Appendix A

Technical Papers

TECHNICAL PAPER A-1
DEVELOPMENT OF PROJECTED FIRM DEMANDS FOR MUNICIPAL AND OTHER FIRM USES (EXCLUDING POWER PLANTS)
February 2019[1]

INTRODUCTION

For this revision to the LCRA Water Management Plan (WMP), future firm demand assumptions were updated. This technical paper addresses the demand assumptions for municipal and other firm uses of LCRA customers, excluding power plants.[2] Demands for power plants are addressed in a separate technical memorandum. The demands generally are based on demands from the Texas Water Development Board for the Lower Colorado Regional Planning Group (Region K) for the 2021 Regional Water Plan, the City of Austin's Water Forward Task Force and recent actual use. The demands used for this WMP update are for 2025. Demands for municipal and other non-power plant firm uses are developed for two conditions: a high-use water demand for hot and dry years and an average-use water demand for all other years.

DEVELOPMENT OF DEMANDS FOR HIGH-WATER-USE YEARS

Region K municipal demands reflect 2011 gallons per capita per day (GPCD) water use, with population projected into future decades. The approach for the regional plan, based on 2011 GPCD, reflects a future demand for a hot and dry high-use demand year. Many of LCRA's customers are included as specific water user groups in the Region K demand set. Decadal demands are available for these customers, including for 2020 and 2030. 2025 Region K demands have been developed as the midpoint of the 2020 and 2030 demands.[3] Table 1 presents the 2025 Region K projected demands for 10 of LCRA's larger customers, reflecting the demands for a high-water-use year.

LCRA has customers not identified as specific water user groups in Region K. For those customers, 2025 demands for a high-water-use year were developed based on recent water use. Table 2 presents the 2025 high-water-use-year demand projections for customers with demands greater than 1,000 acre-feet per year and not included as a specific water user group in Region K.

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[1] Revisions include changes in individual customer demands to ensure consistency with 2021 Region K planning numbers.

[2] The demands for entities that are not customers of LCRA, such as the City of Corpus Christi, are addressed in a separate technical paper regarding modeling assumptions.

[3] The decadal demands for individual entities in the Region K projections are available at http://www.twdb.texas.gov/waterplanning/data/projections/2022/demandproj.asp. Where water user groups had supplies other than Highland Lakes water listed in the 2016 Region K plan, these supplies were subtracted from their demand to get their demand for LCRA water.

Table 1. 2025 Region K Projected Demands for 10 LCRA Customers

Customer	2025 Projected Demands (acre-feet per year)
Austin[a]	215,900[b]
Cedar Park	20,000
West Travis County Public Utility Agency	11,600
Leander	10,700
Pflugerville	9,800
Travis County WCID No. 17	9,600
Brazos River Authority	4,800
Marble Falls	2,900
Horseshoe Bay	2,800
Dripping Springs WSC	2,200

[a] Includes wholesale customers of Austin that do not hold a contract with LCRA.

[b] Additional demand of 2,747 ac-ft/yr above the listed projected demand is met using City of Austin wastewater return flows.

Table 2. 2025 Projected Demands for Specified LCRA Customers

Customer	2025 Projected Demands (acre-feet per year)
Underground Services Markham	9,300
OXEA	5,300
Domestic Use on Highland Lakes	5,100
Horseshoe Bay Resort	1,500

Projected 2025 high-use water demand for the City of Austin is 215,900 acre-feet per year, and the total for customers other than the City of Austin is 130,100 acre-feet per year.

DEVELOPMENT OF DEMANDS FOR NON-HIGH-WATER-USE YEARS

The demands referenced in the prior section are for high-water-use years. For this WMP update, an average demand level is used for all other years. The City of Austin has developed average-water-use demands for future decades as part of its Austin Water Forward Task Force. A 2025 projected demand of 167,300 acre-feet has been developed as the mid-point between 2020 and 2030 demands, approximately 77 percent of the 2025 value of 215,900 acre-feet from Region K for a high-use year.

For customers other than Austin, a ratio of the demands for average-use year to the demands for a high-use year has been calculated based the average water use in 2012 through 2017 (approximately 77,000 acre-feet) as compared to actual water use in a high-use year, i.e., in 2011. Water use in 2011 for these customers was 85,000 acre-feet, resulting in a ratio of average-use to high-use of 0.838. This ratio is applied to the projected 2025 high-use demand to develop the projected 2025 non-high-use demand. The total non-Austin demand for a non-high-use year is 109,000 acre-feet.

IDENTIFICATION OF HIGH-USE AND NON-HIGH-USE DEMAND YEARS

For this WMP update, a method for selecting between high-water-use demands and non-high-water-use demands was developed based on temperature and accumulated precipitation. Specifically, the method relies on the accumulated precipitation for the months of April to September, and the average daily-maximum temperature for those months. The historic average precipitation for those months over the period since 1940 is 18 inches. The historic average daily-maximum temperature is 90 degrees. In order to employ conservatism favoring higher overall demands during the period of record, the methodology relies on values which are one standard deviation from those historic medians. Specifically for years in which the average daily-maximum temperature (from April to September) was greater than 88.2 degrees and the precipitation was less than 23.65 inches, the demands are modeled as high-use demands. For all other years, the demands are average-use demands.

Figures 1 and 2 present the weather-varied projected 2025 Austin water demands and the non-Austin water demands for the model period 1940-2016 for municipal and other firm uses (excluding power plants). Over this period, 35 years are categorized as high-use years, and 42 years are categorized as non-high-use years.

Figure 1 – Weather-varied Demand for City of Austin

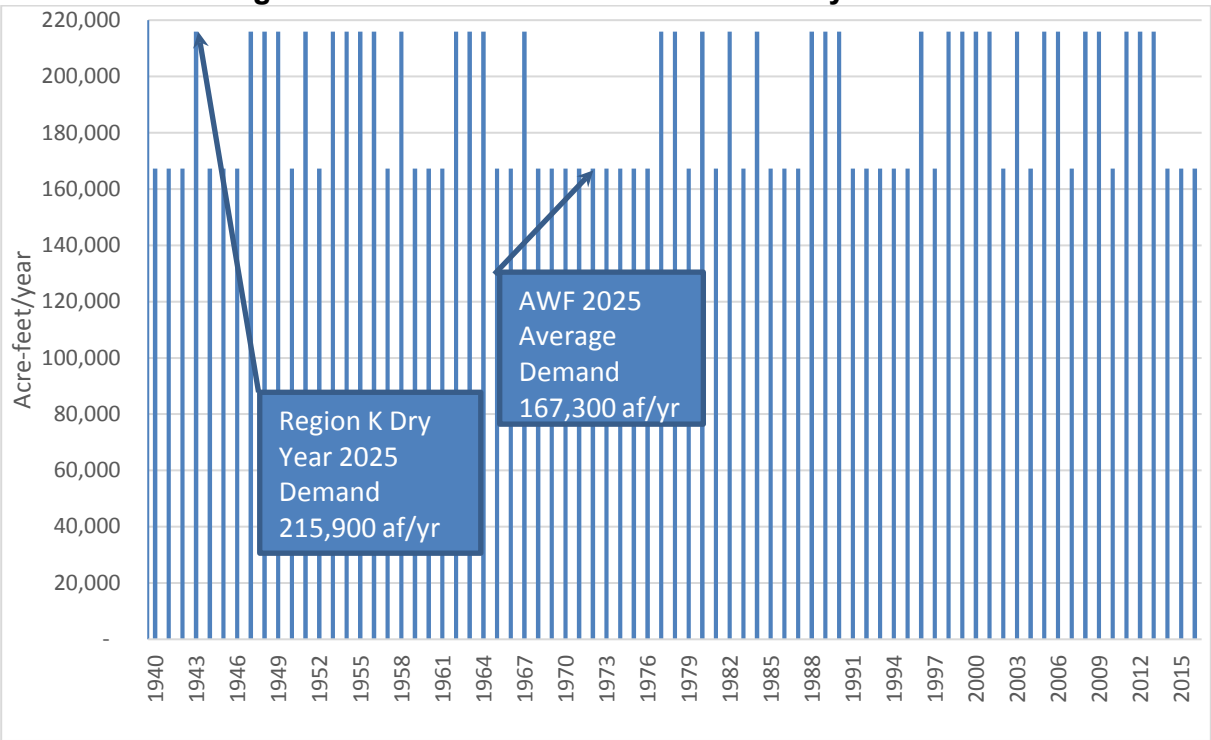
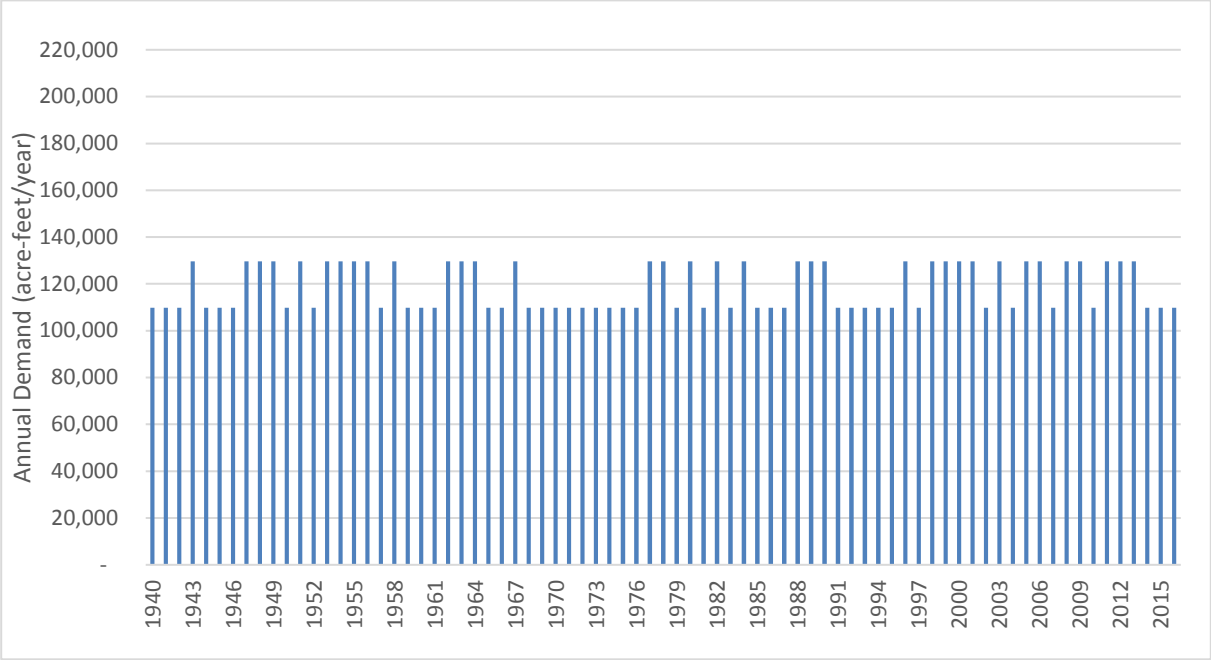


Figure 2 – Weather-varied Demand for Other Municipal Customers



TECHNICAL PAPER A-2
DEVELOPMENT OF PROJECTED FIRM DEMANDS FOR POWER PLANTS
February 2019

INTRODUCTION

For this revision to the LCRA Water Management Plan (WMP), future firm customer demands were updated to reflect the projected demand in 2025. This technical paper addresses the projected demands at power plants supplied with water by LCRA. The demands generally are based on recent actual water use and are weather-varied for most facilities.

GENERAL DEMAND METHODOLOGY

LCRA supplies water to the following customer power plant facilities: Bastrop Energy Center Power Plant, Decker Power Plant, Fayette Power Project (owned by LCRA and the City of Austin), Thomas C. Ferguson Power Plant, Lost Pines Power Park, and the South Texas Project (operated by STP Nuclear Operating Company).

The Lost Pines Power Park is supplied almost entirely with groundwater, and LCRA projects its demands through 2025 will continue to be met with groundwater. Thus, no demands for the Lost Pines Power Park are included in this WMP update.

The water use for the Decker Power Plant and the Fayette Power Project are simulated in the Water Management Plan model as a demand from the Colorado River. The demands from the Colorado River are used to offset both the natural evaporation from the cooling reservoirs and the forced evaporation that results from the generation of electricity at those facilities. The historic demands for these facilities vary greatly. For this WMP update, the demands for these facilities are weather-varied as presented below.

The Bastrop Energy Partners facility also diverts water from the Colorado River. This facility does not have a cooling reservoir. In recent years, the demand for water at Bastrop Energy Center Power Plant has been relatively constant at about 2,300 acre-feet per year.

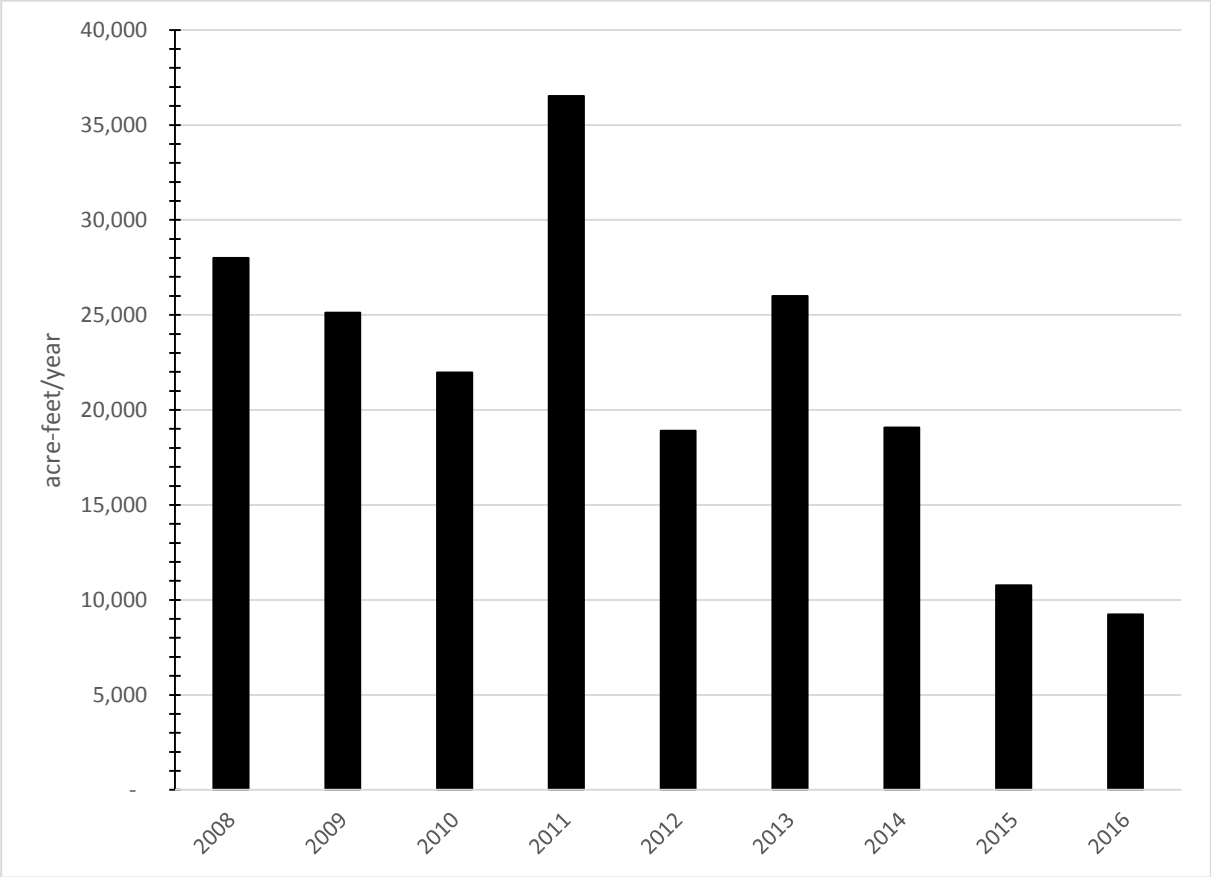
The Ferguson Power Plant diverts water from Lake LBJ, with the lake serving as a cooling reservoir. For this lake and power plant, there is both natural and forced evaporation. The modeling of the WMP includes Lake LBJ as an impoundment, and the natural evaporation is weather-varied within the model based on historic evaporation rates. For this WMP update, the demands for forced evaporation are projected as a constant, equal to the recent high-water use at the facility.

The South Texas Project diverts water from the Colorado River into an off-channel reservoir that serves as a cooling reservoir. For this reservoir and power plant, there is both natural and forced evaporation. The modeling of the WMP includes the cooling reservoir as an impoundment, and the natural evaporation is weather-varied within the model based on historic evaporation rates. Actual demands for the forced evaporation are relatively constant and for this WMP update, the demands for forced evaporation are projected as a constant, equal to the customer's recent high-water use in 2007.

WEATHER-VARIED METHODOLOGY FOR THE DECKER POWER PLANT AND FAYETTE POWER PROJECT

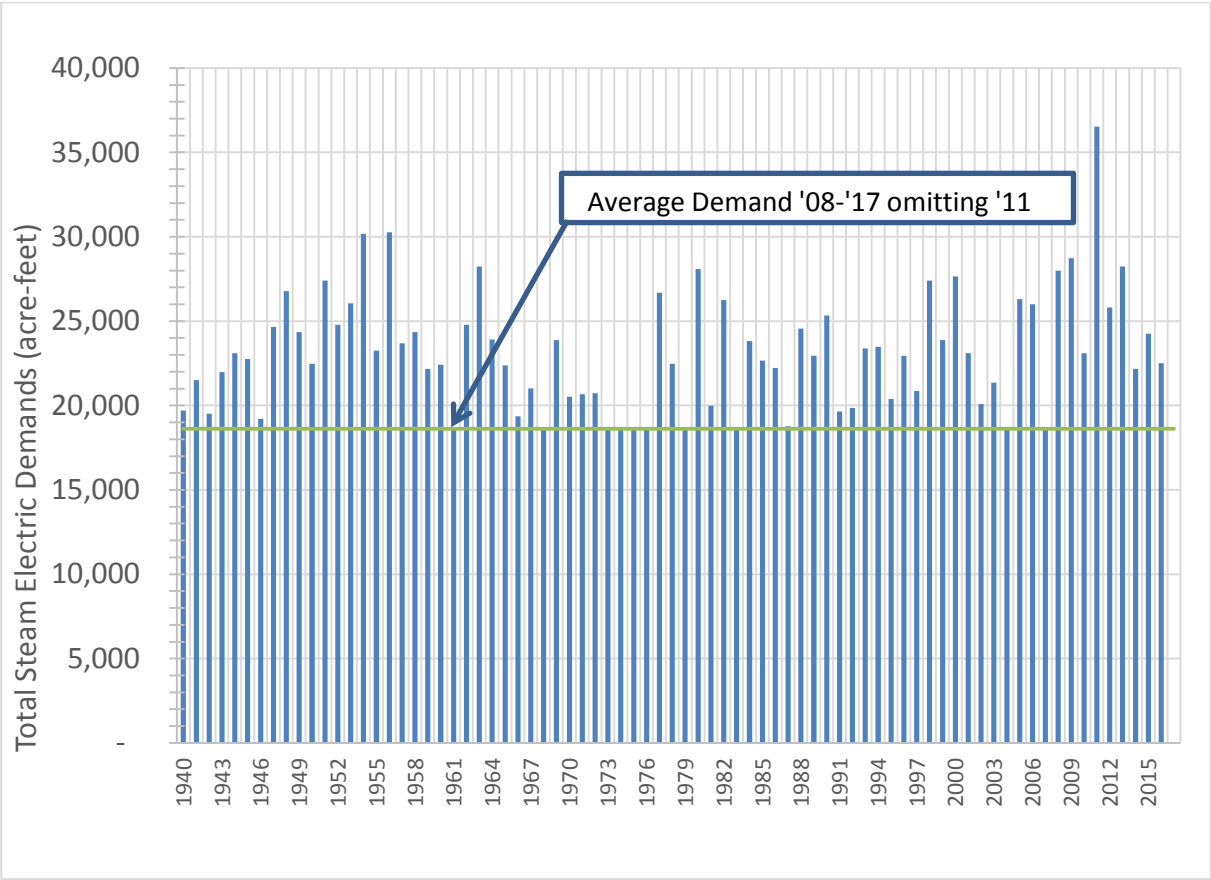
Diversions from the Colorado River for the Decker Power Plant and Fayette Power Project have varied significantly from year to year as shown in Figure 1.

Figure 1. Total Annual Diversions to the Decker Power Plant and Fayette Power Project



As stated above, the diversion demands for these facilities vary based on the natural evaporation from the cooling reservoirs and from forced evaporation, which is a function of the power demands. For this WMP update, LCRA staff developed a relationship between warm season temperature and demand that results in demands that equal or exceed the actual water use for each of the past 10 years, and has a minimum annual demand level approximately equal to the average demand over the past 10 years, omitting 2011. Figure 2 shows the actual diversions from the Colorado River to these facilities and the projected demands for this WMP update.

Figure 2. Total Projected Demands for the Decker Power Plant and Fayette Power Project



SUMMARY OF PROJECTED DEMANDS FOR POWER PLANTS

As part of this WMP update, a weather-varied approach is used for most power plants supplied water by LCRA. For the Thomas C. Ferguson Power Plant and South Texas Project, the natural evaporation from the cooling reservoirs varies based on monthly evaporation data, while the forced evaporation is a constant demand each year. For the Decker Power Plant and Fayette Power Project, demands are weather-varied and reflect both the natural evaporation and forced evaporation. For the Bastrop Energy Partners facility, the demand will be modeled as a fixed amount each year.

Table 1 summarizes the projected annual demands for power plants for this WMP update.

Table 1. Power Plant Demand Summary

	Minimum	Average	Maximum
Decker Power Plant	4,200	5,300	8,300
FPP – Austin	5,300	6,600	10,300
FPP – LCRA	9,100	11,300	17,900
Ferguson Power Plant[1]	1,800	1,800	1,800
STPNOC[2]	39,400	39,400	39,400
Bastrop Energy Partners	2,300	2,300	2,300

[1] Demand shown is for forced evaporation. Natural evaporation from Lake LBJ is simulated within the modeling.
[2] Demand shown is for forced evaporation. Natural evaporation from the cooling reservoir is simulated within the modeling.

TECHNICAL PAPER A-3
DEVELOPMENT OF PROJECTED AGRICULTURAL DEMANDS BY DOWNSTREAM IRRIGATION OPERATIONS
February 2019

DEMANDS

LCRA supplies water for agricultural irrigation to four canal operations in the lower Colorado River basin as shown on Exhibit 1. For this revision to the LCRA Water Management Plan (WMP), future agricultural demand assumptions were updated based on recent work by the Lower Colorado Regional Water Planning Group (Region K) for the 2021 Regional Water Plan, and prior work by LCRA for the 2015 WMP. Year 2020 demand projections from Region K were used because 2020 demands are the highest expected for the time in which this WMP revision is expected to be in place (from 2020 through 2025).

Region K developed demand projections based on actual 2011 water use and acreage. The Region K demands include adjustments based on expected reductions in water use on an acre-foot per acre basis, as compared to use in 2011 due to acre-feet per acre duties and surcharges in LCRA's interruptible agricultural contracts.

Region K demand projections are presented in Table 1.

Table 1. Region K 2020 Demands for Downstream Agricultural Operations (in acre-feet)

	First season	Second season	Total
Garwood rice	71,711	28,289	100,000
Gulf Coast rice	90,010	46,656	136,666
Gulf Coast other[1]	12,914	7,110	20,024
Gulf Coast total	102,924	53,766	156,690
Lakeside rice	102,982	29,929	132,911
Lakeside other[2]	-	2,400	2,400
Lakeside total	102,982	32,329	135,311
Pierce Ranch[3]	21,000	9,000	30,000
Total	298,617	123,384	422,001

[1]Gulf Coast other demands are split approximately 65 percent first season and 35 percent second season.
[2]Lakeside other is assumed as wildlife management, all in second season.
[3]Pierce Ranch annual demands are split 70 percent first season and 30 percent second season.

The demands presented above reflect maximum-year demands. As in prior WMPs, agricultural demands for similar acreages are expected to vary based on weather conditions. This variability is captured using regression equations, with inputs of seasonal evaporation and precipitation, to produce weather-varied demands for each year of the Water Availability

Model (WAM) period of simulation. The regression equations from the 2015 WMP were used, with limited adjustments, in order to constrain the computed demands so as not to exceed the maximum-year demands from Region K.

Using the regression equations, weather-varied demands were developed for the WAM period of simulation (1940 to 2016). The weather-varied demands do not exceed the maximum year demands developed by Region K. The average and maximum annual demands for each irrigation operation are shown in Table 2. The annual weather-varied demands for the four operations are shown in figures 1 through 5.

Table 2. Weather-varied Annual Demands for Downstream Agricultural Operations (in acre-feet)

	Average	**Maximum**
Garwood	87,897	100,000
Gulf Coast	139,391	156,690
Lakeside	114,086	135,311
Pierce Ranch	26,827	30,000
Total	368,200	422,001

The weather-varied agricultural demands are inputs for the WMP WAM simulations, representing non-curtailed demands for each year of the simulation. The weather-varied demands do not reflect reduced planting that may occur under limited supply conditions. Any reduced plantings due to curtailments are simulated within the WAM modeling logic based on reductions in available supply.

Exhibit 1. Irrigation Operations and Diversion Points

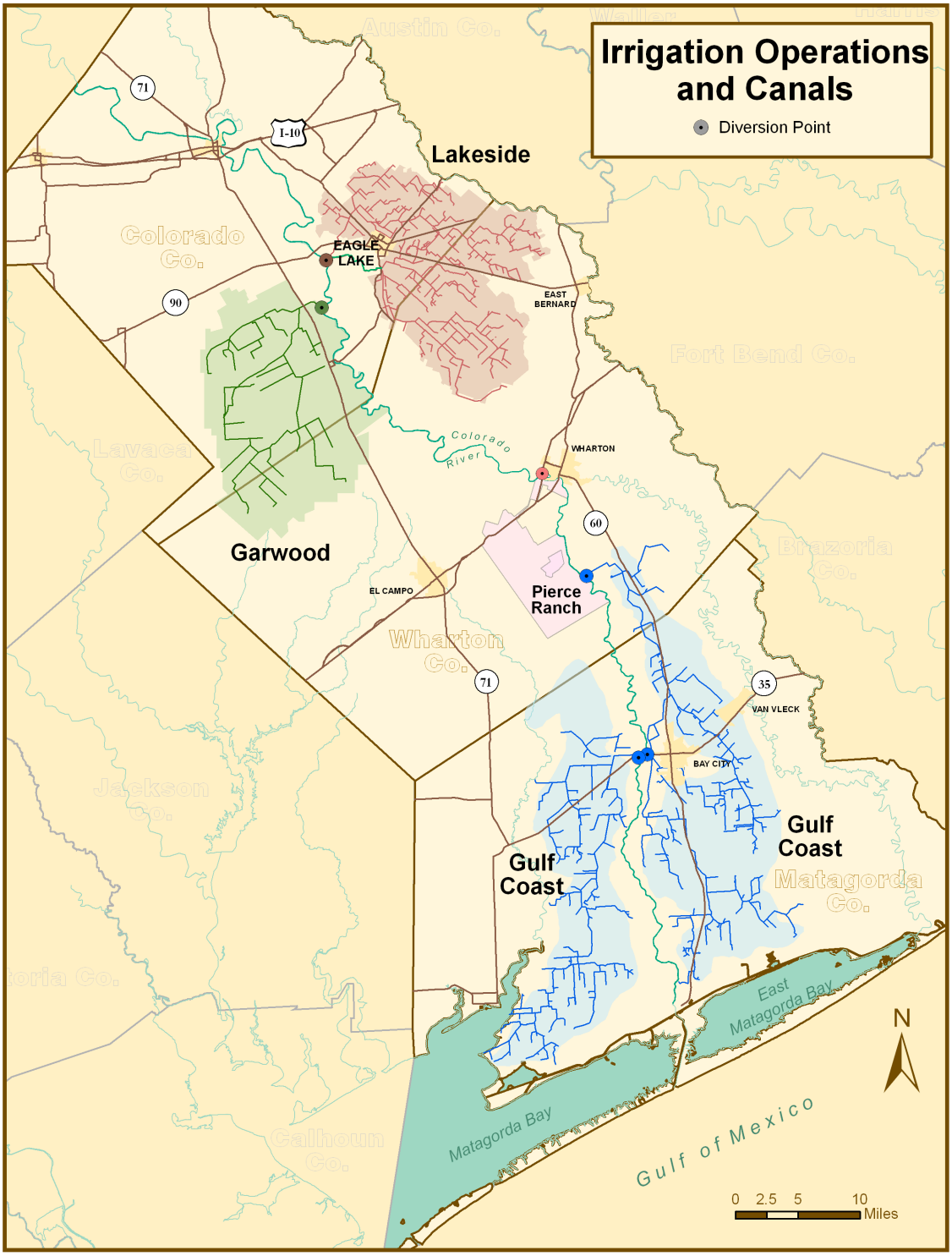


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Figure 1. Weather-varied Total Agricultural Demands

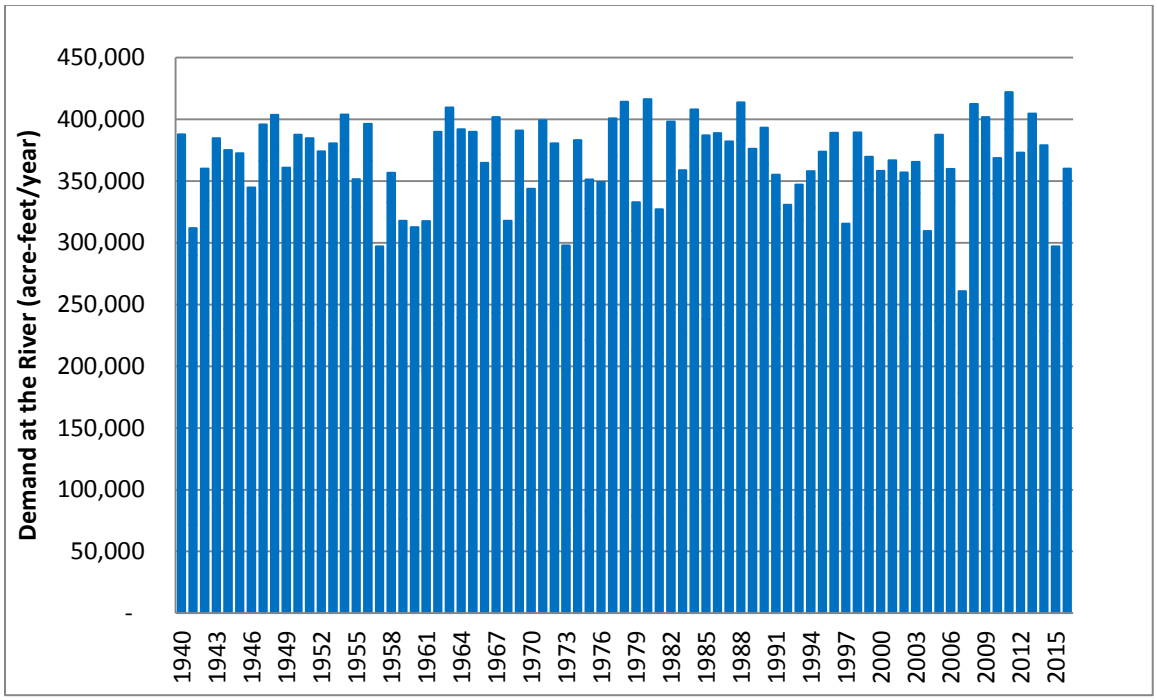


Figure 2. Weather-varied Garwood Demands

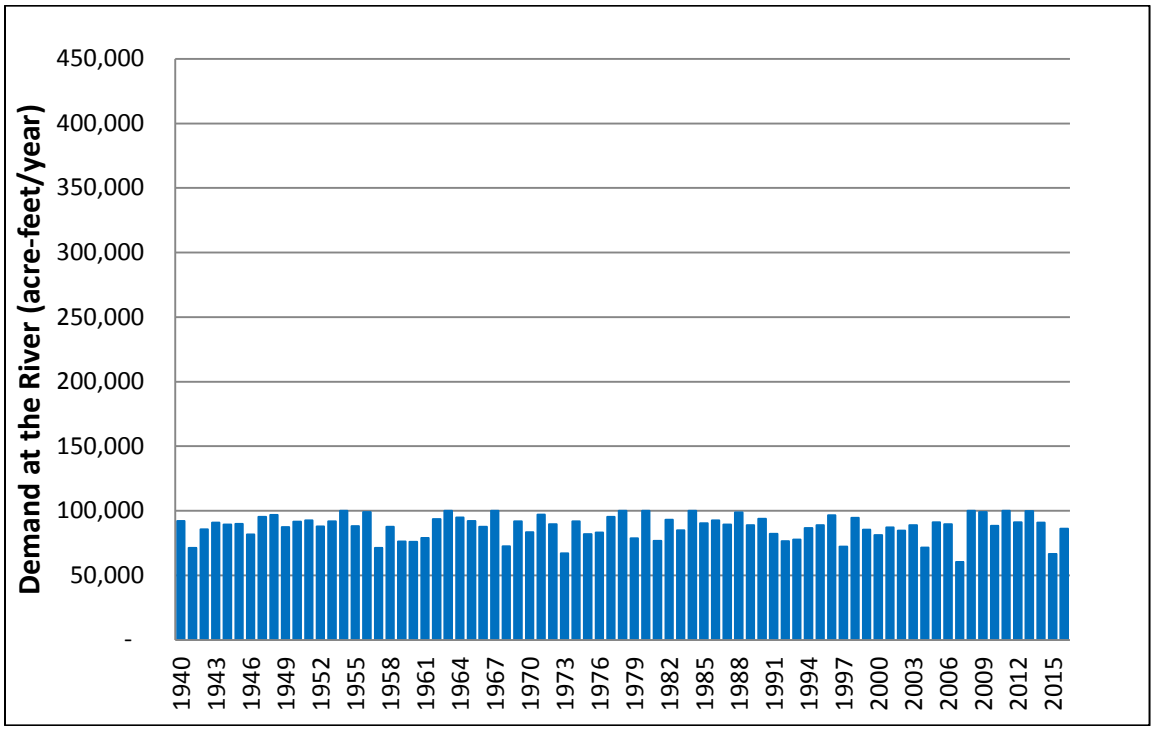


Figure 3. Weather-varied Gulf Coast Demands

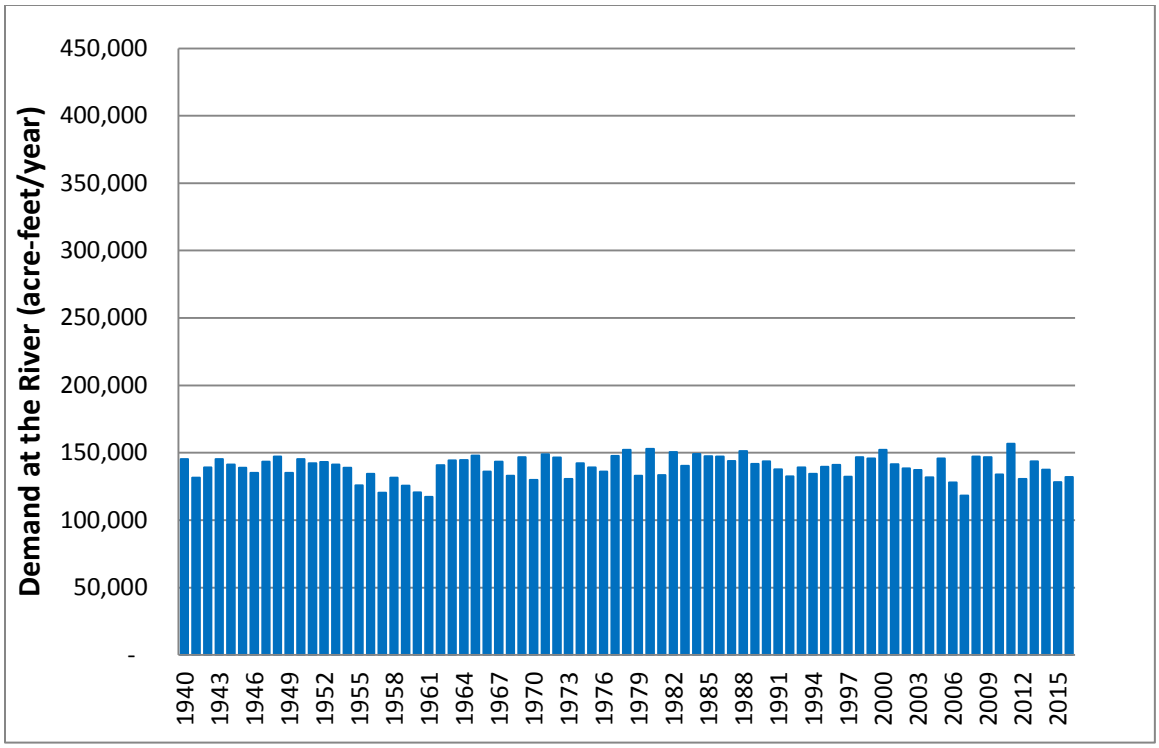


Figure 4. Weather-varied Lakeside Demands

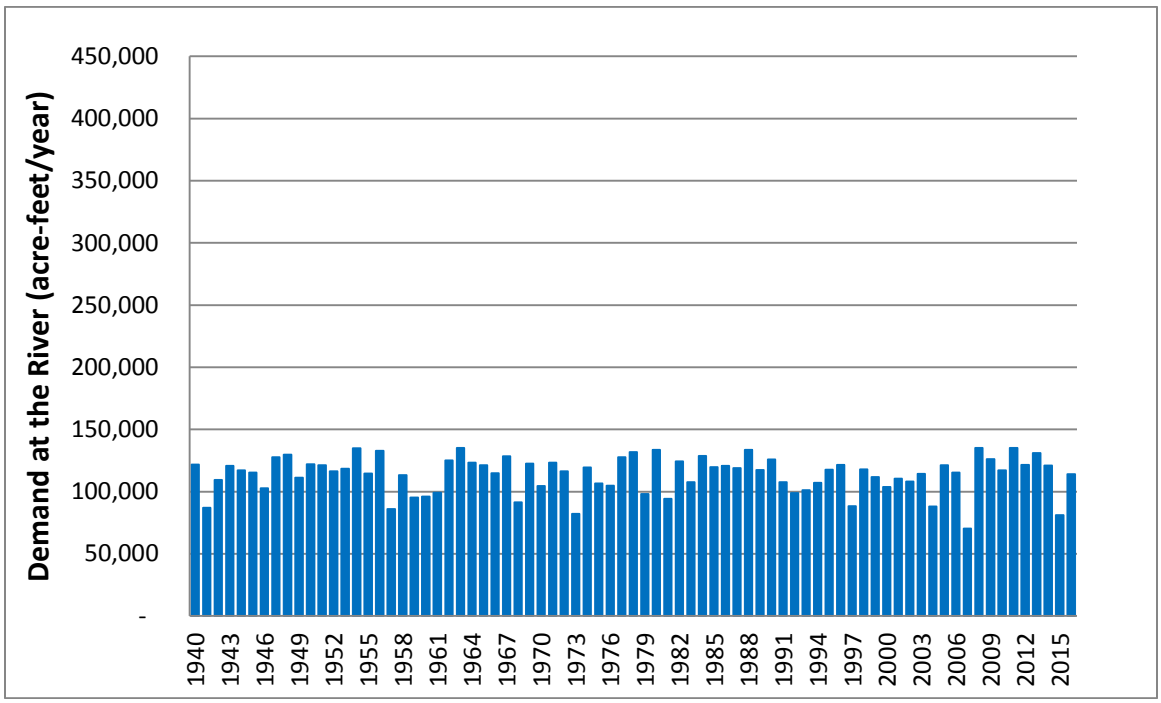
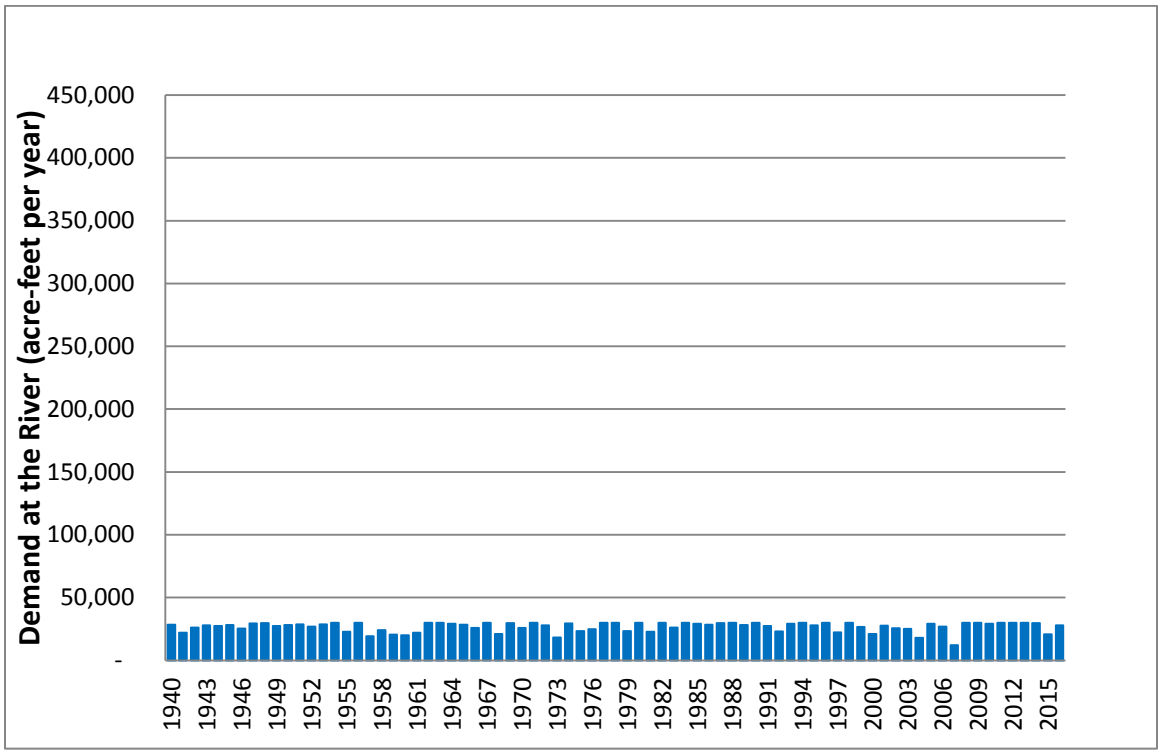


Figure 5. Weather-varied Pierce Ranch Demands



TECHNICAL PAPER A-4
DEVELOPMENT OF ORDERED WATER VERSUS DIVERSION FACTORS FOR WATER MANAGEMENT PLAN WATER AVAILABILITY MODELING
February 2019

Agricultural diversions are not necessarily the same as agricultural demands in the lower Colorado River basin. This is due to an advance order requirement of up to seven days (or longer) in order to provide water supplies in a reliable manner. To more accurately simulate releases to meet agricultural demands, factors were calculated as the average of actual orders and diversions for irrigation seasons of 2001 to 2016.

Background

Orders. Each day, the three LCRA-operated irrigation divisions (Garwood, Lakeside and Gulf Coast) and Pierce Ranch (independently operated) estimate their future daily water demands based on equipment capacities, acreage planted and individual farm orders. The amount of time it takes to deliver water released from Mansfield Dam to downstream irrigation operations can be up to seven days (or longer) and delivery to locations at the ends of the canal systems can add additional days. Therefore, the irrigation operations must forecast their demands several days in advance of the actual diversion.

Releases. On a daily basis, LCRA's River Operations Center (ROC) determines the sources of water available to meet the forecasted demands requested by each of the irrigation operations. Sources include the amount of downstream run-of-river flows the ROC reliably foresees occurring, City of Austin return flows, actual inflows into the Highland Lakes for which there is a senior downstream demand, and stored water from lakes Buchanan and Travis made available in accordance with the LCRA's Water Management Plan (WMP). Based on the availability of these sources and water right priority, the ROC determines each day how much water must be passed through lakes Buchanan and Travis or released from storage in the lakes to satisfy the downstream demands for diversions or environmental needs that will occur over the next several days.

Diversions. Diversions are made by each of the irrigation operations based on current weather conditions and daily demands. Garwood Irrigation Division has a single pump station and a small on-channel reservoir, created by a low head dam on the Colorado River, from which to pump water. Lakeside Irrigation Division has one pump station on the river but no reservoir on the river and must capture water as it flows by. The Pierce Ranch operation has a single pumping station and no on-channel reservoir. Gulf Coast Irrigation Division has pumping stations located on both the east and west banks of the Colorado River and has small pumping reservoirs created by on-channel dams at Lane City and Bay City.

Diversions by the irrigation operations sometimes vary from requested orders based on several factors, particularly local or regional rainfall events that can cause an interruption or reduction in the amount of water actually diverted by each irrigation operation. The difference between the water ordered and released and water diverted represents an operational inefficiency accounted for in the modeling of the WMP. The water not diverted at the irrigation operations helps meet freshwater inflow needs and demands for other users that do not require a steady or constant supply of water, such as STPNOC.

Methodology

Historic release and diversion data demonstrates that actual releases from lakes Buchanan and Travis are larger than the actual diversions. This is because orders do not reflect that rainfall and other unforeseen events over the travel time period of several days may result in reduced diversions or a complete shutdown of diversion pumps. Use of diversion data alone would underestimate actual irrigation water demands on the Highland Lakes.

LCRA has developed factors to characterize the difference between orders and diversions for each irrigation operation. Orders determined using these factors simulate demands on the overall system to estimate reservoir releases, which more closely approximates observed system operations. The difference between orders and diversions is higher in seasons with more rainfall and lower in seasons with little rainfall. LCRA developed different factors for wet, moderate and dry seasons. A wet season was considered when rainfall was greater than 19.7 inches in first season months (March to July) and greater than 13.4 inches in second season months (August to October). A dry season was considered when rainfall was less than 13.4 inches in the first season and less than 8.1 inches in the second season. Seasons with rainfall in between these thresholds for wet and dry were classified as normal. Aerial rainfall for Texas Water Development Board quadrangle 811 as revised in 2017 was used for the classification.

RESULTS

LCRA staff analyzed the actual records of orders and diversions by irrigation operation for the period of 2001 through 2016 for the years they operated. The percentage of water ordered that is diverted, on average, is shown in Tables 1, 2 and 3. The additional percentage factor added to demands in the WMP Water Availability Model to determine the simulated orders is determined by taking of the inverse of the percentages in Tables 1, 2 and 3 and subtracting 1.0. The resulting factors are shown in Exhibits 4, 5 and 6.

Table 1 – Average Wet Seasonal Diversions as Percentage of Orders by Operation

Season	Garwood	Lakeside	Gulf Coast	Pierce Ranch
First Season (March to July)	63%	58%	80%	62%
Second Season (August to October)	76%	59%	83%	76%

Table 2 – Average Moderate Seasonal Diversions as Percentage of Orders by Operation

Season	Garwood	Lakeside	Gulf Coast	Pierce Ranch
First Season (March to July)	76%	74%	85%	70%
Second Season (August to October)	78%	65%	88%	63%

Table 3 – Average Dry Seasonal Diversions as Percentage of Orders by Operation

Season	Garwood	Lakeside	Gulf Coast	Pierce Ranch
First Season (March to July)	82%	83%	88%	77%
Second Season (August to October)	82%	75%	83%	76%

Table 4 – Additional Percentage to Add to Wet Seasonal Demands

Season	Garwood	Lakeside	Gulf Coast	Pierce Ranch
First Season (March to July)	58%	72%	25%	62%
Second Season (August to October)	32%	71%	20%	32%

Table 5 – Additional Percentage to Add to Moderate Seasonal Demands

Season	Garwood	Lakeside	Gulf Coast	Pierce Ranch
First Season (March to July)	31%	35%	17%	43%
Second Season (August to October)	31%	55%	14%	57%

Table 6 – Additional Percentage to Add to Dry Seasonal Demands

Season	Garwood	Lakeside	Gulf Coast	Pierce Ranch
First Season (March to July)	22%	20%	13%	29%
Second Season (August to October)	22%	33%	21%	32%

TECHNICAL PAPER A-5
DEVELOPMENT OF COMBINED FIRM YIELD OF LAKES BUCHANAN AND TRAVIS
February 2019

1.0 INTRODUCTION

The Final Judgment and Decree relating to the adjudication of water rights for the Lower Colorado River Authority and the City of Austin, which was issued on April 20, 1988, in the 264th Judicial District Court of Bell County, Texas, requires LCRA, pursuant to provisions in its Certificates of Adjudication 14-5478 and 14-5482 that authorize lakes Buchanan and Travis, respectively, to determine the "combined firm yield" of lakes Buchanan and Travis when operated as a reservoir system. As stipulated in Paragraph 2.B(6) of the Buchanan and Travis Certificates, the combined firm yield value represents the maximum amount of water that LCRA can commit to supply annually under Certificates of Adjudication 14-5478 and 14-5482 on a firm, uninterruptible basis to its customers.

TCEQ rules define firm yield as:

> That amount of water that the reservoir could have produced annually if it had been in place during the worst drought of record. In performing this simulation, naturalized streamflows will be modified as appropriate to account for the full exercise of upstream senior water rights is assumed as well as the passage of sufficient water to satisfy all downstream senior water rights valued at their full authorized amounts and conditions as well as the passage of flows needed to meet all applicable permit conditions relating to instream and freshwater inflow requirements.[1]

As described more fully in Section 3.1.2 of this paper, for purposes of this WMP, the combined firm yield calculation employs a cutoff assumption with respect to portions of the upper basin, including above O.H. Ivie Reservoir, similar to previous calculations. [2]

2.0 COMBINED FIRM YIELD DETERMINATION

The approach for determining the combined firm yield of lakes Buchanan and Travis involves application of the Water Availability Model (WAM) of the Colorado River basin developed by the Texas Natural Resource Conservation Commission, the predecessor agency to the Texas Commission on Environmental Quality (TCEQ), in 2001 pursuant to Senate Bill 1 (75th Texas Legislature). This WAM accounts individually for each of the existing surface water rights in the Colorado River basin, including those that authorize lakes Buchanan and Travis. Using monthly streamflow values throughout the basin corresponding to historical hydrologic and climatic conditions, the WAM simulates on a monthly basis the supply, or volume, of surface water available to satisfy the authorized diversion amount for each individual water right.

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[1] 30 Tex. Admin. Code § 297.1(20).

[2] The 1988 Final Judgment and Decree also referred to the Combined Theoretical Yield, the yield of lakes Buchanan and Travis if: 1) there were no other impoundment, diversion or use of the flows of the Colorado River and its tributaries upstream; 2) no portion of the inflows to lakes Buchanan and Travis is passed to honor downstream senior water rights; and 3) Lakes Buchanan and Travis are operated as a system. For this WMP revision, the Combined Theoretical Yield has not been calculated.

In the WAM's monthly simulation process, individual water rights are considered in priority order in accordance with the prior appropriation doctrine, i.e., water is provided to the oldest (or most senior) water right first during times of shortage. Water rights are prioritized according to their priority date, which generally corresponds to the date a particular water right was issued by the State, or for some older rights, the first date when actual surface water usage was documented.

Each of the reservoirs in the Highland Lakes chain is represented in the WAM for the Colorado River basin. Demands for water from lakes Buchanan and Travis are specified in the model in accordance with authorized uses and, in some cases, consistent with contractual agreements between LCRA and its customers. For example, the contractual demand for backup water from lakes Buchanan and Travis for the City of Austin's water rights to provide a firm supply for Austin's municipal and industrial customers is included in the WAM. For the combined firm yield analysis, the total annual demand amount specified in the WAM for lakes Buchanan and Travis is, by definition, equal to the combined firm yield of the reservoirs. This quantity is determined through an iterative process whereby multiple simulations are made until all of the available supply of water stored in the reservoirs or flows into the reservoirs, after all senior water rights are fully satisfied, is completely utilized to meet the specified firm yield demand during the most severe drought period within the hydrologic record analyzed, which defines the drought of record.

For this combined firm yield analysis, monthly historical hydrologic and climatic conditions for the period from 1940-2016 are considered. For lakes Buchanan and Travis, the drought of record that determines the combined firm yield value occurs during the most recent drought period, specifically, the period from October 2007 through April 2015. The WAM's representation of lakes Buchanan and Travis attempts to refill both reservoirs multiple times within each simulated timestep. Accordingly, the simulated storage for the lakes may have been full after the first attempt to refill (priority date of 1926) but may end up slightly below full at the end of the timestep. Rather than preserving the intital simulated storage of the system after the 1926 refill occurs, a "99.9 percent rule" has been employed and applied to the final simulated storage of lakes Buchanan andTravis at the end of each monthly timestep for the purposes of defining the beginning of the critical drought period. Using this guideline, when the system storage is greater than 99.9 percent of its conservation storage, the system is deemed to be full for the purposes of determining the beginning of the critical drought period and calculating the associated firm annual yield.

Based on the WAM simulations with this guideline in place, the critical drought period extends from October 2007 (the first month after both reservoirs are full), to April 2015 when they are essentially empty and began to refill, which is a total drought duration of 91 months, or 7.58 years. The firm annual yield was determined by adding all of the diversions and releases made from lakes Buchanan and Travis for the period from full to minimum storage and dividing this total quantity by the number of years in the critical drought period (7.58). These computations are summarized in Table 1. This critical drought period is evident on the time-series graph presented in Figure 1, depicting the monthly combined storage in lakes Buchanan and Travis from the 1940-2016 firm yield WAM simulation. As shown, the combined water in storage in the reservoirs almost falls to zero during this period (April 2015), which is the fundamental basis for the determination of the combined firm yield of the reservoir system.

The annual withdrawal amount determined from the WAM simulations to be the combined firm yield value for lakes Buchanan and Travis is 418,848 acre-feet per year as compared to 445,266 acre-feet per year calculated in the original WMP, and 434,154 in the 2015 WMP. (The initial WMP also reported as part of the Combined Firm Yield an additional 90,546 acre-feet per year associated with O.H. Ivie Reservoir.) This is the annualized average amount of water that can be withdrawn from the two reservoirs every year during the critical drought period without causing the reservoirs to go dry. The reduction in combined firm yield from the original WMP is mainly due to sedimentation in the reservoirs that has occurred since the firm yield calculations were performed for the original WMP, as well as the lower inflows experienced in the 2007-2014 period. LCRA has conducted sediment surveys in the recent past utilizing the Texas Water Development Board's Hydrographic Survey program, and results from these surveys have been used to estimate 2025 sedimentation conditions in the reservoirs for this WMP revision.

3.0 ASSUMPTIONS

Assumptions regarding how lakes Buchanan and Travis are represented and operated in the WAM, and the extent to which water from these reservoirs is used to meet specific demands can vary considerably depending on the purpose for which WAM simulations are being made. For purposes of the lakes Buchanan andTravis combined firm yield calculation in support of this WMP update, the specific assumptions utilized are outlined and described in the following sections. The particular version of the WAM for the Colorado River basin with these specific combined firm yield assumptions incorporated is referred to as the CFY-WAM.

3.1 General Assumptions

3.1.1 TCEQ's Water Availability Model of the Colorado River basin (Run 3) forms the basic structure for the CFY-WAM. The July 2018 version of the Texas A&M University "Water Rights Analysis Package" (WRAP)[3] is the underlying program code used for all CFY-WAM simulations.

3.1.2 A "no-call" assumption[4] with respect to upper basin water rights has been incorporated into the CFY-WAM. This "no-call" assumption, in effect, makes all water rights upstream of the dams that form Ivie and Brownwood reservoirs senior in priority to the Highland Lakes and other downstream water rights; however, the existing priorities of all of the water rights located upstream of these dams are maintained relative to each other, as are those for all of the water rights located downstream of these dams.

[3] Wurbs, R. A. (2018) Water rights analysis package (WRAP) modeling system reference manual. Tech. Rep. 255, Texas Water Resources Institute, College Station, TX.
Wurbs, R. A. (2018) Water rights analysis package (WRAP) modeling system users manual. Tech. Rep. 256, Texas Water Resources Institute, College Station, TX.

[4] The "no-call" assumption in the WAM is an attempt to reflect the various agreements that LCRA has with upstream reservoir owners, i.e. Colorado River Municipal Water District, San Angelo Water Supply Corporation, and Brown County WID No. 1, and to better represent actual conditions with regard to the operation of existing water rights throughout the basin.

3.1.3 The 1940-2016 monthly naturalized flows[5] and net evaporation rates approved by the TCEQ in 2018 are used in the CFY-WAM. These data are considered to be representative of actual variations in hydrologic and climatic conditions sufficient to support meaningful and accurate simulations of water availability, including through drought periods.

3.1.4 Potential droughts worse than the historical drought of record are not simulated. As stated previously, the firm yield is based upon a repeat of the historic drought of record. As new hydrologic and climatic conditions are encountered, there is the potential a new drought of record will be determined.

3.1.5 In the CFY-WAM, water demands for all surface water rights in the Colorado River basin are set at their full authorized diversion amounts, and all reservoirs are specified at their authorized storage capacities, except for lakes Buchanan and Travis (See section 3.4.1-3 for more detail). The authorized demands and priority dates for the major downstream water rights senior in priority to the Highland Lakes are listed in Table 2. (Note, this table only reflects those senior water rights authorized to divert more than 1,500 acre-feet; all senior water rights are reflected in the model.)

3.1.6 Water rights, represented in the WAM as senior to LCRA's lakes Buchanan and Travis, that are based on a requirement to maintain an upstream water supply contract with LCRA were included in the CFY-WAM model if their contract was long-term with a municipal or industrial purpose of use.

3.2 City of Austin Return Flows

3.2.1 The use of surface water by the City of Austin either from diversions under Austin's municipal water rights or from releases from lakes Buchanan and Travis under contract with LCRA is assumed to generate treated wastewater effluent discharged as return flows back into the Colorado River downstream of Austin. In the CFY-WAM, these return flows are determined using procedures consistent with those employed by the Region K Water Planning Group involving the following calculations:

1) At the end of each monthly time step during a CFY-WAM simulation, the total amount of Colorado River water used by the City of Austin to satisfy its municipal and industrial (M&I)[6] water demands is noted.

2) The corresponding quantity of Austin's treated wastewater effluent then is calculated by applying the appropriate monthly factor from the following list

[5] Naturalized flows provide the basic hydrologic inputs to the WAM, and they consist of complete records over the WAM simulation period of historical monthly flows at specific locations throughout the Colorado River basin (usually at streamflow gauging stations) after adjustment for the effects of historical surface water use activities, including diversions, return flows, and reservoir storage and evaporation losses. For the CFY-WAM, the 1940-2016 naturalized flows were provided by TCEQ in 2018 and were developed using the same methodology applied in developing the original WAM for the Colorado River basin.

[6] In the CFY-WAM, Austin's municipal and industrial demands are set at the total amount of annual diversions authorized under Austin's municipal water rights, Certificates of Adjudication 14-5471 and 14-5489, and these demands equal 291,703 acre-feet per year. These demands do not include any Austin water usage for power generation.

to Austin's total M&I demands. These factors were derived from Austin's actual river diversions and return flows as reported for the 2000-2005 period.

Jan	Feb	Mar	Apr	May	Jun
0.7873	0.8027	0.7994	0.6487	0.5509	0.5379

Jul	Aug	Sep	Oct	Nov	Dec
0.4597	0.4213	0.4821	0.5806	0.7215	0.7735

This calculation process results in an annual total of approximately 176,600 acre-feet per year of return flows that are discharged back into the Colorado River.

3) At the beginning of each monthly time step during the CFY-WAM simulation, the calculated amount of Austin's treated wastewater effluent from the previous time step is returned to the Colorado River at a location approximately four river miles downstream of the Highway 71/183 bridge in Austin (mouth of Walnut Creek), and these return flows are then available for use in priority order by all downstream water rights.

4) No direct or indirect reuse of Austin's treated wastewater effluent or return flows is explicity represented in the CFY-WAM simulations. Austin's return flows are discharged to the river and made available for use by all downstream water users in accordance with the prior appropriation doctrine and consistent with the 2007 Settlement Agreement.

3.3 LCRA Downstream Water Rights

3.3.1 One hundred thousand acre-feet per year of LCRA's Garwood water right authorization is represented with an agriculture use pattern at the authorized downstream location for the Garwood water right.

3.3.2 The remaining 33,000 acre-feet per year of LCRA's Garwood water right authorization as well as all of LCRA's other downstream water rights are set at their full authorized diversion amounts and modeled as industrial use at the authorized downstream locations at the Garwood, Lakeside, Pierce Ranch and Gulf Coast operations (although the water rights now are authorized for multiple purposes of use, including municipal and agricultural). The general industrial monthly distribution factors included in TCEQ's Run 3 WAM are used to distribute the annual authorized diversion amounts to monthly demands in the CFY-WAM. The demands for the different lower basin water rights are considered in priority order in the CFY-WAM simulation process including the provision in the City of Austin water right 14-5471 that subordinates the LCRA-owned Gulf Coast, Lakeside and Pierce Ranch water rights to a portion of the City of Austin's Lake Austin Rights.

3.3.3 LCRA's downstream water rights are not simulated as being supplemented or backed up with interruptible stored water from lakes Buchanan and Travis.

3.3.4 No return flows from the downstream water rights are discharged back to the Colorado River.

3.3.5 LCRA is currently in the final stage of constructing the Arbuckle Reservoir, an off-channel reservoir authorized under LCRA's Gulf Coast water right and located near Lane City. The total senior authorized amount of LCRA's Gulf Coast water right is represented in the CFY-WAM as being divided equally into two parts (114,285 acre-feet of the total 228,570 acre-feet per year authorized) with the first part of this authorization being associated with the portion of the irrigation division on the western side of the Colorado River and simulated as a regular run-of-river water right from the Bay City dam. The remaining portion of the senior authorization is represented as a run-of-river right diverting near Lane City with the additional ability to divert water into the Arbuckle Reservoir for the purposes of meeting demands when there is less run-of-river water in later time steps.

3.4 Lakes Buchanan and Travis Storage and Releases

3.4.1 The conservation storage capacities of all reservoirs in the Colorado River basin represented in the WAM, except lakes Buchanan and Travis, are set at their full authorized storage amounts as stipulated in their respective water rights. The conservation storage capacities for lakes Buchanan and Travis are set at their estimated 2025 conservation capacities based on recent sediment surveys.

3.4.2 The conservation storage capacity of Lake Buchanan at elevation 1020.0 feet above mean sea level (feet msl) is specified as 866,011 acre-feet. This maximum storage capacity is used in the WAM simulations for all months of the year.

3.4.3 The conservation storage capacity of Lake Travis at elevation 681.0 feet msl is specified as 1,130,706 acre-feet. This maximum storage capacity is used in the WAM simulations for all months of the year.

3.4.4 With the exception of the City of Austin, South Texas Project and the Lometa system, direct diversions or releases of water are made from lakes Buchanan and Travis to satisfy the demands of LCRA's contractual customers even if their actual diversions are not made directly from lakes Buchanan or Travis. Diversions are made from the Colorado River above Lake Buchanan for the Lometa system. Releases are made to backup demands for the City of Austin and South Texas Project as described in section 3.4.6.

3.4.5 Conveyance losses are not simulated in the model. (However, such losses are accounted for in LCRA's water supply commitments.)

3.4.6 Stored water is released from lakes Buchanan and Travis to backup the following downstream water demands:

- City of Austin's municipal and industrial demands (excluding power generation).
- South Texas Project demands for power generation per contract provisions. (See section 3.6.).

3.4.7 Stored water is released from Lake Buchanan to maintain the intervening Highland Lakes (Inks, LBJ, Marble Falls and Lake Austin) full at all times.

3.4.8 Procedures for diverting water from either Lake Buchanan or Lake Travis to meet LCRA customer demands use the reservoir system operating rules embedded in the basic WRAP program. Because the firm yield model's primary focus is to provide firm supply from either reservoir, the model only allocates water between lakes Buchanan and Travis at a coarse level as described in this paragraph – actual operations include a greater level of control over releases than can be simulated by the model. In the firm yield model, at any time, the relative storage conditions of the two reservoirs determine from which reservoir diversions or releases are to be made, with the overall objective of using water from Lake Travis at a somewhat higher rate than from Lake Buchanan, particularly when storage levels are higher. Procedures for making diversions or releases under the current reservoir operating rules in the CFY-WAM are as follows:

1) An Upper Zone (Zone 1) and a Lower Zone (Zone 2) are defined in each reservoir using 500,000 acre-feet for Lake Buchanan and 390,197 acre-feet for Lake Travis as the zone delineators.

2) When the storage in one reservoir is in Zone 1 (Upper Zone) and the storage in the other reservoir is in Zone 2 (Lower Zone), diversions or releases to meet demands are made from the reservoir with storage in Zone 1 (i.e., from the reservoir that contains more water in storage relative to its conservation storage capacity).

3) When both reservoirs are in the same storage zone, a quantity called the "zone storage factor" is calculated for each reservoir equal to the percent the zone is full. For example, if both reservoirs are in Zone 1 (Upper Zone) and Lake Travis contains 800,000 acre-feet of water, then the zone storage factor for Lake Travis would be equal to 409,803 (800,000 – 390,197) divided by the volume of Zone 1 in Lake Travis (equal to the full conservation storage capacity minus 390,197).

4) When both reservoirs are in Zone 1 (Upper Zone), the zone storage factor for Lake Travis is multiplied by 2, and if this quantity is greater than or equal to the zone storage factor for Lake Buchanan, diversions or releases are made from Lake Travis. If this quantity is less than the zone storage factor for Lake Buchanan, then diversions or releases are made from Lake Buchanan.

5) When both reservoirs are in Zone 2 (Lower Zone), if the zone storage factor for Lake Travis is greater than or equal to the zone storage factor for Lake Buchanan, diversions or releases are made from Lake Travis. If the zone storage factor for Lake Travis is less than the zone storage factor for Lake Buchanan, then diversions or releases are made from Lake Buchanan.

3.5 Environmental Flow Requirements

3.5.1 No environmental flow requirements for instream flows or freshwater inflows to Matagorda Bay are imposed on LCRA's Lake Buchanan or Lake Travis water rights in the CFY-WAM, and, consequently, no water is released from or passed through the Highland Lakes to support environmental flow requirements at any location downstream along the Colorado River.

(Notwithstanding the assumptions in the CFY-WAM model, 33,440 acre-feet per year of the combined firm yield have been set aside to help meet environmental flow needs.)

3.6 South Texas Project

3.6.1 The consumptive demand for the South Texas Project is set equal to the full authorized consumptive demand stated in Certificate of Adjudication 14-5437, as amended (80,125 acre-feet per year representing four generating units).

3.6.2 The current Water Delivery Plan (WDP) for providing backup water to the South Texas Project, which was adopted as part of the 2006 Settlement Agreement between LCRA and STP Nuclear Operating Company (STPNOC), is implemented in the CFY-WAM. As structured, this WDP stipulates LCRA shall initiate staged deliveries of water to STPNOC from LCRA's available sources upstream of the Bay City Dam when the water surface elevation of STPNOC's main cooling reservoir (MCR) falls below 35 feet msl, and shall continue such deliveries to assist with maintaining the level of the MCR above a minimum elevation of 27 feet msl.

3.6.3 The WDP does not specifically state how the water deliveries are to be staged with regard to either timing or the quantities to be delivered; it only requires they commence when the level of the MCR falls below elevation 35 feet msl. For purposes of the CFY-WAM, the operating procedures for delivery of water is assumed to be consistent with the previous water delivery plan.

3.6.4 The total backup supply from the Highland Lakes for STPNOC is limited to a rolling 5-year average of 40,000 acre-feet per year.

3.6.5 The CFY-WAM assumes STPNOC will divert under Certificate of Adjudication 14-5437, as amended, whenever the streamflow exceeds the parameters in the certificate without regard to any operational preferences related to salinity or conductivity.

TABLE 1 FIRM ANNUAL YIELD COMPONENTS AND THEIR ASSOCIATED WAM WATER RIGHT ID'S USED TO DETERMINE BUCHANAN-TRAVIS FIRM ANNUAL YIELD		
MUNICIPAL AND INDUSTRIAL FIRM SUPPLIES FROM BUCHANAN-TRAVIS		321,386
11405715002	596	
11405730001	24,725	
11405790001	11,868	
11204007001	17,802	
11405677001	6,330	
61405482001C	196,784	
61405480001	15,700	
61405473001	10,470	
61405474001	37,110	
BACKUP PROVIDED FOR AUSTIN M&I WATER RIGHTS		73,783
61405471005RMBU	48,340	
61405471005LMBU	12,976	
61405489003MBU	12,468	
BACKUP FOR SOUTH TEXAS PROJECT		22,750
61405437001BU	22,750	
BUCHANAN-TRAVIS 2007-2014 DROUGHT FIRM ANNUAL YIELD		417,919
Minimum System Storage (acre-feet)	7,045	
Critical Period Defining Yield (months)	91	
Duration of Critical Period (years)	7.58	
Approximate Yield Value of Remaining Storage	929	
BUCHANAN-TRAVIS FIRM ANNUAL YIELD INCLUDING MINIMUM STORAGE (Sum of Demands Met plus Yield Value of Remaining Storage)		418,848

TABLE 2

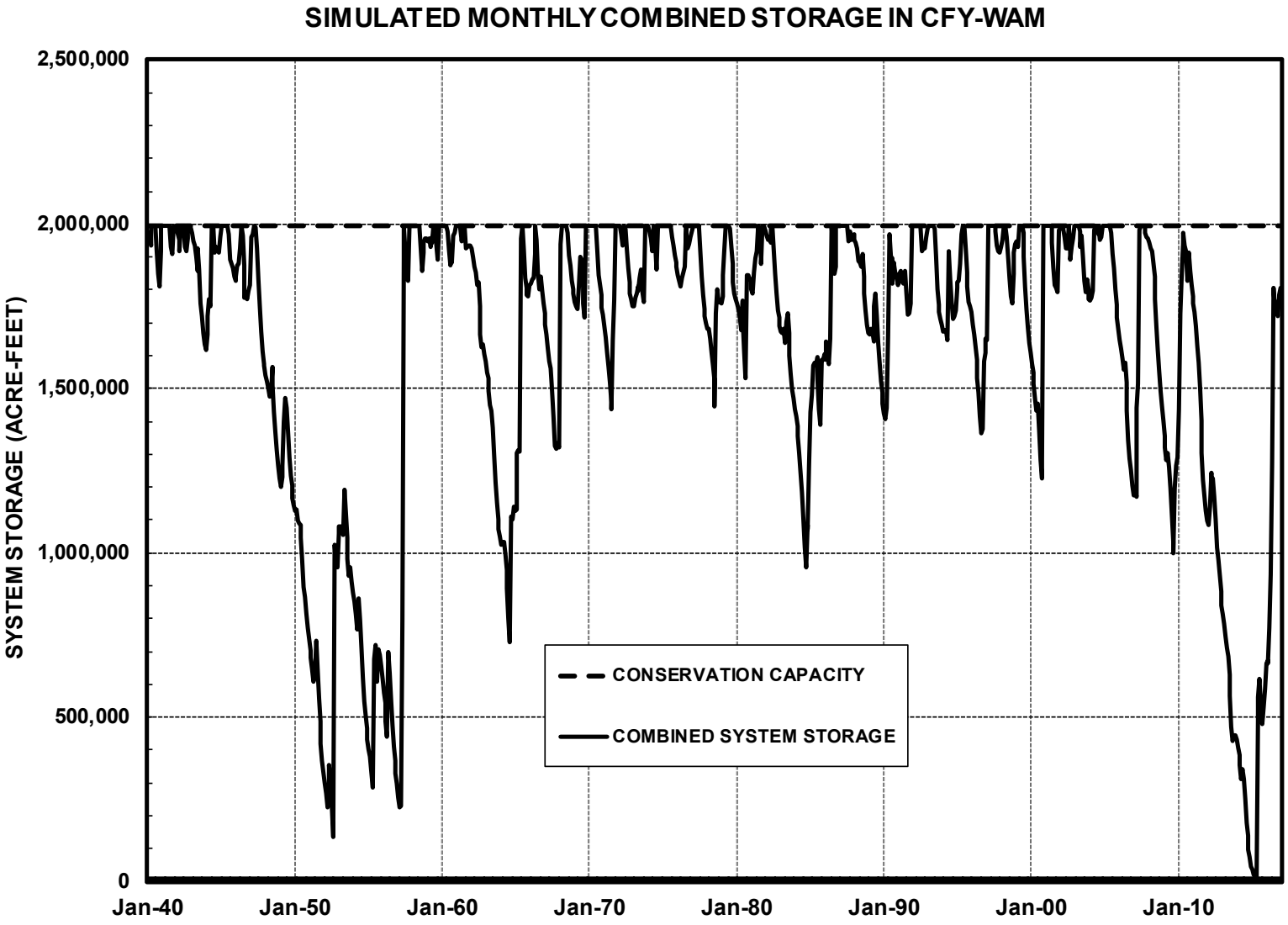
DOWNSTREAM WATER RIGHTS SENIOR IN PRIORITY TO THE HIGHLAND LAKES

WATER RIGHT OWNER/WATER RIGHT	AUTHORIZED USES	AUTHORIZED DIVERSION AMOUNT (acre-feet/year)	PRIORITY DATE
City of Austin			
14-5471D	Municipal	250,000	6/30/1913 [a]
	Irrigation	21,403	6/27/1914
	Municipal, Industrial, Power	24,000	6/27/1914
LCRA (Lakeside) [b]			
14-5475B	Municipal	52,500	01/04/1901
	Industrial		
	Irrigation	55,000	9/2/1907
	Mining		
LCRA (Garwood)			
14-5434F	Municipal	133,000	11/01/1900
	Industrial		
	Irrigation		
City of Corpus Christi			
14-5434B	Municipal	35,000	11/02/1900
	Industrial		
	Irrigation		
LCRA (Pierce Ranch)			
14-5477D	Irrigation	55,000	09/01/1907
	Industrial		
LCRA (Gulfcoast) [b]			
14-5476D	Irrigation	228,570	12/01/1900
	Industrial		
	Mining		
TOTAL	All	854,473	

[a] Any water right owned by LCRA with a priority date junior to November 15, 1900 is specifically subordinated to this right.

[b] Lakeside and and Guldcoast water rights have additional authorized diversions for 78,750 and 33,930 acre-feet per year, respecctively, with a junior priority date of November 1, 1987.

FIGURE 1 MONTHLY COMBINED STORAGE IN LAKES BUCHANAN AND TRAVIS FROM FIRM YIELD WAM SIMULATION



TECHNICAL PAPER A-6
ASSUMPTIONS UNDERLYING THE WATER AVAILABILITY MODEL USED TO SUPPORT DEVELOPMENT OF THE LCRA WATER MANAGEMENT PLAN REVISION
February 2019

This paper summarizes the basic assumptions included in the Nov. 8, 2018, version of the Water Availability Model (WAM) supporting the revision of the Water Management Plan (WMP) ("the "WMP WAM"). The WMP WAM incorporates estimated 2025 conditions for firm demands for LCRA's municipal, industrial and other firm water customers, reservoir storage capacity for lakes Buchanan and Travis, and irrigation demands for LCRA's lower basin customers.

1. GENERAL

1.1. The TCEQ's Water Availability Model of the Colorado River basin (Run 3) forms the basic structure for the WMP WAM, and this model is assumed to appropriately reflect water rights and hydrologic conditions in the basin to provide for meaningful and accurate simulations of water availability. The July 2018 version of the Texas A&M University "Water Rights Analysis Package" (WRAP)[1] is the program code used for all WAM simulations.

1.2. To support the revision of the WMP, TCEQ's WAM was adapted to better represent an operational model of LCRA's water supply system, including the incorporation of specific rules to approximate the operation of lakes Buchanan and Travis and provide water to LCRA's water customers.

1.3. The WMP WAM includes the "no-call" assumption with regard to all water rights located upstream of lakes Buchanan and Travis ("cutoff model").[2] This assumption, in effect, makes all water rights upstream of lakes Buchanan and Travis senior in priority to lakes Buchanan and Travis and other downstream water rights.

1.4. The 1940-2013 monthly naturalized flows and net evaporation rates included in the TCEQ's Run 3 WAM for the Colorado River basin have been extended through calendar year 2016[3], and this extended database was used to define the simulation period for the WMP WAM. These data are representative of actual variations in hydrologic conditions and support meaningful and accurate simulations of water availability, including through the 1950s and the recent drought of record.

1.5. Water demands for all surface water rights in the Colorado River basin that are not partially or wholly supplied by LCRA's water delivery system (lakes Buchanan and Travis and LCRA's lower basin water rights) are conservatively assumed to be equal

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[1] Wurbs, R. A. , Water Rights Analysis Package (WRAP) Modeling System Reference Manual. Technical Report No. 255, Texas Water Resources Institute, College Station, TX. 12th Edition, July 2018
Wurbs, R. A., Water Rights Analysis Package (WRAP) Modeling System Users Manual. Technical Report No. 256, Texas Water Resources Institute, College Station, TX. 12th Edition, July 2018

[2] The "no-call" assumption in the WAM is an attempt to reflect the various agreements that LCRA has with upstream reservoir owners, i.e. Colorado River Municipal Water District, San Angelo Water Supply Corporation, and Brown County WID No. 1, and to better represent actual conditions with regard to the operation of existing water rights throughout the basin.

[3] The naturalized flows for the 1999-2016 period were developed using the same methodology applied in developing the original WAM for the Colorado River basin.

to the maximum annual diversion amounts authorized by their individual water rights as reflected in TCEQ's Run 3 WAM.

2. LOWER BASIN RELIABLE RUN-OF-RIVER SUPPLIES

2.1. In the WMP WAM, to more accurately reflect the actual quantity of releases (inflow pass-throughs and stored water) from lakes Buchanan and Travis needed to meet LCRA's downstream demands in a manner consistent with historical operations, the supply of run-of-river water originating downstream of Mansfield Dam made available for diversion by these water users was limited to quantities historically proven to be reliable in the lower segments of the Colorado River and the return flows discharged from the City of Austin and City of Pflugerville wastewater treatment plants.[4]

2.2. The downstream reliable river flows (not including discharged return flows) were estimated by LCRA staff for specific reaches of the river using streamflows during low-flow periods in 1999 and 2005. These quantities are stipulated in the WMP WAM as follows:

Mansfield Dam to Austin gauge	2,600	ac-ft/month
Austin gauge to Bastrop gauge	0	ac-ft/month
Bastrop gauge to Columbus gauge	3,900	ac-ft/month
Columbus gauge to Wharton gauge	3,133	ac-ft/month
Wharton gauge to Bay City gauge	1,567	ac-ft/month

Hence, with regard to flows originating downstream of Mansfield Dam, there is a maximum of 11,200 ac-ft of downstream flow plus Austin and Pflugerville return flows in any given month assumed to be reliably available for supplying LCRA's downstream irrigation demands and certain other water supply customers, as discussed in section 2.3. The effective available flow simulated at any location is the lessor of the remaining reliable downsream river flow (including discharged return flows) and the unrestricted modeled available flow.

2.3. Irrigation demands at the four downstream irrigation operations (Lakeside, Garwood, Pierce Ranch and Gulf Coast) are subject to the availability of the reliable downstream river flows, as are, Austin's run-of-river diversions at the Fayette Power Project (FPP), the LCRA Garwood amendment (14-5434E) used at the FPP, Gulf Coast industrial customers, and the City of Corpus Christi's water right. This method provides for a more realistic simulation of operations under the revised WMP, including the pass-through of run-of-river water originating upstream of Mansfield Dam and the releases of stored water from lakes Travis and Buchanan. In actual operations, LCRA does not intend to limit the ability of a downstream water right holder to divert any run-of-river water that may be legally available under its water right.

[4] This limitation on available flows in the lower Colorado River is considered to be appropriate based on LCRA's historical operational experience attempting to provide pass-through flow and stored water from lakes Buchanan and Travis to downstream water users on a daily basis while also taking into consideration the actual river flows in the lower basin below Mansfield Dam that can be effectively diverted on a daily basis by the lower basin water users.

2.4. Prior to any diversions being made, the total quantity of reliable downstream river flow at any location along the lower Colorado River is equal to the sum of Austin and Pflugerville return flows and the sum of the incremental reliable downstream river flows that originate in each of the upstream reaches of the river. The effective available flow at any location is the lessor of the remaining reliable downsream river flow and the unrestricted modeled available flow.

2.5. The total quantity of reliable downstream river flow at any location along the lower Colorado River is reduced as diversions are made upstream in priority order by the individual irrigation operations, industrial diversions made under the Gulf Coast water right, Austin at FPP, Garwood amendment at FPP, and the City of Corpus Christi's Garwood water right at their respective diversion points.

3. MUNICIPAL, INDUSTRIAL, POWER GENERATION AND OTHER FIRM DEMANDS AND SUPPLIES

3.1. For the WMP WAM, municipal, industrial, power generation and other firm water demands partially or wholly supplied by LCRA represent projected 2025 conditions. For this WMP update, a method for setting highwater-use demands in some years and non-high-water-use demands in other years was developed based on historic weather conditions. The weather-varied method and development of a data set for 2025 demands is discussed in separate technical papers. All of the municipal, industrial, power generation and other firm water demands supplied from LCRA are satisfied either from run-of-river diversions or backed up with stored water from lakes Buchanan and Travis. Before providing stored water supplies from lakes Buchanan and Travis, demands at Lake Austin and Fayette Power Plant are provided run-of-river supplies under the Garwood water right (14-5434E) as described in Section 10. Demands with a diversion point authorized by the Gulf Coast water right (14-5476) are first supplied using run-of-river diversions, then from stored water in the Arbuckle Reservoir before using lakes Buchanan and Travis stored water as described in Section 11.

3.2. The City of Austin owns several water rights that are used to meet Austin's demands before using stored water from lakes Travis and Buchanan.

3.2.1. Austin's municipal and industrial (M&I) demands are met first from the city's Certificate of Adjudication 14-5471, as amended, with stored water backup from lakes Buchanan and Travis. 3,375 ac-ft/year of Austin's M&I demand is met with direct reuse from Austin's treated wastewater effluent. Direct reuse demands are supplied in a given month from the effluent generated the previous month from Austin municipal demands.

3.2.2. An additional demand of 2,747 ac-ft/year, which is satisfied from direct reuse of effluent, also has been included in the WMP WAM for Austin. This demand is considered a historic direct reuse demand that is not included in the 2025 Austin M&I demand projections.

3.2.3. Demands for Austin's Sand Hill power plant have been set as 1,209 ac-ft/year which is met from direct reuse from Austin effluent.

3.2.4. Demands for Austin's Decker Power Plant are weather varied and are set as the demand expected from the Colorado River. These demands are satisfied first using Austin's Decker water right (Certificate of Adjudication 14-5489, as amended), then backed up with water from lakes Buchanan and Travis consistent with the 1999 agreement.

3.2.5. Demands for Austin at FPP are weather varied and are set as the demand expected from the Colorado River. These demands are satisfied first using Austin's Certificate of Adjudication 14-5471, as amended, and are subject to available reliable downstream river flows, per Sections 2.2 and 2.3 above, then backed up entirely with water from lakes Buchanan and Travis consistent with LCRA's separate contract with Austin for FPP.

3.2.6. The Lady Bird Lake portion of Austin's Certificate of Adjudication 14-5471, as amended, (subject to available reliable downstream river flowsper Sections 2.2 and 2.3 above) is used first to satisfy demands for Austin at FPP limited to 24,000 ac-ft/year.

3.2.7. A portion of Austin's municipal demand for its Water Treatment Plant #4 (WTP#4), recently re-named the Berl Handcox Sr. Water Treatment Plant, is represented as being supplied from Lake Travis under LCRA's Lake Travis water right.

4. EFFLUENT AND RETURN FLOWS

4.1. Effluent from the City of Austin's wastewater treatment plants is determined using factors that correspond with high-demand (dry) years and another set of factors for average-demand (average) years:

- At the end of each monthly time step during a WAM simulation, the total amount of Colorado River diversions made by the City of Austin to satisfy its M&I water demand is recorded (diversions from Lake Austin for Davis and Ullrich WTPs and diversions from Lake Travis for WTP#4).
- The total quantity of treated wastewater effluent associated with Austin's total M&I river diversions is then calculated by applying the corresponding monthly factors from the following table to Austin's total amount of M&I diversions. The dry-year factors were derived based on Austin's actual river diversions and effluent (return flows and direct reuse) reported for the years 2011-2013. The average-year factors were derived based on Austin's actual river diversions and effluent (return flows and direct reuse) reported for the years 2010 and 2014. The first three months of 2010 were excluded because the monthly factors are greater than one. Presumably, more effluent was produced than diversions in these months due to stormwater runoff entering the wastewater collection system.
- Dry-Year Effluent Factors:

Jan	Feb	Mar	Apr	May	Jun
0.86319	0.87198	0.84237	0.68663	0.70612	0.57487
Jul	Aug	Sep	Oct	Nov	Dec
0.58209	0.51627	0.61787	0.76588	0.83466	0.89932

- Average-Year Effluent Factors:

Jan	Feb	Mar	Apr	May	Jun
0.89507	0.87112	0.88406	0.80554	0.73167	0.72502
Jul	Aug	Sep	Oct	Nov	Dec
0.69100	0.53978	0.76530	0.65358	0.77627	0.80485

- At the beginning of the following time step, the calculated amount of Austin's effluent from the previous time step is reduced by the amount of Austin's M&I demand expected to be satisfied by direct reuse, and the direct reuse for the Sand Hill power plant.
- The remaining effluent represents the total amount of return flow discharged to the Colorado River at the beginning of the current time step.

4.2. For the WMP WAM, no indirect reuse of Austin's return flows is included.

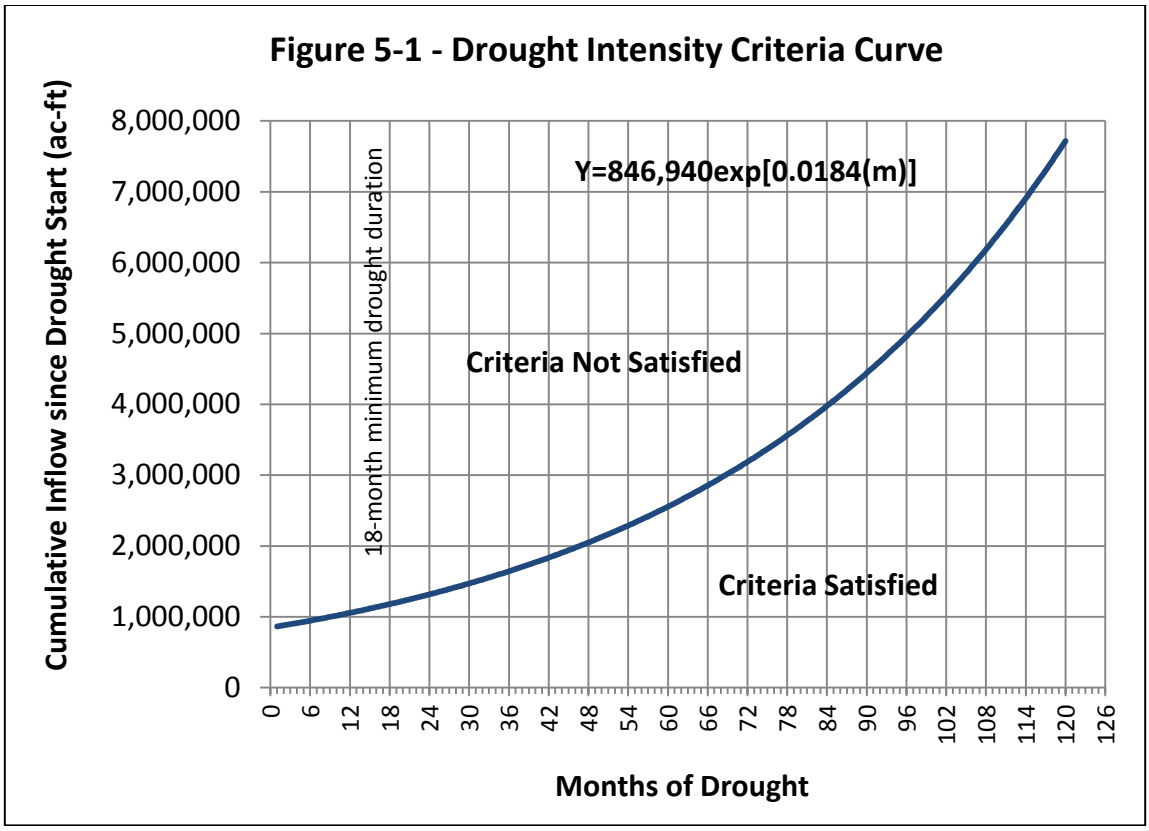
4.3. Return Flows for the City of Pflugerville are based on the amounts of municipal demands multiplied by a return flow factor of 0.6 and are discharged into Wilbarger Creek.

5. DROUGHT CONDITION DETERMINATION

5.1. A three-tier drought condition framework has been established for the WMP WAM. Extraordinary Drought, Less Severe Drought and Normal conditions are defined by lakes Buchanan and Travis combined storage on March 1 and July 1 and inflow quantities over specified periods of time leading up to those dates. For each drought condition, the model applies different provisions for the curtailment of interruptible stored water. (See Section 6, below.) The model also considers the drought condition for certain provisions regarding support levels for freshwater inflows to Matagorda Bay and determines the amount of water to be provided for those purposes under various conditions.

5.2. Extraordinary Drought

5.2.1. For droughts at least 18 months in duration: The model engages Extraordinary Drought provisions when combined storage in lakes Buchanan and Travis is below 1.3 million ac-ft on March 1 or July 1 AND it has been at least 18 months since the combined storage was 98 percent full or greater (combined drawdown less than 40,000 ac-ft) AND the cumulative inflows are equal to or less than the cumulative inflows over the same number of months on the curve representing cumulative inflows during the 1950s drought. This curve is shown in Figure 5-1.



5.2.2. For large drops in storage: The model engages Extraordinary Drought provisions when comined storage in lakes Buchanan and Travis is below 1.4 million ac-ft on July 1 AND combined storage dropped by more than 300,000 acre-feet during the period from March 1 to July 1.

5.2.3. Exit. The model lifts Extraordinary Drought provisions on the March 1 or July 1 evaluation date when combined storage in lakes Buchanan and Travis has been at or above 1.3 million ac-ft at any time during the previous season. (For the purpose of drought condition evaluation, for the March 1 evaluation date, the "previous season" is the period from July to February; for the July 1 evaluation date, the "previous season" is the period from March to June.) However, the three drought trackers (drought duration, cumulative inflow and Extraordinary Drought inflow test) do not reset until the combined drawdown at the beginning of any month is less than 40,000 ac-ft. Consequently, absent a reset of the drought trackers, the Extraordinary Drought provisions will re-engage if the combined storage in lakes Buchanan and Travis is below 1.3 million ac-ft and the cumulative inflows are equal to or less than the cumulative inflows (described above) on a subsequent March 1 or July 1. If the criteria for lifting Extraordinary Drought provisions are met, the Less Severe Drought provisions automatically engage unless criteria for lifting Less Severe Drought also are met.

5.3. Less Severe Drought

5.3.1. Engagement. The model engages Less Severe Drought provisions from a Normal condition if either of two separate sets of criteria are met:

1) Combined storage in lakes Buchanan and Travis is below 1.5 million ac-ft on March 1 or July 1 AND over the previous three months, the cumulative inflows were less than 50,000 ac-ft.
2) Combined storage in lakes Buchanan and Travis is below 1.4 million ac-ft on March 1 or July 1 AND over the previous three months, the cumulative inflows are less than the 33rd percentile of inflows for that three-month period.
3) The model engages Less Severe Drought provisions when lifting from an Extraordinary Drought condition unless the criteria (below) for lifting Less Severe Drought also are met.

5.3.2. Exit. The model lifts Less Severe Drought provisions and returns to Normal conditions if either of two separate sets of criteria are met:

1) Combined storage in lakes Buchanan and Travis has been at or above 1.5 million ac-ft at any time during the previous season,
2) Combined storage in lakes Buchanan and Travis has been at or above 1.4 million ac-ft at any time during the previous season AND over the three months preceding March 1 or July 1, the cumulative inflows were greater than or equal to the median for the three-month period.

If neither of the above Less Severe Drought condition exit criteria is met, the Less Severe Drought condition is maintained for the upcoming season, unless the Extraordinary Drought criteria is met, as described above. If the criteria for engaging Extraordinary Drought provisions are met on an evaluation date while in Less Severe Drought, the Extraordinary Drought provisions take effect.

5.4. Normal Conditions

5.4.1. Engagement. If not in Extraordinary Drought or Less Severe Drought in the previous season AND if the criteria for engagement of Extraordinary Drought or Less Severe Drought are not met on March 1 or July 1, then Normal conditions are in effect.

5.4.2. Exit. The model removes provisions for Normal Conditions if the criteria are met for engaging either Extraordinary Drought or Less Severe Drought on March 1 or July 1.

6. LCRA INTERRUPTIBLE AGRICULTURAL SUPPLY

6.1. Water demands associated with the four downstream irrigation operations (Garwood, Lakeside, Pierce Ranch and Gulf Coast) corresponding to years 2020-2025 conditions have been projected as documented in a separate technical paper.

6.2. A generalized pattern of monthly use has been applied to the weather-varied demands to derive monthly demand estimates.

6.3. The model seeks to meet water demands associated with the four downstream irrigation operations first with available run-of-river supplies originating downstream of Mansfield Dam, then with the Arbuckle Reservoir for Gulf Coast Division only,

then with available inflows passed through lakes Buchanan and Travis, and finally, with any available interruptible stored water from lakes Buchanan and Travis.

6.4. The supply of run-of-river water originating downstream of Mansfield Dam assumed to be available for diversion by the downstream irrigation operations is limited to the available supply of reliable river flows as described in Section 2.

6.5. The Garwood run-of-river water right is the most senior major water right in the Colorado River basin. As such, it has higher reliability and lower needs for interruptible stored water as a portion of total supply, compared to the non-Garwood irrigation operations. The Garwood Irrigation Operation's stored water needs are met under a separate agreement from the non-Garwood irrigation operations. In the WMP WAM, Garwood is not limited to a set quantity of interruptible stored water and stored water cutoff triggers are deactivated for Garwood. This is included as a conservative assumption based upon the historically high reliability of the Garwood water right and correspondingly low demand for backup water under historic hydrologic conditions. In actual operations, Garwood would be subject to curtailment or cutoff consistent with the purchase agreement for the Garwood water rights.

6.6. For the non-Garwood irrigation operations (Gulf Coast, Lakeside and Pierce Ranch), the amount of interruptible stored water made available for diversion is set according to which of the three-tier drought conditions is engaged and by the combined storage on March 1 for first crop and July 1 for second crop. If the criteria for Extraordinary Drought are met, no stored water is made available for the non-Garwood irrigation operations. The model also includes an approach for simulating a "look-ahead" test whereby, no stored water is made available for the non-Garwood irrigation operations if combined storage is below certain trigger levels on March 1 or July 1. The look-ahead provision is discussed in more detail in Section 6.7. In either of the above cases, seasons when no stored water is made available for the non-Garwood irrigation operations in the coming season, their entire demand is set to zero. The amounts of stored water available when Less Severe Drought and Normal Conditions are engaged are provided in the following tables:

6.6.1. Less Severe Drought

First Crop		**Second Crop**	
Combined storage on March 1 (ac-ft)	**Interruptible Supply (ac-ft)***	**Combined storage on July 1 (ac-ft)**	**Interruptible Supply (ac-ft)***
Below 1,100,000	0	Below 1,100,000	0
1,100,000 to 1,499,999	88,200 to 155,000	1,100,000 to 1,499,999	39,700 to 55,000
1,500,000 or above	Not Applicable	1,500,000 or above	Not Applicable
Anytime cutoff for remainder of season if combined storage drops to or below 1 million ac-ft		Anytime cutoff for remainder of season if combined storage drops to or below 1 million ac-ft	

* Non-Garwood

6.6.2. Normal Conditions

First Crop		Second Crop	
Combined storage on March 1 (ac-ft)	**Interruptible Supply (ac-ft)***	**Combined storage on July 1 (ac-ft)**	**Interruptible Supply (ac-ft)***
Below 1,100,000	0	Below 1,100,000	0
1,100,000 to 1,300,000	107,100 to 178,000	1,100,000 to 1,400,000	39,700 to 66,000
Above 1,300,000	178,000	Above 1,400,000	66,000
Anytime cutoff for remainder of season if combined storage drops to or below 1 million ac-ft		Anytime cutoff for remainder of season if combined storage drops to or below 1 million ac-ft	

* Non-Garwood

6.7. The WMP WAM includes a proxy for the look-ahead test. Under a look-ahead test, interruptible stored water (non-Garwood) would be cut off if the LCRA Board of Directors determines combined storage would fall below 600,000 ac-ft in the next 12 months or below 900,000 ac-ft during the upcoming crop season. A proxy for the look-ahead test was developed using stochastic methods based on cumulative inflows to lakes Buchanan and Travis being less than the 99th percentile flows (flows expected to be exceeded 99 percent of the time) and interruptible stored water being provided to meet demands for all of the irrigation operations. The combined storage level for the beginning of the crop season at which storage would not drop below 900,000 ac-ft during the upcoming crop season was determined. The levels for staying above 900,000 in the upcoming crop season are always higher than the triggers for not dropping below 600,000 ac-ft in the next 12 months, so the level for staying above 900,000 ac-ft are used in the WMP WAM as the look-ahead proxy. Representing the look-ahead provision, if the combined storage is less than 1.22 million ac-ft on March 1, no stored water is made available for the non-Garwood irrigation operations for first crop. If the combined storage is less than 1.19 million ac-ft on July 1, no stored water is made available for the non-Garwood irrigation operations for second crop. Interruptible stored water for the Garwood irrigation operation is not subject to the look-ahead provision.

6.8. For the non-Garwood irrigation operations to simulate possible reductions in acreage due to limited stored water availability, first crop demands are reduced by multiplying by the ratio of the amount of stored water available for first crop according to the allocation table divided by the maximum stored water allocation. Second crop demands are reduced by multiplying by the minimum of the first crop ratio or the amount of stored water available for second crop according to the allocation table divided by the maximum stored water allocation.

6.9. If no interruptible stored water is available for the upcoming crop season, the model sets demands to zero for the non-Garwood irrigation operations.

6.10. If the allocated quantity of interruptible stored water for the non-Garwood irrigation operations is exhausted before the end of the season, a mid-crop cutoff occurs, and no additional stored water is made available for the remainder of the season. This WMP revision would allow all or part of a second crop allocation of water to be used to finish first crop if water would be available for second crop following a mid-crop cutoff of first crop due to the first crop allocation being exhausted. Note this shift of water use from second crop to first crop is not explicitly modeled.

6.11. If the interruptible stored water supply is exhausted prior to the end of the crop season and combined storage is below 1.3 million ac-ft, pass-through of run-of-river inflow to lakes Buchanan and Travis also is cutoff for the non-Garwood irrigation operations. If the interruptible stored water supply is exhausted prior to the end of the crop season and combined storage is at or above 1.3 million ac-ft, pass-through of run-of-river inflow to lakes Buchanan and Travis is provided, if available, to the extent needed to finish the crop.

6.12. If interruptible stored water is not available for first crop, it also is not available for second crop.

6.13. Return flows to the Colorado River from the downstream irrigation operations are discharged at the beginning of the next month after each crop season (August for first crop and November for second crop), with these return flows calculated based on the following percentages of the total water supply utilized by each of irrigation operation during that season:

Garwood	3 percent	Lakeside	2 percent
Pierce Ranch	18 percent	Gulf Coast	10 percent

7. LAKES BUCHANAN AND TRAVIS STORAGE AND RELEASES

7.1. Based on the most recent sedimentation studies conducted by the Texas Water Development Board, the combined conservation storage capacity of lakes Buchanan and Travis is projected to decrease to 1,996,717 ac-ft in 2025 due to sedimentation.

7.2. The conservation storage capacity of Lake Buchanan at elevation 1,020 feet msl is projected to decrease to approximately 866,011 ac-ft in 2025.

7.3. The conservation storage capacity of Lake Travis at elevation 681 feet msl is projected to decrease to approximately 1,130,706 ac-ft in 2025.

7.4. To reflect expected operating procedures and flood management guidelines during the timeframe of this WMP, the top of the conservation pool for Lake Buchanan is set at 1,018 feet msl in the WMP WAM from May through October, and 1020 feet msl November through April.

7.5. To be consistent with current LCRA operations and accounting procedures, the quantity referred to as “storable inflows” to lakes Buchanan and Travis is determined as the volume of available inflows capable of being stored in the reservoirs at the 1926 priority date immediately after inflows to the reservoirs have been passed downstream to satisfy the demands of senior water rights. The storable inflows quantity is the amount of inflows made available to satisfy environmental flow needs. Stored water also is made available for satisfying Subsistence instream flow needs,

if necessary. Additionally, as discussed further below, storable inflows from one month may be carried over to the following month for purposes of helping to meet the Threshold bay and estuary criteria.

7.6. A release of 20,000 ac-ft/year is made from lakes Buchanan and Travis to true-up the capability of the model with the real world capability to deliver stored water to downstream customers and to meet environmental flow obligations. This release is associated with channel losses, temporary bank storage, and uncertainty caused by the attenuation of releases and timing of downstream flows. This release is not simulated as available for meeting instream flow obligations. This release, along with the reliable flow concept discussed in Section 2, firm delivery losses discussed in Section 7.7, order-but-not-diverted concept discussed in Section 7.8, was included in the calibration model used in support of the 2015 WMP, which demonstrated the WAM model was capable of reasonably reproducing historical combined storage of lakes Buchanan and Travis. Releases from lakes Buchanan and Travis, made to true-up the model with the real world capability of delivering water downstream, are made available only to help meet freshwater inflow needs and for meeting instream flow requirements of water rights not supplied by LCRA. Because this true-up release is used by the monthly WAM to better represent daily operational uncertainties, it is not considered to be reliable for customers that order water or for meeting instream flow requirements. Thus, these releases are disregarded when determining the required releases from lakes Buchanan and Travis for such needs.

7.7. Requirements for releases from lakes Buchanan and Travis to satisfy the demands of LCRA's downstream firm M&I water users below Travis County are increased by the following factors to account for delivery inefficiencies and losses along the Colorado River. These factors are in addition to the true-up release described in Section 7.6. In the WMP WAM, the additional water released described in this section becomes available for diversion and use by all downstream users once it passes the points of diversion associated with the release, with the exception of those demands whose run-of-river supplies are limited to the reliable downstream river flows as described in Section 2, i.e., the LCRA irrigation operations, Austin's FPP demand, LCRA's FPP demand and the Corpus Christi demand. Arbuckle Reservoir does not attempt to refill using the releases described in this section. The delivery factors below were calculated using a method developed by LCRA staff for estimating inefficiencies and losses associated with the conveyance of stored water.

Diverter	Delivery Factor
FPP	6.5 percent
Matagorda County Industrial/Power Generation	10.9 percent
South Texas Project	11.5 percent

7.8. Requirements for releases from lakes Buchanan and Travis to satisfy the demands of the downstream irrigation operations (to the extent there are demands for a particular month) are increased by the following seasonal delivery factors applied each month to account for delivery losses along the lower Colorado River and for water ordered to meet requested demands but not diverted due to weather or other circumstances. These factors were developed using historical release and diversion

data for each of the irrigation operations from 2001 to 2016. Separate seasonal factors were developed for wet, moderate and dry weather conditions. The weather condition for each season is read into the model, and the appropriate delivery factors are applied for the specific irrigation operation. First crop seasonal factors are applied in the months March to July and second crop seasonal factors are applied in the months August to October. Once such ordered water passes the associated points of diversion, it is available for meeting the bay inflow criteria or for diversion and use by downstream water rights whose run-of-river supplies are not limited to the reliable downstream river flows. As described in Section 11, Arbuckle Reservoir attempts to refill with ordered-not-diverted water subject to limitations.

Wet-Weather Factors:

Season	Garwood	Gulf Coast	Lakeside	Pierce Ranch
First Crop	58%	25%	72%	62%
Second Crop	32%	20%	71%	32%

Moderate Weather Factors:

Season	Garwood	Gulf Coast	Lakeside	Pierce Ranch
First Crop	31%	17%	35%	43%
Second Crop	31%	14%	55%	57%

Dry-Weather Factors:

Season	Garwood	Gulf Coast	Lakeside	Pierce Ranch
First Crop	22%	13%	20%	29%
Second Crop	22%	21%	33%	32%

7.9. Releases of stored water from Lake Buchanan are made to maintain the intervening Highland Lakes (Inks Lake, Lake LBJ and Lake Marble Falls) within an established operating range at all times. In addition, releases of stored water from Lake Travis are made to maintain Lake Austin and Lady Bird Lake within historic operating ranges.

7.10. Procedures in the WMP WAM for making releases from either Lake Buchanan or Lake Travis to meet downstream water demands use the reservoir system operating rules embedded in the basic WRAP program. Because the WMP's primary focus is to preserve sufficient combined storage in both reservoirs to meet firm customer demands relative to the amount of interruptible stored water that can be provided, the model only allocates water between lakes Buchanan and Travis at a very coarse level as described in this section. Actual operations include a greater level of control over releases than can be simulated by the WMP WAM.

In the WMP WAM, the relative storage conditions of the two reservoirs are considered to determine from which reservoir releases are to be made with two overall objectives. The first objective is to use water from Lake Travis at a somewhat higher rate than from Lake Buchanan when both reservoirs are in the upper zone (as described below) to minimize flood spills from Lake Travis when Lake Buchanan is not full. The second objective is to balance releases when both reservoirs are in

the lower zone (as described below). Procedures for making releases under the current reservoir operating rules in the WMP WAM for lakes Buchanan and Travis are as follows:

(1) An Upper Zone and Lower Zone are defined in each reservoir using 500,000 ac-ft for Lake Buchanan and 390,197 ac-ft for Lake Travis as the zone delineators.

(2) When the storage in one reservoir is in the Upper Zone and the storage in the other reservoir is in the Lower Zone, releases to meet downstream water demands are made from the reservoir with storage in the Upper Zone.

(3) When both reservoirs are in the same storage zone, releases are balanced between reservoirs based on the reservoir with the higher rank index value. The rank index value calculated for each reservoir is equal to the percent the zone is full multiplied by weighting factors discussed below.

(4) When both reservoirs are in the Upper Zone, the weighting factor for Lake Travis is two and one for Lake Buchanan. With this specification, the final rank index is calculated by multiplying the percent full of the Lake Travis Upper Zone by two and multiplying the percent full of Lake Buchanan Upper Zone by one, with the higher of the two values dictating which reservoir makes the release. For example, if both reservoirs are in the Upper Zone and Lake Travis contains 590,197 ac-ft of water, then the rank index for Lake Travis would be equal to about 0.54, or a 27 percent full Upper Zone multiplied by a weighting factor of two. Percent full is calculated as 200,000 (current storage 590,197 ac-ft – 390,197 ac-ft Zone 1 storage) divided by the volume of the Lake Travis Upper Zone of 740,509 ac-ft (1,130,706 ac-ft full conservation storage capacity - 390,197 ac-ft volume of the Lake Travis Lower Zone).

(5) When both reservoirs are in the Lower Zone, the weighting factor for both lakes Travis and Buchanan is one.

8. ENVIRONMENTAL INSTREAM FLOW CRITERIA

8.1. The Subsistence, Base Dry and Base Average instream flow criteria described in Lower Colorado River, Texas, Instream Flow Guidelines (2008)[5] are in effect in the WMP WAM at the Austin, Bastrop, Columbus and Wharton gauges on the Colorado River.

8.2. In applying these criteria, the Subsistence instream flow criteria are engaged all the time. The engagement of the Base Dry and the Base Average instream flow criteria is determined based on the combined storage in the lakes Buchanan and Travis on March 1, July 1 and Nov. 1 of any given year. If the combined storage exceeds 1.8 million ac-ft, then the Base Dry criteria are engaged; otherwise, they are disengaged. If the combined storage exceeds 1.96 million ac-ft, then the Base Average criteria are engaged; otherwise, they are disengaged.

[5] BIO-WEST, Inc. (2008); Lower Colorado River, Texas, Instream Flow Guidelines, Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker; prepared for Lower Colorado River Authority and San Antonio Water System; Round Rock, Texas.

8.3. After storable inflows are fully utilized, releases of stored water from lakes Buchanan and Travis are made to help satisfy the Subsistence instream flow criteria all of the time for the Austin, Bastrop and Columbus river gauges. After storable inflows are fully utilized, releases of stored water from lakes Buchanan and Travis are made to help satisfy the Subsistence instream flow criteria at Wharton when combined storage is equal to or greater than 900,000 ac-ft. When combined storage is less than 900,000 ac-ft, the criteria in Section 8.4 apply at Wharton.

8.4. When combined storage is less than 900,000 ac-ft, releases of storable inflows are made to satisfy Subsistence instream flow criteria at the Wharton river gauge while releases of stored water are made to meet the greater of 107 cfs or 50 percent of the applicable Wharton river gauge Subsistence instream flow citieria.

8.5. Only releases of storable inflows to lakes Buchanan and Travis, to the extent they are available, are made to help satisfy the Base Dry and Base Average instream flow criteria.

8.6. In determining the quantity of lakes Buchanan and Travis water required to be released or passed to offset a river flow deficit with regard to a particular instream flow criterion, only the currently available reliable river flows as defined in Section 2, plus any releases from lakes Buchanan and Travis for downstream users, environmental flows and delivery inefficiencies as defined in Sections 7.7 and 7.8 passing the subject environmental flow location, are considered.

8.7. The WAM is based on a monthly time step. Intra-daily or instantaneous flows were not simulated.

9. ENVIRONMENTAL BAY & ESTUARY FRESHWATER INFLOW CRITERIA

9.1. The requirements for passing Colorado River flows to Matagorda Bay are based on the recommendations of the Matagorda Bay Health Evaluation (MBHE) study[6], and have been operationalized for use in the WMP revision. The environmental requirements in the WMP WAM are based on two-month volumes of inflows with subsequent adjustments if the three-month seasonal bay inflow recommendations of the MBHE study have already been satisfied.

9.2. The two-month bay inflow needs as included in the WMP WAM vary by season according to the amount of combined storage in lakes Buchanan and Travis as of March 1 for the spring season (March-June), July 1 for the fall season (July-October), and Nov. 1 for the intervening period (November-February). For example for March, for the MBHE Operational Inflow Level 1 criteria of 76,000 ac-ft to be satisfied, the total inflows for the months of February and March must equal or exceed 76,000 ac-ft. This two-month target is repeated in the months of April, May and June, such that for the criteria to be satisfied, the total of the current month and preceding month must equal or exceed 76,000 ac-ft. The different two-month bay inflow needs are listed in the following table by season or period.

[6] Lower Colorado River Authority and San Antonio Water System (2008); Final Report, Matagorda Bay Inflow Criteria (Colorado River), Matagorda Bay Health Evaluation; Austin, Texas.

MBHE Operational Inflow Level	Two-Month Bay Inflow Need (ac-ft) Spring Season March-June	Fall Season July-October	Associated Buchanan-Travis Combined Storage (million ac-ft)
Level-1	76,000	54,000	1.00 - 1.30
Level-2	112,000	80,000	1.30 - 1.50
Level-3	164,000	117,000	1.50 - 1.95
Level-4	289,000	205,000	1.95 – Full

MBHE Operational Inflow Level	Two-Month Bay Inflow Need (ac-ft) Intervening Period November-February	Associated Buchanan-Travis Combined Storage (million ac-ft)
Level-1	35,000	1.00 - 1.30
Level-2	52,000	1.30 - 1.50
Level-3	76,000	1.50 - 1.85
Level-4	133,000	1.85 – Full

9.3. For engaging the operational criteria, the March 1 combined storage in lakes Buchanan and Travis is used to establish the two-month bay inflow needs at the end of the subsequent months of March, April, May and June. Similarly, the July 1 combined storage in lakes Buchanan and Travis is used to establish the two-month bay inflow needs at the end of the subsequent months of July through October, and the Nov. 1 combined storage in lakes Buchanan and Travis is used to establish the two-month bay inflow needs at the end of the subsequent months of November through February. At the end of each of these months during the WAM simulations, the volume of additional bay inflow beyond the available river inflow that is required to fully satisfy the two-month bay inflow need is released from the available storable inflows to lakes Buchanan and Travis. An exception to this procedure is noted in Section 9.4.

9.4. For May and June during the spring season and September and October during the fall season, an additional check is made to determine if the three-month cumulative inflow to the bay has satisfied the corresponding MBHE three-month bay inflow need. If it has, then the effective two-month bay inflow need for the particular month is set equal to the two-month intervening bay inflow need for the corresponding MBHE Operational Inflow Level. The relevant MBHE three-month bay inflow needs, after rounding, corresponding to the four different MBHE inflow levels (and their associated Buchanan-Travis combined storage) for the three-month periods ending in May and June and September and October are listed in the following table. It should be noted this check against the MBHE bay inflow needs in the WMP WAM is made for only the complete three-month consecutive periods that fall within the MBHE Operational seasons as defined above.

MBHE Inflow ID	MBHE 3-Month Bay Inflow Need (ac-ft) Spring Season	Fall Season
MBHE-1	114,000	81,000
MBHE-2	169,000	120,000
MBHE-3	246,000	175,000
MBHE-4	433,000	308,000

9.5. On a monthly basis, only releases of storable inflows to lakes Buchanan and Travis, to the extent they are available, are made to help satisfy bay inflow needs. Previously stored water is not released to meet bay inflow targets, with the exception of the Threshold need, which may call for the release of a limited amount of storable inflows from the preceding month as described in Section 9.8.

9.6. In the WMP WAM, after the amount of water needed for bay inflow criteria is calculated, limitations on the amount of storable inflow provided are engaged based on the provisions described below:

9.6.1. If combined storage on the evaluation date is less than 1.3 million ac-ft and interruptible stored water for agricultural operations in Gulf Coast, Lakeside and Pierce Ranch is cut off for the season, Threshold is the only freshwater inflow criteria in effect until the next evaluation date. (For the November to February period, if interruptible stored water for agricultural operations in Gulf Coast, Lakeside and Pierce Ranch was cutoff for the second season then Threshold is the only freshwater inflow criteria in effect.)

9.6.2. Anytime combined storage falls below 1 million ac-ft, the only bay criteria in effect is Threshold for that month.

9.6.3. The maximum release of storable inflows in the current month to meet freshwater inflow criteria based on combined storage at the end of the previous month is limited to the following amounts:

Combined storage	Maximum release of storable inflow to meet bay criteria
Less than 1.3 million ac-ft	25,000 ac-ft
1.3 to 1.5 million ac-ft	56,000 ac-ft
Greater than 1.5 million ac-ft	82,000 ac-ft

9.6.4. Releases of storable inflows to meet bay criteria that exceed 15,000 ac-ft in a month are limited to the following percentages of storable inflows after the release of water for instream flow needs and the release of 15,000 ac-ft for bay needs:

Combined storage	Release will be no more than listed percentage of storable inflow for the month
Less than 1.5 million ac-ft	50 %
1.5 million ac-ft or greater	60 %

9.7. Under the operational methodology, a minimum Threshold bay inflow criteria of 15,000 ac-ft per month also is in effect every month, including those months when the combined storage in lakes Buchanan and Travis is less than the minimum storage for Level 1. To the extent available river inflows entering the river below Longhorn Dam are not adequate to meet this requirement, storable inflows to lakes Buchanan and Travis are passed through the reservoirs downstream to the bay to help satisfy the Threshold requirement, regardless of the combined storage of lakes Buchanan and Travis or the season of the year. In most cases, previously stored water is not released to meet Threshold freshwater inflow targets. An exception to this provision is provided below.

9.8. If combined storage at the beginning of a month is greater than 1 million ac-ft, and all of the prior month's storable inflows were not released, up to 5,000 ac-ft of the prior month's remaining storable inflows is carried forward and made available for release to the extent needed to help meet the Threshold bay inflow criteria.

9.9. In determining the quantity of storable inflows to lakes Buchanan and Travis required to be released to offset a bay inflow deficit with regard to a particular bay inflow need, the total inflow to Matagorda Bay is considered (and not solely the reliable flows discussed in Section 2).

9.10. Arbuckle Reservoir is used to help meet Bay demands that would otherwise be met from storable inflows from lakes Buchanan and Travis. Arbuckle Reservoir operations are described in section 11.

10. UPSTREAM DIVERSIONS UNDER GARWOOD WATER RIGHT (Certificate 14-5434E)

10.1. LCRA firm demands (non-City of Austin demands) at FPP and Lake Austin are supplied using 14-5434E as a run-of-river supply, before providing stored water from lakes Buchanan and Travis.

10.2. Diversions under 14-5434E are subject to the environmental instream flow criteria specified in the water right.

10.3. Firm diversions under 14-5434E are limited to 33,000 ac-ft per year and are limited in the model to not exceed about 9,000 ac-ft per month (i.e., the monthly equivalent of 150 cfs diversion rate).

11. ARBUCKLE RESERVOIR OPERATIONS

11.1. Arbuckle Reservoir serves any demand that would otherwise be served from lakes Buchanan and Travis at any of the authorized Gulf Coast diversion points (Gulf Coast Irrigation Division, Gulf Coast area industrial, South Texas Project and water provided to supplement freshwater inflows to Matagorda Bay).

11.2. The model seeks to meet demands first using available run-of-river flows originating downstream of Mansfield Dam, then with water stored in Arbuckle Reservoir, then with run-of-river flows originating upstream of Mansfield Dam, and finally with stored water from lakes Buchanan and Travis.

11.3. In the WMP WAM, Arbuckle Reservoir is used to help meet the Bay Threshold criteria, even if there is no obligation based on storable inflows into lakes Buchanan

and Travis. Up to 50 percent of the water in Arbuckle Reservoir, in excess of 20,000 ac-ft of conservation storage in the reservoir, is released to help meet the monthly Bay Threshold criteria.

11.4. Arbuckle Reservoir is filled from run-of-river flows not needed for other demands and ordered-but-not-diverted releases from lakes Buchanan and Travis. Available run-of-river flows are diverted under the Gulf Coast water right at its priority date.

11.4.1. Arbuckle Reservoir is not filled from any source unless at least 15,000 ac-ft has flowed into the bay in the current month.

11.4.2. Arbuckle Reservoir does not call on run-of-river flows originating above Lake Travis.

11.4.3. Interruptible stored water from lakes Buchanan and Travis that is ordered but not diverted by the irrigation operations becomes available for diversion to Arbuckle Reservoir, subject to a simulated 15,000 ac-ft bypass to help meet the bay Threshold criteria

12. SOUTH TEXAS PROJECT

12.1. The consumptive demand for South Texas Project is met from the main cooling reservoir (MCR). The MCR is refilled from Certificate of Adjudication 14-5437 and backup water from LCRA.

12.2. The current Water Delivery Plan (WDP) for providing backup water to the South Texas Project, which was adopted as part of the 2006 Settlement Agreement between LCRA and STP Nuclear Operating Company (STPNOC) (Jan. 1, 2006), is implemented in the WMP WAM. As structured, this WDP stipulates LCRA shall initiate staged deliveries of water to STPNOC from LCRA's available sources upstream of the Bay City Dam when the water surface elevation of STPNOC's MCR falls below 35 feet msl. Under the WDP, deliveries are continued to be made to assist with maintaining the level of the MCR above a minimum elevation of 27 feet msl.

12.3. The WDP does not specifically state how the water deliveries are to be staged with regard to either timing or the quantities to be delivered; it only requires they commence when the level of the MCR falls below elevation 35 feet msl. For modeling purposes, the operating procedures for delivery of water is assumed to be consistent with the previous water delivery plan.

12.4. In the WMP WAM, the total supply for STPNOC from run-of-river diversions is limited to the 102,000 ac-ft/year stipulated in Certificate of Adjudication 14-5437, as amended, and the backup supply from lakes Buchanan and Travis is limited to a rolling five-year average of 20,000 ac-ft/year (Supply under Certificate of Adjudication 14-5437 is not limited to the reliable flows discussed in Section 2).

12.5. The WMP WAM assumes STPNOC will divert under Certificate of Adjudication 14-5437 whenever the streamflow exceeds the parameters in the certificate without regard to any operational preferences related to salinity or conductivity.

13. MISCELLANEOUS

13.1. Diversions from the Colorado River authorized under the City of Corpus Christi's Garwood water right are set to the full authorized diversion amount of 35,000 ac-ft/year. A uniform monthly demand pattern is assumed for these.

TECHNICAL PAPER A-7
PROPOSED METHODOLOGY FOR IDENTIFYING A DROUGHT POTENTIALLY WORSE THAN THE DROUGHT OF RECORD
February 2019

1.0 BACKGROUND

The LCRA Water Management Plan, as approved by the Texas Commission on Environmental Quality (TCEQ), provides for special curtailment policies and procedures during drought conditions potentially worse than the drought of record.[1] The "Drought of Record[2]" is a criterion used by the State of Texas for the permitting and planning of firm surface water supplies. However, droughts worse than this may occur in the future. Recognizing this possibility, the method outlined in this technical paper is meant to establish when a drought worse than the Drought of Record may be underway. This will allow additional water supply management strategies to be implemented in a timely manner.

Droughts can be characterized in many ways. For purposes of this document a hydrologic drought (a drought that affects water supplies) is implied throughout. A drought can vary in terms of both duration and intensity. Severe droughts may be more intense but have shorter durations or have longer durations and less intensity. This technical paper presents a methodology to identify droughts potentially worse than the recent new Drought of Record in terms of the combined impacts of duration and intensity, to allow LCRA to take prudent management actions in a timely manner.

An important element of developing a comprehensive methodology is to be able to identify a drought potentially worse than the Drought of Record while the drought is still in progress. This allows appropriate and timely measures to be implemented to help mitigate potential shortages during such an event. Timely action under a drought potentially worse than the Drought of Record can lessen the need for more restrictive demand reductions and the resulting consequences of more severe water supply shortages. In general, the earlier demand reduction measures can be taken in a drought, the less likely it becomes that more restrictive measures will be needed later in the drought cycle. It can only be known for sure that a drought is worse than the Drought of Record either after the drought is over or after inflow conditions have been so low for so long that the combined firm yield could not have been sustained. It could then be too late to take demand reduction measures to avert a severe shortage and the potential to run out of water. Similarly, declaring a drought worse than the Drought of Record too early can lead to false alarms. False alarms can be costly to customers and stakeholders while eroding the effectiveness of declarations. The method outlined below has been developed to strike a balance between early detection and minimizing false alarms.

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[1] TEX. WATER COMM'N., *Order Approving Lower Colorado River Authority's Drought Management Plan*, Ordering Provision 1.f. (Dec. 23, 1991).

[2] Drought of record--The historic period of record for a watershed in which the lowest flows were known to have occurred based on naturalized streamflow. 30 TAC §297.1(19).

Precautionary actions taken earlier in a drought provide for greater water supply security than the Drought of Record criteria alone. Procedures have been developed for identifying a drought potentially worse than the Drought of Record for the water supply reservoirs in the Highland Lakes (lakes Buchanan and Travis). These procedures should continue to be updated as additional data and methods become available. This document sets forth the current understanding of best management practices for anticipating drought conditions potentially worse than the Drought of Record and the technical basis for declaring a drought potentially worse than Drought of Record.

2.0 CRITERIA FOR DECLARATION OF A DROUGHT WORSE THAN DROUGHT OF RECORD

The proposed criteria should include all of the following:

- Drought duration of more than 24 months since the start of the drought.
- Drought intensity greater than that of the Drought of Record as measured by inflows into the Highland Lakes.
- Combined storage of lakes Buchanan and Travis of 600,000 acre-feet or less.

Alternately, if a drought in progress has exceeded 84 months in duration, and the content criteria also is met, a declaration of a Drought Worse than Drought of Record should be made regardless of the status of the intensity criteria.

2.1 Duration Criterion

To meet the duration criteria, the duration of the drought must be at least 24 months since lakes Buchanan and Travis were both full. A hydrologic drought could be in progress at any time that combined conservation storage of lakes Buchanan and Travis is less than full. For the purposes of this method, full is defined as when either of the following criteria is met:

a) Combined storage in lakes Buchanan and Travis is at or above 98 percent of the combined managed conservation storage. The managed combined content is no more than about 2,011,000 acre-feet but may be lower depending upon operational guidelines which may change seasonally or for special purposes. When Lake Buchanan is limited to not exceeding elevation 1,018 feet msl, the managed combined conservation storage is about 1,967,000 acre-feet.
b) Lakes Travis and Buchanan have each been at their respective managed conservation storage maximum capacity within 30 days of each other.

2.2 Inflow Criterion

The LCRA inflow data set is compared to an inflow criterion curve. The LCRA inflow data is computed from measurements at principle U.S. Geological Survey (USGS) and LCRA jointly monitored gauges above lakes Buchanan and Travis on the Colorado River, Llano River, Pedernales River and Sandy Creek according to LCRA methods.[3] Measurements may be preliminary, provisional or published and are subject to

[3] LCRA River Operations Center, Procedures Manual, Monthly Highland Lakes Water Balance, Section 0510.

revision until published. Measurements reflect upstream diversions made by upstream water right holders.

An inflow criterion curve has been developed and tested against the period of record to verify it can adequately identify intense droughts. The curve has been increased by 5 percent over the historical values to account for inflow measurement uncertainty. The curve can be expressed by the following equation:

$$I1 = (22{,}292 * m + 787{,}402) * 1.05$$

Where:
I1 = cumulative inflow in acre-feet since Travis and Buchanan were each full using the determination of full described above and a 5 percent increase for gauge uncertainty.
m = months since lakes Travis and Buchanan were each full using the determination described above.

If the cumulative inflow since the start of a drought in progress is more than the criterion curve value for the same duration of drought, the intensity criterion is not met. Conversely, if the cumulative inflow is below the criterion curve, then criterion is met and the drought is considered more intense than the Drought of Record. The curve is shown in Figure 1 and the values are provided in Table 1.

Figure 1 - Drought Intensity

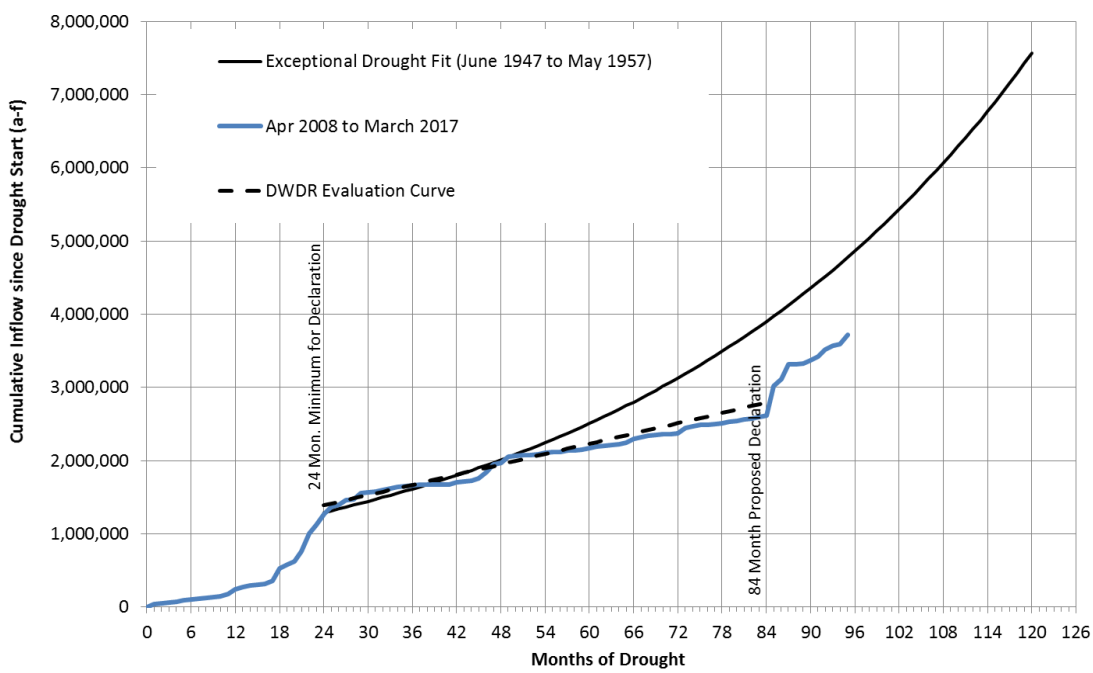

Table 1. Table of Evaluation Curve Values

months	Cumulative Inflow (acre-feet)	months	Cumulative Inflow (acre-feet)	months	Cumulative Inflow (acre-feet)
1	850,179	29	1,505,564	57	2,160,948
2	873,585	30	1,528,970	58	2,184,355
3	896,992	31	1,552,377	59	2,207,762
4	920,399	32	1,575,783	60	2,231,168
5	943,805	33	1,599,190	61	2,254,575
6	967,212	34	1,622,597	62	2,277,981
7	990,618	35	1,646,003	63	2,301,388
8	1,014,025	36	1,669,410	64	2,324,795
9	1,037,432	37	1,692,816	65	2,348,201
10	1,060,838	38	1,716,223	66	2,371,608
11	1,084,245	39	1,739,630	67	2,395,014
12	1,107,651	40	1,763,036	68	2,418,421
13	1,131,058	41	1,786,443	69	2,441,828
14	1,154,465	42	1,809,849	70	2,465,234
15	1,177,871	43	1,833,256	71	2,488,641
16	1,201,278	44	1,856,663	72	2,512,047
17	1,224,684	45	1,880,069	73	2,535,454
18	1,248,091	46	1,903,476	74	2,558,861
19	1,271,498	47	1,926,882	75	2,582,267
20	1,294,904	48	1,950,289	76	2,605,674
21	1,318,311	49	1,973,696	77	2,629,080
22	1,341,717	50	1,997,102	78	2,652,487
23	1,365,124	51	2,020,509	79	2,675,894
24	1,388,531	52	2,043,915	80	2,699,300
25	1,411,937	53	2,067,322	81	2,722,707
26	1,435,344	54	2,090,729	82	2,746,113
27	1,458,750	55	2,114,135	83	2,769,520
28	1,482,157	56	2,137,542	84	2,792,927

2.3 Content Criterion

The content criterion for a drought potentially worse than the Drought of Record is that the combined storage of lakes Buchanan and Travis is less than 600,000 acre-feet. This level of combined storage has never been previously observed[4] and provides a practical restriction to reduce false alarms.

[4] The lowest recorded combined storage of 621,221 acre-feet was observed in Sept. 9, 1952.

3.0 DECLARATION AND CANCELLATION

For a declaration of drought potentially worse than the Drought of Record, all three of the intensity, duration and content criteria should be simultaneously satisfied. Alternately, if a drought in progress has exceeded seven years in duration, and combined storage is below the 600,000 acre-feet criterion, a declaration of a drought potentially worse than the Drought of Record also should be made regardless of the status of the intensity criterion.

Criterion for the cancellation of a declaration of drought potentially worse than Drought of Record may be based upon an increase in combined storage to a level of 1.4 million acre-feet.

4.0 ANALYSIS OF HISTORICAL DROUGHTS

Other droughts during the period of gauged record have been shorter in duration than the Drought of Record. Inflows for these shorter duration droughts were analyzed according to this procedure. Cumulative inflows of the selected historical droughts of shorter duration are shown in Figure 2. This figure shows that, for some of these droughts of shorter duration, cumulative inflows early in the drought cycle satisfied the intensity criterion but the duration of these droughts was shorter or they did not achieve the lake content criterion necessary for declaration of a drought potentially worse than Drought of Record.

In summary, none of these other historical droughts would have triggered a declaration of a drought potentially worse than Drought of Record based on this procedure and current criteria. A summary of the droughts and respective criteria are shown in Table 2.

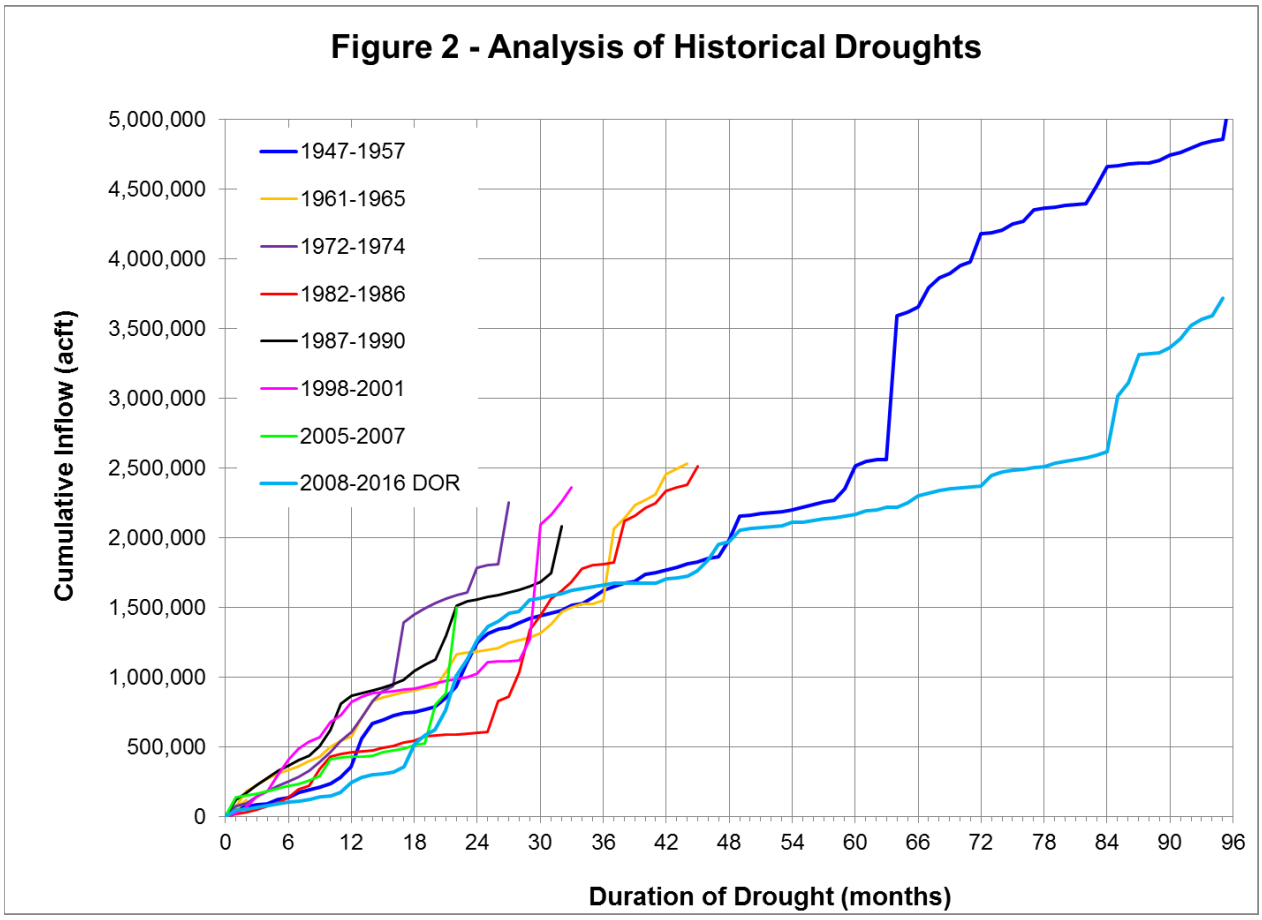

Table 2. Summary of Selected Historical Droughts Compared to Drought Potentially Worse Than Drought of Record Declaration Criteria

Years of Drought	Simultaneous Criteria			Eligible for Declaration
	Inflows < DOR	Duration ≥ 24 months	Storage < 600,000 ac-ft	
1945-1954	No	Yes	No	No
1961-1965	Yes	Yes	No	No
1971-1974	No	No	No	No
1982-1986	Yes	Yes	No	No
1987-1990	No	No	No	No
1998-2001	Yes	Yes	No	No
2005-2007	No	No	No	No
2008-2016	Yes	Yes	No	No