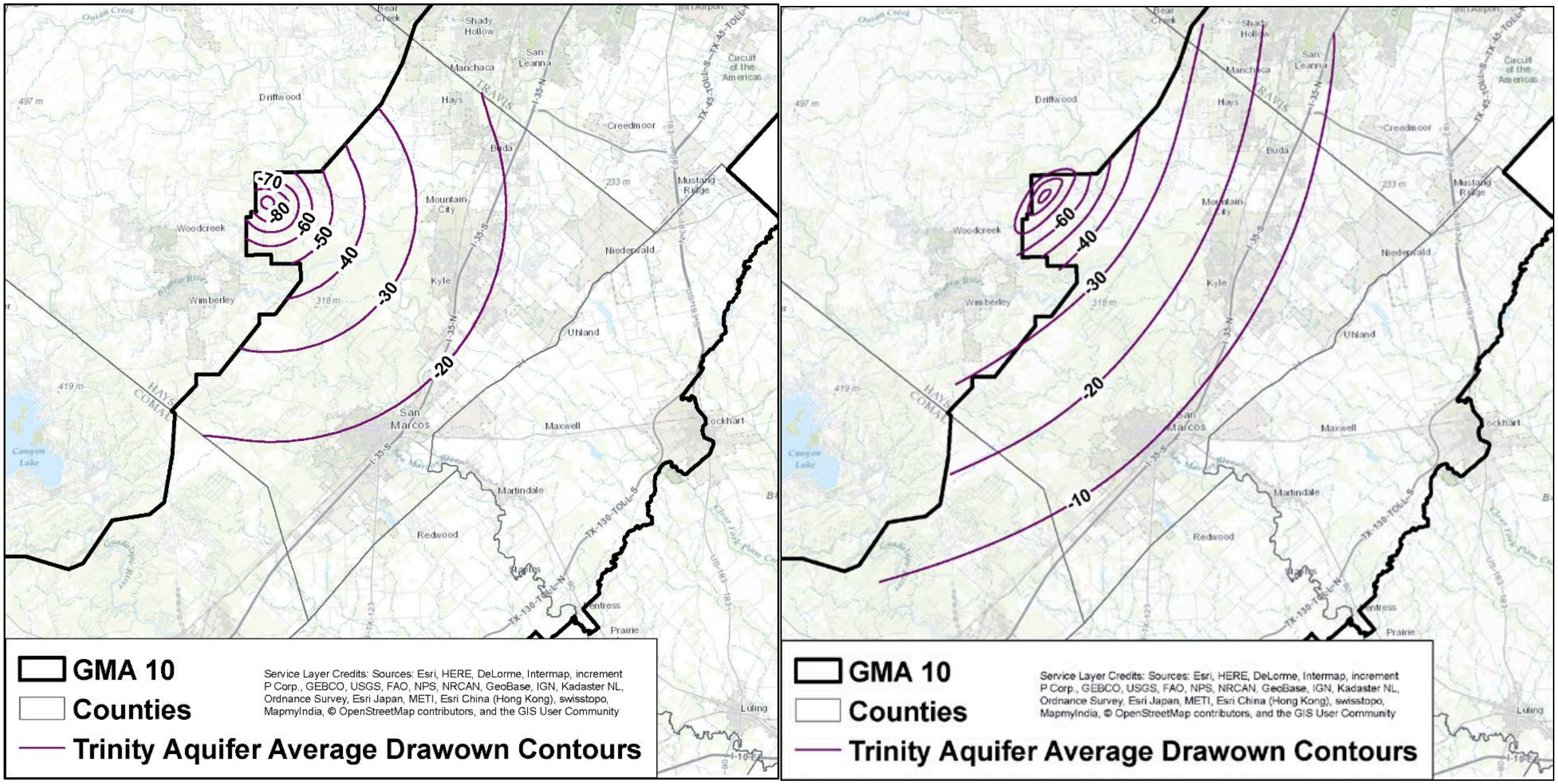


Figure 12. Comparison of modeled Trinity Aquifer average drawdown contours (left) to elongated contours designed to conceptually represent the effect of horizontal anisotropy (right).

Scenarios 6 through 10: Vertical Anisotropy of 1.0 for the Hensel

As mentioned above, the impacts of pumping in the Cow Creek on overlying units such as the lower Glen Rose are strongly influenced by the vertical anisotropy of the Hensel. The calibrated value for vertical anisotropy used in scenarios 1 through 5 above is 0.01. Since the horizontal hydraulic conductivity of the Hensel is 10^{-4} feet per day, the model vertical hydraulic conductivity used in scenarios 1 through 5 is 10^{-6} feet per day. This reflects a conceptual model of the Hensel as a highly confining unit, though because there were no observation wells in the shallower units during the EP pumping test, there is not a high degree of confidence in this calibrated value. Figure 13 shows the drawdown that would occur in the Cow Creek and lower Glen Rose units with pumping of 1,717 gallons per minute (2.47 million gallons per day) for different values of vertical hydraulic conductivity for the Hensel. As shown in Figure 13, higher values of vertical hydraulic conductivity in the Hensel lead to reduced drawdown impacts in the Cow Creek and increased drawdown impacts in the lower Glen Rose (and other overlying units).

Scenarios 6 through 10 are identical in purpose to scenarios 1 through 5 except that the vertical anisotropy of the Hensel has been increased to 1.0. This reflects a vertical hydraulic conductivity for the unit of 10^{-4} feet per day.

Table 4. Predictive simulation drawdowns (in feet) for scenarios 6 through 10 with a vertical anisotropy ratio for the Hensel of 1.0.

Hensel Vertical Hydraulic Conductivity Scenario	Hensel Vertical Hydraulic Conductivity = 10^{-4} feet/day				
Aquifer Impact Scenario	Scenario 6: 2.47 MGD	Scenario 7: 60 ft Above Cow Creek Top	Scenario 8: Cow Creek Top	Scenario 9: Lower Glen Rose Top	Scenario 10: GMA 10 Hays DFC 25 ft
EP Well Field Cow Creek Pumping Rate	1717 gpm	917 gpm	1069 gpm	461 gpm	1175 gpm
Drawdown Location	**Center of Proposed EP Well Field (Bridges 4 Well)**				
Edwards	-4	-2	-2	-1	-2
Upper Glen Rose	-41	-22	-26	-11	-28
Lower Glen Rose	-220	-118	-137	-59	-151
Hensel	-360	-192	-224	-97	-246
CowCreek	-679	-363	-423	-182	-465
Trinity Average	*-636*	*-340*	*-396*	*-171*	*-435*
Drawdown Location	**Average for GMA 10 in Hays County**				
Edwards	-2	-1	-1	-1	-1
Upper Glen Rose	-5	-3	-3	-1	-3
Lower Glen Rose	-33	-17	-20	-9	-22
Hensel	-34	-18	-21	-9	-23
CowCreek	-37	-20	-23	-10	-25
Trinity Average	*-37*	*-20*	*-23*	*-10*	*-25*

Table 4 shows the results of scenarios 6 through 10. In scenario 6, the 1,717 gallons per minute results in 679 feet of drawdown in the Cow Creek and 220 feet of drawdown in the lower Glen Rose. As the drawdown impacts are distributed across more aquifer units with the higher vertical anisotropy, the pumping rates associated with the drawdown conditions of scenarios 7, 8 and 9 are higher than the pumping rates for scenarios 2, 3 and 4. The most significant difference in these scenarios is in Scenario 10 which reflects the Trinity Aquifer average drawdown of 25 feet for GMA 10 in Hays County. The Scenario 10 pumping of 1,175 gallons per minute is nearly 3 times the pumping of Scenario 5.

A key takeaway from Figure 13 and a comparison of scenarios 1 through 5 to scenarios 6 through 10 is that the drawdown results and productivity of the EP well are very sensitive to the Hensel vertical hydraulic conductivity.

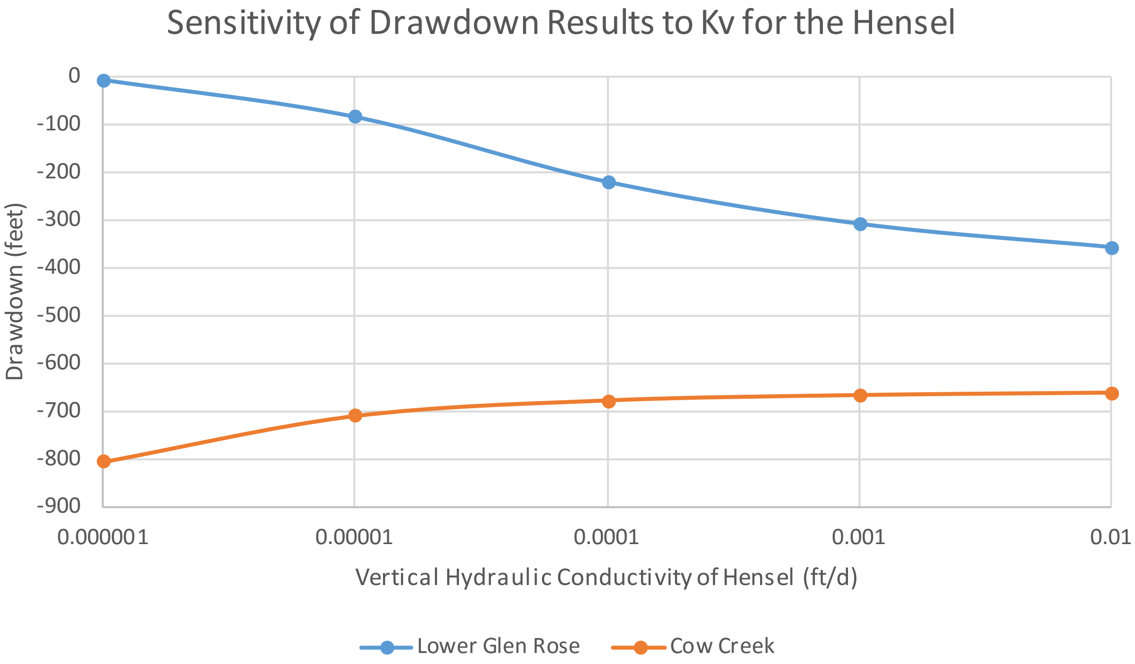


Figure 13. Sensitivity of Cow Creek and lower Glen Rose drawdown to the vertical hydraulic conductivity of the Hensel. Assumes pumping in the EP well field of 2.47 million gallons per day. Drawdowns after 50 years shown for Bridges 1 well.

LIMITATIONS:

All modeling studies inherently have simplifications and limitations to their applicability. This analysis is no different. As described above, the modeling code selected for this analysis (TTIM) is better suited to local/well field-scale analyses than for large, regional-scale analysis such as GMA 10. For this reason, the largest scale of impacts we have presented here is for the portion of GMA 10 in Hays County.

TTIM does not directly account for recharge from precipitation to the aquifer, though because it assumes an infinite aquifer extent, it allows for lateral flow – and increases in lateral flow – that would be observed in a system connected to an up-dip recharge area. At the time of this writing, the Texas Water Development Board is in the process of soliciting qualifications from firms to develop a groundwater availability model covering the Trinity Aquifer throughout GMA 10. While the analysis presented here has limitations, particularly as it relates to drawdowns over large areas, it is our opinion that this is the best tool available to evaluate impacts to the Trinity aquifer and its component units. During the next round of joint planning (2021) it is likely that a more comprehensive tool will be available for regional scale analyses.

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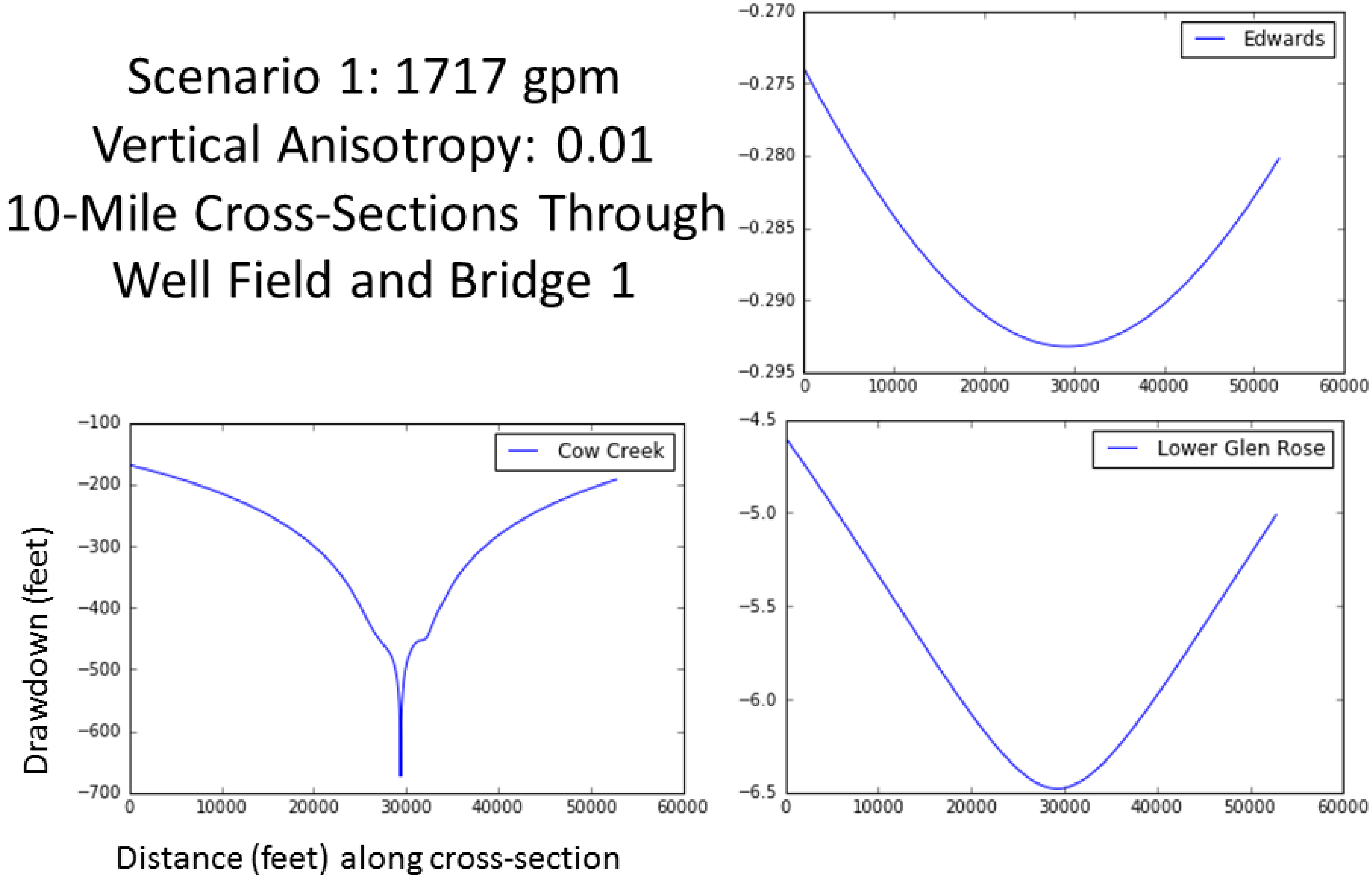
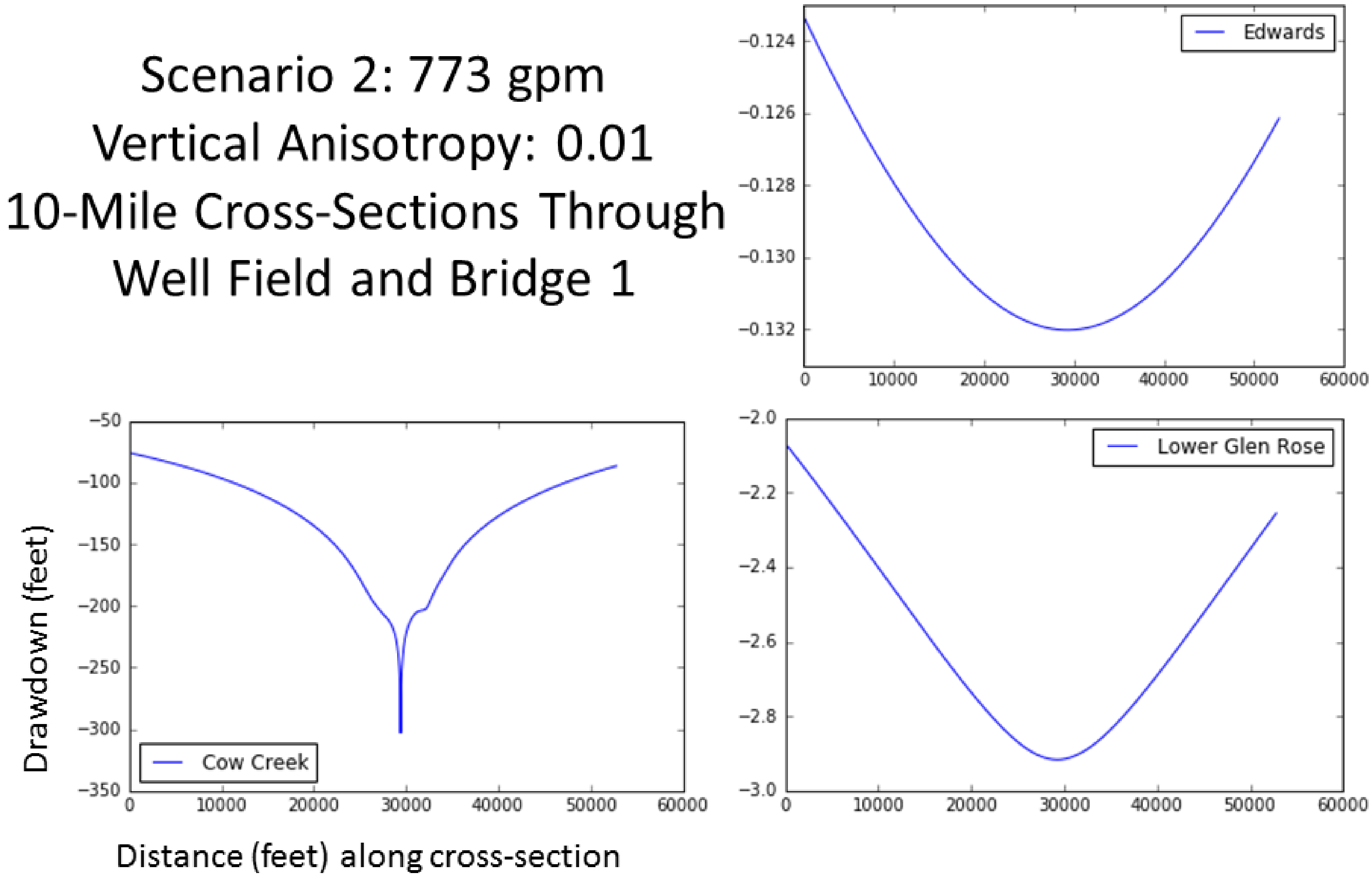
APPENDIX

Drawdown Profiles for Predictive Pumping Scenarios 1 through 10



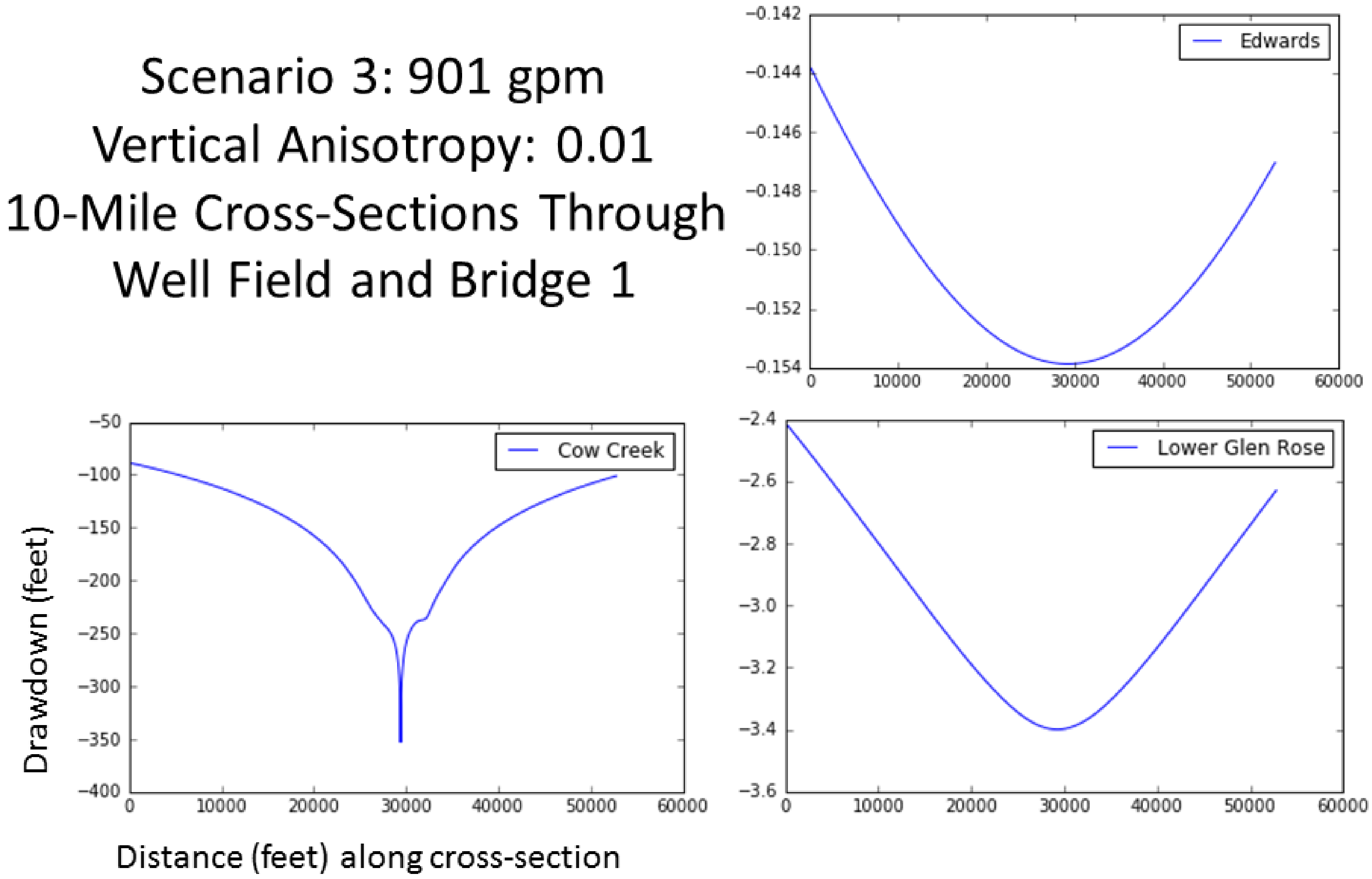
Scenario 1: 1717 gpm
Vertical Anisotropy: 0.01
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-1. Drawdown profiles for Scenario 1 across a 10-mile cross-section through the EP well field.



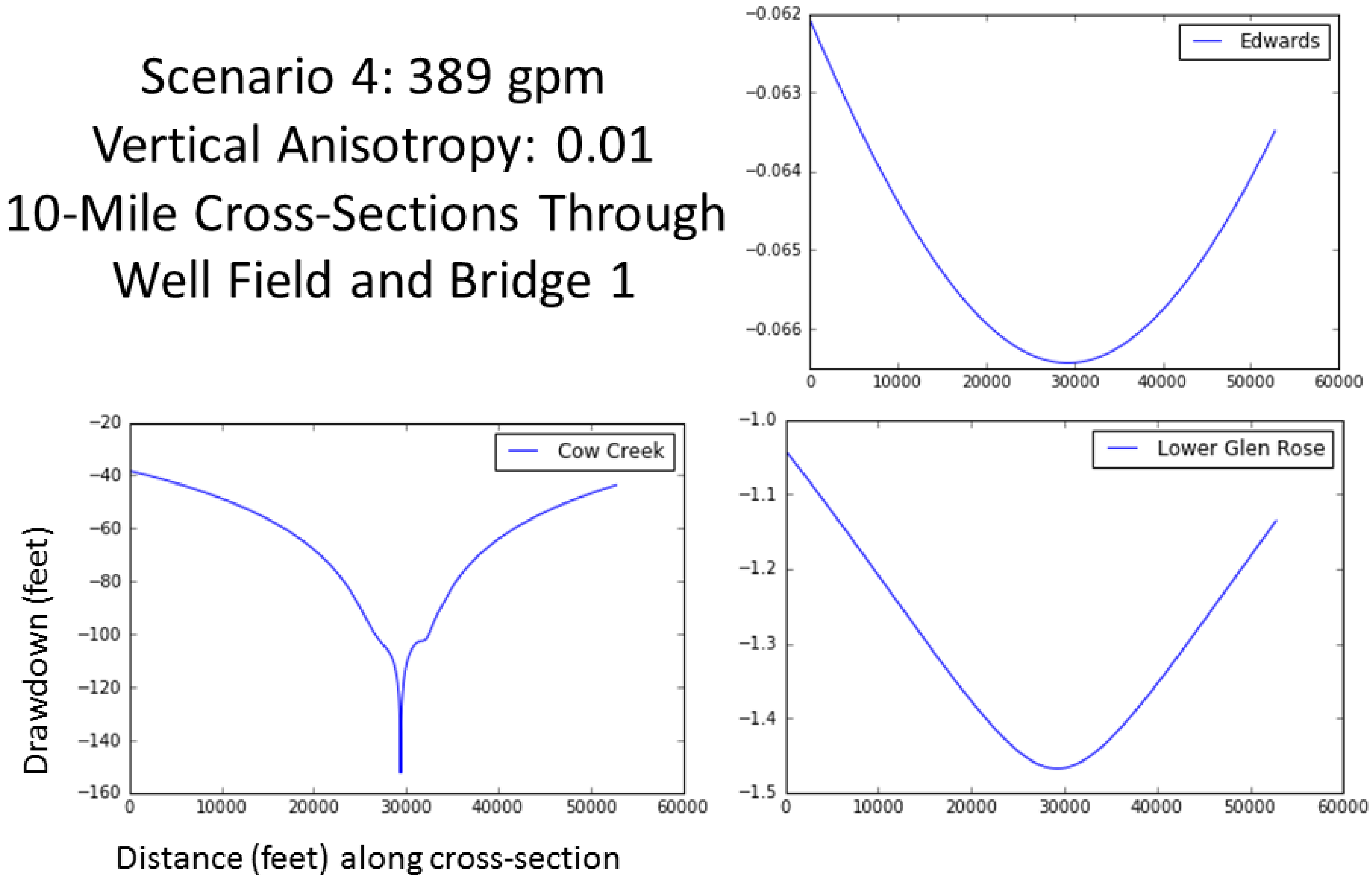
Scenario 2: 773 gpm
Vertical Anisotropy: 0.01
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-2. Drawdown profiles for Scenario 2 across a 10-mile cross-section through the EP well field.



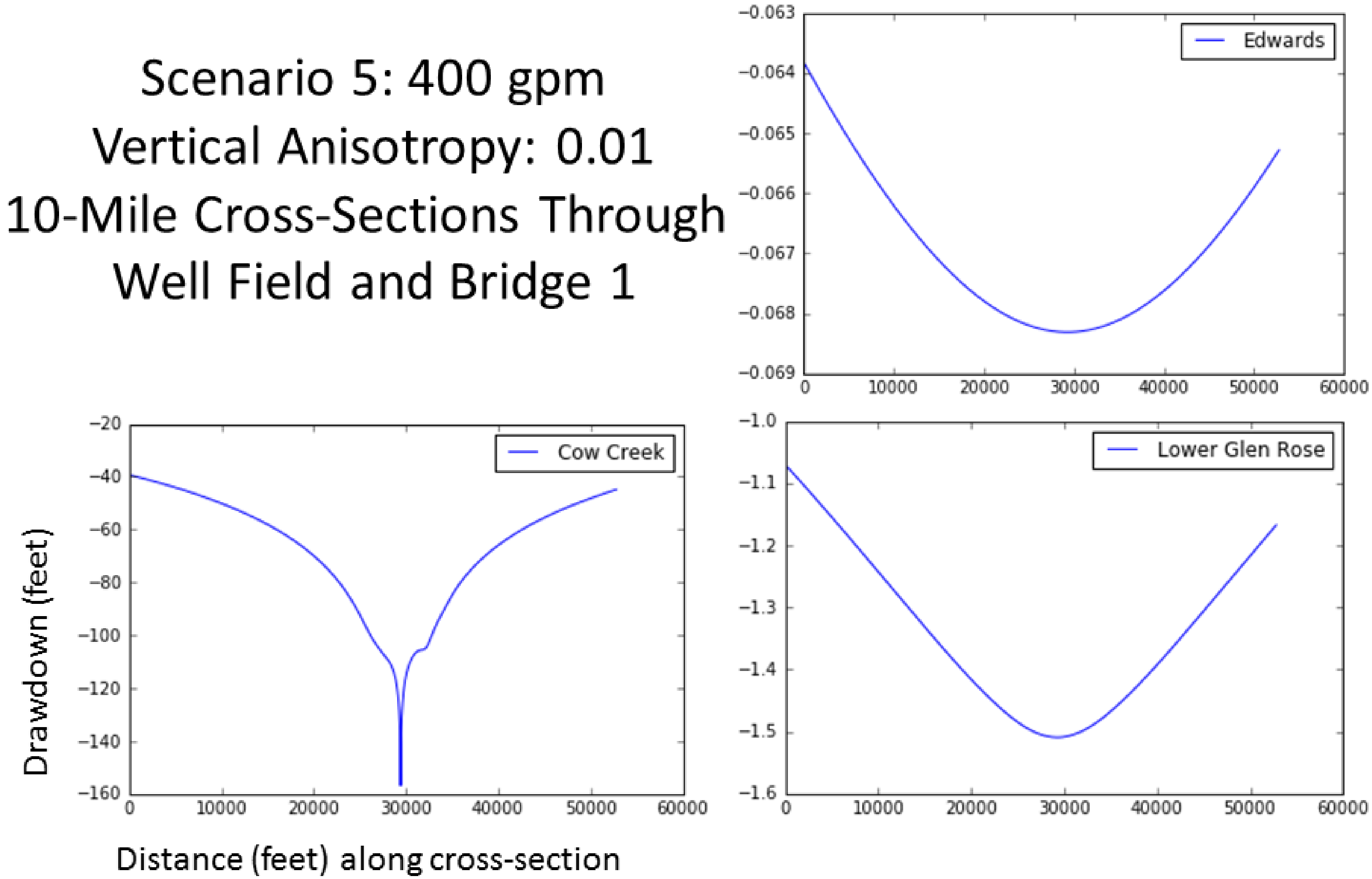
Scenario 3: 901 gpm
Vertical Anisotropy: 0.01
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-3. Drawdown profiles for Scenario 3 across a 10-mile cross-section through the EP well field.



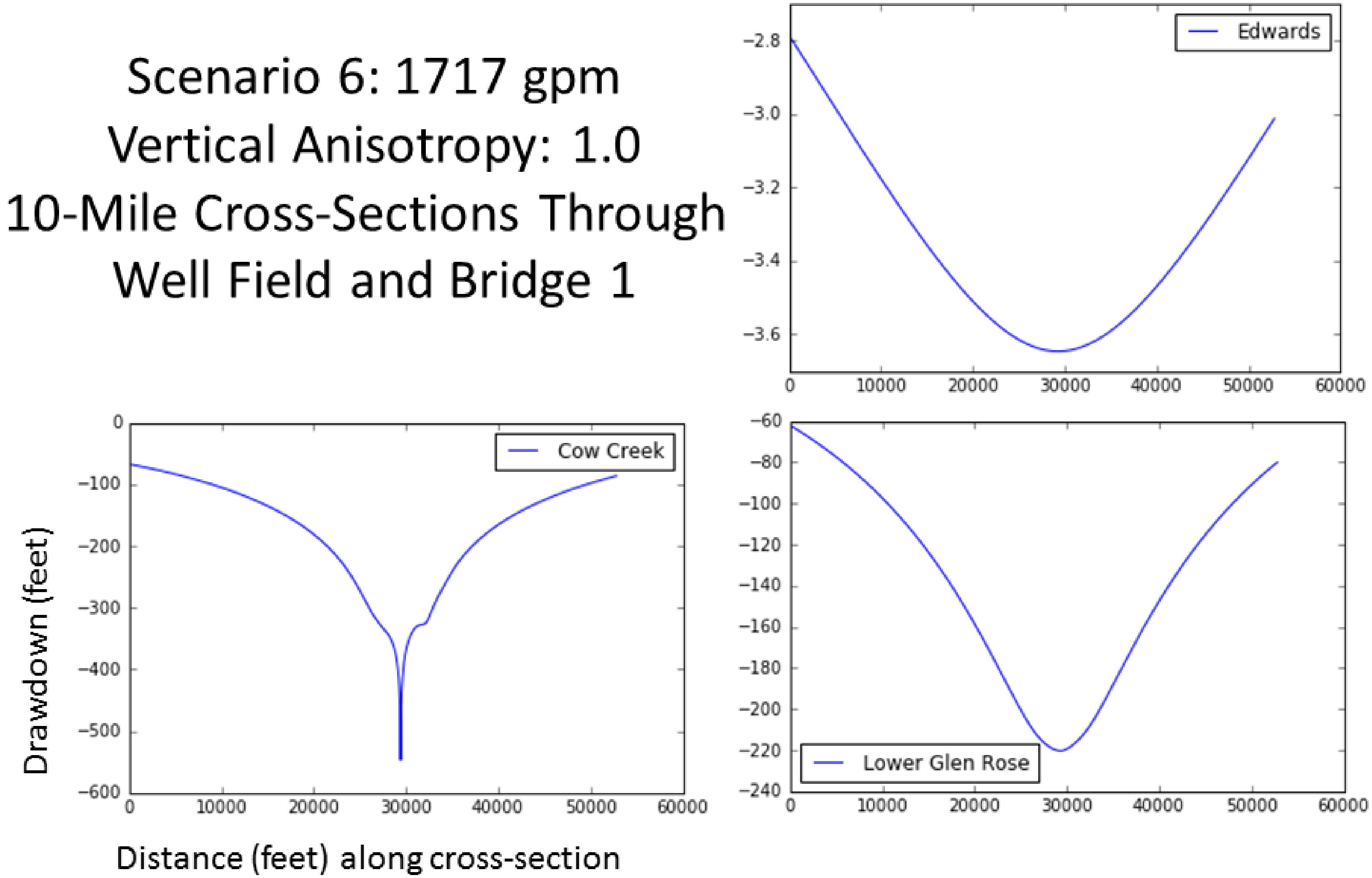
Scenario 4: 389 gpm
Vertical Anisotropy: 0.01
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-4. Drawdown profiles for Scenario 4 across a 10-mile cross-section through the EP well field.



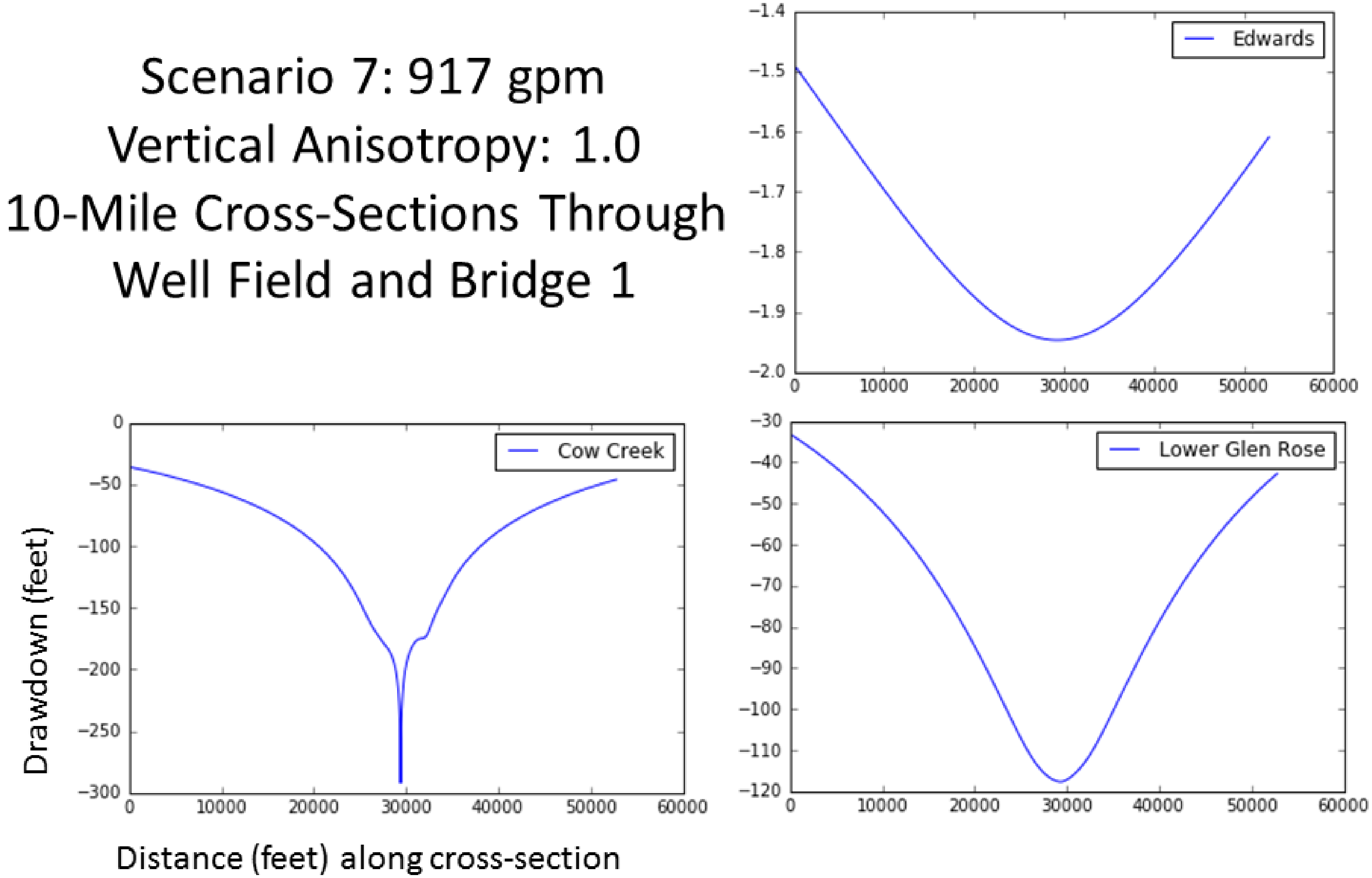
Scenario 5: 400 gpm
Vertical Anisotropy: 0.01
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-5. Drawdown profiles for Scenario 5 across a 10-mile cross-section through the EP well field.



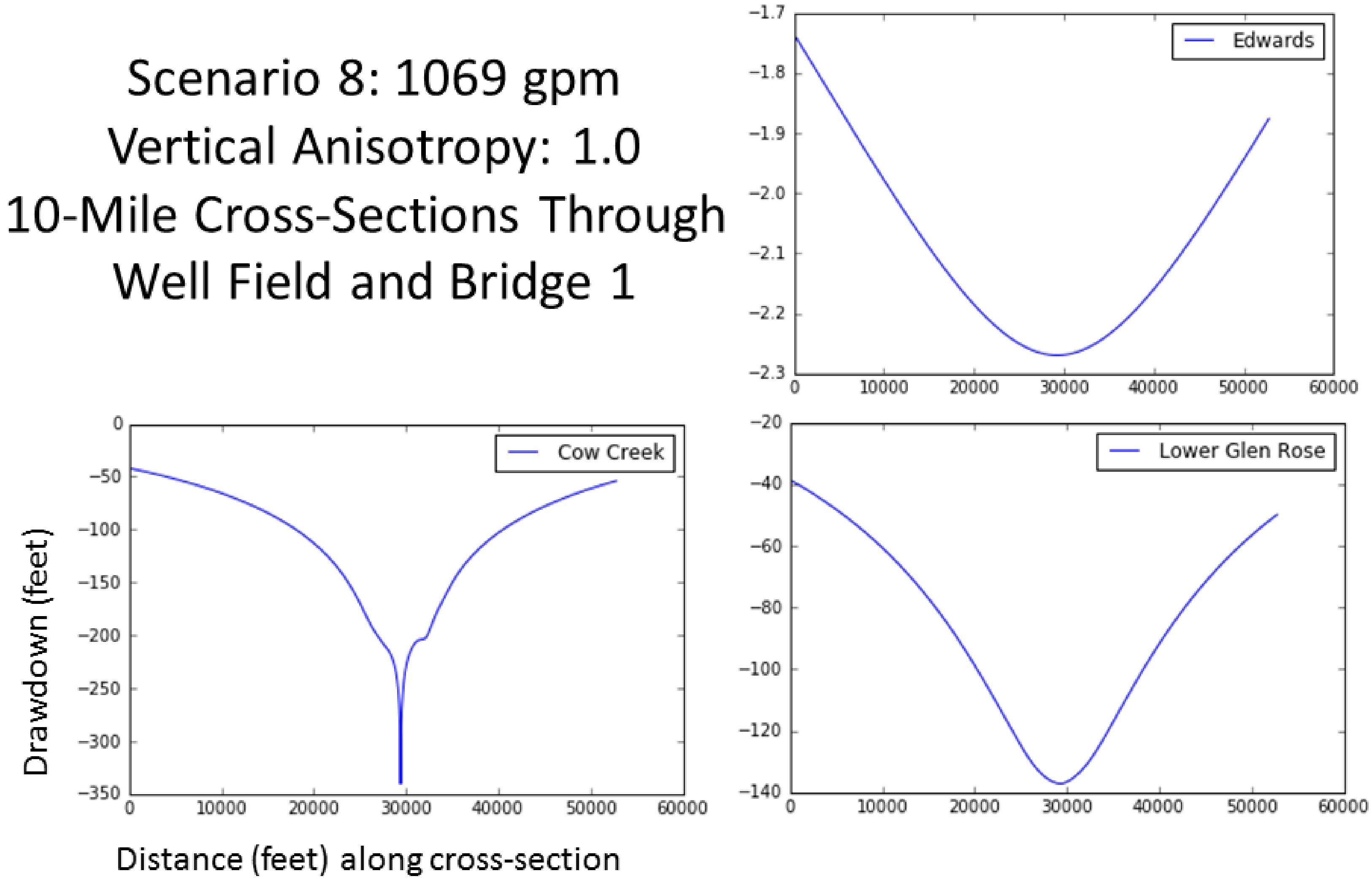
Scenario 6: 1717 gpm
Vertical Anisotropy: 1.0
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-6. Drawdown profiles for Scenario 6 across a 10-mile cross-section through the EP well field.



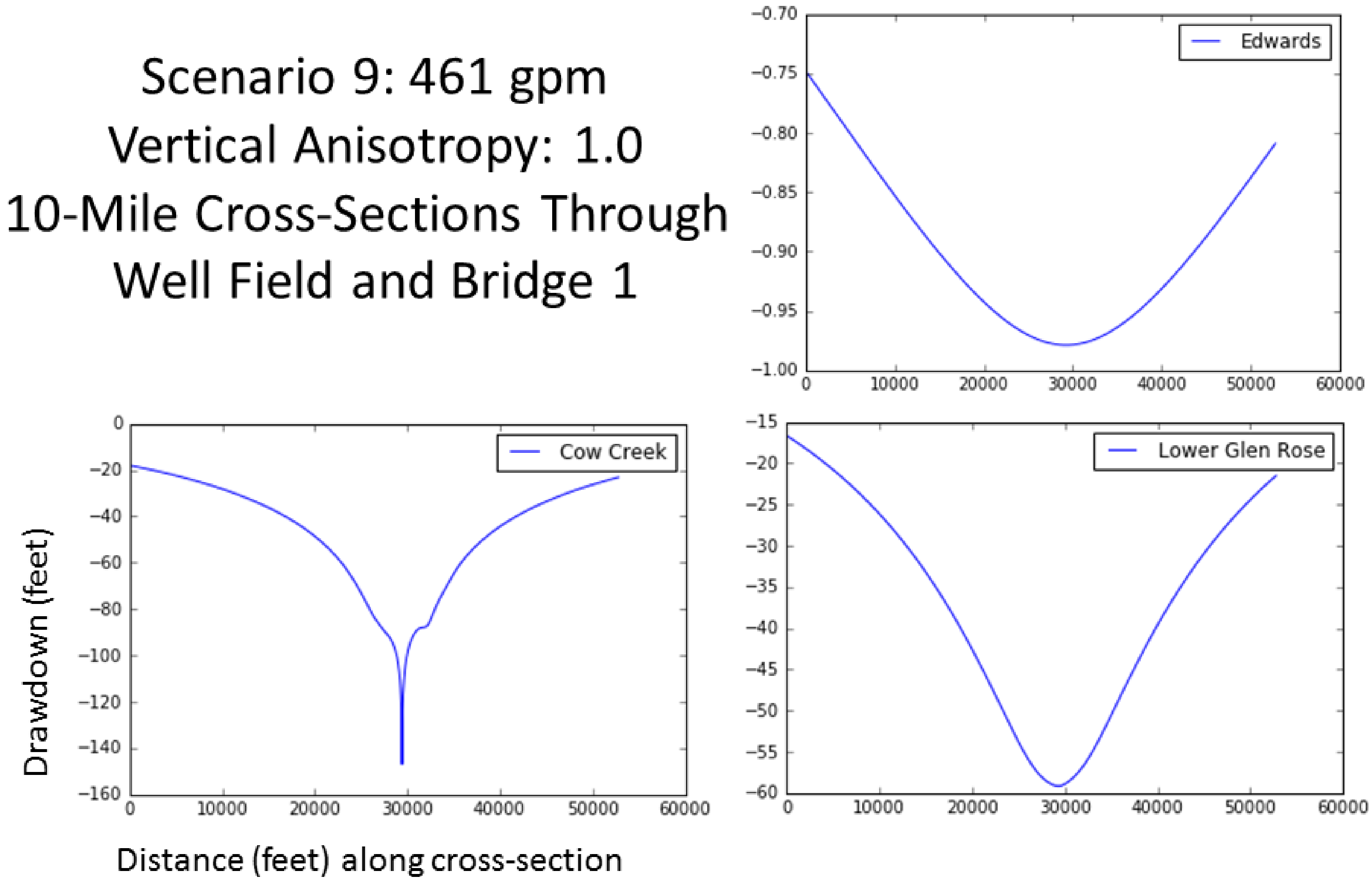
Scenario 7: 917 gpm
Vertical Anisotropy: 1.0
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-7. Drawdown profiles for Scenario 7 across a 10-mile cross-section through the EP well field.



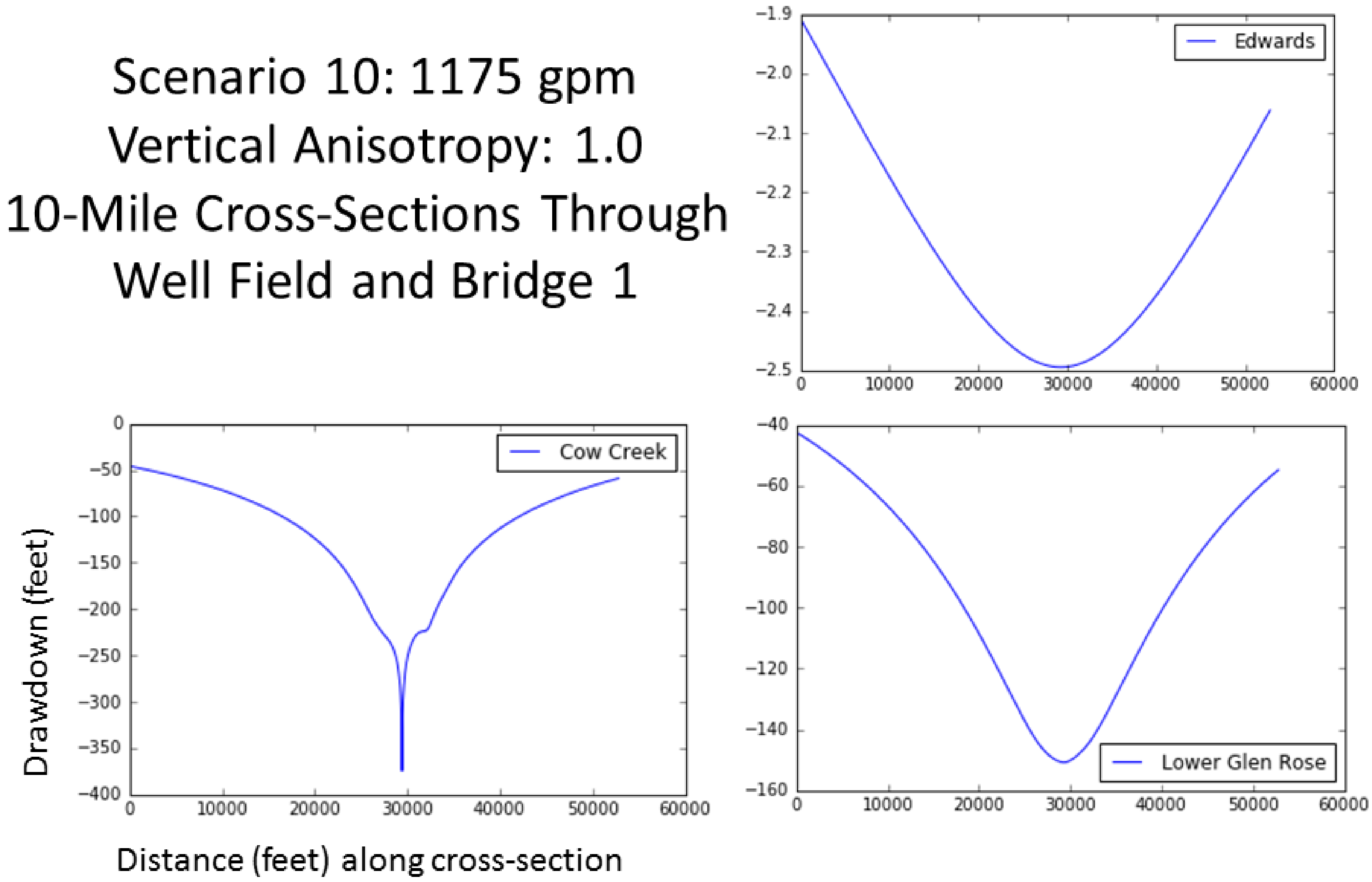
Scenario 8: 1069 gpm
Vertical Anisotropy: 1.0
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-8. Drawdown profiles for Scenario 8 across a 10-mile cross-section through the EP well field.



Scenario 9: 461 gpm
Vertical Anisotropy: 1.0
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-9. Drawdown profiles for Scenario 9 across a 10-mile cross-section through the EP well field.



Scenario 10: 1175 gpm
Vertical Anisotropy: 1.0
10-Mile Cross-Sections Through
Well Field and Bridge 1

Figure A-10. Drawdown profiles for Scenario 10 across a 10-mile cross-section through the EP well field.