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

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Abbreviations

DFC	Desired Future Conditions
GCD	Groundwater Conservation District
GMA	Groundwater Management Area
RWPG	Regional Water Planning Group
MAG	Modeled Available Groundwater
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, Comal Trinity GCD, Edwards Aquifer Authority, Kinney County GCD, Medina County GCD, Plum Creek Conservation District, and Uvalde County Underground Water Conservation District (UWCD) (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 for purposes of joint planning. This document is the preliminary Explanatory Report for this aquifer.

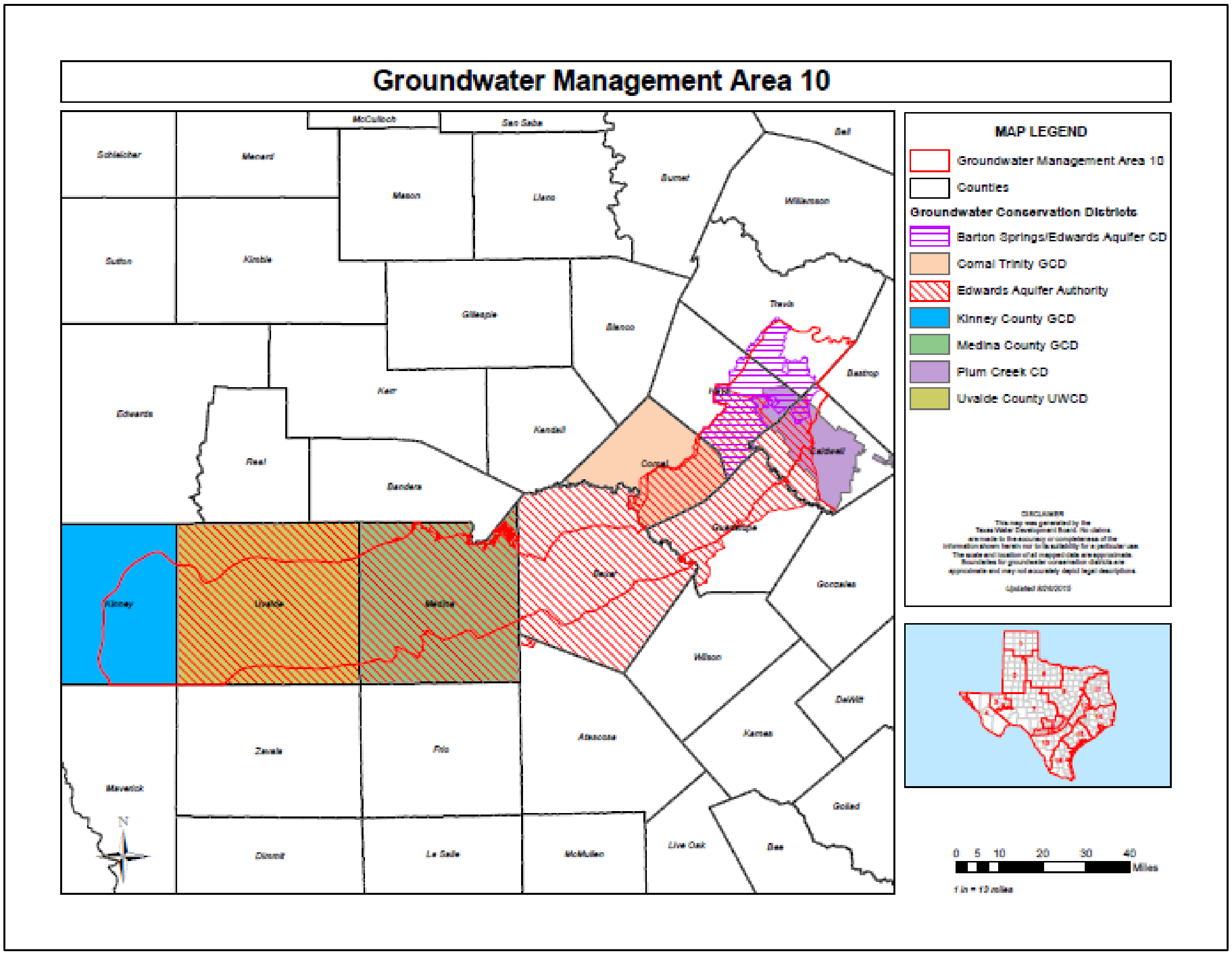

Figure 1. Map of the administrative boundaries of GMA 10 designated for joint-planning purposes and the GCDs in the GMA (From Texas Water Development Board website)

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) has low yields and poor water quality due to its evaporite beds. The middle Trinity Aquifer (comprising the lower Glen Rose Limestone, the Hensel Sand, and Cow Creek Limestone) is the most widely used portion of the aquifer. The lower Trinity Aquifer (comprising the Hosston Sand and Sligo Limestone) is 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.

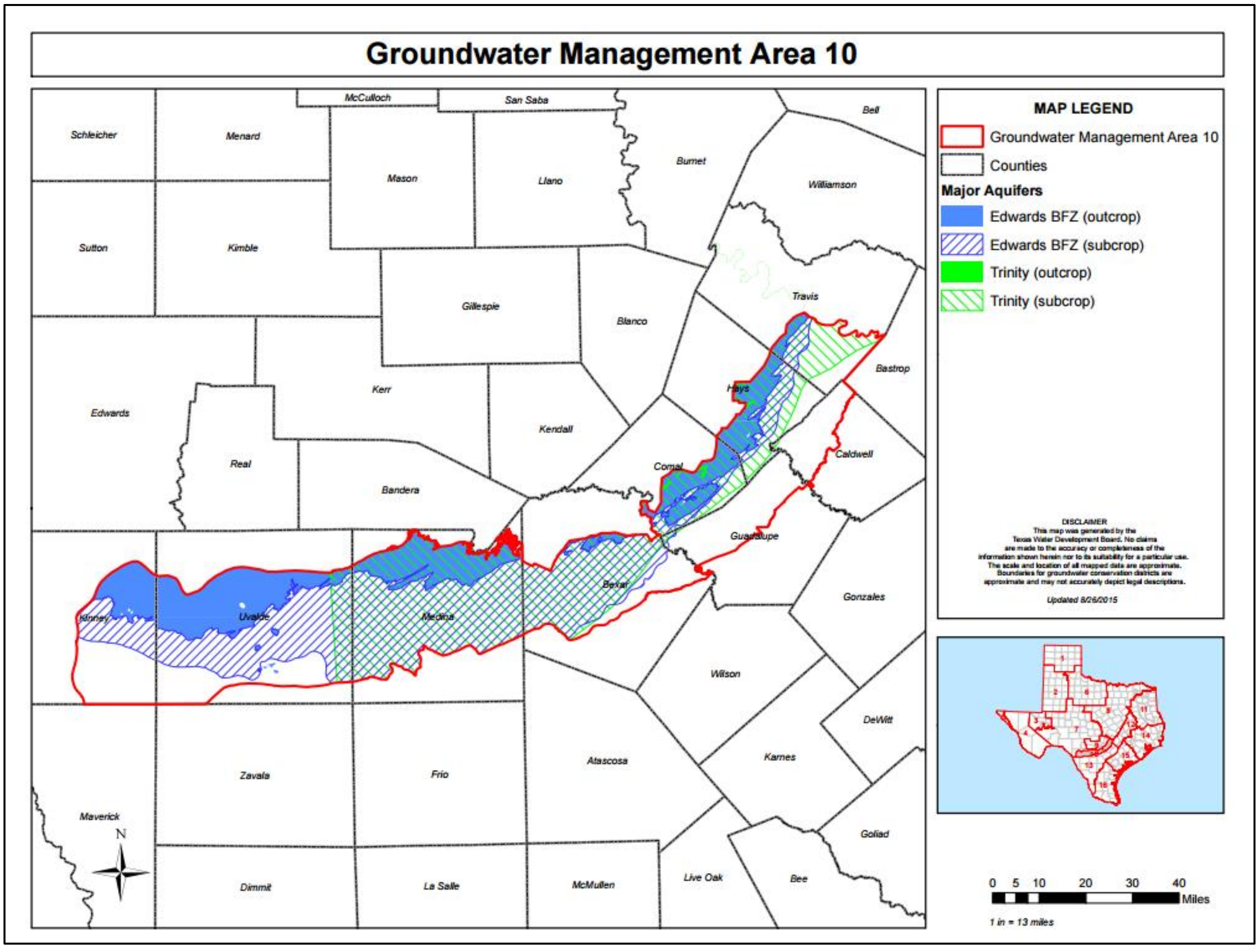

Figure 2. Map showing the extent of the Trinity Aquifer in GMA 10 (From Texas Water Development Board website)

3. Desired Future Conditions

The desired future conditions (DFC) adopted on 8/23/2010 for the Trinity Aquifer are as follows: *Average regional well drawdown not exceeding 25 feet during average recharge conditions (including exempt and non-exempt use); within Hays-Trinity Groundwater Conservation District: no drawdown; within Uvalde County: 20 feet; not relevant in Trinity-Glen Rose GCD.* (TWDB, 2015)

GMA 10 has proposed to maintain the same DFCs in the second round as in the first round for this aquifer, with the exception of Hays-Trinity GCD, which is no longer in GMA 10. This second round of proposed DFCs was approved at the GMA 10 meeting on March 14, 2016 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 March 14, 2016.

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 water plan;

3. Hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage 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 as recognized 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 GCDs in GMA 10 regard the Trinity Aquifer as an alternative water supply that poses little threat to the overlying Edwards Aquifer—and in fact can lessen demands placed upon it. The proposed DFC is an expression of average drawdown of the potentiometric surface. Table 1 is an estimate 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)

County	**Estimated Annual Modeled Available Groundwater (acre-ft/yr)**
Bexar	19,998
Caldwell	0
Comal	29,284
Guadalupe	0
Hays	3,557*
Medina	5,369
Travis	641
Uvalde	639
Total	**59,488***

*The Hays County total has been reduced by 258 acre-ft/yr to account for the Hays-Trinity GCD, which was included in Thorkildsen and Backhouse (2010), but is no longer in GMA 10.

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 2 provides the amount of groundwater in acre-feet supplied by the Trinity Aquifer for the period 2000-2013. The Trinity Aquifer does not provide the majority of groundwater in any county, although the Trinity Aquifer share has increased from 2000 to 2012 in Comal, Hays, and Travis counties. The TWDB does not report any pumping from the Trinity Aquifer in Caldwell or Kinney counties.

Table 2. Total groundwater pumpage values by county from the Trinity Aquifer in acre-ft/yr. Note that pumping estimates may include areas of the Trinity Aquifer outside of GMA 10. Values from https://www.twdb.texas.gov/waterplanning/waterusesurvey/historical-pumpage.asp

County	Bexar	Comal	Guadalupe	Hays	Medina	Travis	Uvalde
2000	7,974	2,895	0	2,236	42	1,868	49
2001	8,761	2,422	0	2,441	33	1,969	46
2002	9,425	2,229	0	2,212	35	1,944	45
2003	8,681	2,169	0	2,115	36	1,944	43
2004	9,301	5,642	0	2,024	35	1,754	40
2005	11,579	5,404	0	2,249	186	1,929	61
2006	11,353	6,916	4	3,497	248	3,591	96
2007	8,698	6,896	4	3,818	242	2,838	91
2008	10,020	4,270	4	3,670	220	3,461	170
2009	11,675	4,166	6	4,262	248	4,594	163
2010	15,475	2,456	9	4,985	356	8,801	246
2011	18,530	4,678	6	6,110	479	10,364	257
2012	17,854	7,119	8	5,286	338	7,636	195
2013	14,763	4,180	7	5,061	332	8,808	180

District-level water use numbers compiled by two GCDs in the GMA 10 area are also available, but only for recent years. Uvalde County UWCD values are sourced from their annual water use report database and provided in Table 3. These numbers are higher than the county-wide values provided by the TWDB, particularly in 2009 and 2010.

Table 3. Total groundwater pumpage values in Uvalde County according the UCUWCD (2011) in acre-ft/yr. Values from UCUWCD (2011).

Aquifer	2007	2008	2009	2010
Trinity	228	267	1,667	908

The Barton Springs Edwards Aquifer Conservation District (BSEACD) values are based on meter readings from district wells 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.

Table 4. Total groundwater pumpage values for Middle Trinity Aquifer and Lower Trinity Aquifer according to BSEACD (acre-ft/yr). Values from BSEACD (2013).

County	Aquifer	2007	2008	2009	2010	2011
Hays	Middle Trinity	0	0	0	0	27
	Lower Trinity	--	--	--	--	--
Travis	Middle Trinity	0.4	0.3	0.4	0.3	5
	Lower Trinity	11	28	18	20	17

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 has led to the need for viable alternative supplies. The proposed DFC allows for a modeled available groundwater that is significantly above the current use of the aquifer and allows room for development of the aquifer as an alternative supply while protecting existing groundwater supplies.

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 2017 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 3 by decade in acre-ft/yr. Also shown in Table 3 are demands, existing supplies, and water-supply strategies. Note that these are county totals, not just the portions of each county in GMA 10.

The projections in Table 5 show that for the 2017 State Water Plan planning period (2020-2070), there is a progressively increasing water-supply deficit, increasing from 135,000 acre-ft in 2020 up to 497,000 acre-ft in 2060. 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 DFC allows for drawdown of the Trinity Aquifer to allow for its use in the future as water supply of growing importance to the region.

Table 5. 2017 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	Aquifer	2020	2030	2040	2050	2060	2070
Bexar	Demands	367,664	404,641	438,621	473,953	509,657	543,989
	Existing Supplies	348,478	350,452	352,909	353,419	354,103	354,936
	Needs	61,498	87,009	110,801	139,602	169,573	199,085
	Strategy Supplies	111,676	139,674	172,615	211,590	259,448	304,681
Caldwell	Demands	7,939	8,992	10,069	11,191	12,362	13,557
	Existing Supplies	10,563	10,606	10,627	10,640	10,648	10,660
	Needs	201	701	1,368	2,223	3,154	4,080
	Strategy Supplies	2,953	2,869	2,938	3,540	4,291	5,305
Comal	Demands	42,660	50,555	58,562	66,459	74,986	83,562
	Existing Supplies	41,807	43,550	45,235	46,693	48,391	50,200
	Needs	5,348	8,434	14,812	21,304	28,198	35,022
	Strategy Supplies	20,102	27,743	33,285	38,881	44,989	51,406
Guadalupe	Demands	36,487	42,642	48,287	54,229	61,977	68,632
	Existing Supplies	50,679	53,749	54,937	54,805	54,708	54,696
	Needs	1,486	4,320	7,660	12,375	17,412	22,356
	Strategy Supplies	9,021	14,143	16,304	24,352	28,173	37,388
Hays	Demands	38,017	48,140	61,376	74,249	93,141	115,037
	Existing Supplies	55,922	56,144	56,441	57,070	58,244	59,679
	Needs	580	4,148	12,635	22,756	38,594	57,222
	Strategy Supplies	14,073	28,579	40,651	51,238	69,741	88,522
Medina	Demands	68,171	66,673	65,147	63,688	62,364	61,252
	Existing Supplies	39,514	39,783	40,056	40,267	40,513	40,768
	Needs	32,510	30,527	28,580	26,707	24,938	23,445
	Strategy Supplies	2,142	2,601	3,208	3,745	4,306	4,918
Travis	Demands	290,697	346,067	398,642	436,992	470,440	509,035
	Existing Supplies	423,296	421,001	419,022	411,952	401,880	392,060
	Needs	3,199	19,203	27,658	41,766	85,617	134,438
	Strategy Supplies	148,005	193,633	228,203	275,798	306,286	338,800
Uvalde	Demands	75,595	73,694	71,705	69,993	68,451	67,179
	Existing Supplies	47,888	47,480	47,559	47,664	47,742	47,742
	Needs	30,747	28,756	26,657	24,815	23,135	21,744
	Strategy Supplies	2,642	3,109	3,791	4,559	5,168	5,797
Total	**Demands**	**927,230**	**1,041,404**	**1,152,409**	**1,250,754**	**1,353,378**	**1,462,243**
	Existing Supplies	**1,018,147**	**1,022,765**	**1,026,786**	**1,022,510**	**1,016,229**	**1,010,741**
	Needs	**135,569**	**183,098**	**230,171**	**291,548**	**390,621**	**497,392**
	Strategy Supplies	**310,614**	**412,351**	**500,995**	**613,703**	**722,402**	**836,817**

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 6 provides the proposed Trinity Aquifer withdrawals developed by Regional Water Planning Groups K and L for the 2012 State Water Plan. Additionally, Table 6 above shows the total of water management strategies developed as part of the 2017 State Water Plan.

Table 6. Proposed Trinity Aquifer development in Regions L and K from 2010 to 2060. Values from SCTRWPG (2010) and LCRWPG (2010)

County	Bexar	Hays	Hays
Water Utility Group	Bexar Metropolitan Water District*	County Line Water Supply Company	Manufacturing
Regional Water Planning Group	L	L	K
Water Management Strategy	Development of Local Groundwater Supplies (Trinity Aquifer)	Development of Local Groundwater Supplies (Trinity Aquifer)	New well field for Trinity Aquifer
Source Name	Trinity Aquifer	Trinity Aquifer	Trinity Aquifer
2010	2,016	---	--
2020	2,016	1,129	--
2030	2,016	1,452	75
2040	2,016	1,613	200
2050	2,016	1,936	301
2060	2,016	2,420	400

*Bexar Metropolitan Water District was acquired by San Antonio Water System in 2012

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 2012 State Water Plan. The estimated MAG of 59,488 acre-ft/yr is greater than estimated current use and water-management strategies targeting the aquifer.

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 total estimated recoverable storage 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 total estimated recoverable storage 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.

Total estimated recoverable storage 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 total estimated recoverable storage 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 7 provides the total estimated recoverable storage 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 7. 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 8 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 Aquifer Assessment 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 9 provides the estimated annual volume of flow into the Trinity Aquifer in GMA 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: BSEACD (2013) suggests that there might be some vertical leakage from the Edwards Aquifer into the Trinity Aquifer, 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. 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 10 provides estimated cross-formational flow from the Trinity Aquifer to the Edwards Aquifer within the Edwards Aquifer Authority (EAA).

Table 8. Recharge values for the Trinity Aquifer provided by the Medina County Groundwater Conservation District (acre-ft) and TWDB Aquifer Assessment 10-06

Area	Source	Aquifer	Estimated annual amount of recharge from precipitation to the district
MCGCD	GAM Run 09-31	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 is expected. 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. 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 9. 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 10. 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 08-67	from Trinity Aquifer to Edwards and associated limestones	13,622

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. The proposed DFC allows for considerable drawdown and a significantly larger modeled available groundwater than is the current amount of groundwater use.

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.

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 2011 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 2012 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 GMA10 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 on the basis of 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 March 14, 2016. 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 11. Public comments for GMA 10 are included in Appendix B.

Table 11. Dates on which each GCD held a public meeting allowing for stakeholder input on the DFCs

GCD	Date
Barton Springs/Edwards Aquifer Conservation District	May 26, 2016
Comal Trinity GCD	May 15, 2016
Edwards Aquifer Authority	May 10, 2016
Kinney County GCD	May 12, 2016
Medina County GCD	May 18, 2016
Plum Creek Conservation District	May 17, 2016
Uvalde County UWCD	April 10, 2016

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.

Numerous comments on the GMA 10's proposed DFCs were received from stakeholders. All individual comments and detailed GMA 10 responses to each are included in Appendix B of this Explanatory Report and are incorporated into the discussion herein by reference. Some comments were specifically on the Trinity Aquifer or were reasonably inferred to be directed to the Trinity Aquifer DFC. Some did not designate which aquifer's DFC was being addressed but were considered by the GMA, where possible and pertinent, to be applicable to all DFCs. And some comments were not DFC recommendations *per se*, rather general observations on joint groundwater planning. Comments and assessments related to the Trinity Aquifer DFC are summarized below.

The most common recommendation or suggestion related specifically to the Trinity Aquifer DFC focused on use of a "zero drawdown" alternative approach. The GMA-10 responses to Comments #4, 8, 9, 10, 11, 12, 13, 14, 15, and 16, and Note B in Appendix B provide the rationale for not utilizing a zero-drawdown DFC for the Trinity Aquifer in GMA 10. In summary:

- 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.

In addition to those comments specifically addressing the Trinity Aquifer DFC, a number of commenters questioned or proposed changes to the purpose, scope, schedule, and/or basis of essentially all GMA 10 DFCs, including the Trinity Aquifer DFC (see Comments #3, 5, 6, 7, 8, and 17; and the more general comments of #27-33). GMA 10's responses to these comments in Appendix B reinforce the fact that statutes and regulations constrain the actions and outputs of any GMA, including GMA 10, in these matters.

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 of Waste 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 the aquifer while maximizing groundwater production.

15. References

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Appendix A

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

Prepared in Support of the 2016 Region J Regional Water Plan

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Executive Summary

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

Based on projected water demands and existing water supplies, the Region J planning group identified water needs (potential shortages) that would occur within its region under a repeat of the drought of record for six water use categories. The TWDB then estimated the socioeconomic impacts of those needs—if they are not met—for each water use category and as an aggregate for the region.

The analysis was performed using an economic 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 during a drought of record within each of the planning decades. For each water use category, the evaluation focused on estimating income losses and job losses. 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 were estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses.

It is estimated that not meeting the identified water needs in Region J would result in an annually combined lost income impact of approximately $62 million in 2020, increasing to $71 million in 2070 (Table ES-1). In 2020, the region would lose approximately 1,400 jobs, and by 2070 job losses would increase to approximately 1,600.

All impact estimates are in year 2013 dollars and were calculated using a variety of data sources and tools including the use of a region-specific IMPLAN model, data from the TWDB annual water use estimates, the U.S. Census Bureau, Texas Agricultural Statistics Service, and Texas Municipal League.

Table ES-1: Region J Socioeconomic Impact Summary

Regional Economic Impacts	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$62	$71	$75	$69	$69	$71
Job losses	1,435	1,591	1,643	1,551	1,563	$1,599
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$8	$12	$13	$9	$8	$9
Water trucking costs ($ millions)* -	$0	$0	$0	$0	$0	$0
Utility revenue losses ($ millions)*	$9	$10	$10	$10	$10	$10
Utility tax revenue losses ($ millions)*	$0	$0	$0	$0	$0	$0
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$11	$11	$12	$13	$13	$14
Population losses	263	292	302	285	287	294
School enrollment losses	49	54	56	53	53	54

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate 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 existing businesses and industry, 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.

Administrative rules (31 Texas Administrative Code §357.33 (c)) require that regional water planning groups evaluate the social and economic impacts of not meeting water needs as part of the regional water planning process, and rules direct the TWDB staff to provide technical assistance upon request. Staff of the TWDB's Water Use, Projections, & Planning Division designed and conducted this analysis in support of the Region J Regional Water Planning Group.

This document summarizes the results of the analysis and discusses the methodology used to generate the results. Section 1 summarizes the water needs calculation performed by the TWDB based on the regional water planning group's data. Section 2 describes the methodology for the impact assessment and discusses approaches and assumptions specific to each water use category (i.e., irrigation, livestock, mining, steam-electric, municipal and manufacturing). Section 3 presents the results for each water use category with results summarized for the region as a whole. The appendix presents details on the socioeconomic impacts by county.

1.1 Identified Regional Water Needs (Potential Shortages)

As part of the regional water planning process, the TWDB adopted water demand projections for each water user group (WUG) with input from the planning groups. WUGs are composed of cities, utilities, combined rural areas (designated as county-other), and the county-wide water use of irrigation, livestock, manufacturing, mining and steam-electric power. The demands are then compared to the existing water supplies of each WUG to determine potential shortages, or needs, by decade. Existing water supplies are legally and physically accessible for immediate use in the event of drought. Projected water demands and existing supplies are compared to identify either a surplus or a need for each WUG.

Table 1-1 summarizes the region's identified water needs in the event of a repeat of drought of the 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 meet 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 and economic growth. To provide a general sense of proportion, total projected needs as an overall percentage of total demand by water use category are presented in aggregate in Table 1-1. Projected needs for individual water user groups within the aggregate vary greatly, and may reach 100% for a given WUG and water use category. Detailed water needs by WUG and county appear in Chapter 4 of the 2016 Region J Regional Water Plan.

Table 1-1 Regional Water Needs Summary by Water Use Category

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	Water Needs (acre-feet per year)	143	143	142	142	141	141
	% of the category's total water demand	1%	1%	0	0	0	0
Livestock	Water Needs (acre-feet per year)	214	214	214	214	214	214
	% of the category's total water demand	7%	7%	7%	7%	7%	7%
Manufacturing	Water Needs (acre-feet per year)	-	-	-	-	-	-
	% of the category's total water demand	-	-	-	-	-	-
Mining	Water Needs (acre-feet per year)	38	98	112	76	47	43
	% of the category's total water demand	11%	23%	25%	18%	12%	11%
Municipal	Water Needs (acre-feet per year)	3,462	3,768	3,925	4,033	4,143	4,228
	% of the category's total water demand	14%	14%	14%	14%	14%	14%
Steam-electric power	Water Needs (acre-feet per year)	-	-	-	-	-	-
	% of the category's total water demand	-	-	-	-	-	-
Total water needs (acre-feet per year)		**3,857**	**4,223**	**4,393**	**4,465**	**4,545**	**4,626**

2 Economic Impact Assessment Methodology Summary

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 (volume), and thereby determine a maximum impact per acre-foot of shortage for each of the socioeconomic measures. The calculations of economic impacts were based on the overall composition of the economy using many underlying economic "sectors." Sectors in this analysis refer to one or more of the 440 specific production sectors of the economy designated within IMPLAN (Impact for Planning Analysis), the economic impact modeling software used for this assessment. Economic impacts within this report are estimated for approximately 310 of those sectors, with the focus on the more water intense production sectors. The economic impacts for a single water use category consist of an aggregation of impacts to multiple related economic sectors.

2.1 Impact Assessment Measures

A required component of the regional and state water plans is to estimate the potential economic impacts of shortages due to a drought of record. Consistent with previous water plans, several key variables 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 GDP made by an individual producer, industry, sector, or group of sectors within a year. For a shortage, value added is a measure of the income losses to the region, county, or WUG and includes 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.
Financial Transfer Impacts	**Description**
Tax losses on production and imports	Sales and excise taxes (not collected due to the shortage), customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies.
Water trucking costs	Estimate for shipping potable water.
Utility revenue losses	Foregone utility income due to not selling as much water.
Social Impacts	**Description**
Description	A welfare measure of the lost value to consumers accompanying less water use.
Population losses	A welfare measure of the lost value to consumers accompanying less water use.
School enrollment losses	School enrollment losses (K-12) accompanying job losses.

2.1.1 Regional Economic Impacts

Two key measures were included within the regional economic impacts classification: income losses and job losses. Income losses presented consist of the sum of value added losses and additional purchase costs of electrical power. Job losses are also presented as a primary economic impact measure.

Income Losses - Value Added Losses

Value added is the value of total output less the value of the intermediate inputs also used in production of the final product. Value added is similar to Gross Domestic Product (GDP), a familiar measure of the productivity of an economy. The loss of value added due to water shortages was estimated by input-output analysis using the IMPLAN software package, and includes the direct, indirect, and induced monetary impacts on the region.

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 were represented in this analysis by the additional costs associated with power purchases from other generating plants within the region or state. Consequently, the analysis employed additional power purchase costs as a proxy for the value added impacts for that water use category, and these are included as a portion of the overall income impact for completeness.

For the purpose of this analysis, it was 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 from the recent drought period in 2011.

Job Losses

The number of jobs lost due to the economic impact was estimated using IMPLAN output associated with the water use categories noted in Table 1-1. Because of the difficulty in predicting outcomes and a lack of relevant data, job loss estimates were not calculated for the steam-electric power production or for certain municipal water use categories.

2.1.2 Financial Transfer Impacts

Several of the impact measures estimated within the analysis are presented as supplemental information, providing additional detail concerning potential impacts on a sub-portion of the economy or government. Measures included in this category 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. Many of 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 was used to estimate reduced tax collections associated with the reduced output in the economy.

Water Trucking Costs

In instances where water shortages for a municipal water user group were estimated to be 80 percent or more of water demands, it was assumed that water would be trucked in to support basic consumption and

sanitation needs. For water shortages of 80 percent or greater, a fixed cost of $20,000 per acre-foot of water was calculated and presented as an economic cost. This water trucking cost was applied for both the residential and non-residential portions of municipal water needs and only impacted a small number of WUGs statewide.

Utility Revenue Losses

Lost utility income was calculated as the price of water service multiplied by the quantity of water not sold during a drought shortage. Such estimates resulted from city-specific pricing data for both water and wastewater. These water rates were applied to the potential water shortage to determine estimates of lost utility revenue as water providers sold less water during the drought due to restricted supplies.

Utility Tax Losses

Foregone utility tax losses included estimates of uncollected 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.

2.1.3 Social Impacts

Consumer Surplus Losses of 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 the 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. However, consumer's access to that water may be limited, and the associated consumer surplus loss is an estimate of the equivalent monetary value of the negative impact to the consumer's wellbeing, for example, associated with a diminished quality of their landscape (i.e., outdoor use). Lost consumer surplus estimates for reduced outdoor and indoor use, as well as residential and commercial/institutional demands, were included in this analysis. Consumer surplus is an attempt to measure effects on wellbeing by monetizing those effects; therefore, these values should not be added to the other monetary impacts estimated in the analysis.

Lost consumer surplus estimates varied widely by location and type. For a 50 percent shortage, the estimated statewide consumer surplus values ranged from $55 to $2,500 per household (residential use), and from $270 to $17,400 per firm (non-residential).

Population and School Enrollment Losses

Population losses due to water shortages, as well as the related loss of school enrollment, were based upon the job loss estimates and upon a recent study of job layoffs and the resulting adjustment of the labor market, including the change in population.[1] 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 an estimate of the change in the population as the result of a job layoff event. Layoffs impact both out-migration, as well as in-migration into an area, both of which can negatively affect the population of an area. In addition, the study found that a majority of those who did move following a layoff moved to another labor market rather than an adjacent county. Based on this study, a simplified

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[1] Foote, Andre, 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/uploads/150194

ratio of job and net population losses was calculated for the state as a whole: for every 100 jobs lost, 18 people were assumed to move out of the area. School enrollment losses were estimated as a proportion of the population lost.

2.2 Analysis Context

The context of the economic impact analysis involves situations where there are physical shortages of surface or groundwater due to drought of record conditions. Anticipated shortages 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.

2.2.1 IMPLAN Model and Data

Input-Output analysis using the IMPLAN (Impact for Planning Analysis) software package was the primary means of estimating value added, jobs, and taxes. This analysis employed county and regional level models to determine key 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 2011 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 440 sector specific Industry Codes, and those that rely on water as a primary input were assigned to their relevant planning water user categories (manufacturing, mining, irrigation, etc.). 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. Similar calculations were performed for the job and tax losses on production and import impact estimates. Note that the value added estimates, as well as the job and tax estimates from PLAN, 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.

2.2.2 Elasticity of Economic Impacts

The economic impact of a water need is based on the relative size of the water need to the water demand for each water user group (Figure 2-1). Smaller water shortages, for example, less than 5 percent, were 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 deepens, 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 such ability to adjust, an elasticity adjustment function was used in estimating impacts for several of the measures. Figure 2-1 illustrates the general relationship for the adjustment functions. Negative impacts are assumed to begin accruing when the shortage percentage reaches the lower bound b1 (10 percent in Figure 2-1), with impacts then increasing linearly up to the 100 percent impact level (per unit volume) once the upper bound for adjustment reaches the b2 level shortage (50 percent in Figure 2-1 example).

Initially, the combined total value of the three value added components (direct, indirect, and induced) was calculated and then converted into a per acre-foot economic value based on historical TWDB water use estimates within each particular water use category. As an example, if the total, annual value added for livestock in the region was $2 million and the reported annual volume of water used in that industry was 10,000 acre-feet, the estimated economic value per acre-foot of water shortage would be $200 per acre-foot. Negative economic impacts of shortages were then estimated using this value as the maximum impact estimate ($200 per acre-foot in the example) applied to the anticipated shortage volume in acre-feet and adjusted by the economic impact elasticity function. This adjustment varied with the severity as percentage of water demand of the anticipated shortage. If one employed the sample elasticity function shown in Figure 2-1, a 30% shortage in the water use category would imply an economic impact estimate of 50% of the original $200 per acre-foot impact value (i.e., $100 per acre-foot).

Such adjustments were not required in estimating consumer surplus, nor for the estimates of utility revenue losses or utility tax losses. Estimates of lost consumer surplus relied on city-specific demand curves with the specific lost consumer surplus estimate calculated based on the relative percentage of the city's water shortage. Estimated changes in population as well as changes in school enrollment were indirectly related to the elasticity of job losses.

Assumed values for the bounds b1 and b2 varied with water use category under examination and are presented in Table 2-2.

Figure 2-1 Example Economic Impact Elasticity Function (as applied to a single water user's shortage)

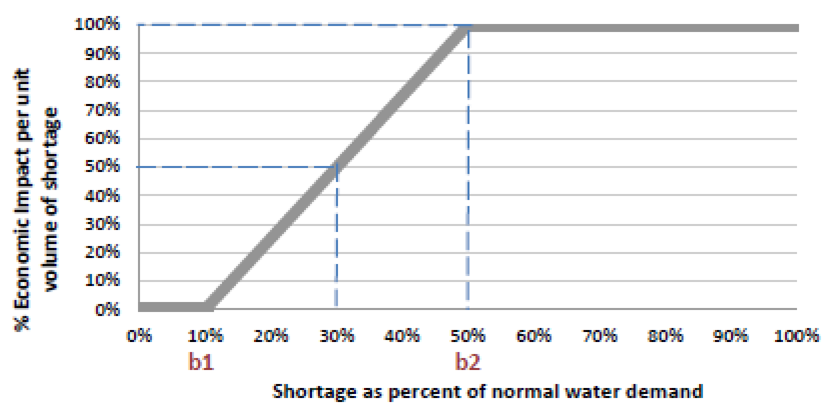

Table 2-2 Economic Impact Elasticity Function Lower and Upper Bounds

Water Use Category	Lower Bound (b1)	Upper Bound (b2)
Irrigation	**5%**	**50%**
Livestock	**5%**	**10%**
Manufacturing	**10%**	**50%**
Mining	**10%**	**50%**
Municipal (non-residential water intensive)	**50%**	**80%**
Steam-electric power	**20%**	**70%**

2.3 Analysis Assumptions and Limitations

Modeling of complex systems requires making assumptions and accepting limitations. This is particularly true when attempting to estimate a wide variety of economic impacts over a large geographic area and into future decades. Some of the key assumptions and limitations of the methodology include:

1. The foundation for estimating socioeconomic impacts of water shortages resulting from a drought are the water needs (potential shortages) that were identified as part of the regional water planning process. These needs have some uncertainty associated with them, but serve as a reasonable basis for evaluating potential economic impacts of a drought of record event.

2. All estimated socioeconomic impacts are snapshot estimates of impacts 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 severe drought conditions. The evaluation assumed that no recommended water management strategies are implemented. In other words, growth occurs, future shocks are imposed on an economy at 10-year intervals, and the resulting impacts are estimated. Note that the estimates presented were not cumulative (i.e., summing up expected impacts from today up to the decade noted), but were simply an estimate of the magnitude of annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated 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, supplies of limited resources, and other structural changes to the economy that may occur into the future. This 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 analysis is not a 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 procedures to weigh future costs differently through time.

5. Monetary figures are reported in constant year 2013 dollars.

6. Impacts are annual estimates. The estimated economic model 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.

7. 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 categories (value added and consumer surplus) are both valid impacts but should not be summed.

8. The value added, jobs, and taxes on production and import impacts include the direct, indirect and induced effects described in Section 2.2.1. 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.

9. The majority of impacts estimated in this analysis may be considered smaller than those that might occur under drought of record conditions. 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 these types of economic impact modeling efforts, 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, which is one reason why the impact estimates are likely conservative.

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

11. The model did 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 the landscaping industry immediately following a drought;
b. The cost and years to rebuild liquidated livestock herds (a major capital item 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 accurately 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.

3 Analysis Results

This section presents a breakdown of the results of the regional analysis for Region J. Projected economic impacts for six water use categories (irrigation, livestock. municipal, manufacturing, mining, and steam-electric power) are also reported by decade.

3.1 Overview of the Regional Economy

Table 3-1 presents the 2011 economic baseline as represented by the IMPLAN model and adjusted to 2013 dollars for Region J. In year 2011, Region J generated about $5 billion in gross state product associated with 64,100 jobs based on the 2011 IMPLAN data. These values represent an approximation of the current regional economy for a reference point.

Table 3-1 Region J Economy

Income ($ millions)*	Jobs	Taxes on production and imports ($ millions)*
$4,967	**64,121**	**$357**

[1]Year 2013 dollars based on 2011 IMPLAN model value added estimates for the region.

The remainder of Section 3 presents estimates of potential economic impacts for each water use category 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.

3.2 Impacts for Irrigation Water Shortages

Two of the 6 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 3-2. 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. Two factors led to excluding any reported tax impacts: 1) Federal support (subsidies) has lessened greatly since the year 2011 IMPLAN data was collected, and 2) It was not considered realistic to report increasing tax revenue collections for a drought of record.

Table 3-2 Impacts of Water Shortages on Irrigation in Region

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

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.3 Impacts for Livestock Water Shortages

Five of the 6 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 3-3. Note that tax impacts are not reported for this water use category for similar reasons that apply to the irrigation water use category described above.

Table 3-3 Impacts of Water Shortages on Livestock in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$5	$5	$5	$5	$5	$5
Job losses	$288	$288	$288	$288	$288	$288

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000***

3.4 Impacts for Municipal Water Shortages

Four of the 6 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 the two subtypes of use within municipal use: residential, and non-residential. The latter includes commercial and institutional users. Consumer surplus measures were made for both residential and nonresidential demands. In addition, available data for the non-residential, water-intensive portion of municipal demand allowed use of IMPLAN and TWDB Water Use Survey data to estimate income loss, jobs, and taxes. Trucking cost estimates, calculated for shortages exceeding 80 percent, assumed a fixed cost of $20,000 per acre-foot to transport water for municipal use. The estimated impacts to this water use category appear in Table 3-4.

Table 3-4 Impacts of Water Shortages on Municipal Water Users in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$53	$55	$56	$57	$59	$61
Job losses	1,066	1,109	1,119	1,153	1,194	1,229
Tax losses on production and imports[1] ($ millions)*	$5	$5	$5	$5	$6	$6
Consumer surplus losses ($ millions)*	$11	$11	$12	$13	$13	$14
Trucking costs ($ millions)*	$0	$0	$0	$0	$0	$0
Utility revenue losses ($ millions)*	$9	$10	$10	$10	$10	$10
Utility tax revenue losses ($ millions)*	$0	$0	$0	$0	$0	$0

[1] Estimates apply to the water-intensive portion of non-residential municipal water use.
**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by azero ($0) indicate income losses less than $500,000.***

3.5 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in none of the 6 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use category appear in Table 3-5.

Table 3-5 Impacts of Water Shortages on Manufacturing in Region

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

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.6 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in 3 of the 6 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use type appear in Table 3-6.

Table 3-6 Impacts of Water Shortages on Mining in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$5	$12	$14	$7	$5	$5
Job losses	81	194	236	110	81	81
Tax losses on production and imports ($ millions)*	$3	$7	$8	$4	$3	$3

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.7 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in 4 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 3-7.

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

- Are reflected as an income loss proxy in the form of the estimated additional purchasing costs for power from the electrical grid 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.
- Does 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 3-7 Impacts of Water Shortages on Steam-Electric Power in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	-	-	-	-	-	-

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.8 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 3-8.

Table 3-8 Region-wide Social Impacts of Water Shortages in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$11	$11	$12	$13	$13	$14
Population losses	263	29200%	302	285	287	294
School enrollment losses	49	$54	$56	$53	$53	$54

**** Year 2013 dollars, rounded. Entries denoted by a dash***

Appendix - 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 2013 dollars, rounded). Values presented only for counties with projected economic impacts for at least one decade.

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

		Income Losses (Millions $)*						Job Losses						Consumer Surplus (Millions $)*					
County	Water Use Category	2020	2030	2040	2050	2060	2070	2020	2030	2040	2050	2060	2070	2020	2030	2040	2050	2060	2070
Kinney	Livestock	$0	$0	$0	$0	$0	$0	1	1	1	1	1	1	-	-	-	-	-	-
Kinney Total		$0	$0	$0	$0	$0	$0	1	1	1	1	1	1	-	-	-	-	-	-

Socioeconomic Impacts of Projected Water Shortages
for the Region K Regional Water Planning Area

Prepared in Support of the 2016 Region K Regional Water Plan

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September, 2015

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Executive Summary

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

Based on projected water demands and existing water supplies, the Region K planning group identified water needs (potential shortages) that would occur within its region under a repeat of the drought of record for six water use categories. The TWDB then estimated the socioeconomic impacts of those needs—if they are not met—for each water use category and as an aggregate for the region.

The analysis was performed using an economic 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 during a drought of record within each of the planning decades. For each water use category, the evaluation focused on estimating income losses and job losses. 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 were estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses.

It is estimated that not meeting the identified water needs in Region K would result in an annually combined lost income impact of approximately $1.6 billion in 2020, increasing to $3.6 billion in 2070 (Table ES-1). In 2020, the region would lose approximately 9,900 jobs, and by 2070 job losses would increase to approximately 45,000.

All impact estimates are in year 2013 dollars and were calculated using a variety of data sources and tools including the use of a region-specific IMPLAN model, data from the TWDB annual water use estimates, the U.S. Census Bureau, Texas Agricultural Statistics Service, and Texas Municipal League.

Table ES-1: Region K Socioeconomic Impact Summary

Regional Economic Impacts	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$1,560	1,557	1,233	1,093	1,975	3,568
Job losses	9,877	11,880	10,414	11,894	24,187	45,282
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$236	$217	$160	$113	$145	$248
Water trucking costs ($ millions)* -	$3	$4	$4	$2	$6	
Utility revenue losses ($ millions)*	$23	$84	$138	$205	$339	$592
Utility tax revenue losses ($ millions)*	$0	$1	$2	$3	$6	$10
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$1	$29	$51	$105	$194	$347
Population losses	1,813	2,181	1,912	2,184	4,441	8,314
School enrollment losses	335	403	354	404	822	1,538

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

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 existing businesses and industry, 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.

Administrative rules (31 Texas Administrative Code §357.33 (c)) require that regional water planning groups evaluate the social and economic impacts of not meeting water needs as part of the regional water planning process, and rules direct the TWDB staff to provide technical assistance upon request. Staff of the TWDB's Water Use, Projections, & Planning Division designed and conducted this analysis in support of the Region K Regional Water Planning Group.

This document summarizes the results of the analysis and discusses the methodology used to generate the results. Section 1 summarizes the water needs calculation performed by the TWDB based on the regional water planning group's data. Section 2 describes the methodology for the impact assessment and discusses approaches and assumptions specific to each water use category (i.e., irrigation, livestock, mining, steam-electric, municipal and manufacturing). Section 3 presents the results for each water use category with results summarized for the region as a whole. The appendix presents details on the socioeconomic impacts by county.

2.1 Identified Regional Water Needs (Potential Shortages)

As part of the regional water planning process, the TWDB adopted water demand projections for each water user group (WUG) with input from the planning groups. WUGs are composed of cities, utilities, combined rural areas (designated as county-other), and the county-wide water use of irrigation, livestock, manufacturing, mining and steam-electric power. The demands are then compared to the existing water supplies of each WUG to determine potential shortages, or needs, by decade. Existing water supplies are legally and physically accessible for immediate use in the event of drought. Projected water demands and existing supplies are compared to identify either a surplus or a need for each WUG.

Table 1-1 summarizes the region's identified water needs in the event of a repeat of drought of the 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 meet 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 and economic growth. To provide a general sense of proportion, total projected needs as an overall percentage of total demand by water use category are presented in aggregate in Table 1-1. Projected needs for individual water user groups within the aggregate vary greatly, and may reach 100% for a given WUG and water use category. Detailed water needs by WUG and county appear in Chapter 4 of the 2016 Region K Regional Water Plan.

Table 1-1 Regional Water Needs Summary by Water Use Category

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	Water Needs (acre-feet per year)	335,489	319,584	304,106	289,044	274,387	260,124
	% of the category's total water demand						
Livestock	Water Needs (acre-feet per year)	55%	54%	53%	52%	50%	49%
	% of the category's total water demand	570	692	810	913	1,059	1,216
Manufacturing	Water Needs (acre-feet per year)	1%	1%	1%	1%	1%	1%
	% of the category's total water demand	4,260	8,618	9,747	10,719	12,153	14,164
Mining	Water Needs (acre-feet per year)	20%	33%	35%	36%	38%	41%
	% of the category's total water demand	7,389	27,362	45,011	66,372	118,804	180,979
Municipal	Water Needs (acre-feet per year)	2%	8%	11%	14%	24%	32%
	% of the category's total water demand	25,363	26,751	26,775	31,974	42,212	54,627
Steam-electric power	Water Needs (acre-feet per year)	14%	14%	14%	16%	21%	26%
	% of the category's total water demand	373,071	383,007	386,449	399,022	448,615	511,110
Total water needs (acre-feet per year)		373,071	383,007	386,449	399,022	448,615	511,110

3 Economic Impact Assessment Methodology Summary

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 (volume), and thereby determine a maximum impact per acre-foot of shortage for each of the socioeconomic measures. The calculations of economic impacts were based on the overall composition of the economy using many underlying economic "sectors." Sectors in this analysis refer to one or more of the 440 specific production sectors of the economy designated within IMPLAN (Impact for Planning Analysis), the economic impact modeling software used for this assessment. Economic impacts within this report are estimated for approximately 310 of those sectors, with the focus on the more water intense production sectors. The economic impacts for a single water use category consist of an aggregation of impacts to multiple related economic sectors.

2.1 Impact Assessment Measures

A required component of the regional and state water plans is to estimate the potential economic impacts of shortages due to a drought of record. Consistent with previous water plans, several key variables 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 GDP made by an individual producer, industry, sector, or group of sectors within a year. For a shortage, value added is a measure of the income losses to the region, county, or WUG and includes 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.
Financial Transfer Impacts	**Description**
Tax losses on production and imports	Sales and excise taxes (not collected due to the shortage), customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies.
Water trucking costs	Estimate for shipping potable water.
Utility revenue losses	Foregone utility income due to not selling as much water.
Social Impacts	**Description**
Description	A welfare measure of the lost value to consumers accompanying less water use.
Population losses	A welfare measure of the lost value to consumers accompanying less water use.
School enrollment losses	School enrollment losses (K-12) accompanying job losses.

2.1.1 Regional Economic Impacts

Two key measures were included within the regional economic impacts classification: income losses and job losses. Income losses presented consist of the sum of value added losses and additional purchase costs of electrical power. Job losses are also presented as a primary economic impact measure.

Income Losses - Value Added Losses

Value added is the value of total output less the value of the intermediate inputs also used in production of the final product. Value added is similar to Gross Domestic Product (GDP), a familiar measure of the productivity of an economy. The loss of value added due to water shortages was estimated by input-output analysis using the IMPLAN software package, and includes the direct, indirect, and induced monetary impacts on the region.

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 were represented in this analysis by the additional costs associated with power purchases from other generating plants within the region or state. Consequently, the analysis employed additional power purchase costs as a proxy for the value added impacts for that water use category, and these are included as a portion of the overall income impact for completeness.

For the purpose of this analysis, it was 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 from the recent drought period in 2011.

Job Losses

The number of jobs lost due to the economic impact was estimated using IMPLAN output associated with the water use categories noted in Table 1-1. Because of the difficulty in predicting outcomes and a lack of relevant data, job loss estimates were not calculated for the steam-electric power production or for certain municipal water use categories.

2.1.2 Financial Transfer Impacts

Several of the impact measures estimated within the analysis are presented as supplemental information, providing additional detail concerning potential impacts on a sub-portion of the economy or government. Measures included in this category 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. Many of 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 was used to estimate reduced tax collections associated with the reduced output in the economy.

Water Trucking Costs

In instances where water shortages for a municipal water user group were estimated to be 80 percent or more of water demands, it was assumed that water would be trucked in to support basic consumption and

sanitation needs. For water shortages of 80 percent or greater, a fixed cost of $20,000 per acre-foot of water was calculated and presented as an economic cost. This water trucking cost was applied for both the residential and non-residential portions of municipal water needs and only impacted a small number of WUGs statewide.

Utility Revenue Losses

Lost utility income was calculated as the price of water service multiplied by the quantity of water not sold during a drought shortage. Such estimates resulted from city-specific pricing data for both water and wastewater. These water rates were applied to the potential water shortage to determine estimates of lost utility revenue as water providers sold less water during the drought due to restricted supplies.

Utility Tax Losses

Foregone utility tax losses included estimates of uncollected 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.

2.1.3 Social Impacts

Consumer Surplus Losses of 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 the 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. However, consumer's access to that water may be limited, and the associated consumer surplus loss is an estimate of the equivalent monetary value of the negative impact to the consumer's wellbeing, for example, associated with a diminished quality of their landscape (i.e., outdoor use). Lost consumer surplus estimates for reduced outdoor and indoor use, as well as residential and commercial/institutional demands, were included in this analysis. Consumer surplus is an attempt to measure effects on wellbeing by monetizing those effects; therefore, these values should not be added to the other monetary impacts estimated in the analysis.

Lost consumer surplus estimates varied widely by location and type. For a 50 percent shortage, the estimated statewide consumer surplus values ranged from $55 to $2,500 per household (residential use), and from $270 to $17,400 per firm (non-residential).

Population and School Enrollment Losses

Population losses due to water shortages, as well as the related loss of school enrollment, were based upon the job loss estimates and upon a recent study of job layoffs and the resulting adjustment of the labor market, including the change in population.1 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 an estimate of the change in the population as the result of a job layoff event. Layoffs impact both out-migration, as well as in-migration into an area, both of which can negatively affect the population of an area. In addition, the study found that a majority of those who did move following a layoff moved to another labor market rather than an adjacent county. Based on this study, a simplified ratio of job and net population losses was calculated for the state as a whole: for every 100 jobs lost, 18 people were assumed to move out of the area. School enrollment losses were estimated as a proportion of the population lost.

2.2 Analysis Context

The context of the economic impact analysis involves situations where there are physical shortages of surface or groundwater due to drought of record conditions. Anticipated shortages 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.

2.2.1 IMPLAN Model and Data

Input-Output analysis using the IMPLAN (Impact for Planning Analysis) software package was the primary means of estimating value added, jobs, and taxes. This analysis employed county and regional level models to determine key 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 2011 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 440 sector specific Industry Codes, and those that rely on water as a primary input were assigned to their relevant planning water user categories (manufacturing, mining, irrigation, etc.). 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. Similar calculations were performed for the job and tax losses on production and import impact estimates. Note that the value added estimates, as well as the job and tax estimates from PLAN, 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.

2.2.2 Elasticity of Economic Impacts

The economic impact of a water need is based on the relative size of the water need to the water demand for each water user group (Figure 2-1). Smaller water shortages, for example, less than 5 percent, were 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 deepens, 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 such ability to adjust, an elasticity adjustment function was used in estimating impacts for several of the measures. Figure 2-1 illustrates the general relationship for the adjustment functions. Negative impacts are assumed to begin accruing when the shortage percentage reaches the lower bound b1 (10 percent in Figure 2-1), with impacts then increasing linearly up to the 100 percent impact level (per unit volume) once the upper bound for adjustment reaches the b2 level shortage (50 percent in Figure 2-1 example).

Initially, the combined total value of the three value added components (direct, indirect, and induced) was calculated and then converted into a per acre-foot economic value based on historical TWDB water use estimates within each particular water use category. As an example, if the total, annual value added for livestock in the region was $2 million and the reported annual volume of water used in that industry was 10,000 acre-feet, the estimated economic value per acre-foot of water shortage would be $200 per acre-foot. Negative economic impacts of shortages were then estimated using this value as the maximum impact estimate ($200 per acre-foot in the example) applied to the anticipated shortage volume in acre-feet and adjusted by the economic impact elasticity function. This adjustment varied with the severity as percentage of water demand of the anticipated shortage. If one employed the sample elasticity function shown in Figure 2-1, a 30% shortage in the water use category would imply an economic impact estimate of 50% of the original $200 per acre-foot impact value (i.e., $100 per acre-foot).

Such adjustments were not required in estimating consumer surplus, nor for the estimates of utility revenue losses or utility tax losses. Estimates of lost consumer surplus relied on city-specific demand curves with the specific lost consumer surplus estimate calculated based on the relative percentage of the city's water shortage. Estimated changes in population as well as changes in school enrollment were indirectly related to the elasticity of job losses.

Assumed values for the bounds b1 and b2 varied with water use category under examination and are presented in Table 2-2.

Figure 2-1 Example Economic Impact Elasticity Function (as applied to a single water user's shortage)

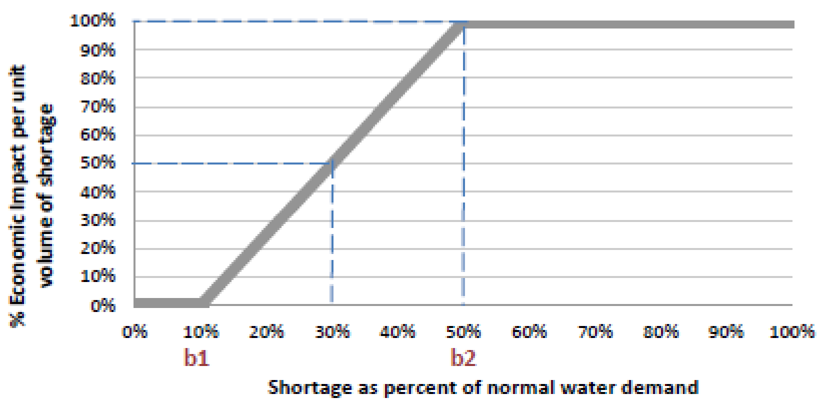

Table 2-2 Economic Impact Elasticity Function Lower and Upper Bounds

Water Use Category	Lower Bound (b1)	Upper Bound (b2)
Irrigation	**5%**	**50%**
Livestock	**5%**	**10%**
Manufacturing	**10%**	**50%**
Mining	**10%**	**50%**
Municipal (non-residential water intensive)	**50%**	**80%**
Steam-electric power	**20%**	**70%**

2.3 Analysis Assumptions and Limitations

Modeling of complex systems requires making assumptions and accepting limitations. This is particularly true when attempting to estimate a wide variety of economic impacts over a large geographic area and into future decades. Some of the key assumptions and limitations of the methodology include:

1. The foundation for estimating socioeconomic impacts of water shortages resulting from a drought are the water needs (potential shortages) that were identified as part of the regional water planning process. These needs have some uncertainty associated with them, but serve as a reasonable basis for evaluating potential economic impacts of a drought of record event.

2. All estimated socioeconomic impacts are snapshot estimates of impacts 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 severe drought conditions. The evaluation assumed that no recommended water management strategies are implemented. In other words, growth occurs, future shocks are imposed on an economy at 10-year intervals, and the resulting impacts are estimated. Note that the estimates presented were not cumulative (i.e., summing up expected impacts from today up to the decade noted), but were simply an estimate of the magnitude of annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated 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, supplies of limited resources, and other structural changes to the economy that may occur into the future. This 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 analysis is not a 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 procedures to weigh future costs differently through time.

5. Monetary figures are reported in constant year 2013 dollars.

6. Impacts are annual estimates. The estimated economic model 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.

7. 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 categories (value added and consumer surplus) are both valid impacts but should not be summed.

8. The value added, jobs, and taxes on production and import impacts include the direct, indirect and induced effects described in Section 2.2.1. 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.

9. The majority of impacts estimated in this analysis may be considered smaller than those that might occur under drought of record conditions. 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 these types of economic impact modeling efforts, 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, which is one reason why the impact estimates are likely conservative.

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

11. The model did 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:

e. The likely significant economic rebound to the landscaping industry immediately following a drought;
f. The cost and years to rebuild liquidated livestock herds (a major capital item in that industry);
g. Direct impacts on recreational sectors (i.e., stranded docks and reduced tourism); or,
h. 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 accurately 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.

3 Analysis Results

This section presents a breakdown of the results of the regional analysis for Region K. Projected economic impacts for six water use categories (irrigation, livestock. municipal, manufacturing, mining, and steam-electric power) are also reported by decade.

3.1 Overview of the Regional Economy

Table 3-1 presents the 2011 economic baseline as represented by the IMPLAN model and adjusted to 2013 dollars for Region K. In year 2011, Region K generated about $88 billion in gross state product associated with 975,000 jobs based on the 2011 IMPLAN data. These values represent an approximation of the current regional economy for a reference point.

Table 3-1 Region K Economy

Income ($ millions)*	Jobs	Taxes on production and imports ($ millions)*
$88,344	**975,269**	**$6,335**

[1]Year 2013 dollars based on 2011 IMPLAN model value added estimates for the region.

The remainder of Section 3 presents estimates of potential economic impacts for each water use category 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.

3.2 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 3-2. 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. Two factors led to excluding any reported tax impacts: 1) Federal support (subsidies) has lessened greatly since the year 2011 IMPLAN data was collected, and 2) It was not considered realistic to report increasing tax revenue collections for a drought of record.

Table 3-2 Impacts of Water Shortages on Irrigation in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$56	$52	$49	$46	$43	$40
Job losses	1,338	1,258	1,181	1,108	1,039	974

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.3 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 for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 3-3. Note that tax impacts are not reported for this water use category for similar reasons that apply to the irrigation water use category described above.

Table 3-3 Impacts of Water Shortages on Livestock in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	-	-	-	-	-	-
Job losses	-	-	-	-	-	-

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000***

3.4 Impacts for Municipal Water Shortages

Eleven 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 the two subtypes of use within municipal use: residential, and non-residential. The latter includes commercial and institutional users. Consumer surplus measures were made for both residential and nonresidential demands. In addition, available data for the non-residential, water-intensive portion of municipal demand allowed use of IMPLAN and TWDB Water Use Survey data to estimate income loss, jobs, and taxes. Trucking cost estimates, calculated for shortages exceeding 80 percent, assumed a fixed cost of $20,000 per acre-foot to transport water for municipal use. The estimated impacts to this water use category appear in Table 3-4.

Table 3-4 Impacts of Water Shortages on Municipal Water Users in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$1	$152	$175	$376	$1,135	$2,325
Job losses	21	2,634	3,074	6,604	19,795	40,435
Tax losses on production and imports[1] ($ millions)*	$0	$12	$14	$30	$92	$187
Consumer surplus losses ($ millions)*	$1		$51	$105	$194	$347
Trucking costs ($ millions)*	-	$3	$4	$4	$2	$6
Utility revenue losses ($ millions)*	$23	$84	$138	$205	$339	$592
Utility tax revenue losses ($ millions)*	$0	$1	$2	$3	$6	$10

[1] Estimates apply to the water-intensive portion of non-residential municipal water use.
**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by azero ($0) indicate income losses less than $500,000.***

3.5 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in 3 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 3-5.

Table 3-5 Impacts of Water Shortages on Manufacturing in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$35	$35	$70	$88	$106	$126
Job losses	390	575	788	985	1,165	1,365
Tax losses on production and imports ($ millions)*	$4	$6	$8	$10	$13	$16

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.6 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in 4 of the 14 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use type appear in Table 3-6.

Table 3-6 Impacts of Water Shortages on Mining in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$1,403	$1,236	$872	$485	$299	$342
Job losses	8,128	7,414	5,371	3,196	2,187	2,508
Tax losses on production and imports ($ millions)*	$230	$197	$136	$71	$39	$44

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.7 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in 4 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 3-7.

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

- Are reflected as an income loss proxy in the form of the estimated additional purchasing costs for power from the electrical grid 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.
- Does 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 3-7 Impacts of Water Shortages on Steam-Electric Power in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$63	$66	$66	$98	$392	$736

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.8 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 3-8.

Table 3-8 Region-wide Social Impacts of Water Shortages in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$1	$29	$51	$105	$194	$347
Population losses	1,813	2,181	1,912	2,184	4,441	8,314
School enrollment losses	335	403	354	404	822	1,538

**** Year 2013 dollars, rounded. Entries denoted by a dash***

Appendix - 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 2013 dollars, rounded). Values presented only for counties with projected economic impacts for at least one decade.

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

		Income Losses (Millions $)*						**Job Losses**						**Consumer Surplus (Millions $)***					
County	Water Use Category	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Hays	Mining	3	4	6	6	$7	$8	29	42	57	62	74	87	-	-	-	-	-	-
Hays	Municipal	-	-	-	44	$214	$557	-	-	-	771	3,705	9,655	-	$0	$1	$7	$22	$52
Hays Total		$3	$4	$6	$50	$221	$565	29	42	57	833	3,779	9,741	-	$0	$1	$7	$22	$52
Travis	Municipal	-	$149	$173	$256	$469	$702	-	2,589	3,041	4,531	8,242	12,299	$0	$27	$44	$83	$126	$170
Travis	Steam Electric Power	-	-	-	$32	$325	$668	-	-	-	-	-	-	-	-	-	-	-	-
Travis Total		-	$149	$173	$288	$794	$1,370	-	2,589	3,041	4,531	8,242	12,299	$0	$27	$44	$83	$126	$170

Socioeconomic Impacts of Projected Water Shortages for the Region L Regional Water Planning Area

Prepared in Support of the 2016 Region L Regional Water Plan

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September, 2015

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Executive Summary

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

Based on projected water demands and existing water supplies, the Region L planning group identified water needs (potential shortages) that would occur within its region under a repeat of the drought of record for six water use categories. The TWDB then estimated the socioeconomic impacts of those needs—if they are not met—for each water use category and as an aggregate for the region.

The analysis was performed using an economic 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 during a drought of record within each of the planning decades. For each water use category, the evaluation focused on estimating income losses and job losses. 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 were estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses.

It is estimated that not meeting the identified water needs in Region L would result in an annually combined lost income impact of approximately $62 million in 2020, increasing to $71 million in 2070 (Table ES-1). In 2020, the region would lose approximately 1,400 jobs, and by 2070 job losses would increase to approximately 1,600.

All impact estimates are in year 2013 dollars and were calculated using a variety of data sources and tools including the use of a region-specific IMPLAN model, data from the TWDB annual water use estimates, the U.S. Census Bureau, Texas Agricultural Statistics Service, and Texas Municipal League.

Table ES-1: Region L Socioeconomic Impact Summary

Regional Economic Impacts	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$1,990	$2,928	$3,320	$3,841	$4,633	$5,911
Job losses	18,277	20,809	23,550	25,559	30,450	50,102
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$175	$187	$193	$182	$192	$290
Water trucking costs ($ millions)* -	$0	$0	$0	$1	$1	$3
Utility revenue losses ($ millions)*	$210	$304	$418	$537	$625	$809
Utility tax revenue losses ($ millions)*	$4	$6	$8	$10	$12	$15
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$29	$58	$108	$171	$264	$403
Population losses	3,356	3,821	4,324	4,693	5,591	9,199
School enrollment losses	621	707	800	868	1.034	1,702

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate 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 existing businesses and industry, 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.

Administrative rules (31 Texas Administrative Code §357.33 (c)) require that regional water planning groups evaluate the social and economic impacts of not meeting water needs as part of the regional water planning process, and rules direct the TWDB staff to provide technical assistance upon request. Staff of the TWDB's Water Use, Projections, & Planning Division designed and conducted this analysis in support of the Region L Regional Water Planning Group.

This document summarizes the results of the analysis and discusses the methodology used to generate the results. Section 1 summarizes the water needs calculation performed by the TWDB based on the regional water planning group's data. Section 2 describes the methodology for the impact assessment and discusses approaches and assumptions specific to each water use category (i.e., irrigation, livestock, mining, steam-electric, municipal and manufacturing). Section 3 presents the results for each water use category with results summarized for the region as a whole. The appendix presents details on the socioeconomic impacts by county.

3.1 Identified Regional Water Needs (Potential Shortages)

As part of the regional water planning process, the TWDB adopted water demand projections for each water user group (WUG) with input from the planning groups. WUGs are composed of cities, utilities, combined rural areas (designated as county-other), and the county-wide water use of irrigation, livestock, manufacturing, mining and steam-electric power. The demands are then compared to the existing water supplies of each WUG to determine potential shortages, or needs, by decade. Existing water supplies are legally and physically accessible for immediate use in the event of drought. Projected water demands and existing supplies are compared to identify either a surplus or a need for each WUG.

Table 1-1 summarizes the region's identified water needs in the event of a repeat of drought of the 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 meet 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 and economic growth. To provide a general sense of proportion, total projected needs as an overall percentage of total demand by water use category are presented in aggregate in Table 1-1. Projected needs for individual water user groups within the aggregate vary greatly, and may reach 100% for a given WUG and water use category. Detailed water needs by WUG and county appear in Chapter 4 of the 2016 Region L Regional Water Plan.

Table 1-1 Regional Water Needs Summary by Water Use Category

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	Water Needs (acre-feet per year)	105,799	$97,325	$89,057	$81,302	$73,968	$67,383
	% of the category's total water demand	31%	0	0	0	0	0
Livestock	Water Needs (acre-feet per year)	-	-	-	-	-	-
	% of the category's total water demand	-	-	-	-	-	-
Manufacturing	Water Needs (acre-feet per year)	6,616	$10,213	$13,778	$19,265	$29,210	$40,376
	% of the category's total water demand	5%	8%	9%	12%	17%	23%
Mining	Water Needs (acre-feet per year)	10,822	$10,481	$8,694	$5,147	$2,073	$666
	% of the category's total water demand	22%	0	0	0	0	0
Municipal	Water Needs (acre-feet per year)	86,856	124,059	$168,754	$215,946	$268,513	$322,831
	% of the category's total water demand	19%	24%	29%	34%	39%	43%
Steam-electric power	Water Needs (acre-feet per year)	4,506	29,778	37,178	53,599	70,696	70,696
	% of the category's total water demand	8%	33%	37%	44%	48%	46%
Total water needs (acre-feet per year)		**3,857**	**214,599**	**271,856**	**317,461**	**375,259**	**444,460**

4 Economic Impact Assessment Methodology Summary

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 (volume), and thereby determine a maximum impact per acre-foot of shortage for each of the socioeconomic measures. The calculations of economic impacts were based on the overall composition of the economy using many underlying economic "sectors." Sectors in this analysis refer to one or more of the 440 specific production sectors of the economy designated within IMPLAN (Impact for Planning Analysis), the economic impact modeling software used for this assessment. Economic impacts within this report are estimated for approximately 310 of those sectors, with the focus on the more water intense production sectors. The economic impacts for a single water use category consist of an aggregation of impacts to multiple related economic sectors.

2.1 Impact Assessment Measures

A required component of the regional and state water plans is to estimate the potential economic impacts of shortages due to a drought of record. Consistent with previous water plans, several key variables 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 GDP made by an individual producer, industry, sector, or group of sectors within a year. For a shortage, value added is a measure of the income losses to the region, county, or WUG and includes 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.
Financial Transfer Impacts	**Description**
Tax losses on production and imports	Sales and excise taxes (not collected due to the shortage), customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies.
Water trucking costs	Estimate for shipping potable water.
Utility revenue losses	Foregone utility income due to not selling as much water.
Social Impacts	**Description**
Description	A welfare measure of the lost value to consumers accompanying less water use.
Population losses	A welfare measure of the lost value to consumers accompanying less water use.
School enrollment losses	School enrollment losses (K-12) accompanying job losses.

2.1.1 Regional Economic Impacts

Two key measures were included within the regional economic impacts classification: income losses and job losses. Income losses presented consist of the sum of value added losses and additional purchase costs of electrical power. Job losses are also presented as a primary economic impact measure.

Income Losses - Value Added Losses

Value added is the value of total output less the value of the intermediate inputs also used in production of the final product. Value added is similar to Gross Domestic Product (GDP), a familiar measure of the productivity of an economy. The loss of value added due to water shortages was estimated by input-output analysis using the IMPLAN software package, and includes the direct, indirect, and induced monetary impacts on the region.

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 were represented in this analysis by the additional costs associated with power purchases from other generating plants within the region or state. Consequently, the analysis employed additional power purchase costs as a proxy for the value added impacts for that water use category, and these are included as a portion of the overall income impact for completeness.

For the purpose of this analysis, it was 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 from the recent drought period in 2011.

Job Losses

The number of jobs lost due to the economic impact was estimated using IMPLAN output associated with the water use categories noted in Table 1-1. Because of the difficulty in predicting outcomes and a lack of relevant data, job loss estimates were not calculated for the steam-electric power production or for certain municipal water use categories.

2.1.2 Financial Transfer Impacts

Several of the impact measures estimated within the analysis are presented as supplemental information, providing additional detail concerning potential impacts on a sub-portion of the economy or government. Measures included in this category 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. Many of 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 was used to estimate reduced tax collections associated with the reduced output in the economy.

Water Trucking Costs

In instances where water shortages for a municipal water user group were estimated to be 80 percent or more of water demands, it was assumed that water would be trucked in to support basic consumption and

sanitation needs. For water shortages of 80 percent or greater, a fixed cost of $20,000 per acre-foot of water was calculated and presented as an economic cost. This water trucking cost was applied for both the residential and non-residential portions of municipal water needs and only impacted a small number of WUGs statewide.

Utility Revenue Losses

Lost utility income was calculated as the price of water service multiplied by the quantity of water not sold during a drought shortage. Such estimates resulted from city-specific pricing data for both water and wastewater. These water rates were applied to the potential water shortage to determine estimates of lost utility revenue as water providers sold less water during the drought due to restricted supplies.

Utility Tax Losses

Foregone utility tax losses included estimates of uncollected 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.

2.1.3 Social Impacts

Consumer Surplus Losses of 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 the 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. However, consumer's access to that water may be limited, and the associated consumer surplus loss is an estimate of the equivalent monetary value of the negative impact to the consumer's wellbeing, for example, associated with a diminished quality of their landscape (i.e., outdoor use). Lost consumer surplus estimates for reduced outdoor and indoor use, as well as residential and commercial/institutional demands, were included in this analysis. Consumer surplus is an attempt to measure effects on wellbeing by monetizing those effects; therefore, these values should not be added to the other monetary impacts estimated in the analysis.

Lost consumer surplus estimates varied widely by location and type. For a 50 percent shortage, the estimated statewide consumer surplus values ranged from $55 to $2,500 per household (residential use), and from $270 to $17,400 per firm (non-residential).

Population and School Enrollment Losses

Population losses due to water shortages, as well as the related loss of school enrollment, were based upon the job loss estimates and upon a recent study of job layoffs and the resulting adjustment of the labor market, including the change in population.[2] 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 an estimate of the change in the population as the result of a job layoff event. Layoffs impact both out-migration, as well as in-migration into an area, both of which can negatively affect the population of an area. In addition, the study found that a majority of those who did move following a layoff moved to another labor market rather than an adjacent county. Based on this study, a simplified

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[2] Foote, Andre, 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/uploads/150194

ratio of job and net population losses was calculated for the state as a whole: for every 100 jobs lost, 18 people were assumed to move out of the area. School enrollment losses were estimated as a proportion of the population lost.

2.2 Analysis Context

The context of the economic impact analysis involves situations where there are physical shortages of surface or groundwater due to drought of record conditions. Anticipated shortages 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.

2.2.1 IMPLAN Model and Data

Input-Output analysis using the IMPLAN (Impact for Planning Analysis) software package was the primary means of estimating value added, jobs, and taxes. This analysis employed county and regional level models to determine key 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 2011 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 440 sector specific Industry Codes, and those that rely on water as a primary input were assigned to their relevant planning water user categories (manufacturing, mining, irrigation, etc.). 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. Similar calculations were performed for the job and tax losses on production and import impact estimates. Note that the value added estimates, as well as the job and tax estimates from PLAN, 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.

2.2.2 Elasticity of Economic Impacts

The economic impact of a water need is based on the relative size of the water need to the water demand for each water user group (Figure 2-1). Smaller water shortages, for example, less than 5 percent, were 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 deepens, 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 such ability to adjust, an elasticity adjustment function was used in estimating impacts for several of the measures. Figure 2-1 illustrates the general relationship for the adjustment functions. Negative impacts are assumed to begin accruing when the shortage percentage reaches the lower bound b1 (10 percent in Figure 2-1), with impacts then increasing linearly up to the 100 percent impact level (per unit volume) once the upper bound for adjustment reaches the b2 level shortage (50 percent in Figure 2-1 example).

Initially, the combined total value of the three value added components (direct, indirect, and induced) was calculated and then converted into a per acre-foot economic value based on historical TWDB water use estimates within each particular water use category. As an example, if the total, annual value added for livestock in the region was $2 million and the reported annual volume of water used in that industry was 10,000 acre-feet, the estimated economic value per acre-foot of water shortage would be $200 per acre-foot. Negative economic impacts of shortages were then estimated using this value as the maximum impact estimate ($200 per acre-foot in the example) applied to the anticipated shortage volume in acre-feet and adjusted by the economic impact elasticity function. This adjustment varied with the severity as percentage of water demand of the anticipated shortage. If one employed the sample elasticity function shown in Figure 2-1, a 30% shortage in the water use category would imply an economic impact estimate of 50% of the original $200 per acre-foot impact value (i.e., $100 per acre-foot).

Such adjustments were not required in estimating consumer surplus, nor for the estimates of utility revenue losses or utility tax losses. Estimates of lost consumer surplus relied on city-specific demand curves with the specific lost consumer surplus estimate calculated based on the relative percentage of the city's water shortage. Estimated changes in population as well as changes in school enrollment were indirectly related to the elasticity of job losses.

Assumed values for the bounds b1 and b2 varied with water use category under examination and are presented in Table 2-2.

Figure 2-1 Example Economic Impact Elasticity Function (as applied to a single water user's shortage)

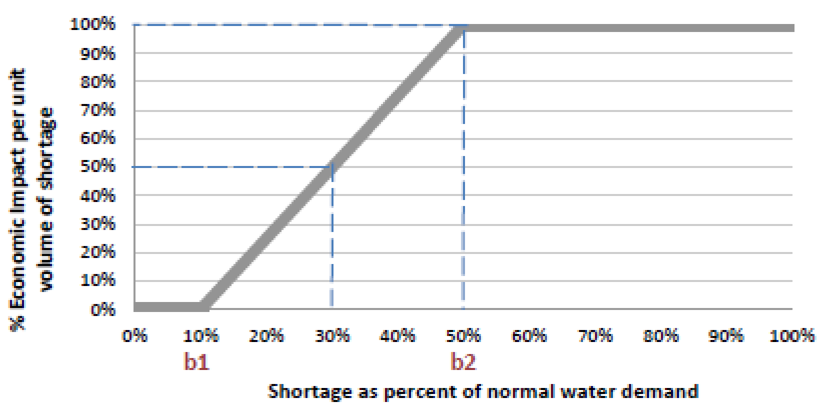

Table 2-2 Economic Impact Elasticity Function Lower and Upper Bounds

Water Use Category	Lower Bound (b1)	Upper Bound (b2)
Irrigation	**5%**	**50%**
Livestock	**5%**	**10%**
Manufacturing	**10%**	**50%**
Mining	**10%**	**50%**
Municipal (non-residential water intensive)	**50%**	**80%**
Steam-electric power	**20%**	**70%**

2.3 Analysis Assumptions and Limitations

Modeling of complex systems requires making assumptions and accepting limitations. This is particularly true when attempting to estimate a wide variety of economic impacts over a large geographic area and into future decades. Some of the key assumptions and limitations of the methodology include:

1. The foundation for estimating socioeconomic impacts of water shortages resulting from a drought are the water needs (potential shortages) that were identified as part of the regional water planning process. These needs have some uncertainty associated with them, but serve as a reasonable basis for evaluating potential economic impacts of a drought of record event.

2. All estimated socioeconomic impacts are snapshot estimates of impacts 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 severe drought conditions. The evaluation assumed that no recommended water management strategies are implemented. In other words, growth occurs, future shocks are imposed on an economy at 10-year intervals, and the resulting impacts are estimated. Note that the estimates presented were not cumulative (i.e., summing up expected impacts from today up to the decade noted), but were simply an estimate of the magnitude of annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated 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, supplies of limited resources, and other structural changes to the economy that may occur into the future. This 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 analysis is not a 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 procedures to weigh future costs differently through time.

5. Monetary figures are reported in constant year 2013 dollars.

6. Impacts are annual estimates. The estimated economic model 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.

7. 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 categories (value added and consumer surplus) are both valid impacts but should not be summed.

8. The value added, jobs, and taxes on production and import impacts include the direct, indirect and induced effects described in Section 2.2.1. 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.

9. The majority of impacts estimated in this analysis may be considered smaller than those that might occur under drought of record conditions. 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 these types of economic impact modeling efforts, 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, which is one reason why the impact estimates are likely conservative.

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

11. The model did 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:

i. The likely significant economic rebound to the landscaping industry immediately following a drought;
j. The cost and years to rebuild liquidated livestock herds (a major capital item in that industry);
k. Direct impacts on recreational sectors (i.e., stranded docks and reduced tourism); or,
l. 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 accurately 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.

3 Analysis Results

This section presents a breakdown of the results of the regional analysis for Region L. Projected economic impacts for six water use categories (irrigation, livestock. municipal, manufacturing, mining, and steam-electric power) are also reported by decade.

3.1 Overview of the Regional Economy

Table 3-1 presents the 2011 economic baseline as represented by the IMPLAN model and adjusted to 2013 dollars for Region L. In year 2011, Region L generated about $119 billion in gross state product associated with 1.4 million jobs based on the 2011 IMPLAN data. These values represent an approximation of the current regional economy for a reference point.

Table 3-1 Region L Economy

Income ($ millions)*	Jobs	Taxes on production and imports ($ millions)*
$118,558	**1,421,846**	**$8,686**

[1]Year 2013 dollars based on 2011 IMPLAN model value added estimates for the region.

The remainder of Section 3 presents estimates of potential economic impacts for each water use category 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.

3.2 Impacts for Irrigation Water Shortages

Eight 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 3-2. 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. Two factors led to excluding any reported tax impacts: 1) Federal support (subsidies) has lessened greatly since the year 2011 IMPLAN data was collected, and 2) It was not considered realistic to report increasing tax revenue collections for a drought of record.

Table 3-2 Impacts of Water Shortages on Irrigation in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$32	$28	$25	$22	$19	$16
Job losses	1,377	1,233	1,091	950	814	701

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.3 Impacts for Livestock Water Shortages

None 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 3-3. Note that tax impacts are not reported for this water use category for similar reasons that apply to the irrigation water use category described above.

Table 3-3 Impacts of Water Shortages on Livestock in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	-	-	-	-	-	-
Job losses	-	-	-	-	-	-

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000***

3.4 Impacts for Municipal Water Shortages

Seventeen 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 the two subtypes of use within municipal use: residential, and non-residential. The latter includes commercial and institutional users. Consumer surplus measures were made for both residential and nonresidential demands. In addition, available data for the non-residential, water-intensive portion of municipal demand allowed use of IMPLAN and TWDB Water Use Survey data to estimate income loss, jobs, and taxes. Trucking cost estimates, calculated for shortages exceeding 80 percent, assumed a fixed cost of $20,000 per acre-foot to transport water for municipal use. The estimated impacts to this water use category appear in Table 3-4.

Table 3-4 Impacts of Water Shortages on Municipal Water Users in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$178	$243	$340	$450	$658	$1,600
Job losses	3,225	4,407	6,169	8,163	11,931	28,863
Tax losses on production and imports[1] ($ millions)*	$15	$21	$29	$38	$56	$136
Consumer surplus losses ($ millions)*	$29	$58	$108	$171	$264	$403
Trucking costs ($ millions)*	$0	$0	$0	$1	$1	$3
Utility revenue losses ($ millions)*	$210	$304	$418	$537	$625	$809
Utility tax revenue losses ($ millions)*	$4	$6	$8	$10	$12	$15

[1] Estimates apply to the water-intensive portion of non-residential municipal water use.
**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by azero ($0) indicate income losses less than $500,000.***

3.5 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in 6 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 3-5.

Table 3-5 Impacts of Water Shortages on Manufacturing in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$724	$889	$1,123	$1,367	$1,709	$2,176
Job losses	8,455	10,113	12,091	14,005	16,702	20,267
Tax losses on production and imports ($ millions)*	$44	$55	$71	$89	$113	$148

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.6 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in 4 of the 21 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use type appear in Table 3-6.

Table 3-6 Impacts of Water Shortages on Mining in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$925	$895	$743	$432	$177	$48
Job losses	5,220	5,055	4,199	2,441	1,002	272
Tax losses on production and imports ($ millions)*	$114	$110	$92	$53	$22	$6

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.7 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in 1 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 3-7.

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

- Are reflected as an income loss proxy in the form of the estimated additional purchasing costs for power from the electrical grid 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.
- Does 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 3-7 Impacts of Water Shortages on Steam-Electric Power in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$132	$872	$1,089	$1,570	$2,070	$2,070

**** Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000.***

3.8 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 3-8.

Table 3-8 Region-wide Social Impacts of Water Shortages in Region

Impact Measures	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$29	$58	$108	$171	$264	$403
Population losses	3,356	3,821	4,324	4,693	5,591	9,199
School enrollment losses	621	$707	$800	$868	$1,034	$1,702

**** Year 2013 dollars, rounded. Entries denoted by a dash***

Appendix - 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 2013 dollars, rounded). Values presented only for counties with projected economic impacts for at least one decade.

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

		Income Losses (Millions $)*						Job Losses						Consumer Surplus (Millions $)*					
County	Water Use Category	2020	2030	2040	2050	2060	2070	2020	2030	2040	2050	2060	2070	2020	2030	2040	2050	2060	2070
Bexar	Irrigation	$2	$1	$1	$1	$1	$1	72	61	51	42	34	27	-	-	-	-	-	-
Bexar	Manufacturing	-	-	-	-	-	$6	-	-	-	-	-	60	-	-	-	-	-	-
Bexar	Municipal	$23	$34	$44	$56	$68	$476	422	613	799	1,015	1,231	8,631	$15	$34	$68	$107	$158	$216
Total Bexar		$25	$35	$45	$57	$69	$483	493	674	849	1,057	1,265	8,718	$15	$34	$68	$107	$158	$216
Caldwell	Municipal	$0	$0	$0	$1	$4	$36	5	7	8	9	70	658	$0	$0	$0	$1	$2	$5
Total Caldwell		$0	$0	$0	$1	$4	$36	5	7	8	9	70	658	$0	$0	$0	$1	$2	$5
Comal	Manufacturing	$4	$3	$3	$3	$3	$2	96	84	76	70	64	59	-	-	-	-	-	-
Comal	Municipal	$710	832	950	1,052	1,195	1,350	8,327	9,757	11,149	12,341	14,017	15,834	-	-	-	-	-	-
Total Comal		-	-	-	-	$61	$161	-	-	-	-	1,110	2,914	$1	$4	$10	$20	$32	$49
Guadalupe	Manufacturing	$710	$832	$950	$1,052	$1,256	$1,510	8,327	9,757	11,149	12,341	15,127	18,748	$1	$4	$10	$20	$32	$49
Guadalupe	Municipal	-	-	-	-	2	16	-	-	-	-	28	219	-	-	-	-	-	-
Total Guadalupe		-	-	$42	$92	$148	$243	-	-	761	1,666	2,687	4,415	$0	$4	$10	$17	$30	$49
Hays	Manufacturing	$14	$16	$18	$20	$21	$23	129	146	165	182	198	214	-	-	-	-	-	-
Hays	Municipal	$1	$1	$2	$3	$30	$292	20	27	35	46	542	5,148	0	1	$2	$4	$18	$57
Total Hays		$15	$17	$20	$22	$51	$316	149	173	201	228	740	5,363	$0	$1	$2	$4	$18	$57
Medina	Irrigation	$11	$10	$10	$9	$7	$6	524	485	447	399	346	301	-	-	-	-	-	-
Medina	Municipal	-	-	-	$0	$2	$3	-	-	-	1	29	60	$0	$0	$0	$0	$0	$1
Total Medina		$11	$10	$10	$9	$9	$10	524	485	447	399	375	361	$0	$0	$0	$0	$0	$1
Uvalde	Irrigation	$9	$8	$7	$6	$5	$4	453	399	344	297	255	221	-	-	-	-	-	-
Uvalde	Municipal	-	-	-	-	-	-	-	-	-	-	-	-	$0	$0	$0	$0	$0	$0
Total Uvalde		$9	$8	$7	$6	$5	$4	453	399	344	297	255	221	$0	$0	$0	$0	$0	$0

APPENDIX B

RESPONSES TO PUBLIC COMMENTS ON PROPOSED DFCs
Received by Members of GMA 10 during Comment Period

List of Comments

1. **Aquifer:** Central Subdivision of Edwards Aquifer. (No aquifer was designated by the commenter, but the context of the comment and its being originally sent to EAA indicate the commentary related to the San Antonio segment of the Edwards Aquifer.)
   Summary of Comment: Must monitor, maintain, protect, and restore springflows at San Marcos Springs, especially by reducing pumping associated with ill-advised, water-intensive (downstream) agricultural practices and land cover changes.
   GMA 10 Response: See Note A below the enumerated comments.

2. **Aquifer:** Central Subdivision of Edwards Aquifer (see parenthetical note in Item 1 above)
   Summary of Comment: DFC must prevent 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 (hereafter referred to as "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.

3. **Aquifer:** Central Subdivision of Edwards Aquifer (see parenthetical note in Item 1 above), but perhaps comment is intended to apply to all aquifers
   Summary of Comment: Texas and GMA 10 must regulate water both above and below ground in a similar fashion, using a non-"schizophrenic" approach.
   GMA 10 Response: GMA 10 agrees that at some temporal and areal scale, groundwater and surface water are hydrologically connected. But Texas law prescribes how both surface water and groundwater are to be regulated, largely reflecting their different ownership. 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. GMA 10 does, however, have an obligation under Texas Water Code Ch. 36.108(d) to consider certain factors before adopting DFCs which includes impacts on "…springflow and other interactions between groundwater and surface water " (TWC Ch. 36.108(d)(4)). See also Note A and the Responses to Comments 21-26 below.

4. **Aquifer:** Undesignated
Summary of Comment: These Commenters suggested GMA 10 use "zero drawdown" as a DFC where applicable. Generally, the Commenters are concerned that the GMA is conflating an *Inevitable* Future Condition that is currently feasible with a *Desired* Future Condition that does no further harm to well-water levels or springflows. The Commenters' specific concerns and rationale for this suggestion and GMA-10's responses are elaborated in comments that follow this over-arching one.
GMA 10 Response: See Note B below. The Commenters may be conflating the goal of zero-drawdown with a common definition of the concept of "sustainability." 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 above notwithstanding, a DFC has a statutory requirement to balance aquifer protection and the maximum groundwater production feasible. 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.

5. **Aquifer:** Undesignated
Summary of Comment: These Commenters offered a number of broad recommendations for improving the groundwater planning and management processes, to include: (a) adopting and applying a set of guiding principles for sustainability; (b) considering management rules that specifically protect minimum springflows; (c) continuing current rational practice of not permitting above the MAG; (d) encouraging use of rainwater harvesting for meeting various demands; and (e) prioritizing the development of water-neutral solutions using GCD rules.
GMA 10 Response: While individual or all GMA 10 members may support such recommendations, these recommendations are not on point with evaluating the currently proposed DFCs, so the GMA cannot respond or act upon them here. Implementing most of these involve approvals of individual Groundwater Conservation Districts (GCDs) rather than a GMA or, as noted by the Commenters, actions by the Texas Legislature and/or administrative agencies like the TWDB or TCEQ.

6. **Aquifer:** Undesignated
Summary of Comment: These Commenters encouraged initiating or continuing various studies and investigations focusing on aquifer science; relationships of headwaters, groundwater, and springflows; groundwater/surface-water relationships; and unpermitted withdrawals of water in riparian alluvium.

GMA 10 Response: GMA 10 members grasp the importance of better understanding the hydrologic relationships between aquifers, including the relationship between groundwater and surface water interactions. For example, The Edwards Aquifer Authority has begun a multiyear study, the Inter-formational Flow Study (IFF), to research the interactions between the Trinity and Edwards Aquifers along four major focus areas between the Nueces River Basin and the Guadalupe/Blanco River Basins. GMA 10 members, including Barton Springs/Edwards Aquifer Conservation District (BSEACD), Trinity Glen Rose Groundwater Conservation District, and Uvalde County Groundwater Conservation District are serving as regional partners in the IFF research effort. In a related multi-year investigation, BSEACD is installing a network of multiport monitoring wells to elucidate the dynamics of cross-formational flows among aquifers in the northern subdivision of GMA 10, including between the Edwards and Trinity Aquifers and between freshwater and brackish groundwater. The districts also agree that more data are needed to have good science for determinations about relationships between recharge to and discharge from aquifers and surface water flows. The need for those data may require or allow revisions to DFCs as such data become available, but the requirement at the present is to make decisions on the proposed DFCs on the basis of currently known science.

7. **Aquifer:** Undesignated/Multiple
Summary of Comment: Because all aquifers are connected, at least to some degree, every fresh and saline aquifer should be considered relevant for planning purposes.
GMA 10 Response: A relevance determination does not equate to importance. An aquifer can be locally important and even regulated by the local GCD without being relevant, at the local GCD's option. Relevance for joint planning purposes reflects the relative size of the water supply compared to other water supplies for one or more Water User Groups or the relative geographic extent of an aquifer, particularly when an aquifer is shared and jointly managed by multiple member GCDS. Relevance may also reflect the need for it to be included in the regional water planning because of its strategic importance or its possible use to support state-funding of a key water project. Those are the key tests for relevance. Every relevant aquifer requires a DFC and a MAG to be established and a set of rules to be promulgated that ensures the DFC is achieved; making every aquifer relevant could be accompanied by unreasonable administrative/regulatory burdens at the GCD(s), GMA, and TWDB levels that exceeds its utility; further, the rulemaking, monitoring, and enforcement efforts could adversely affect establishing DFCs/MAGs for other, clearly more relevant aquifers and their management. In addition, the modeling for the MAG takes into account any appreciable interconnectedness with other aquifers. The GMAs are best able to ascertain the pros and cons of whether a particular aquifer is relevant, and where it is relevant. That said, there is no prohibition on a GMA's declaring all of its aquifers throughout the GMA as relevant, but a requirement to do so conceivably could strain one or more GCDs' limited

resources without a lot of benefit to that GCD. Regardless, very few aquifers in GMA 10 have been declared non-relevant for the purposes of joint planning.

8. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)
   Summary of Comment: The DFC should be calculated using a methodology based on an historic groundwater level baseline from 1950 and that utilizes annual monitoring of well water elevations and springflow to ensure riparian flora and fauna are sustained.
   GMA 10 Response: It seems like this comment applies to GMA 9, not GMA 10. While GMA 10 proposes to use periodic monitoring well data and grid analysis to ascertain compliance with the Trinity DFC (and evaluate the efficacy of the corresponding MAG), it should be recognized that wells in the Trinity in GMA 10 from the 1950s are extremely rare, and those that might have existed were likely only incidental ones in the Upper Trinity. Further, there are no riparian biota related to the Trinity in GMA 10, as it is a confined aquifer there, i.e., without surface outcrop. There are no springs and seeps from the Trinity in GMA 10. The large springs in GMA 10 support abundant, and in some cases, rare biota, but they are solely associated with the Edwards Aquifer. In the judgment of the GMA (and for the San Antonio Pool, the mandate of the Texas Legislature), these prolific karst aquifers are best protected and sustained by establishing and enforcing production limits for the Edwards that incorporate substantial drought management provisions. Their DFCs are most appropriately expressed as resultant springflows, rather than as regional drawdown and annually measuring water levels in wells for compliance. See also Note A below.

9. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)
   Summary of Comment: Zero-drawdown can be successfully achieved with current aquifer uses and conditions.
   GMA 10 Response: It physically could be achieved, but with little to no benefit. 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 of the Trinity here would not conform to highest practicable water withdrawals to meet extant demand while protecting the aquifer. See also the Response to Comment No. 4 above, and Note B below.

10. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)

Summary of Comment: Zero-drawdown is consistent with the *State Water Plan*'s mandate for water management strategies not to exceed the established MAG, and that there are no water management strategies that would be affected by a zero-drawdown DFC. Future growth would be achieved by enhanced conservation, low impact design, and/or rainwater harvesting.
GMA 10 Response: This comment is not correct. Zero-drawdown DFC would produce a new MAG that would be negative for any non-exempt use, which is inconsistent with even the currently permitted Trinity production in GMA 10. Further, Trinity production based on the existing (and proposed) DFCs is already in the regional water plans, and substantial production has historically used other non-Edwards aquifers. See also the Response to Comment No. 4 above, and Note B below.

11. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)
Summary of Comment: The Commenters disavow utility of the TERS estimates for (even) water planning purposes. Zero-drawdown would bring aquifers in GMA 10 into "hydrologic balance" and would increase flows to surface water systems except during extraordinary drought conditions.
GMA 10 Response: This comment is misleading. TERS is not a controlling factor in establishing DFCs and MAGs in GMA 10. The putative hydrologic balance cannot be achieved without considering the sources for satisfying the existing large demands for water in the system equation. Further, the hydrologic system will adjust so it will eventually be in equilibrium or balance with any DFC, if all sources and sink terms in the equation are included, provided water is available in the connected system. In that regard, zero-drawdown is not unique. See also Response to Comment No. 4 above, and Note B below.

12. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)
Summary of Comment: Zero-drawdown would have significant beneficial impact on springflow and every other type of surface-water/groundwater interaction.
GMA 10 Response: No evidence to support this comment relative to GMA 10 aquifers is offered. For the Trinity in GMA 10, zero-drawdown would have no effect or beneficial impact on springflows, as no springflows depend on the Trinity. Additional groundwater withdrawals from an aquifer will induce additional recharge, to a degree dependent on the hydrogeological properties of aquifer systems in communication and their water availability. Whether that is beneficial or not depends on the frame of reference. See also Response to Comment No. 4 above, and Note B below.

13. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)

Summary of Comment: While not expected to be important, fuller aquifers produced by a zero-drawdown DFC would generally tend to reduce subsidence.
GMA 10 Response: Subsidence is not a factor that affects the DFC of any aquifer in GMA 10. See also Response to Comment No. 2.

14. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)
Summary of Comment: "Managed depletion" associated with anything other than zero-drawdown will degrade real and other property values and harm the business climate.
GMA 10 Response: 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. Further, reduced supply of groundwater that would accompany a zero-drawdown DFC would in fact degrade property values and the business climate, rather than enhance it as the Commenters maintain. The GMA 10 members are charged with defining what (non-zero) drawdown may sustain the water supply and thereby protect and enhance property values, while protecting the aquifer, and this is a more rational basis for DFCs. See also the Response to Comment No. 4 above, and Note B below.

15. **Aquifer:** Undesignated/Multiple
Summary of Comment: Zero-drawdown would benefit exempt well owners, because the competition for groundwater with non-exempts would be less. The property rights of the exempt well owners would therefore be enhanced. Non-exempts would have larger curtailments during severe drought than under the proposed DFCs.
GMA 10 Response: The rights to groundwater of exempt users and their ability to access it would not be affected, either beneficially or adversely, by a DFC. But non-exempts are affected in variable ways by a particular DFC. With a zero-drawdown DFC, existing non-exempts users would be required to reduce their groundwater withdrawals, either all of the

time or during certain drought stages, to preserve such a DFC, which would affect reliable access to expected water supplies. See also Note B.

16. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)
Summary of Comment: Zero-drawdown would be no more costly to administer than the existing/proposed DFC, other than updating Management Plans and more stringent rules to implement it. Since equipment for water well monitoring and springflow measurements is the same as now and already in place, there is no difference in feasibility of achieving the DFC between the proposed one and zero-drawdown.
GMA 10 Response: GMA 10 believes the Commenters are misinterpreting the intent of this factor in establishing DFCs. What needs to be addressed is not the administrative and technical work by GCDs in implementing various DFCs, rather it is the likelihood of the groundwater users to be able to physically and economically achieve the DFC. In this respect, a zero-drawdown, DFC would likely create substantial dislocations on non-exempt users by forcing demand reductions and locating alternative sources of water supply. GMA 10 believes that in aggregate a zero-drawdown is not likely to be feasible at all, and would likely create causes of legal action that would unnecessarily interfere with normal groundwater management. See also Response to Comment No. 4, and Note B below.

17. **Aquifer:** Undesignated (but context indicates the comments primarily relate to the Trinity Aquifer)
Summary of Comment: The Commenters feel that the economic benefit of maintaining long-term hydrologic integrity of aquifer/surface-water systems outweighs the economic losses of commercial pumpers.
GMA 10 Response: No evidence or supporting documentation is offered to support this assertion for any aquifer/surface-water system. Neither cost-benefit term has been quantified so it is difficult to assess its validity. For now, GMA 10 considers that it can be used to neither confirm nor refute the reasonableness of the proposed DFCs.

18. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision
Summary of Comment: Commenter requests more time for it and other members of the public to participate in the process, and for the GMA to take more time while considering its decision-making. Commenter also acknowledges that the timing is largely set by the state process.
GMA 10 Response: GMA 10 understands the amount of information to be digested by the public in this process can be daunting, especially that related to the DFC for this particular Aquifer. However, as noted by the Commenter, 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.

19. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision
Summary of Comment: Commenter cautions that the DFC should reflect what is the desired condition of the Aquifer at the end of the 50-year planning period, not what is immediately feasible or possible during the five-year joint planning period.
GMA 10 Response: GMA 10 agrees with the intent of this comment but disagrees with the putative elements in the proposed approach. This is a karst aquifer volume that relatively rapidly discharges and recharges, so its condition does not conform to being managed on a 50-year or even a 5-year cycle. The proposed DFCs reflect enduring goals as to the condition of this aquifer, regardless of when the recurrence of the Drought of Record (DOR) might occur (e.g., in the next five years or in the 45th year of the planning period.) The All Conditions DFC is expressly designed to restrict the acceleration of the Aquifer from non-drought to drought conditions and to increase the effectiveness of the drought management program, regardless of when or how often that transition might occur during the 50-year planning cycle. Again, if conditions change that either require or allow more or less pumping and springflow, then the DFC can be revised in subsequent rounds of joint planning to accommodate those new conditions or information.

20. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision
Summary of Comment: Commenter recommends establishing a series of interim DFC goals, linked to management actions, which in turn lead to the 50-year planning goal.
GMA 10 Response: See the response to Item 19 immediately above. Importantly, the DFC and MAG processes recur every five years, and require readopting the DFCs, revised as necessary to accommodate new information and conditions, at least that often, which essentially become a series of shorter-term "interim" goals that are always consistent with the prevailing 50-year state water plan.

21. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision
Summary of Comment: The GMA and BSEACD should revise the magnitude of the (Extreme Drought) DFC to ensure springflow during a recurrence of a DOR that existed during the DOR period, or about 11 cfs on a monthly average basis, in order to minimize harm to the endangered salamander species, as indicated by the best available science.
GMA 10 Response: As part of its now complete Draft 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. GMA 10 has therefore once again established that springflow as the DFC condition, which BSEACD’s regulatory program and HCP will be designed to achieve.

22. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision
Summary of Comment: The Commenter questions why BSEACD did not utilize studies completed since 2010, when the previous DFC was established, and revise the proposed DFC accordingly.
GMA 10 Response: BSEACD did utilize the most recent data and analyses in finalizing its HCP (available at http://bseacd.org/uploads/BSEACD_DraftHCP_2014_Nov_13_print.pdf) and in recommending the proposed DFC. Generally, the new data and information refined the salamander-DO-springflow relationships, but they did not indicate a need to change the HCP conservation measures dealing with production restrictions or the efficacy of doing so, which would in turn relate to a change in the DFC. What the data did suggest, and what BSEACD later adopted, was the need for some additional mitigation, which was incorporated into the final analyses. Along with some additional commitments made for certain foreseeable circumstances, which are described in detail in the District Draft HCP, the HCP and the DFCs minimize and mitigate take to the endangered species, although as the Commenter asserts, take cannot be completely avoided, only minimized.

23. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision

Summary of Comment: A DFC of less than 9.6 cfs springflow guarantees jeopardy of both species.

GMA 10 Response: This is not correct. The US Fish and Wildlife Service has never asserted that the historical low springflow is equivalent to a jeopardy condition. Jeopardy means that the species population is unable to survive and/or recover. There is no evidence that occurs at any particular springflow, as the DO-springflow characteristics of the proximate habitat are indeterminate. See the Response to Comment No. 21 above for relevant additional information.

24. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision

Summary of Comment: The DFC does not provide a minimum flow to prevent harm to the salamander populations.

GMA 10 Response: This is correct. But the DFC and the HCP are not intended to prevent harm. As the Commenter also noted, the species begins to be adversely, if non-lethally affected (harmed) at combined springflows of about 40 cfs. Take of the species, which is harm associated with BSEACD managed activities (which harm may also be caused by natural conditions), begins about 30 cfs and progressively increases as both springflow and DO concentrations decrease. Harm caused by BSEACD activities would be prohibited under federal law without the Incidental Take Permit (ITP)supported by the District HCP. But the prohibition on such harm ("take") is excepted by that same federal law, as long as an ITP is acquired and jeopardy doesn't occur. Take but not jeopardy is a consequence of the use of the aquifer as a sole-source water supply. And that is the reason BSEACD has developed an HCP and is seeking an Incidental Take Permit.

25. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision

Summary of Comment: Commenter asserts that with diligence and cooperation among the District, its permittees, and various other parties, all or nearly all of the historic pumping could be curtailed during extreme drought given adequate time to make this happen. This comment is apparently based on the reported ability in 2010 of 4.3 cfs of historic-use pumping to switch to alternate sources.

GMA 10 Response: This is a misleading comment. In 2010, authorized historic-use amounted to about 10 cfs. At that time, some permittees with access to alternative supplies informally indicated to the District that during extreme drought they might consider voluntarily and temporarily cease pumping the aquifer and switch to another water source that was then available to them. (By design, the District's mandatory and stringent drought curtailment program largely encouraged this response, although the permittees also have their own vital interest in preserving the water supply from the aquifer as long as possible.) But it is important to recognize that most permittees did not then, and still do not now, have access to such alternative supplies or the ability otherwise to curtail use beyond that required by the District's drought management plan. The continuing best efforts of this set of permittees in further reducing pumping during DOR recurrence are not likely to replicate the reductions suggested earlier by the first set of permittees, because the earlier set consumed the "low hanging fruit" with respect to available alternative water supplies. So contrary to the Commenter's suggestion, the voluntary potential actions of a smaller set of historic users cannot confidently be extrapolated to the remaining larger set of historic users. Only if and until additional water supplies become available to these users at an affordable cost would such additional participation in a curtailment program be likely to occur. However, even then, regardless of what alternative sources are available to any permittee, BSEACD cannot compel, only encourage their switching to other water supplies. The Extreme Drought DFC is based on what BSEACD can legally mandate as part of its regulatory program; it cannot be based on speculative and voluntary commitments of its permittees.

26. **Aquifer:** Freshwater Edwards (BFZ), Northern Subdivision
Summary of Comment: On the basis of its preceding comments (Items 18-25), Commenter proposed the following alternate DFC for the Aquifer's primary, Extreme Drought DFC:

> "The primary Desired Future Condition for Year 2065 for the freshwater portion of the Barton Springs Edwards Aquifer shall be to maintain Barton Springs flows at or above 10 cubic feet per second on a monthly average during a recurrence of the drought of record, and to make progress toward this Desired Future Condition by immediate and near-term District regulatory and non-regulatory actions designed to maintain Barton Springs flows at or above 7.5 cfs on a monthly average during a recurrence of the drought of record."

This DFC expression represents an increased DOR springflow (and concomitant reduction in allowed DOR pumpage) of 1.0 cfs on an interim, near-term basis, presumably to include the DFC for the current joint planning period, and also an increased springflow and concomitant pumpage reduction during a DOR recurrence of 3.5 cfs at the end of the regional water planning period.

GMA 10 Response: The Commenter's objective, while understandable as a stretch goal, does not conform to the realities that permittees face and that relate DFCs and groundwater regulation. Compliance with applicable DFCs is the backbone requirement that must be met in any and all permitting decision now and in the future, so the DFC must be both realistic and achievable immediately and throughout the joint planning period. Absent that condition, the GCDs will be working to manage formidable challenges with limited resources and/or authority. The current and proposed DFCs require the most stringent and achievable degree of curtailment, regardless of whether they might be revised in the future. There is no utility in proposing some unachievable DFC at this point, in that such a goal *per se* does not promote future achievement of that goal. Rather, the efficacy of future DFCs will be determined by changes in the prevailing infrastructural, legal, regulatory, and political environments that are largely beyond the control of BSEACD and GMA 10.

27. **Summary of Comment:** Agriculture needs to be suited to climate.

GMA 10 Response: This is a GCD by GCD issue, not a GMA 10 issue, one which may be addressed in Management Plans of a GCD and in GCD Rules. Further, GCDs can only evaluate whether a particular use is a "beneficial use" which is defined by statute to describe a variety of specific uses including Agriculture. A GCD cannot prioritize use or make value judgments with regard to whether a particular use is "suitable" or not. Article 16. Section 59. of the Texas Constitution says "CONSERVATION AND DEVELOPMENT OF NATURAL RESOURCES AND PARKS AND RECREATIONAL FACILITIES; CONSERVATION AND RECLAMATION DISTRICTS. (a) The conservation and development of all of the natural resources of this State, [...] including [...] the reclamation and irrigation of its arid, semiarid and other lands needing irrigation [...] the preservation and conservation of all such natural resources of the State are each and all hereby declared public rights and duties; and the Legislature shall pass all such laws as may be appropriate thereto." In this, it is the lands needing irrigation beyond what the climate may provide, which is constitutionally addressed.

28. **Summary of Comment:** Regulate water above and below ground.
GMA 10 Response: GCDs have statutory authority to manage groundwater, and have no authority over surface water. Surface water is considered waters of the state and diversions are regulated by the TCEQ. As such, surface water is legislatively outside of a GCDs jurisdictional authority.

29. **Summary of Comment:** Has received little input from stakeholders.
GMA 10 Response: Opportunity, in accordance with statute, has been provided for public input. The statute prescribes a process in which all GMA meetings held during the planning cycle are open to the public. Each of these meetings are noticed in advance and have a specific agenda item allowing public comment. Additionally, the process requires a 90-day public comment period on proposed DFCs and public hearings to be held by each GCD within that comment period to allow opportunity to provide public input.

30. **Summary of Comment:** Not to feel too constrained by what you believe is feasible.
GMA 10 Response: A DFC provides the measure by which feasibility is derived. Further, DFCs require an explanatory report describing how each of the required factors for proposed DFCs was considered. This explanation is intended to collectively describe the rationale for each DFC including the relative consideration of feasibility.

31. **Summary of Comment:** Limit to the MAG
GMA 10 Response: The MAG, as provided for in Chapter 36.1132, is one of several factors in GCD permitting decisions. Given the uncertainty associated with MAG estimates, the more relevant planning objective is achieving a DFC under section 36.108.

32. **Summary of Comment:** Encourage rainwater harvesting.
GMA 10 Response: This is a GCD by GCD issue, not a GMA 10 issue, one which may be addressed in Management Plans of a GCD and in GCD Rules. Encouraging rainwater harvesting along with other water planning strategies are in fact a required goal that all GCDs must address when developing Management Plans.

33. **Summary of Comment:** Encourage water neutral solutions to increase demand
GMA 10 Response: This is a GCD by GCD issue, not a GMA 10 issue, one which may be addressed in Management Plans of a GCD and in GCD Rules.

Continue on to Notes A and B

Note A (for Item 1): In regards to San Marcos (and Comal) Springs, the DFC and the amount of Modeled Available Groundwater (MAG) have been set for the entirety of the EAA-regulated portions of the Edwards Aquifer - Balcones Fault Zone. They were adopted by statute during the 80th Regular Session of the Texas Legislature and can only be amended through subsequent legislative actions. Specifically, Sections 1.14(a), (f) and (h), and Section 1.26 of the EAA Act serve as the current DFC, and Section 1.14(c) of the Act serves as the MAG (equating to 572,000 acre-feet of permitted withdrawal each calendar year). To further protect springflow, the EAA has implemented a Critical Period Management system that requires incrementally greater pumping reductions at five successive stages of declining aquifer levels or springflows. Within the San Antonio Pool of the Edwards Aquifer reductions range between 20 percent and 44 percent of permitted groundwater use based on declining water levels at the J-17 Index well in San Antonio, or reduced springflow at Comal and San Marcos Springs.

Another series of programs and conservation initiatives called the Edwards Aquifer Habitat Conservation Plan (EAHCP), was finalized and permitted by the United States Fish and Wildlife Service in 2013 in an effort to provide further protections for the Edwards Aquifer, springflow, and threatened and endangered species endemic to Comal and San Marcos Springs. Programs within the EAHCP, such as the Voluntary Irrigation Suspension Program Option and Aquifer Storage and Recovery leasing, allow for the conservation of Edwards Aquifer water and non-direct Edwards Aquifer water use during periods of prolonged drought. Habitat protection and restoration measures and research are currently being conducted at both Comal and San Marcos Springs in conjunction with the EAHCP.

Note B (for Item 4, and others): There are several aspects of the Commenters' suggested revision to have a "zero drawdown" DFC that make it difficult to formulate a specific response. This difficulty arises for several reasons. First, it fails to name specifically the aquifer or aquifers covered by their statement, and because of this it introduces several assumptions questioning what these aquifers may be. For example, it could be referring to "all aquifers" in GMA 10. Or it could refer to all "relevant aquifers with a proposed DFC". Or, it could be referring to just one of the aquifers for which GMA 10 has submitted proposed DFCs. GMA 10 has DFCs for the following eight aquifers: Austin Chalk (Uvalde County), Buda Limestone (Uvalde County), Trinity, Edwards (BFZ) Northern Subdivision, Saline Edwards (BFZ) Northern Subdivision, Edwards (BFZ) within Edwards Aquifer Authority, Edwards (Kinney County), and Leona Gravel (Uvalde County). Each aquifer is unique and has an associated groundwater assessment and/or Groundwater Availability Model (GAM) that was used, in part, for determining DFCs. If the GMA 10 Committee were to assume one thing and it was not what the Commenters were referring to, it would only serve to add more confusion.

Second, in this statement, "…***where applicable, specific DFCs be set at a zero drawdown"***, the Commenters do not provide guidance or additional information on what ***"where applicable***" 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 ***"...zero draw down"*** of these aquifers refer or apply.

Third, urging the adoption of a "zero drawdown" DFC for any aquifer may not be legally possible given the facts that, (a) under Texas law, surface landowners own the groundwater under their property and have a right to access some of it at any time; (b) some use is exempt from groundwater permitting and restrictions, such as domestic and livestock use, which consume small quantities of groundwater,and use by certain oil and gas operations that can consume large quantities of groundwater; (c) groundwater conservation districts generally have no legal authority to address issues related to real property subdivision so large parcels can be split with each subdivided parcel carrying its own exempt groundwater production quantity; and (d) the Texas Water Code requires the Districts in a GMA to establish DFCs that balance groundwater protection and maximum practicable production.

Lastly, the ***"...zero drawdown"*** in the Commenters' statement is not clearly defined. GMA 10 is not sure if a zero drawdown is intended to refer to an average drawdown geographically for a set period of time over the entire GMA, or whether it refers to not exceeding a drawdown of zero at any one specific geographical location at any one point of time. These two scenarios could allow for quite a variation between the two.

In order for the TWDB to calculate the Modeled Available Groundwater (MAG), they use the model or assessment that was developed to analyze and propose a DFC. These models include important specific reference parameters like starting dates, the specific aquifer being modeled, the area covered, and the type of draw down analysis, spring flow, and/or other measures involved. Where it is necessary for clarity, DFC statements include these references. For example, the Trinity DFC references include "during average recharge conditions" and the "regional average well drawdown" of 25 feet. Trying to calculate a MAG using a DFC such as suggested by the Commenters with no specific references would only introduce speculative possibilities that would make it impossible to determine a viable MAG.

Attempts by GMA 10 to respond comprehensively to the suggested revision to the proposed DFC(s) without designating additional aquifer-specific information needed, as identified above, would simply be speculative and at end of the day futile. GMA 10 responds to specific comments made in support of a "zero drawdown" DFC in the enumerated sections above.

Appendix C

F I N Avgonzales@swri.edu L T E C H N I C A L M E M O R A N D U M

To: Groundwater Conservation Districts in Groundwater Management Area 10

From: Wade Oliver, P.G., INTERA
James Pinkard, INTERA
Neil Deeds, PhD, PE, INTERA

Date: December 29, 2016

RE: Development of an Analytic Element Tool to Evaluate the Trinity Aquifer in Hays County, Texas

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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.

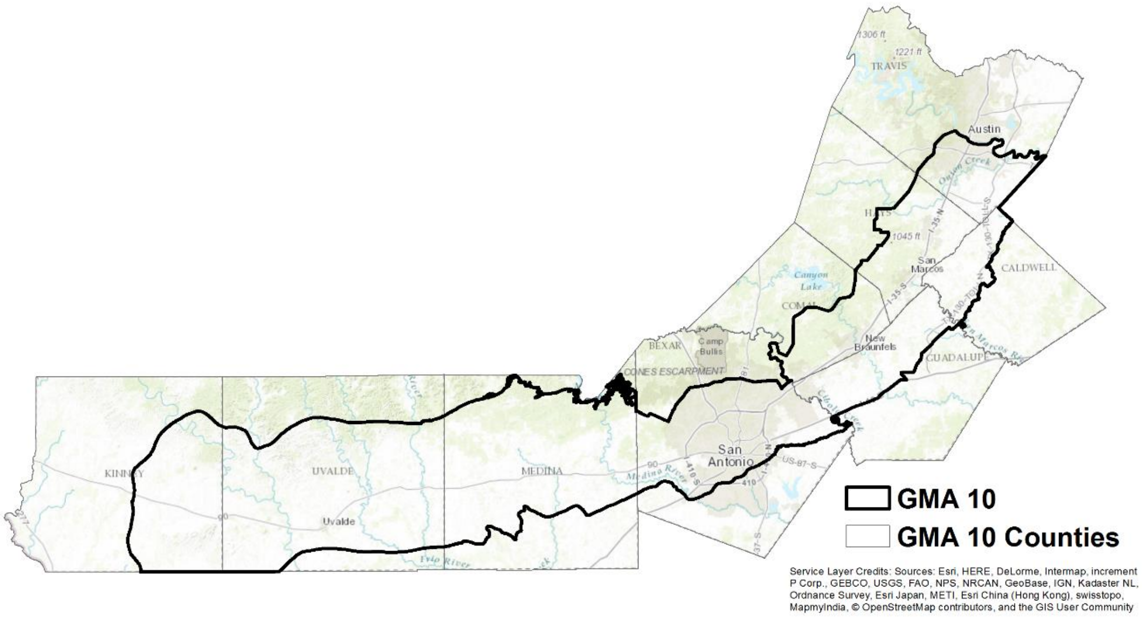


Figure 1. Groundwater Management Area 10 in Central Texas

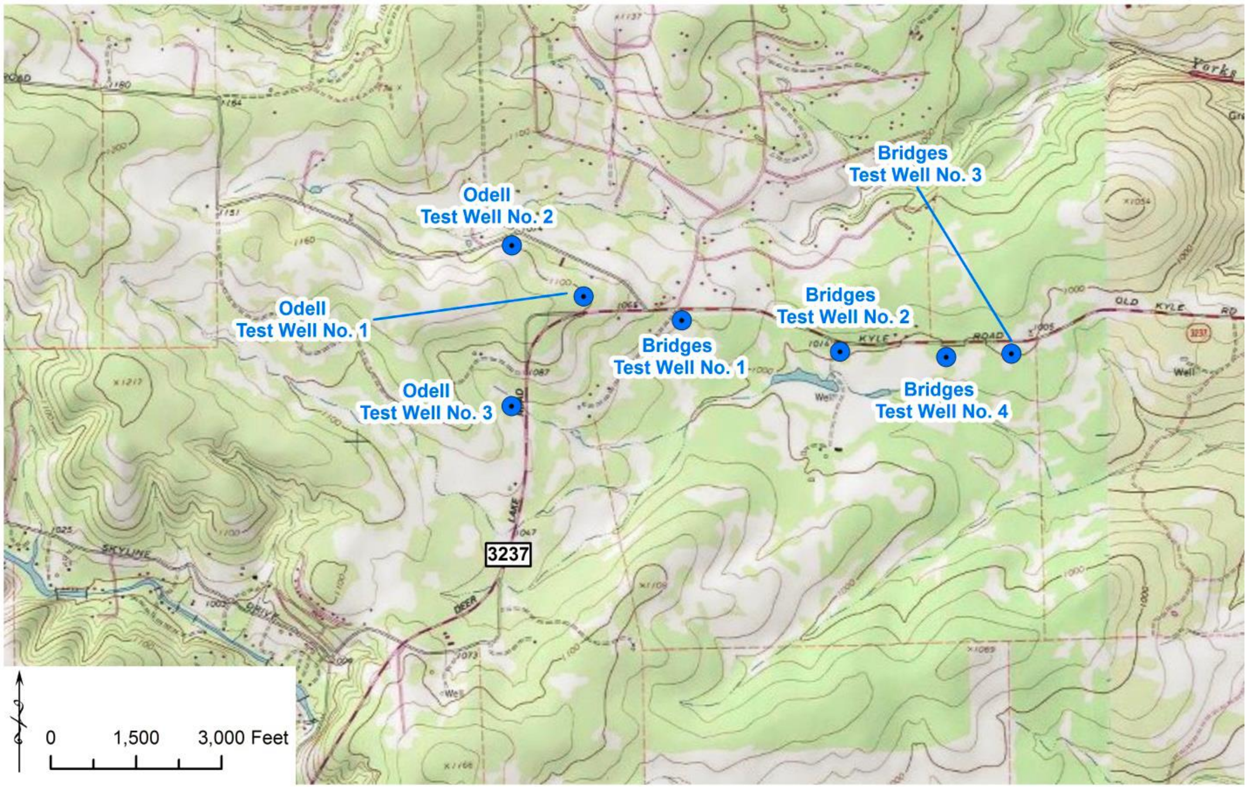


Figure 2. Electro Purification Well Field Layout (from WRGS, 2015)

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).

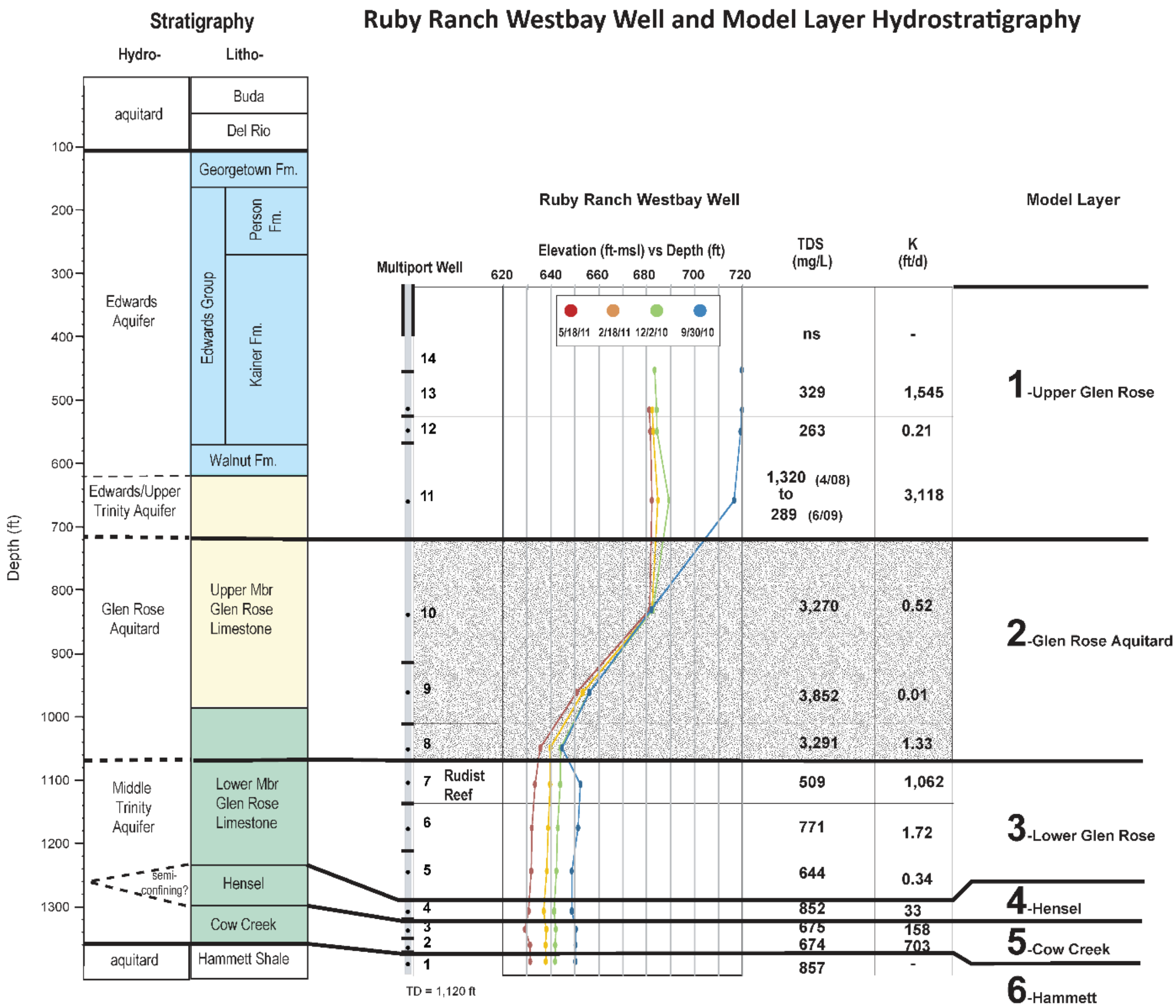


Figure 3. Stratigraphic chart, Ruby Ranch Westbay well, and model layer hydrostratigraphy

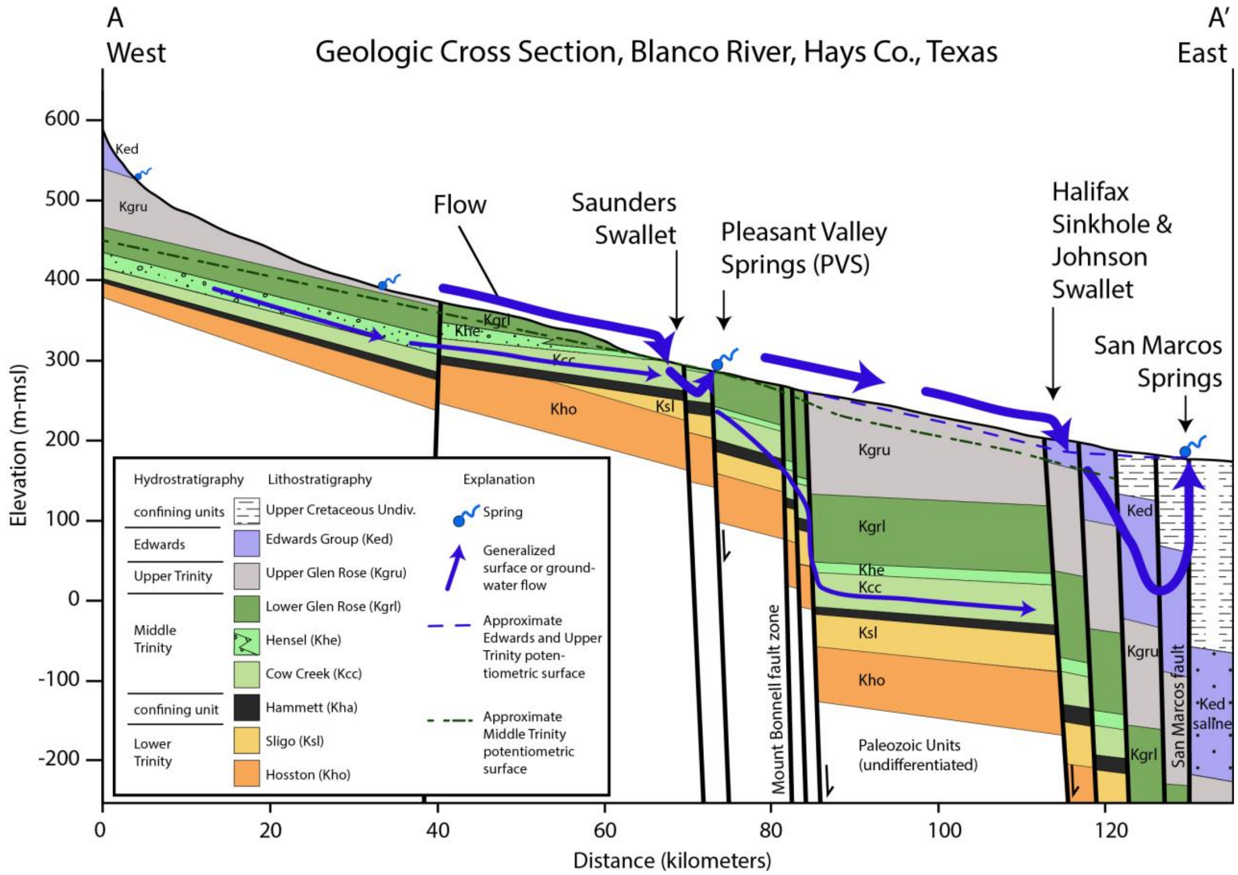


Figure 4. Geologic cross-section along the Blanco River in Hays County (from Wierman and others, 2010).

NUMERICAL MODEL:

<u>Model Code:</u>

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.

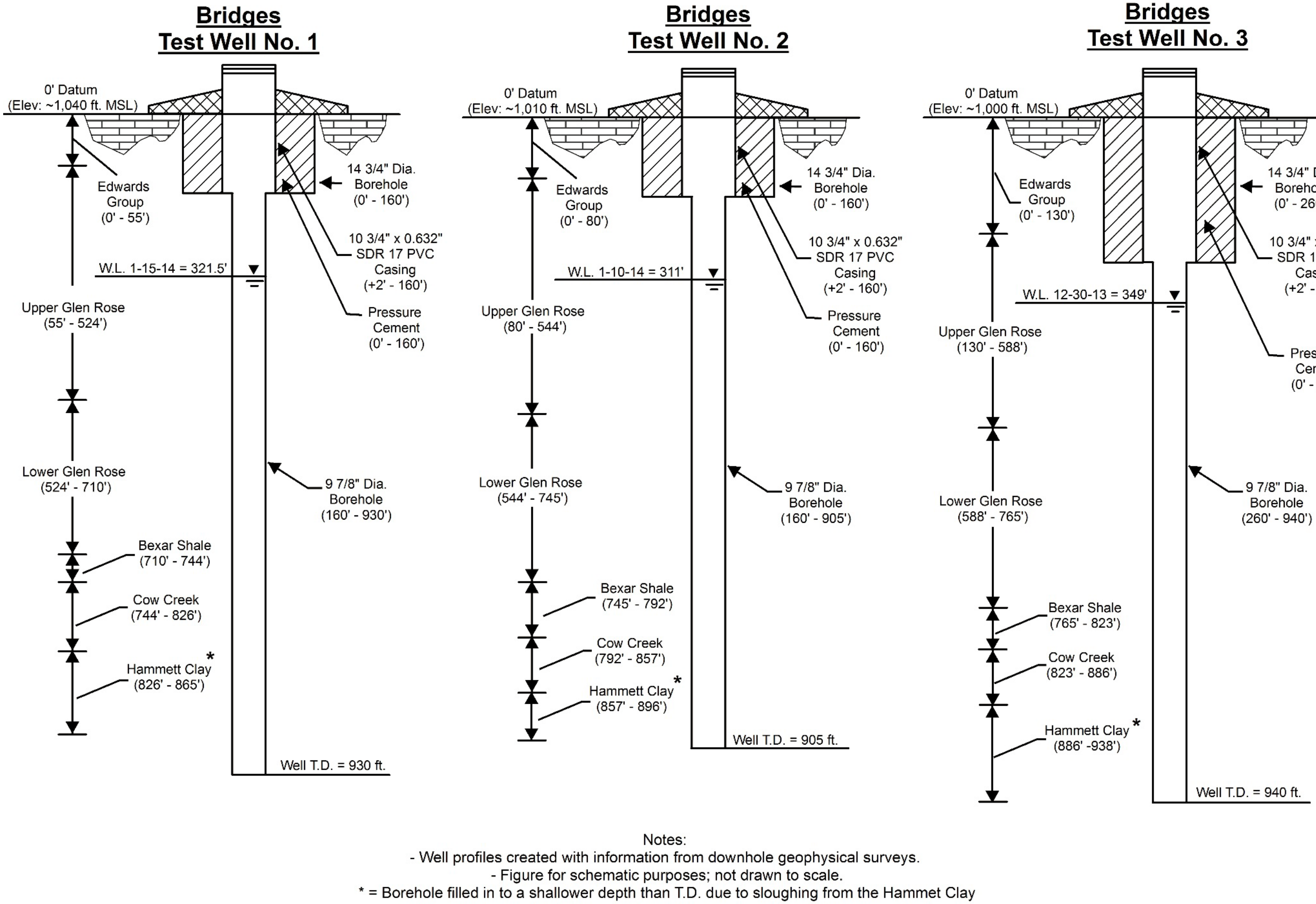
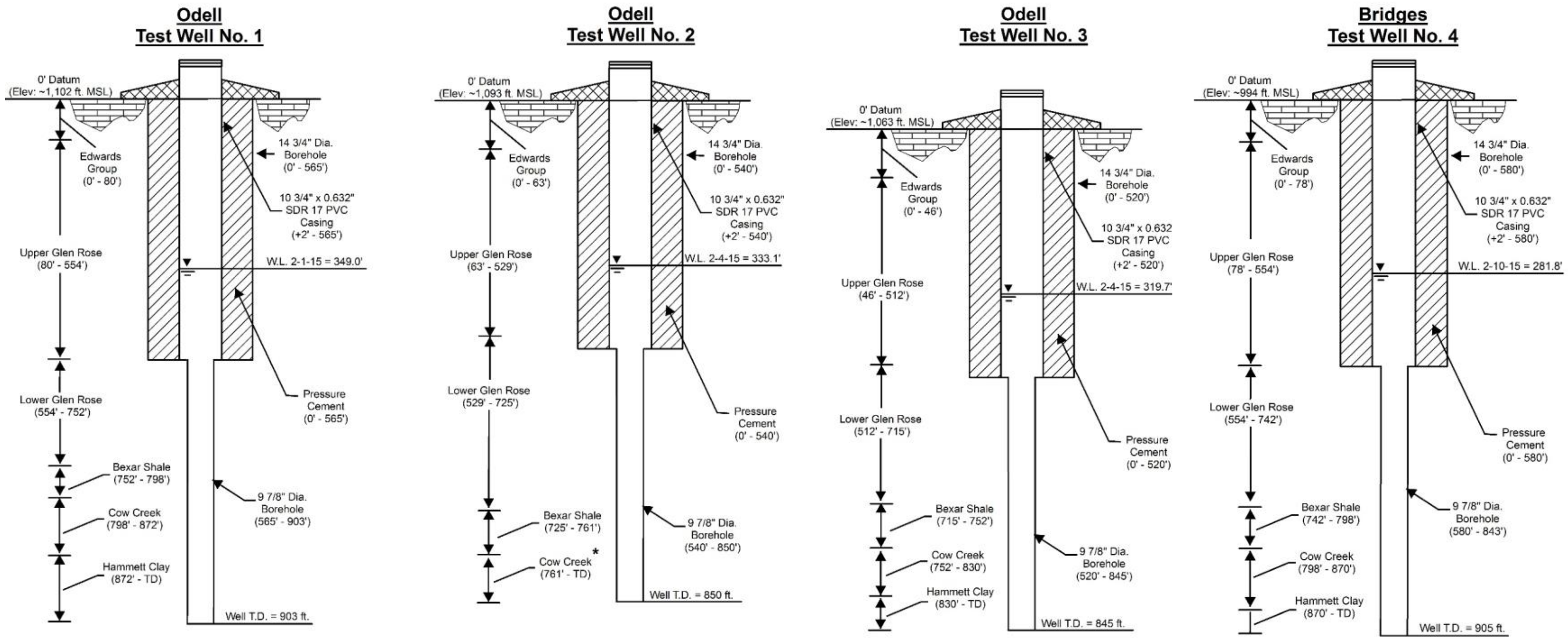


Figure 5. EP well field well completion diagrams (from WRGS, 2015).



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.

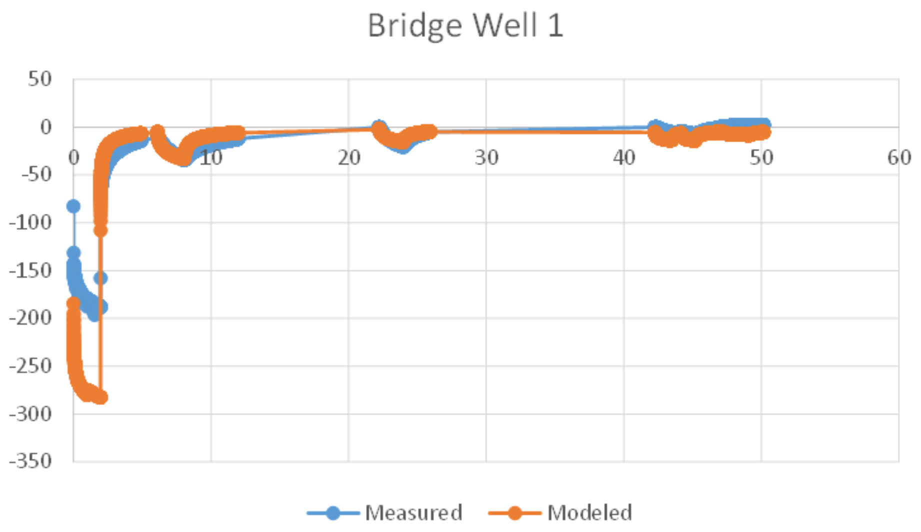


Figure 6. Comparison of measured to modeled drawdowns (in feet) for the Bridges 1 well.

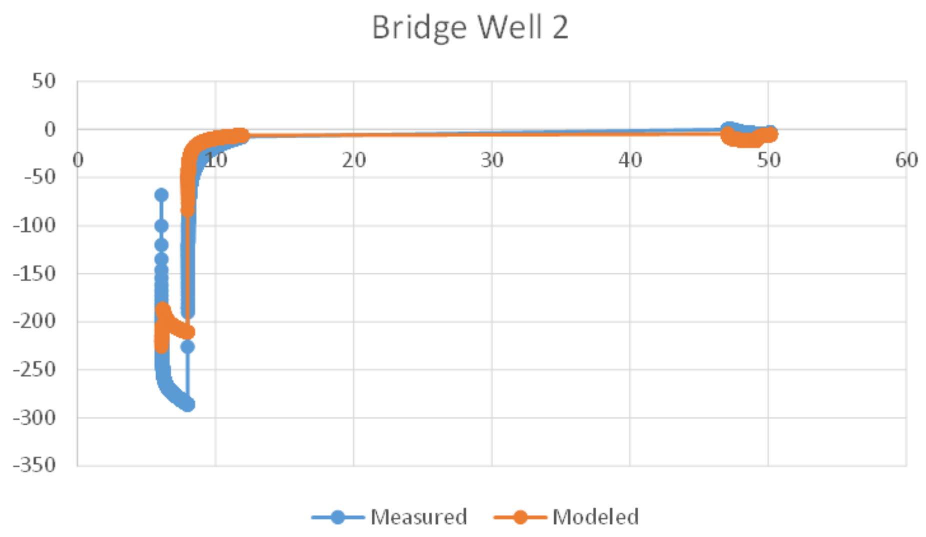


Figure 7. Comparison of measured to modeled drawdowns (in feet) for the Bridges 2 well.

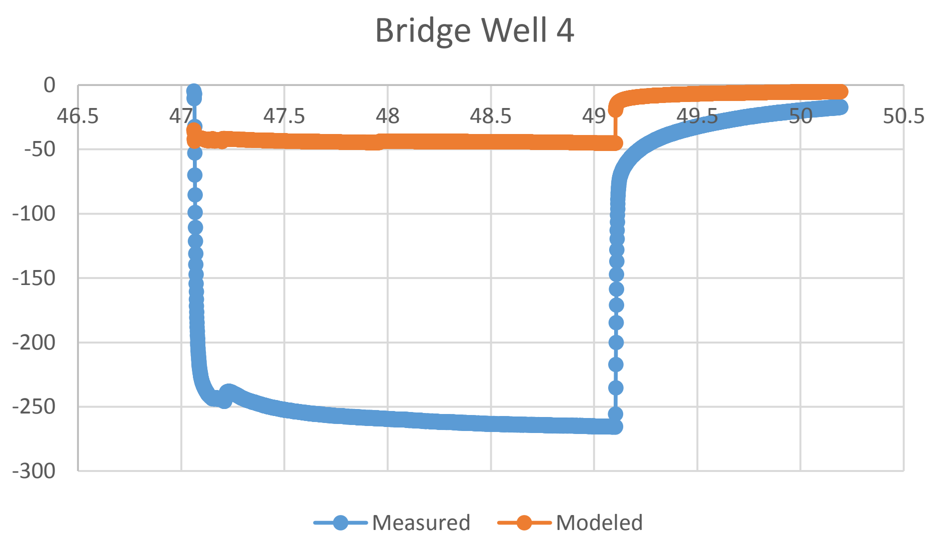


Figure 8. Comparison of measured to modeled drawdowns (in feet) for the Bridges 4 well.

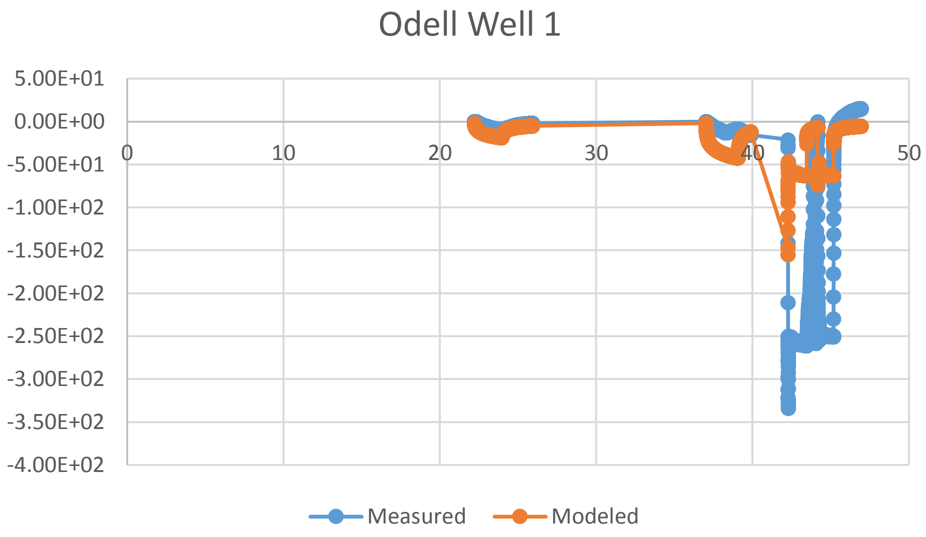


Figure 9. Comparison of measured to modeled drawdowns (in feet) for the Odell 1 well.

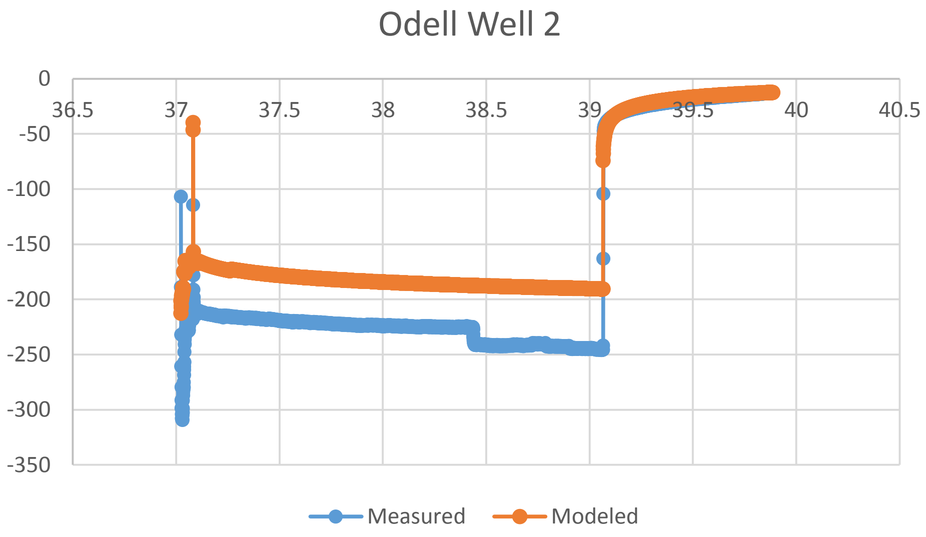


Figure 10. Comparison of measured to modeled drawdowns (in feet) for the Odell 2 well.

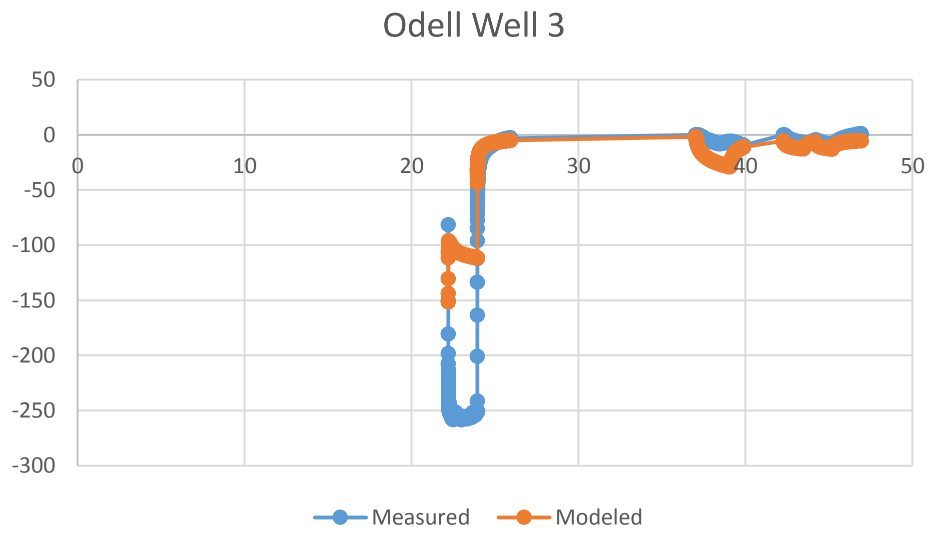


Figure 11. Comparison of measured to modeled drawdowns (in feet) for the Odell 3 well.

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*

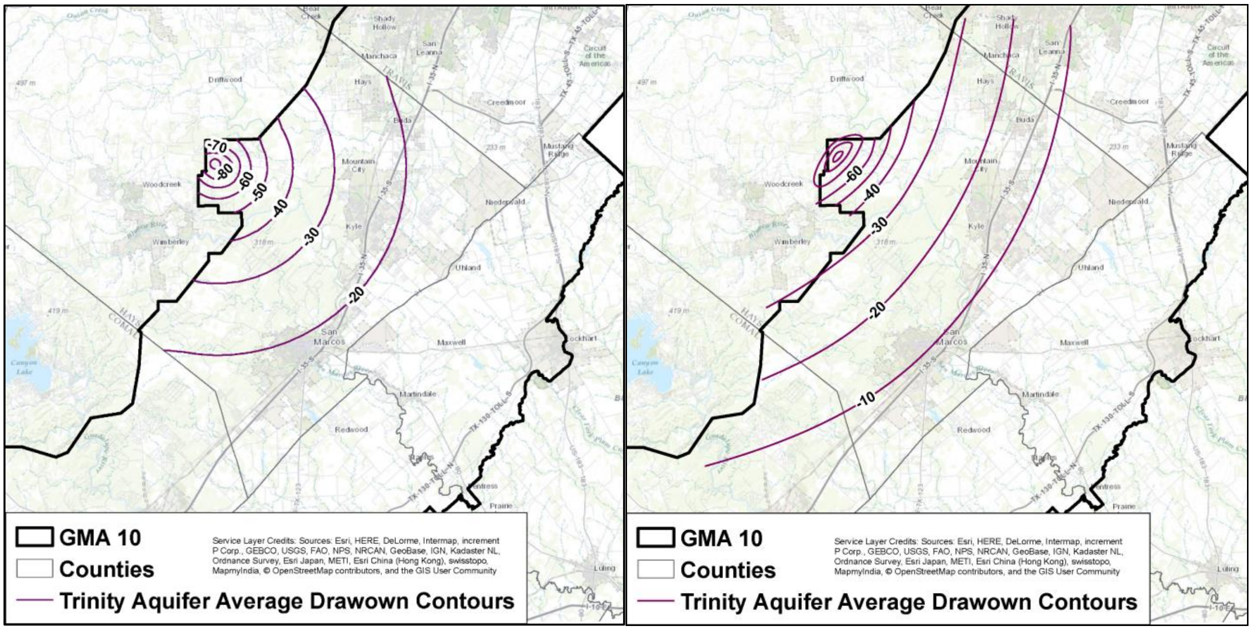


Figure 12. Comparison of modeled Trinity Aquifer average drawdown contours (left) to elongated contours designed to conceptually represent the effect of horizontal anisotropy (right).

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.

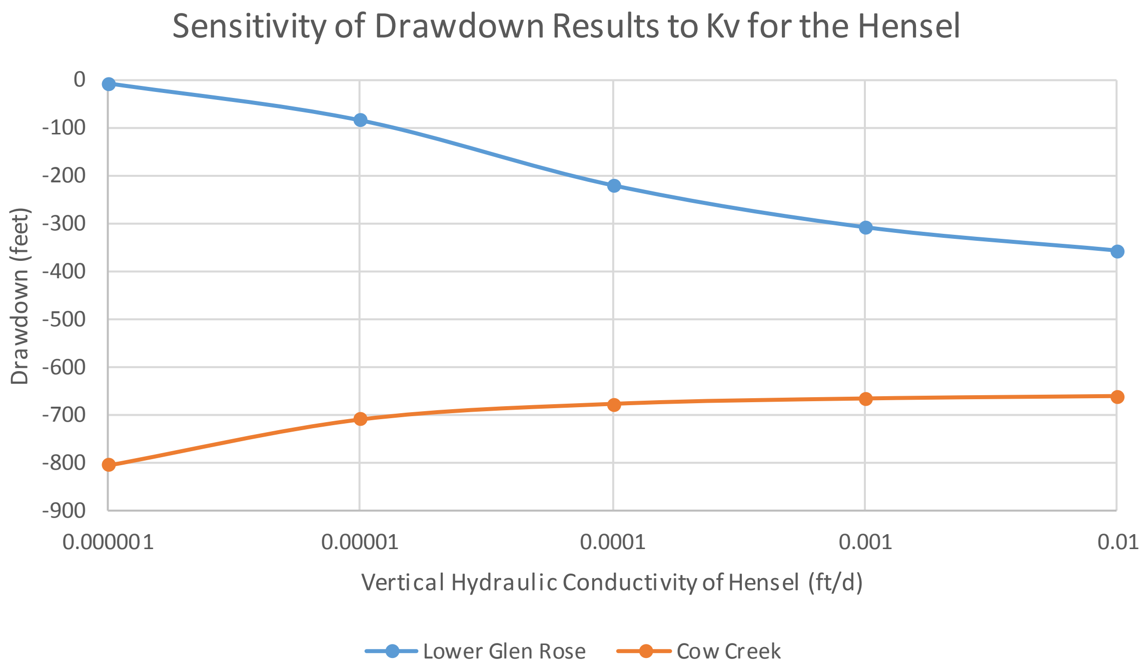


Figure 13. Sensitivity of Cow Creek and lower Glen Rose drawdown to the vertical hydraulic conductivity of the Hensel. Assumes pumping in the EP well field of 2.47 million gallons per day. Drawdowns after 50 years shown for Bridges 1 well.

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

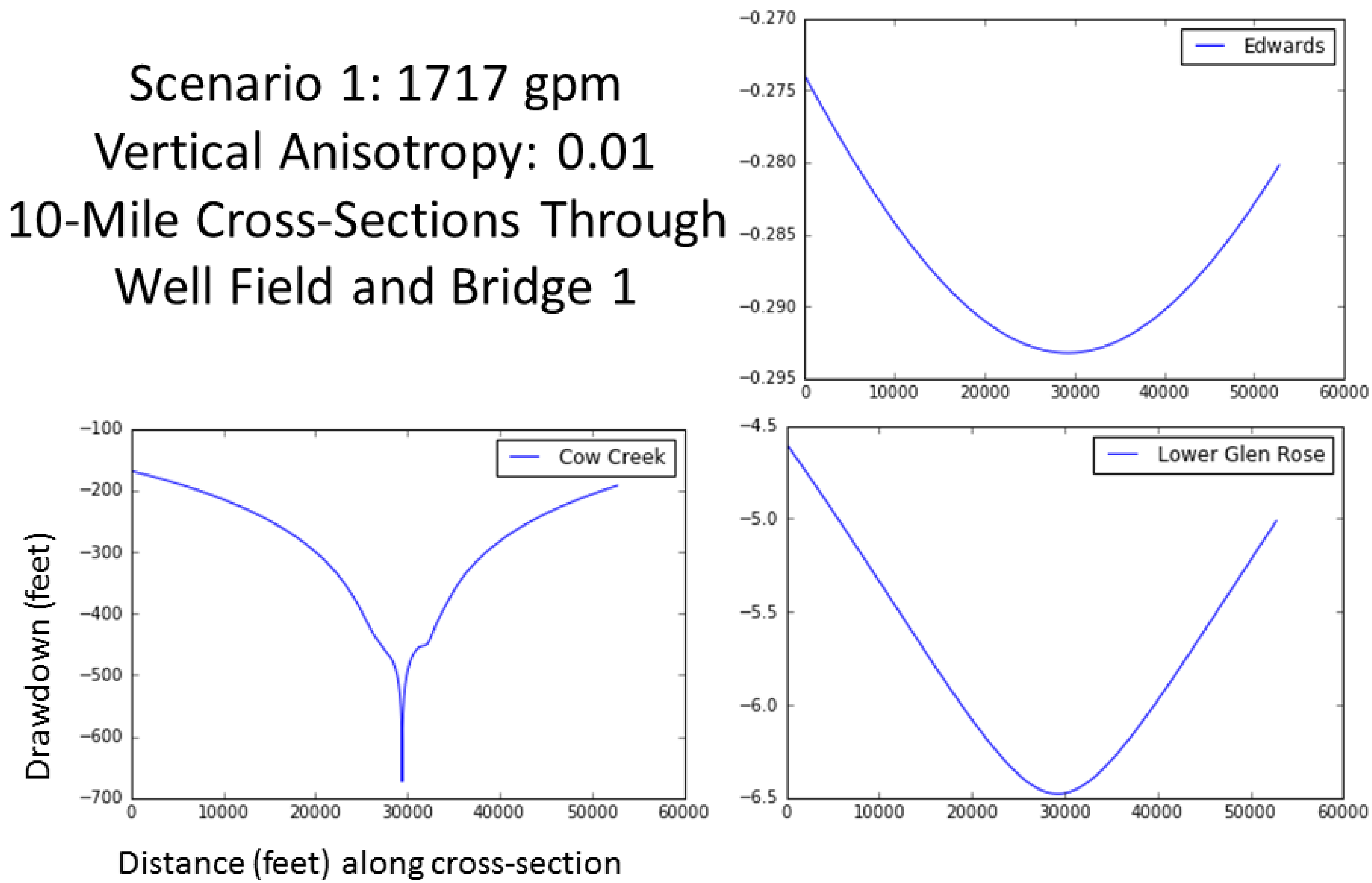

Figure A-1. Drawdown profiles for Scenario 1 across a 10-mile cross-section through the EP well field.

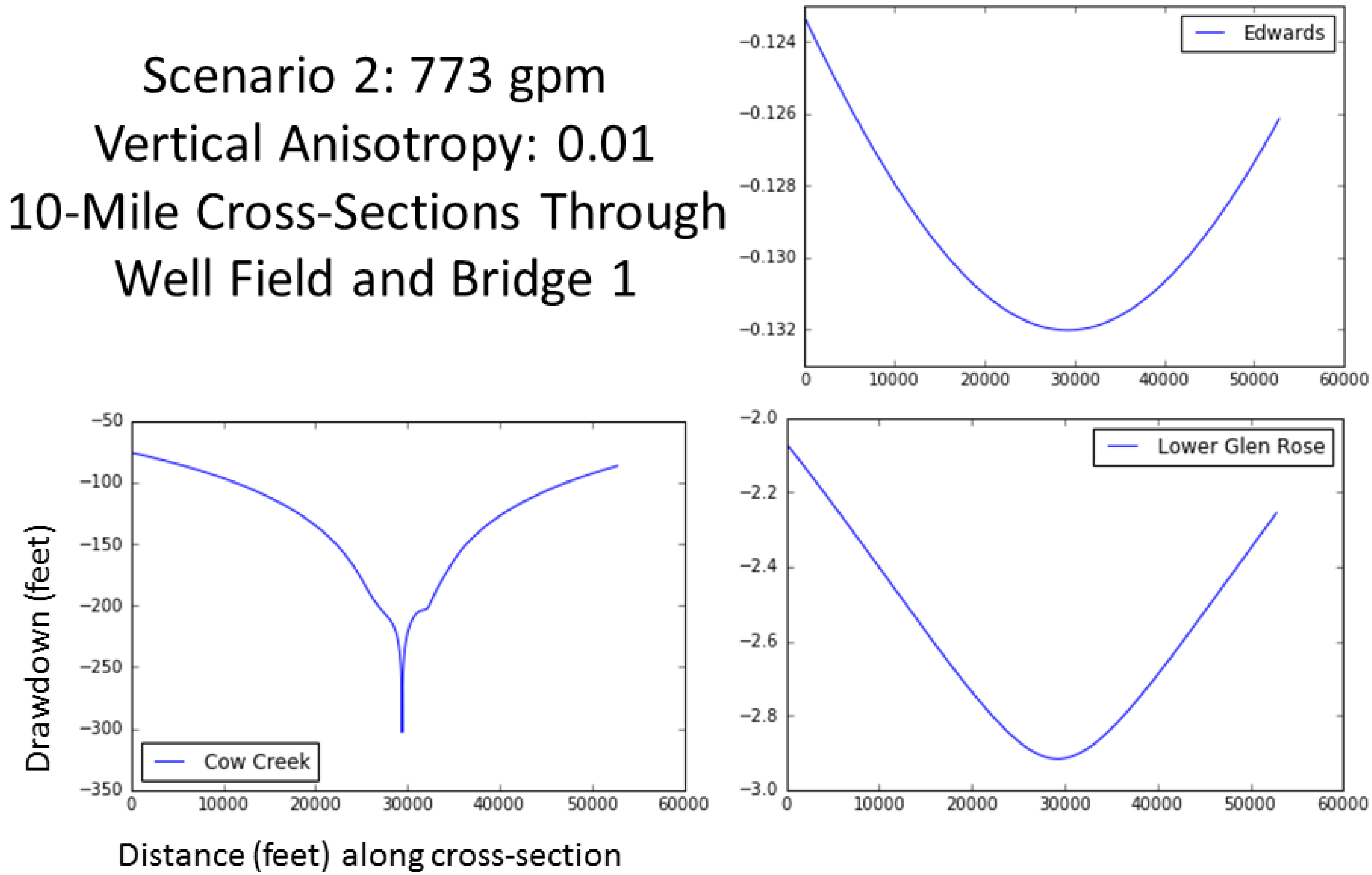

Figure A-2. Drawdown profiles for Scenario 2 across a 10-mile cross-section through the EP well field.

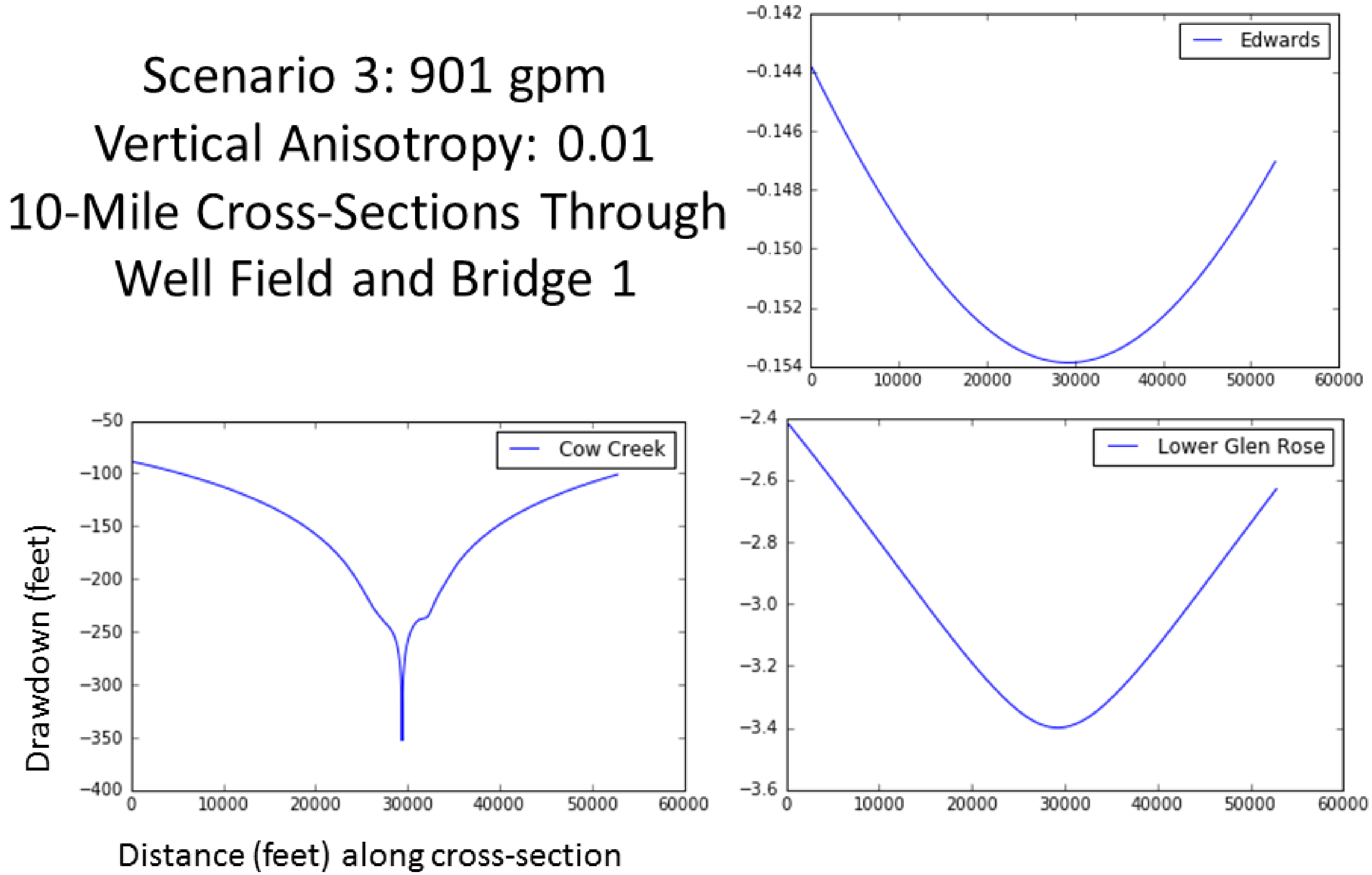

Figure A-3. Drawdown profiles for Scenario 3 across a 10-mile cross-section through the EP well field.

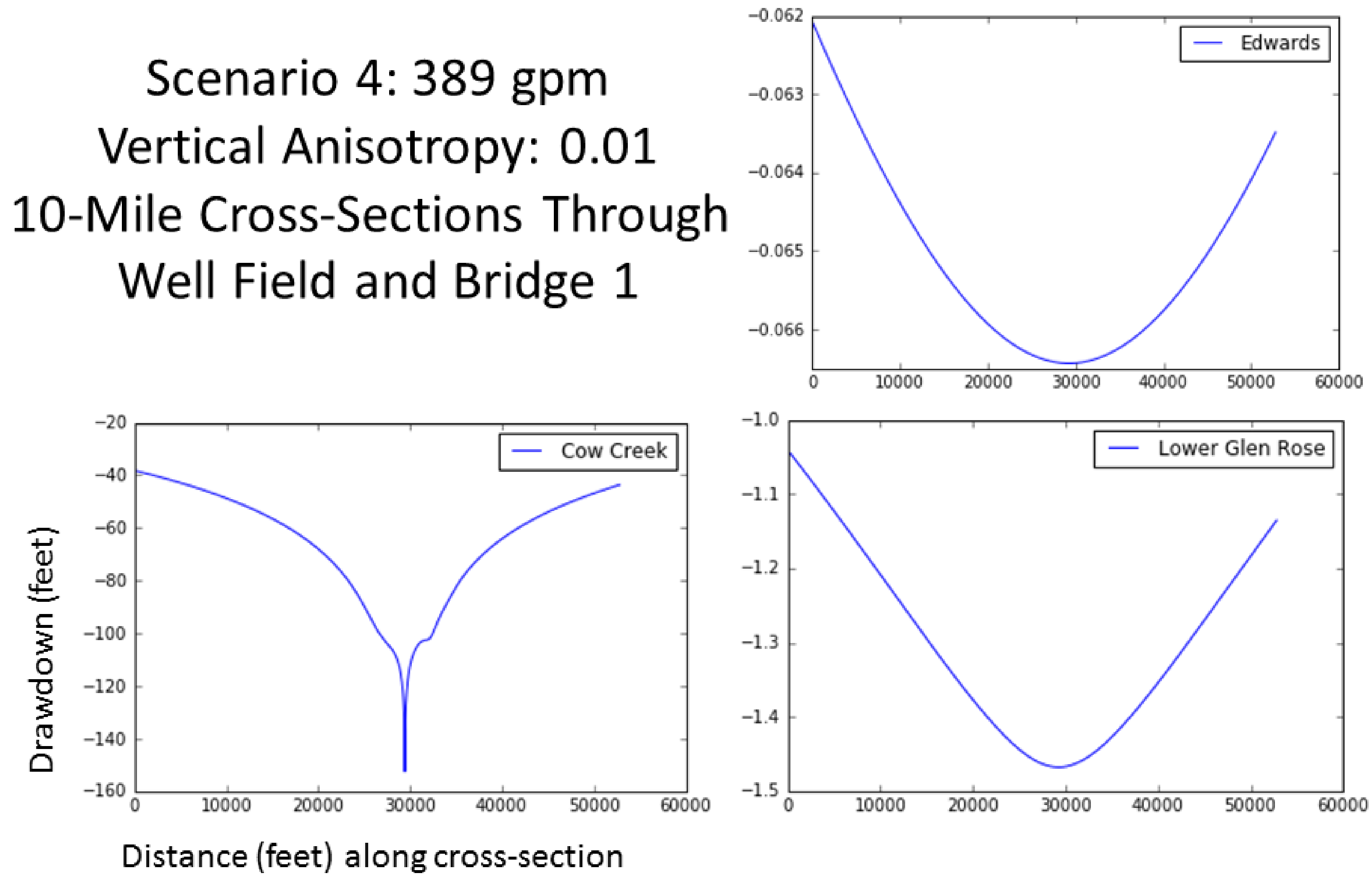

Figure A-4. Drawdown profiles for Scenario 4 across a 10-mile cross-section through the EP well field.

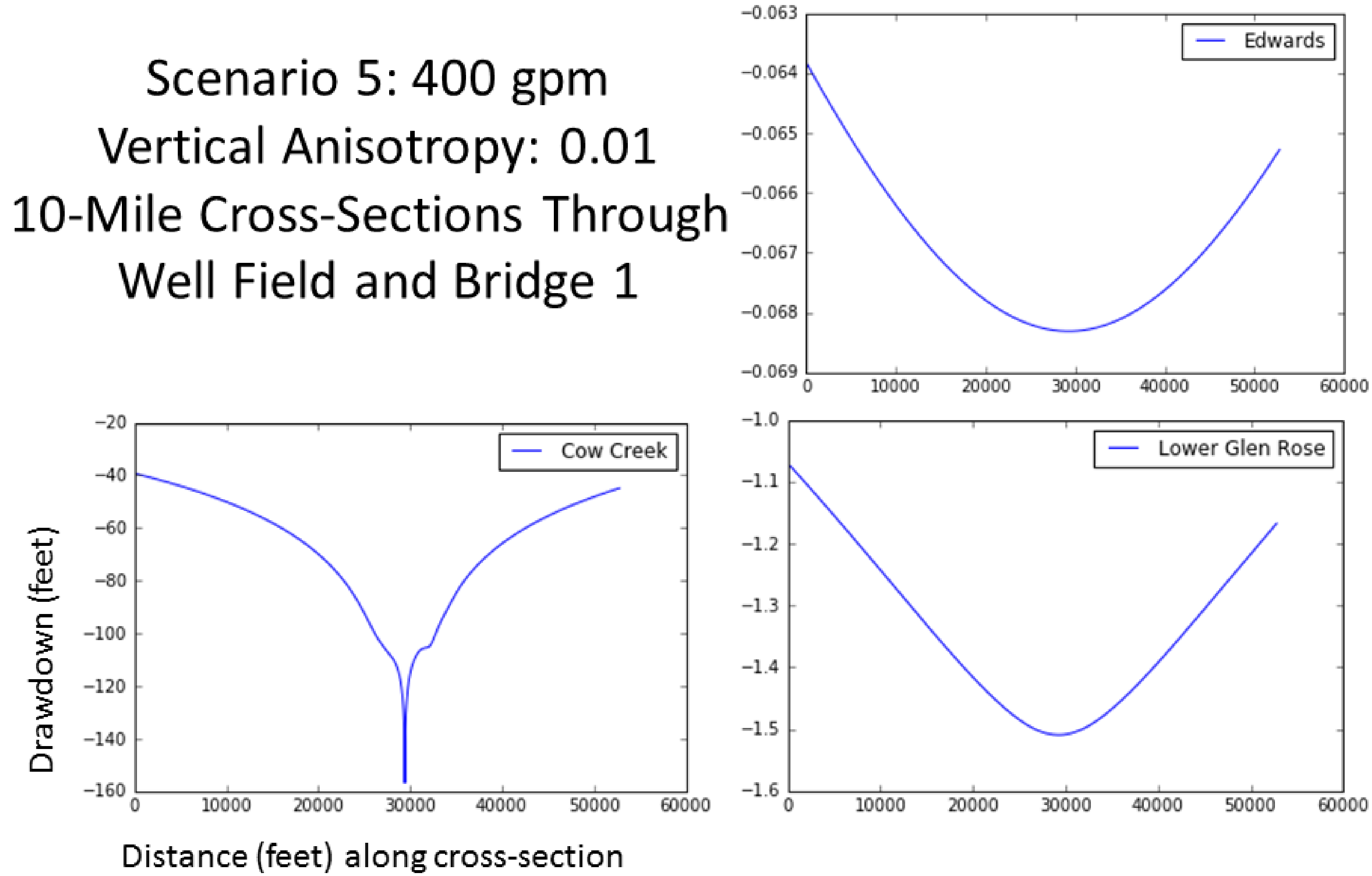

Figure A-5. Drawdown profiles for Scenario 5 across a 10-mile cross-section through the EP well field.

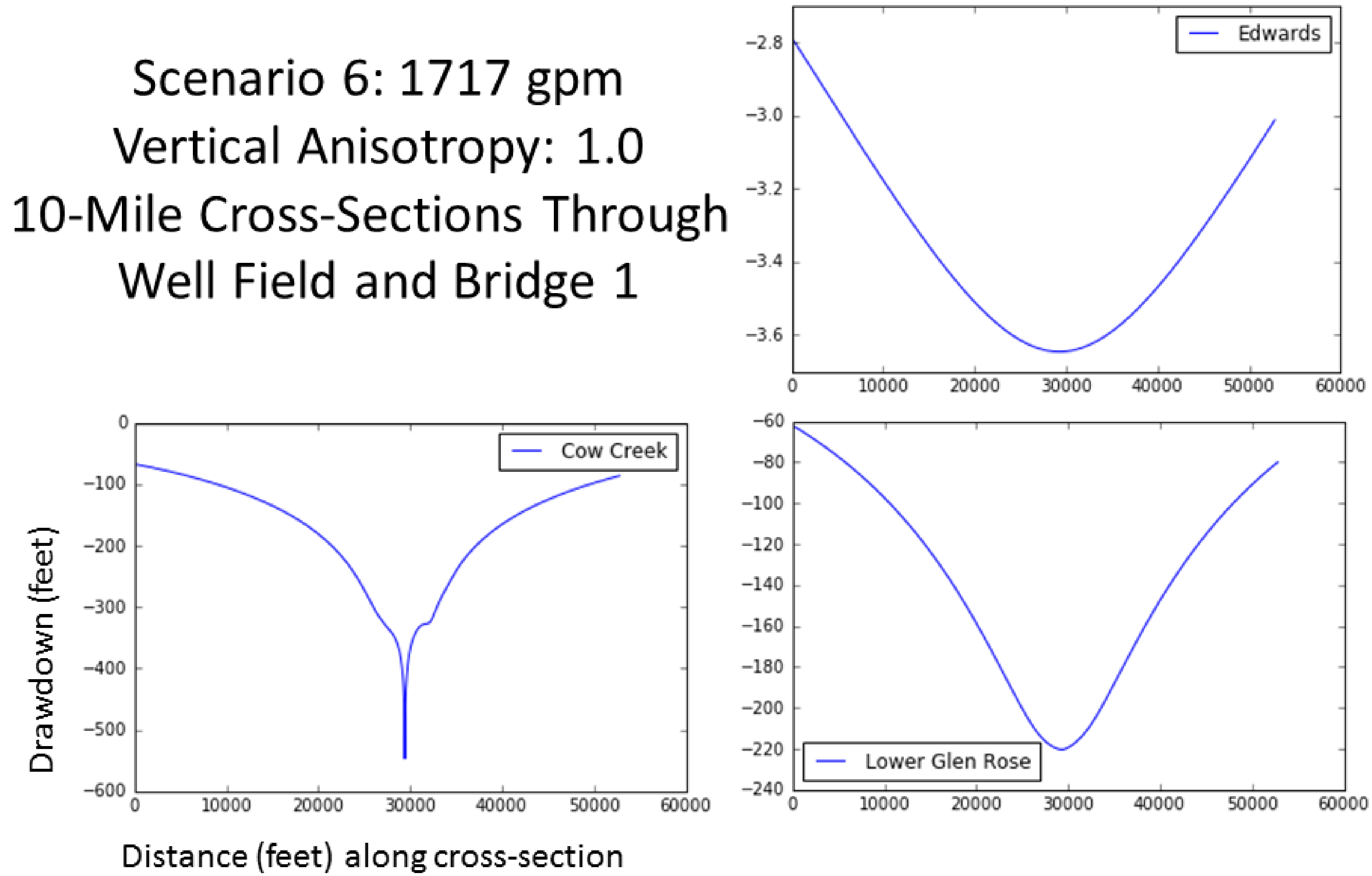

Figure A-6. Drawdown profiles for Scenario 6 across a 10-mile cross-section through the EP well field.

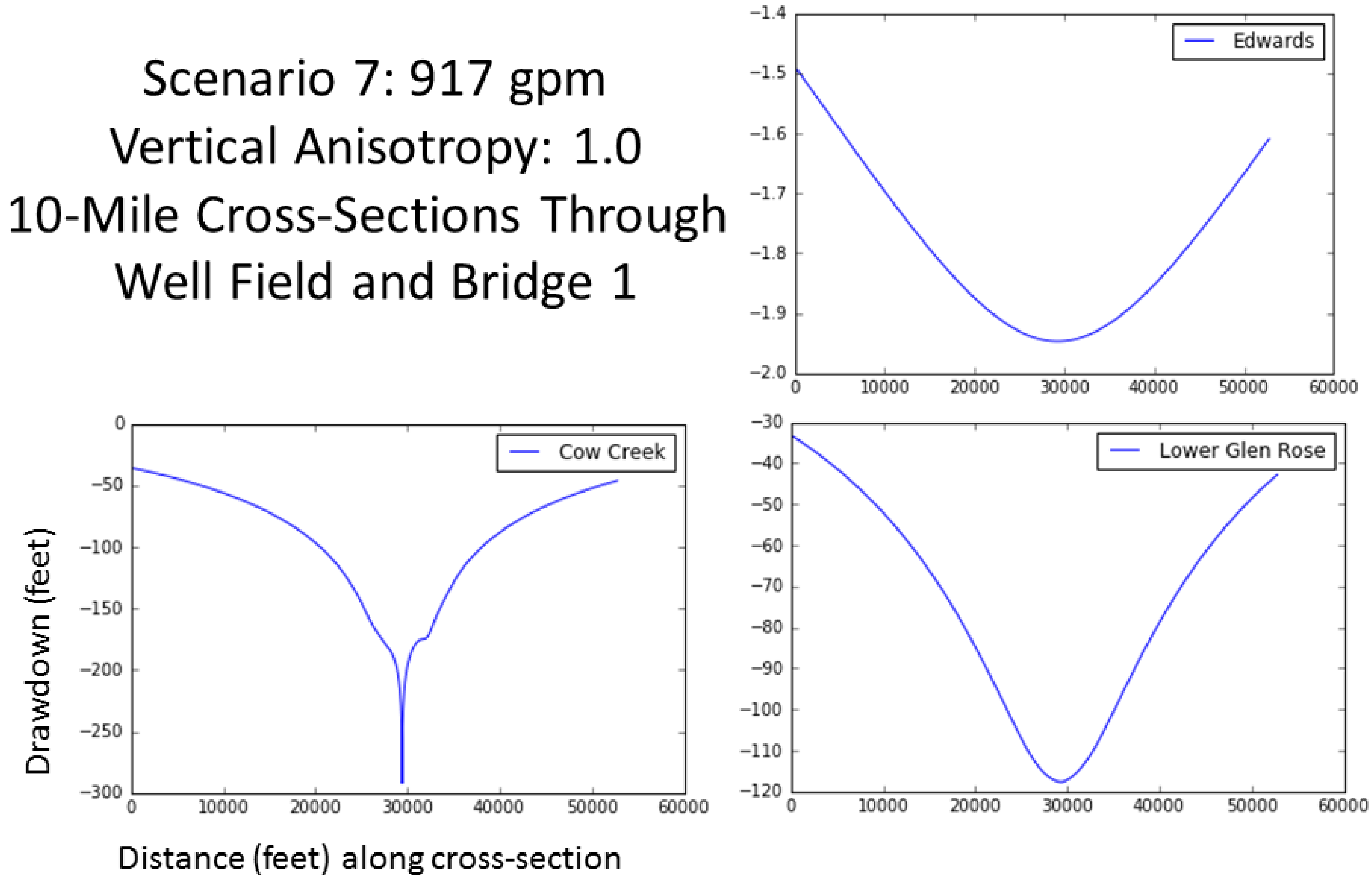

Figure A-7. Drawdown profiles for Scenario 7 across a 10-mile cross-section through the EP well field.

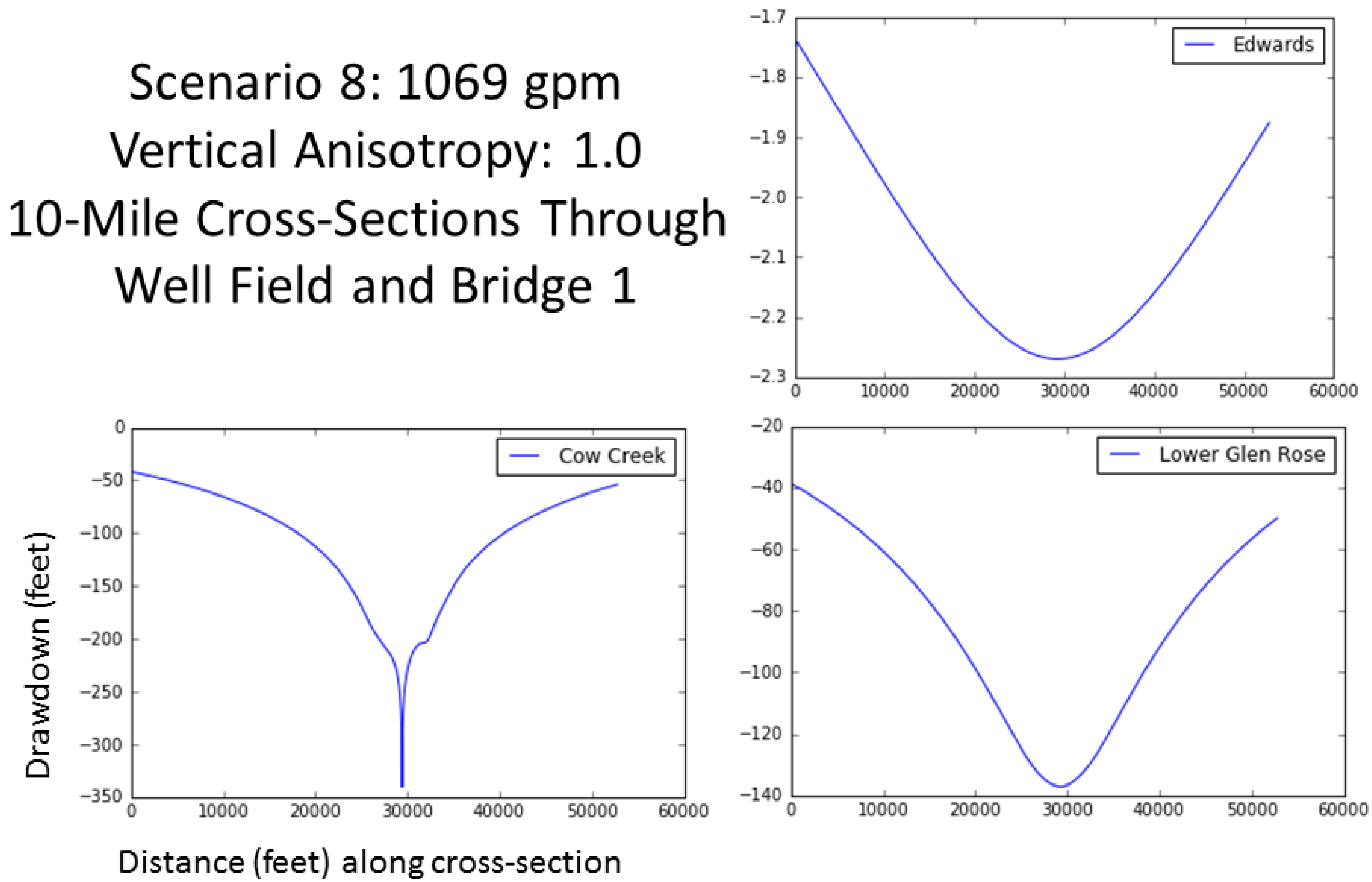

Figure A-8. Drawdown profiles for Scenario 8 across a 10-mile cross-section through the EP well field.

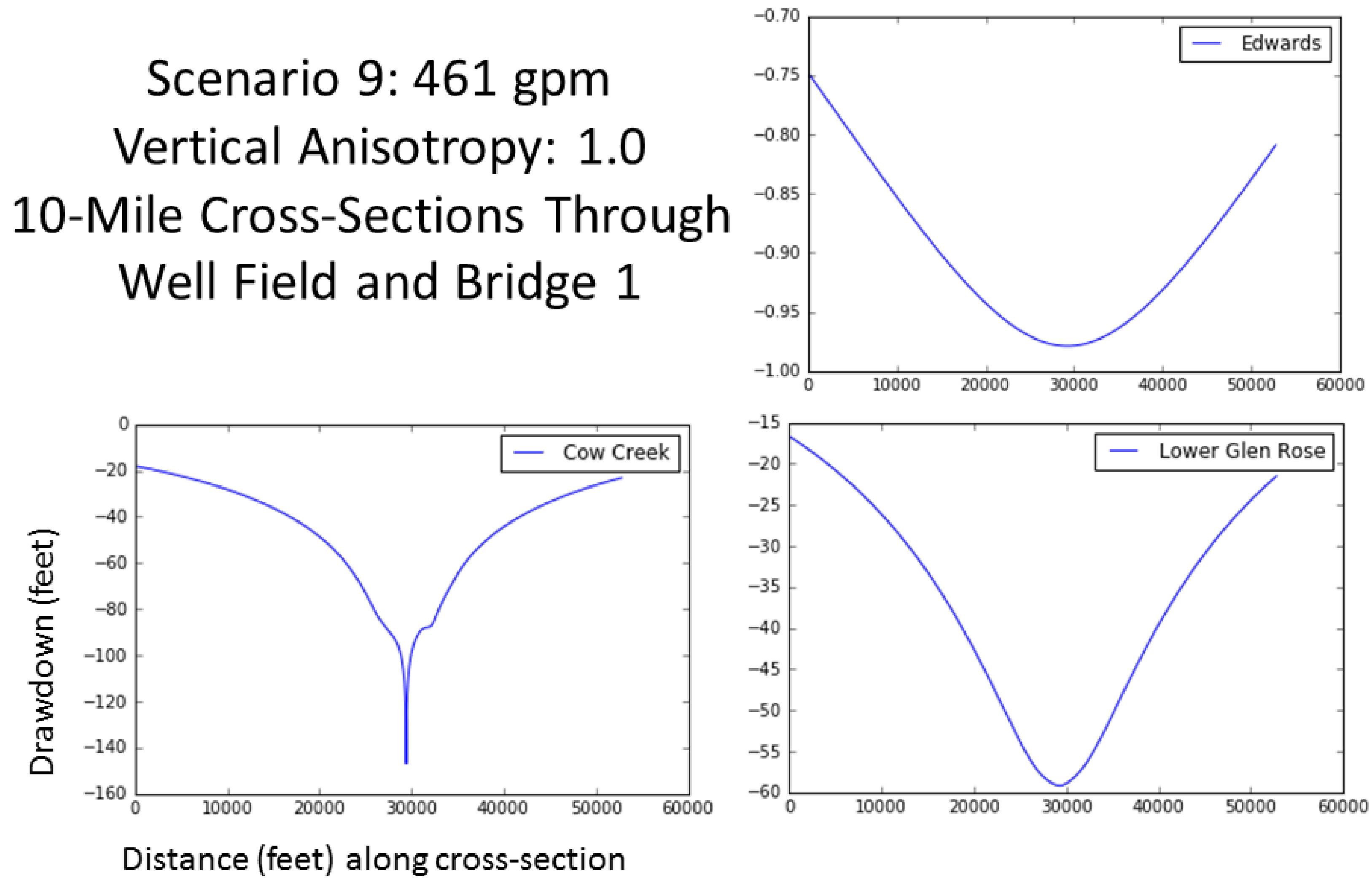

Figure A-9. Drawdown profiles for Scenario 9 across a 10-mile cross-section through the EP well field.

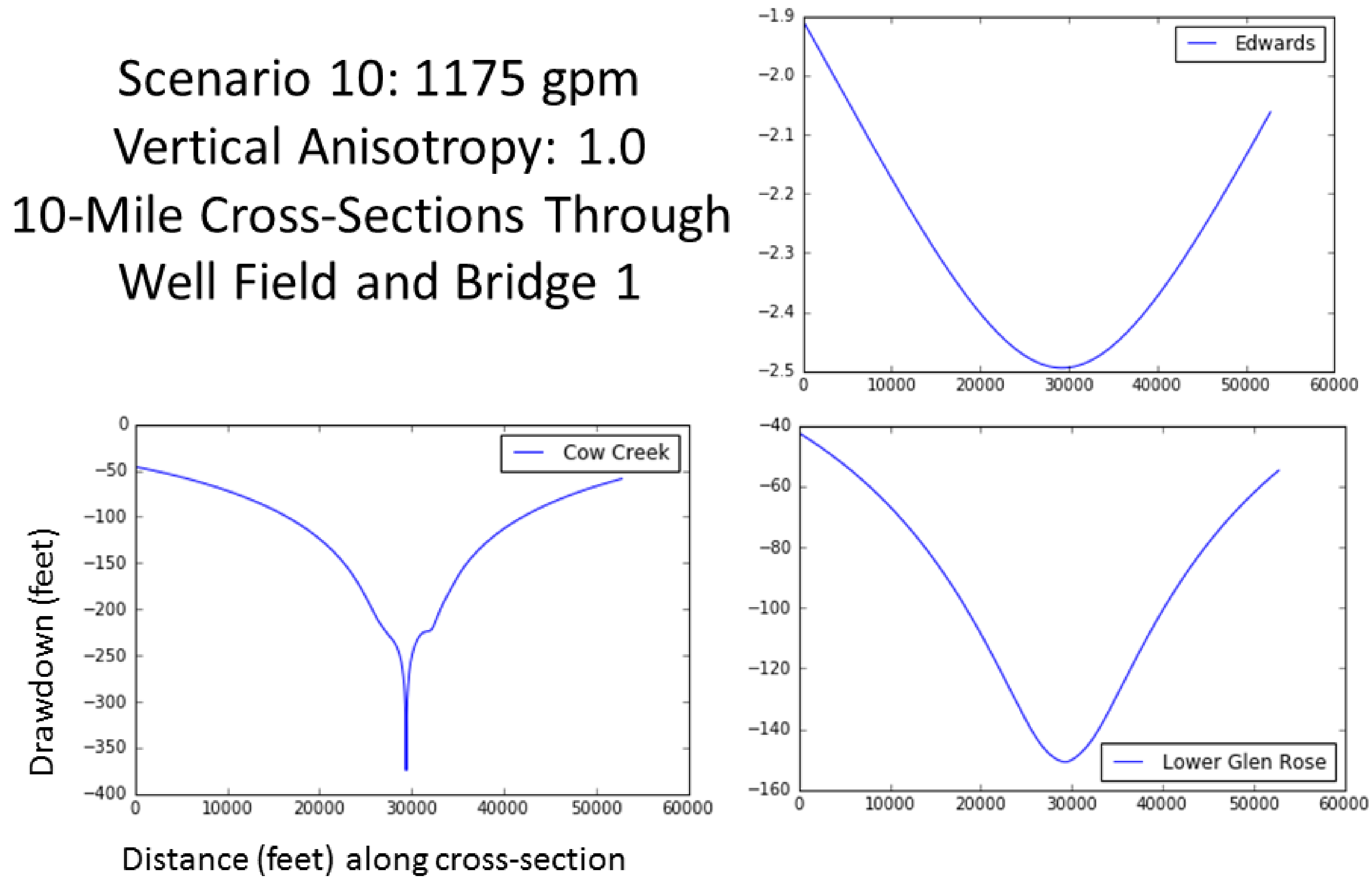

Figure A-10. Drawdown profiles for Scenario 10 across a 10-mile cross-section through the EP well field.