DRAFT

NATURALIZED STREAMFLOW UPDATES AND MODELING REPORT COLORADO RIVER BASIN

Water Availability Division
Texas Commission on Environmental Quality
May 16, 2014

1.0 Executive Summary

The Lower Colorado River Authority (LCRA) filed an application on March 12, 2012 to amend its 2010 Water Management Plan (WMP). In response to comments TCEQ received on the application, and in consideration of continuing severe drought conditions in the Colorado River Basin, TCEQ determined that further evaluation of the WMP was needed in order to take into account recent streamflow conditions. TCEQ performed an intensive and detailed modification of the 1940-1998 naturalized streamflows and updated these streamflows to extend the period of record from 1940-2013.

TCEQ used the extended naturalized streamflows (1940-2013) to model LCRA's proposed interim curtailment curves for interruptible agricultural releases, and to review LCRA's proposal to change the combined firm yield. Based on the updated models, the curtailment curves in the 2012 WMP application would not be sufficient to protect firm customers during extraordinary drought conditions such as those experienced in the 1950s or the current drought, or less severe droughts. TCEQ's modeling demonstrates that the WMP should include a more robust and comprehensive drought management regime that accounts for extraordinary drought conditions and less severe droughts. This drought management regime would likely need to include more stringent curtailment curves with a higher limit on when interruptible water releases would be completely curtailed during drought conditions.

For extraordinary drought conditions, TCEQ looked at a curtailment curve of 1.4 million acre-feet (MAF). At this storage level, the combined storage before which LCRA could supply interruptible water for the Gulf Coast, Lakeside, and Pierce Ranch Districts would be more than twice the storage level of 650,000 that LCRA proposed in its 2012 WMP application. The modeling indicates that if this higher trigger level had been utilized in the extraordinary drought of 2011, there could have been at least a 50% reduction in the amount of interruptible water released or passed through the Highland Lakes for these Districts. TCEQ also proposes criteria that could be used to identify when to initiate extraordinary drought curtailment; reservoir storage, inflows, a criterion that looks at projected combined storage for the next year on a rolling one year basis based on LCRA's four proposed decision dates for interruptible stored water supply, and a determination as to whether combined storage in the Highland Lakes would drop below the value for complete interruptible cutoff during the irrigation season.

TCEQ's review indicates that during periods where storage is between 1.1 and 1.4 MAF but inflows are very low, an additional curtailment curve would be appropriate to account for potentially developing drought conditions that are less severe than extraordinary drought. Additional reductions in interruptible water use during less severe drought conditions would provide an additional margin of safety for firm water customers should drought conditions worsen. For normal conditions, TCEQ looked at a curtailment range from 950,000 acre-feet (AF) to 1.1 MAF. Specifically, TCEQ looked at a curtailment curve which would not allow the lakes to drop below 600,000 AF under normal conditions. Table 1.1 shows a comparison of the curtailment curves for extraordinary drought conditions, less severe drought, and a range of normal conditions, to the curves in LCRA's previous plan and application. Figures 1.1 -1.3 compare TCEQ's proposed curtailment levels for extraordinary drought and normal conditions to those in LCRA's 2012 WMP application. Figure 1.4 provides the detailed curtailment curves for extraordinary drought, less severe drought, and normal conditions.

Table 1.1 Comparison of Trigger Levels for Different Management Regimes

	TCEQ's Proposal			LCRA	
	Extraordinary Drought	Less Severe Drought	Normal Conditions	2012 WMP application	2010 WMP
Lowest level to provide interruptible stored water	1.4 MAF	1.1 MAF to 1.4 AF	950,000 AF to 1.1 MAF	650,000 AF	325,000 AF
Complete curtailment of interruptible stored water releases	1.1 MAF	950,000 AF	900,000 to 950,000 AF	600,000 AF	200,000 AF

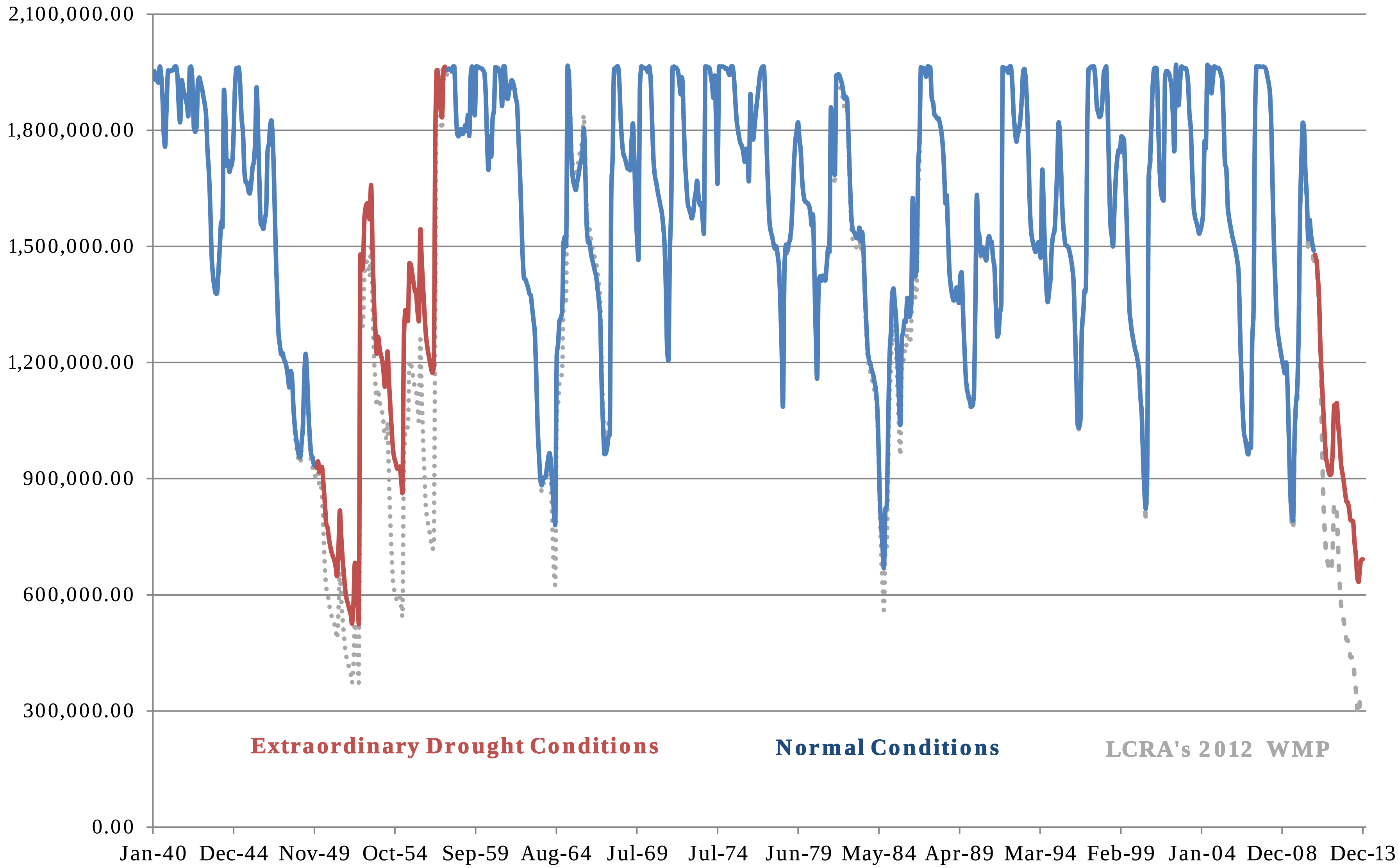

Figure 1.1 Comparison of Combined Storage in the Highland Lakes Using Trigger Levels of 950,000 AF under Normal Conditions and 1.4 MAF under Extraordinary Drought Conditions vs. Combined Storage under LCRA's 2012 WMP Application for the Period 1940-2013

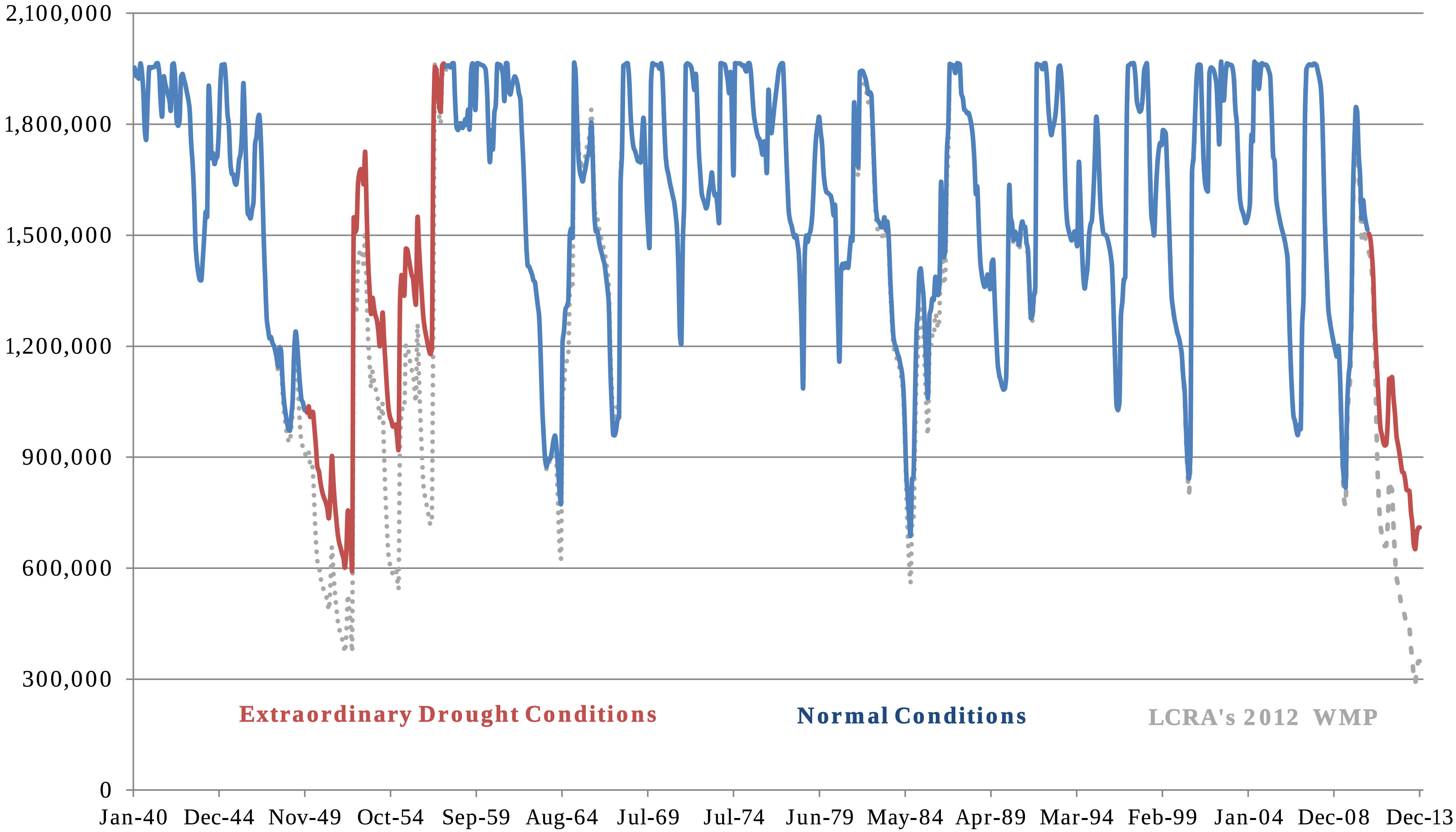

Figure 1.2 Comparison of Combined Storage in the Highland Lakes Using Trigger Levels of 1.0 MAF Under Normal Conditions and 1.4 MAF Under Extraordinary Drought Conditions vs. Combined Storage Under LCRA's 2012 WMP Application for the Period from 1940-2013

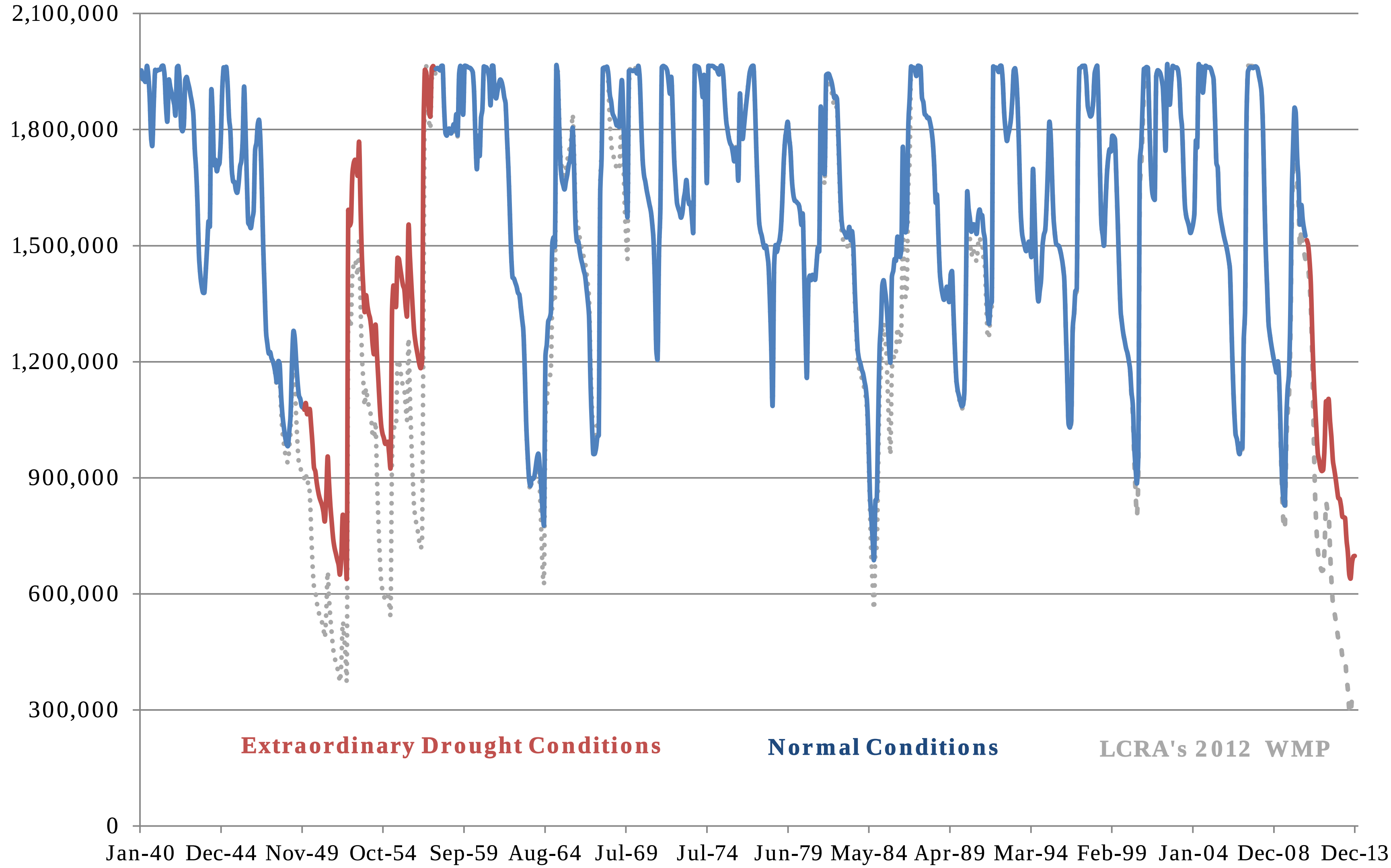

Figure 1.3 Comparison of Combined Storage in the Highland Lakes Using Trigger Levels of 1.1 MAF Under Normal Conditions and 1.4 MAF Under Extraordinary Drought Conditions vs. Combined Storage Under LCRA's 2012 WMP Application for the Period from 1940-2013

Extraordinary Drought

Combined Storage Levels (acre-feet)	Amount of Water Supplied (acre-feet)
Below 1.4 MAF	**No stored water**
1.4 MAF – 1.499 MAF	100,000
1.5 MAF – 1.599 MAF	124,000
1.6 MAF – 1.699 MAF	148,000
Above 1.7 MAF	172,000
Above 1.4 MAF	50,000 for second crop

Complete Curtailment at 1.1 MAF

Criteria for Extraordinary Drought:

1. More than 24 months since the Highland Lakes were completely full; and Drought Intensity greater than or equal to the 1950s drought as measured by inflows to the Highland Lakes; or
2. LCRA's modeling indicates that the combined storage would drop below 600,000 AF in the next twelve months or below between 900,000 and 950,000 AF during the irrigation season.

   Extraordinary Drought curtailment ends when the lakes reach 1.7 MAF and the Drought Intensity Criteria is no longer met.

Less Severe Drought

First Crop

Combined Storage Levels (acre-feet)	Amount of Water Supplied (acre-feet)
Below 1.1 MAF	**No stored water**
1.1 MAF – 1.199 MAF	100,000
1.2 MAF – 1.299 MAF	115,000
1.3 MAF – 1.399 MAF	130,000

Second Crop	
Below 1.1 MAF	**No stored water**
Between 1.1 and 1.4 MAF	46,000

Complete Curtailment at 950,000 AF

Criteria for Less Severe Drought:

The combined storage in the Highland Lakes is below 1.4 MAF; and
Cumulative inflows to the Highland Lakes for the previous three month period are below the 33rd percentile for the period of record for the three month period.

Less Severe Drought curtailment ends when the lakes reach 1.4 MAF.

Range of Normal Conditions

First Crop

Amount of Water Supplied (acre-feet)	At 950,000 AF	At 1.0 MAF	At 1.1 MAF
	Combined Storage Level (AF)		
0	Below 950,000 AF	Below 1.0 MAF	Below 1.1 MAF
121,500	950,000 – 1.0 MAF	N/A	N/A
121,500 – 156,500	1.0 to 1.4 MAF	1.0 to 1.4 MAF	1.1 to 1.4 MAF
202,000	Above 1.4 MAF	Above 1.4 MAF	Above 1.4 MAF
Complete Curtailment	**900,000 AF**	**950,000 AF**	**950,000AF**

Second Crop

Amount of Water Supplied (acre-feet)	At 950,000 AF	At 1.0 MAF	At 1.1 MAF
	Combined Storage Level (AF)		
0	Below 1.0 MAF	Below 1.1 MAF	Below 1.15 MAF
46,000-59,500	1.0 to 1.55 MAF	1.1 to 1.55 MAF	1.15 to 1.55 MAF
76,500	Above 1.55 MAF	Above 1.55 MAF	Above 1.55 MAF
Complete Curtailment	**900,000 AF**	**950,000 AF**	**950,000 AF**

Figure 1.4 Summaries of a Curtailment Curves for Extraordinary and Less Severe Drought Conditions and Normal Conditions

TABLE OF CONTENTS

PAGE

LIST OF TABLES

PAGE

LIST OF FIGURES

PAGE

2.0 INTRODUCTION

2.1 Background

The TCEQ uses its surface water availability models (WAMs) to process applications for new appropriations of water and amendments to existing water rights. The WAM for the Colorado River Basin included naturalized streamflows for the entire basin for the period 1940 to 1998.[1] LCRA filed an application on March 12, 2012 to amend its 2010 WMP. In support of its application, LCRA submitted partial updates to the naturalized streamflows; however, these updates did not include all gages in the basin and did not address all issues with the naturalized streamflow dataset.

In response to comments TCEQ received on the application, and in consideration of continuing severe drought conditions in the Colorado River Basin, TCEQ determined that further evaluation of the WMP was needed in order to take into account recent streamflow conditions. This report describes the methodologies TCEQ Water Availability Division staff used to modify and update the naturalized streamflows from 1940-2013, identifies any modifications to the existing streamflow dataset, and presents water availability modeling results based on the new streamflows.

2.2 Public Input

TCEQ held a meeting on June 26, 2013 to obtain public input, specifically related to data on diversions, water use, and lake operations. At least seventy people attended the meeting, twenty-two people offered oral comments and thirty-four individuals or organizations provided additional information. TCEQ staff carefully considered all of this information as it modified and updated the naturalized streamflows and performed its modeling. As a result of staff's analysis of the information received at the meeting, staff determined that the naturalized flows should be extended through December of 2013. In support of this effort, staff contacted water right holders in the basin and requested that water use reports for 2013 be submitted by January 10, 2014 instead of the typical March 2014 deadline in order to extend the naturalized flows through 2013.

Issues addressed by the public for staff's consideration in its evaluation of the WMP application include:

- the need to incorporate lake recovery after droughts;
- more protection for firm customers, combined storage should not be allowed to drop below 600,000 AF in the WMP models;
- use of appropriate methods to extend the naturalized flow datasets;
- channel loss values in the WAMs;
- appropriate curtailment curves for interruptible agriculture;
- better explanation of the combined firm yield and recalculation of the combined firm yield based on the current drought; and
- the need for specific requirements in the WMP to address extreme drought conditions.

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[1] Water Availability Modeling for the Colorado/Brazos-Colorado Basin. Prepared by R. J. Brandes Company and others for the Texas Natural Resource Conservation Commission. December 2001.

Central Texas Water Coalition, Colorado Water Issues Committee and its members, and the City of Austin provided detailed comments. LCRA and its consultants, Dr. Robert Brandes and Kirk Kennedy provided naturalized streamflows through 2012, additional information on downstream diversions by LCRA's customers, end-of-month content for LCRA's reservoirs for 2013, supporting information used in the creation of the 1940-1998 naturalized streamflow dataset, and updated models supporting the interim and 2020 curtailment curves included in LCRA's 2012 application to amend its WMP.

2.3 General Streamflow Naturalization Process

Naturalized streamflow represents the flow in a river that would have occurred without human impacts, such as reservoir construction, diversions, and return flows. For most Texas river systems, the naturalized flow encompasses at least a fifty-year period of record that includes the drought of the 1950s, recognized as an extremely severe drought throughout much of the state. The period of record also includes major floods and less severe droughts, thereby representing an approximation of historic hydrologic variability.

Naturalized stream flows are calculated by first identifying all U.S. Geological Survey (USGS) gages in a river basin and then selecting a subset of those gages that meet the requirements for having a sufficient period of record and having no known major issues with the gage flow data. Development of the naturalized flows consists of two parts: adjusting the gaged flows to approximate predevelopment conditions and filling in or extending the period of record for a gaging station. Gaged flows are adjusted using the following equation:

$$NF = GF + \sum D - \sum RF + \sum E + \sum \Delta S$$

where NF is the naturalized flow, GF is the gaged flow, D is all diversions upstream of the gage, RF is all return flows upstream of the gage, E is the net reservoir evaporation for all reservoirs upstream of the gage, and ΔS is the change in content for all reservoirs upstream of the gage.[2]

A Geographical Information System (GIS) is used to identify water right diversion locations, reservoirs, and return flow locations. These locations are then grouped within an incremental watershed. An incremental watershed is the area between a downstream gage and the upstream gages that contribute flow to that gage. For gages at the top of watersheds, the incremental area is simply the watershed area that contributes runoff to that gage. The naturalized flow adjustments are performed for incremental watersheds. The incremental flow, or the difference between the flows at the downstream gage and the upstream gage, is added to the flow at the upstream gage, and the simulation uses this total flow to determine water availability for water rights.

Channel losses and springflows are also accounted for in the streamflow naturalization process for the Colorado River Basin. Channel losses represent the amount of water available at an upstream point that may not reach the downstream point due to seepage, evapotranspiration, infiltration, or unaccounted-for diversions. The naturalized flow should already include natural losses. However, because a portion of the water diverted at an upstream point would not reach the downstream point, channel loss adjustments are included in the flow naturalization process. The effects of groundwater pumpage and variable spring flows are calculated and removed from the gaged flows so that the gaged flows represent only watershed runoff. Adjustments are performed and the springflows are added back to the naturalized flow during the simulation.

[2] TNRCC, Draft Technical Paper #1, Evaluation of Naturalized Streamflow Methodologies (1997)

Adjustments to the gaged flows may result in negative incremental flow values. These could result from measurement errors and uncertainty or from issues related to the amount of time it takes for water to travel between stream gages or from diversion points, return flow points or reservoirs to a downstream gage. The naturalized streamflow datasets are adjusted to remove these negative values in order to preserve the total flow quantity during time periods where negative incremental flow occurs.

3.0 DATA COLLECTION AND ANALYSIS

This section provides specific information about TCEQ's intensive and detailed process to modify the existing naturalized streamflows from 1940-1998 and extend those streamflows through 2013. The specific data staff used to develop the extended naturalized streamflows for the period 1999-2013 for the entire Colorado Basin include:

- USGS Gage information
- Springflow information
- Reservoir Storage information
- Evaporation information
- Diversions and water use

Staff used LCRA's 2012 naturalized streamflow dataset as the starting point. However, this dataset did not include all gages in the Colorado River Basin. Naturalized streamflows at upstream locations affect naturalized streamflows at downstream locations because the adjusted naturalized streamflows between upstream gage(s) and a downstream gage are added to the total naturalized streamflows from the upstream gage(s) to produce the total naturalized streamflows at the downstream gage. This process is repeated from the most upstream gage in the basin to the most downstream. Therefore, all gages should be included in a river basin to ensure accuracy of the resulting naturalized streamflow dataset. Staff extended the naturalized streamflow dataset for all basin gages by adding the 1999-2013 period to all upstream gages in the dataset that LCRA did not include in its 2012 naturalized streamflow dataset. In addition LCRA's dataset included simplifying assumptions regarding water use and diversions in the upper basin at gages it did include. TCEQ corrected the diversion data at upstream gages to include actual water use for all years in the extension period from 1999-2013.

As part of its review of existing naturalized streamflow workbooks and LCRA's submittal, staff identified and corrected errors in both the early and later periods. Generally, staff followed the methods used to create the 1940-1998 dataset; however staff modified the earlier dataset where appropriate. Staff removed adjustments for routing loss computations from each workbook. These were calculated in a single workbook using the sum of the historical adjustments for each upstream gage and then routing the adjustment to the downstream gage using the loss factors for each upstream gage. Changes to the naturalized flows in the 1940-1998 period, and any changes made to the calculations for the 1999-2013 period, are discussed in more detail in this section. Appendix A includes graphical comparisons of the extended naturalized streamflow dataset to the previous dataset, for the most downstream gage in each subwatershed.

3.1 USGS Gage Information.

For gages with missing records, relationships with nearby gages are used to complete the streamflow dataset. Staff reviewed gage flow information for the streamflow gages that are used in TCEQ's Colorado River Basin WAM and evaluated the existing streamflow relationships to determine whether these relationships should be modified. The USGS discontinued the following gages; however, information on streamflows at these locations is still available through LCRA's Hydromet system:

- USGS Gage 08144600, San Saba River near Brady - discontinued in October, 2012
- USGS Gage 08138000, Colorado River at Winchell - discontinued in February, 2012.

Additionally, some gages which were discontinued in the 1940-1998 period are now active:

- USGS Gage 08120500, Deep Creek near Dunn - reactivated August, 2001
- USGS Gage 08128000, South Concho River at Christoval, reactivated May, 2001
- USGS Gage 08128400, Middle Concho River above Tankersley - reactivated April, 2001
- USGS Gage 08148500, North Llano River near Junction - reactivated May, 2001

Staff determined that some of the existing relationships should be revised because of the availability of new streamflow information. Staff also modified some existing relationships based on review of the calculations and adjustments to the springflow dataset as discussed in Section 3.2. Staff modified the gage flow relationships for the following gages:

Table 3.1.1 Modifications to Gage Flow Relationships

USGS Gage	WAM Control Point	Time Period	Reason for Modification
08129300	C50000	1996-1998	Review of existing calculation
08130500	C40000	1996-1998	Review of existing calculation
08138000	D10000	1993-1997	New data for overlap period
08144500	E40000	1940-1998	Adjustment to springflow dataset and new data for overlap period
08144600	E30000	1940-1998	Adjustment to springflow dataset and new data for overlap period
08145000	E20000	1940-1998	Adjustment to springflow dataset and new data for overlap period
08146000	E10000	1940-1998	Adjustment to springflow dataset and new data for overlap period
08148500	G50000	1940-1998	Adjustment to springflow dataset
08150000	G40000	1940-1998	Adjustment to springflow dataset
08150700	G30000	1940-1998	Adjustment to springflow dataset
08150800	G20000	1940-1998	Adjustment to springflow dataset

USGS Gage	WAM Control Point	Time Period	Reason for Modification
08151500	G10000	1940-1998	Adjustment to springflow dataset
0815290	H20000	1940-1979 and 1993-1998	New data for the overlap period
08159000	J40000	1940-1960	New data for the overlap period
08159200	J30000	1940-1960	New data for the overlap period
08159500	J20000	1940-1960 and 1975-1997	New data for the overlap period
08162500	K10000	1940-1948 and 2013	Revised relationship

3.2 Springflow Information

Staff reviewed all of the springflow information and updated the naturalized streamflow workbooks and the WAM Flow Adjustment (.fad) records to reflect new information and to remove inconsistencies. More observed data was available for USGS gage 08143900, Springs at Fort McKavett (Main/Govt Springs). Based on the new data, staff modified the existing springflow dataset. Staff continued to use a data relationship with Dove Creek Springs to fill missing records where no observed data was available. Staff recalculated the relationship between the Springs at Fort McKavett and Dove Creek Springs by including the additional data and adjusting the 1940-1998 dataset based on the new relationship.

Staff removed two springs in the watershed above USGS gage 08146000, San Saba River at San Saba (E1000) because of a very poor relationship with Dove Springs. Staff also removed springs in the watershed above USGS gage 08147000, Colorado River near San Saba (F1000). The existing naturalized flow workbooks accounted for springs above USGS gage 08150000, Llano River near Junction (G4000). These springs are not located above the gage and were removed from the naturalized flow workbook for that gage. Staff also removed the springflow adjustment above USGS gage 08148000, Lake Buchanan near Burnet (I4000) from the computations in the workbook. The following springs were removed from the Flow Adjustment records because they were not accounted for in the naturalization process: Wallace Springs (E10360), Fleming/King Springs (E10670), San Saba Springs (F10420), and Parker/Holland/Brister Springs (I40530). Removal of these springs does not mean that staff removed these springflows from the total gage flows or the total naturalized streamflows available to water rights in the model. Removing these springs merely means that the springs were not specifically accounted for but the springflows remain part of the total flow in the river.

3.4 Reservoir Storage Information

Staff reviewed the most current Texas Water Development Board (TWDB) hydrographic survey information for reservoirs within the Colorado River Basin. Staff developed new elevation-capacity-area tables for the period after the survey for any reservoirs which were surveyed within the 1999-2013 period. The USGS discontinued reporting daily storage volumes for several reservoirs within the basin in the period 1999-2013. In November 2002, the USGS discontinued reported daily storage volumes for four reservoirs within the basin, in October 2003 USGS discontinued reporting storage volume for Twin Buttes Reservoir and discontinued reporting storage volume for Oak Creek Reservoir in March 2013. Staff determined reservoir storage volume at these reservoirs by using the reported water surface elevation and the appropriate elevation-capacity-area relationship. Staff adjusted the reported elevation and elevation-area-capacity table for Lake Brownwood to correct a USGS identified error with the reference datum. Staff also corrected the references for Brady Creek Reservoir to ensure that it was not counted twice in the naturalized flow workbooks.

3.4 Evaporation Information

Staff obtained monthly evaporation rates from TWDB for the period January 1999 to September 2013. Evaporation data for the period October-December 2013 was not available at the time the naturalized streamflow datasets were completed. Staff compared total and monthly precipitation records for the October-December 2013 period for J.B. Thomas Reservoir, E.V. Spence Reservoir, O.H. Ivie Reservoir, Lake Brownwood, Lake Buchanan and Lake Travis to historical precipitation during the same three month period from 1954-2012. Based on this analysis, data from October-December 2011 appeared to closely approximate the 2013 data and staff developed estimated evaporation rates for October-December 2013 based on evaporation rates for the period October-December 2011. Staff calculated monthly reservoir evaporation rates for October through December 2013 for reservoirs simulated in the naturalized flow workbooks using the formula:

Lake Evaporation Rate (2011) - 2013 Precipitation + 2013 Effective Runoff.

3.5 Diversions and Water Use

Staff reviewed water use for all water rights included in the diversion workbooks submitted by LCRA and compared this data to TCEQ water use records. Based on this review, staff researched missing data records and contacted some larger water right holders in order to ensure that the workbooks reflect actual diversions at the correct locations. For example, the Colorado River Municipal Water District worked with staff to develop data for its water quality control diversions, authorized by Certificate of Adjudication 14-1008. Staff based diversions for this purpose of use, in the watershed above USGS gages 08121000, Colorado River at Colorado City (A10000) and 08123800, Beals Creek near Westbrook (B30000), on both annual and monthly records. Staff determined monthly values using the annual values and the historical monthly distribution where monthly values were not available. Also, staff discovered that diversions for the City of Llano were accounted for in the watershed above USGS gage 08151500, Llano River at Llano (G10000) and were also included in the calculations for USGS Gage 08154500, Lake Travis near Austin (I20000) for the period 1996-1998. Staff removed these diversions from the Lake Travis gage.

Staff also performed an extensive review of LCRA's two different diversion data submittals. Data for the original extension (1999-2009) was not consistent with data for the 2010-2012 period. Inconsistencies resulted from assignment of LCRA's downstream contracts to specific gages and from some instances where water use was counted twice. During the recent period LCRA improved its methods for tracking and reporting diversions from LCRA's water supply in the Highland Lakes and downstream. Staff worked with LCRA to incorporate the improved data into the naturalized streamflow workbooks so that the period (1998-2013) contains a more accurate record of diversions.

4.0 MODELING RESULTS

Staff used the extended naturalized streamflow dataset (1940-2013) to perform the modeling described in this section. The baseline WAM was an updated water rights dataset for the 2012 WMP application provided by LCRA on March 14, 2014. LCRA's changes to the water rights dataset include a limitation on the maximum annual amounts of stored water that can be provided to the irrigation operations and updates to numerous Target Series (TS) records to add the year 2013. TCEQ's review was based on LCRA's 2012 WMP application. If LCRA's operations change as a result of new permits or amendments, such as the proposed downstream off-channel reservoir, LCRA would need to amend its WMP to reflect those changes, which might require further adjustments to the curtailment curves.

Staff evaluated the effect of the extended naturalized streamflow dataset on LCRA's interim curtailment curves and firm water supply under the 2012 WMP. This analysis does not consider any other obligations LCRA may have under its WMP and does not consider recreational use of the Highland Lakes. The modeling described in this section is intended to demonstrate that higher levels of curtailment provide more protection for firm water customers. The models are not intended to be the final models for the WMP. Should LCRA amend its 2012 WMP application, it would need to adjust its modeling and TCEQ would review those models during technical review of the application.

Based on the model results and in recognition of continuing extreme drought conditions in the Colorado River Basin, staff evaluated a curtailment level of 1.4 MAF for extraordinary drought conditions and performed an analysis to evaluate a more robust and comprehensive management strategy for both extraordinary droughts and less severe droughts. Staff also evaluated curtailment curves for more normal conditions that would prevent the combined storage in the Highland Lakes from dropping below 600,000 AF, if only a normal conditions curtailment curve was utilized. Finally, staff evaluated the effect of the extended naturalized streamflow dataset on the calculation of the combined firm yield for Lakes Buchanan and Travis. All modeling described herein was performed using the August 2013 version of the Water Rights Analysis Package (WRAP) available at https://ceprofs.civil.tamu.edu/rwurbs/wrap.htm.

4.1 Extraordinary Drought Conditions

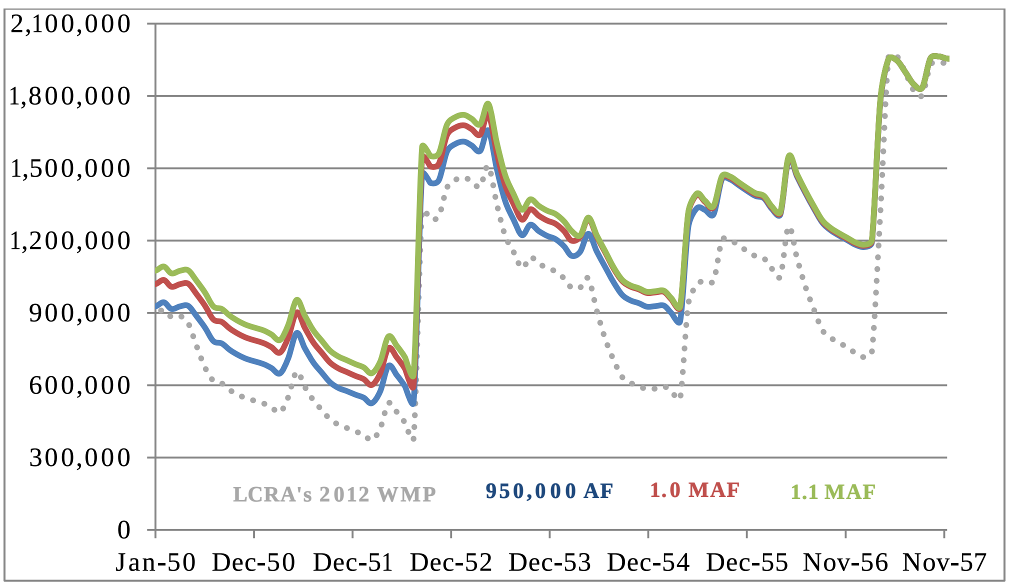
TCEQ staff used the extended naturalized streamflows (1940-2013) to model and evaluate whether LCRA's proposed interim curtailment curves for interruptible agricultural releases were adequate during extraordinary drought conditions. Based on the modeling, the curtailment curves in the 2012 WMP application would not be sufficient to account for the extraordinary drought conditions experienced in the current drought or the drought of the 1950s. TCEQ's modeling demonstrates that the WMP should include more robust drought management during extraordinary drought conditions, including a separate and higher curtailment curve of 1.4 MAF with a higher limit on when interruptible water releases would be completely curtailed.

A curtailment curve for less severe drought is discussed in Section 4.2. A range of normal conditions curtailment curves, discussed in more detail in Section 4.3, address supply of interruptible water during higher storage conditions. However, in more extreme droughts such as the 1950s drought and the current drought, the combined storage can continue to drop even when interruptible agriculture is completely curtailed. For extraordinary drought conditions, such as the drought of the 1950s and the current drought, TCEQ staff looked at a curtailment level of 1.4 MAF, coupled with a range of trigger levels under more normal conditions. These curves would account for ongoing extraordinary drought conditions but also account for higher rainfall events that can occur during lengthy droughts but do not completely refill storage. Specifically staff evaluated the following management regimes:

Table 4.1.1 Range of Combined Storage Trigger Levels

Extraordinary Drought Trigger	Normal Conditions Trigger
1.4 MAF	950,000 AF
	1.10MAF
	1.1 MAF

Staff's analysis in this section focuses on provisions to address supply of interruptible stored water during extraordinary drought conditions that would protect firm customers and facilitate recovery from such a drought. As Figure 4.1.1 illustrates, the curtailment curves in LCRA's 2012 WMP could cause the combined storage to drop below 600,000 AF and a higher combined storage trigger level of 1.4 MAF would be needed during extraordinary drought conditions in order to prevent the combined storage from dropping below 600,000 AF. Staff also notes that although higher trigger levels under normal conditions can result in more water in storage going into extraordinary drought conditions, these higher storage levels can also result in a slight increase in the amount of interruptible water released from storage under the extraordinary drought curtailment curve at the beginning of a shift from a normal conditions curtailment curve to an extraordinary drought curve.



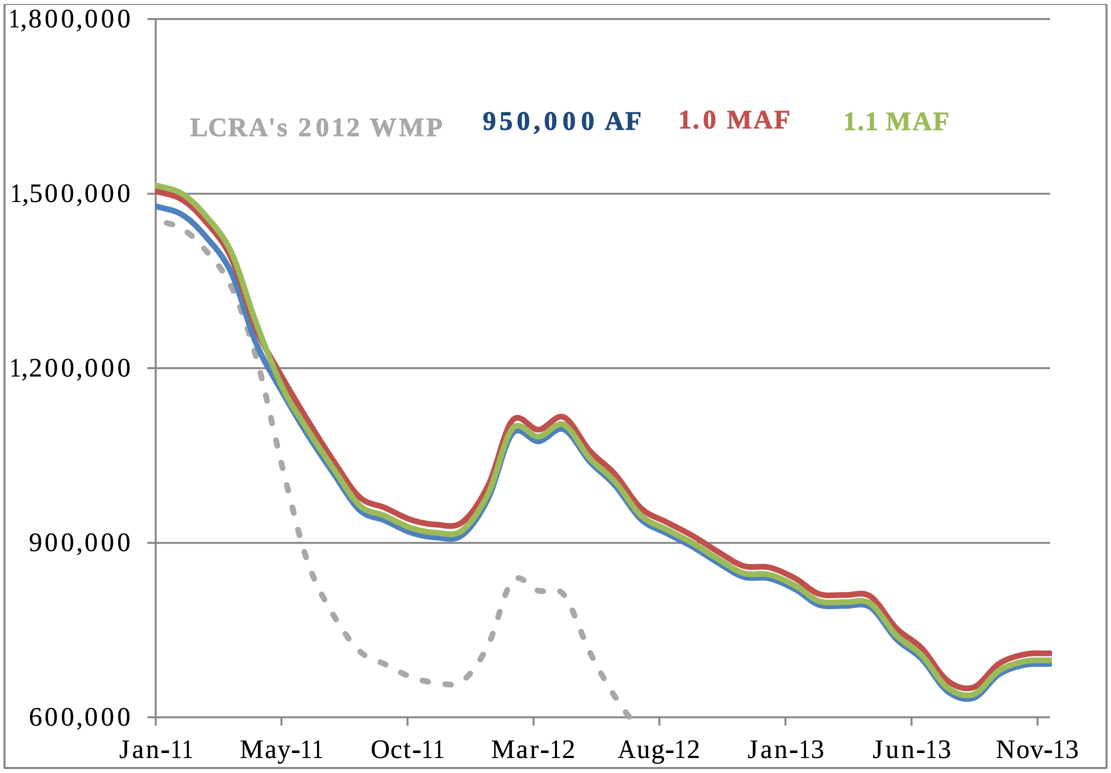


Figure 4.1.1 Comparison of Combined Storage in the Highland Lakes in Extraordinary Drought Conditions Using Different Management Strategies (Note that the combined storage under LCRA's 2012 WMP drops below 600,000 AF in August of 2012)

Staff reviewed information in LCRA's 2012 WMP application and evaluated drought management during the current drought to determine criteria that would identify when either a normal curtailment curve or a more stringent curve during less severe drought conditions would likely be insufficient to address developing extraordinary drought conditions. Staff examined the combined storage resulting from application of the curtailment curves proposed in LCRA's WMP application and a range of higher curtailment curves under normal conditions and less severe drought conditions, as discussed in Sections 4.2 and 4.3, and determined that the criteria below would likely result in deviation from these curves during the 1950s drought and the current drought.

Staff believes the following criteria could be used to determine whether it would be necessary to deviate from either a less severe drought curtailment curve or a normal conditions curtailment curve:

1. More than 24 months since the Highland Lakes were completely full; and Drought Intensity greater than or equal to the 1950s drought as measured by inflows to the Highland Lakes; or
2. LCRA's modeling indicates that the combined storage would drop below 600,000 AF in the next twelve months or that the combined storage would drop below the applicable complete curtailment point during the irrigation season.

The second criteria, based on projected storage would be applied on a rolling basis using the four evaluation dates LCRA proposed in its 2012 WMP Application. For example, on January 1 the evaluation would extend to the following January, on March 1, the evaluation would extend to the following March, and so on. The March 1 and August 1 evaluation could allow LCRA to increase the amount of interruptible stored water or it could allow LCRA to reduce the amount of interruptible stored water. Staff acknowledges that a reduction on March 1 or August 1 may require LCRA to consider its contracting procedures for interruptible customers; however, this may be necessary so that LCRA can take changing conditions into account when determining how much interruptible stored water should be supplied.

Staff constructed models to address the extraordinary drought periods in the 1950s drought and the current drought solely for the purpose of demonstrating that a higher curtailment curve during these conditions would likely be more protective of firm demands by facilitating storage recovery once drought conditions abate. Staff created four model runs to represent these periods: 1940-1949, 1950-1957, 1958-2010, and 2011-2013. Staff created Beginning-Ending Storage (BES) records and ran these models sequentially, i.e. end of period storage from 1940-1949 was used as beginning storage for 1950-1957. Table 4.1.2. shows the specific numerical values of the Extraordinary Drought Curtailment Curve used in this analysis. Figures 4.1.2 – 4.1.4 compare the Extraordinary Drought Curtailment Curve to the range of Normal Conditions Curtailment Curves for First Crop used in this analysis.

Table 4.1.2 Numerical Values for a Modeled Extraordinary Drought Curtailment Curve at 1.4 MAF

Combined Storage Level (acre-feet)	Amount of Water Supplied (acre-feet)
Below 1,400,000	**No stored water**
1.4 MAF – 1.499 MAF	100,000
1.5 MAF – 1.599 MAF	124,000
1.6 MAF – 1.699 MAF	148,000
Above 1.7 MAF	172,000
Above 1.4 MAF	50,000 for second crop

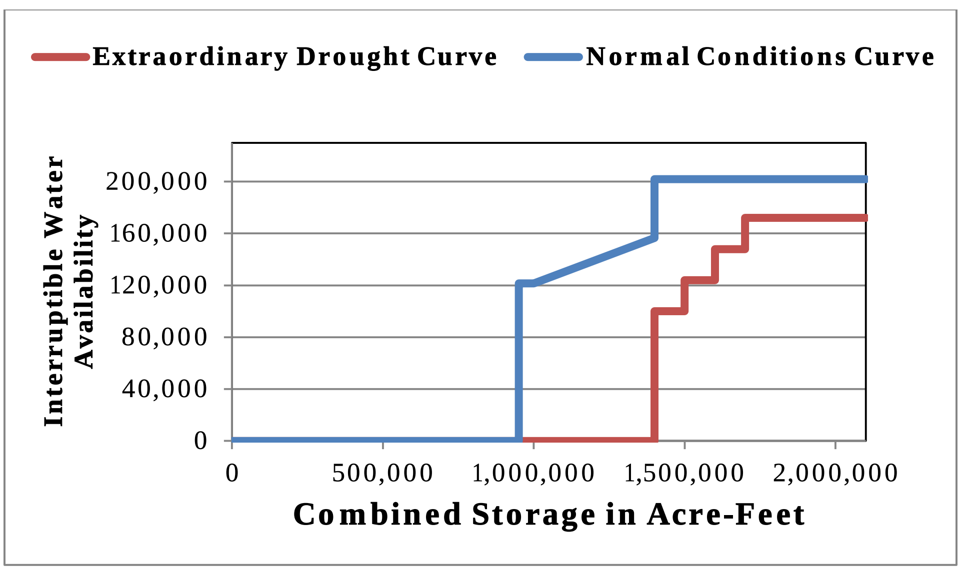


Figure 4.1.2. Comparison of the Extraordinary Drought Curtailment Curve at 1.4 MAF to the Normal Conditions Curtailment Curve at 950,000 AF for First Crop

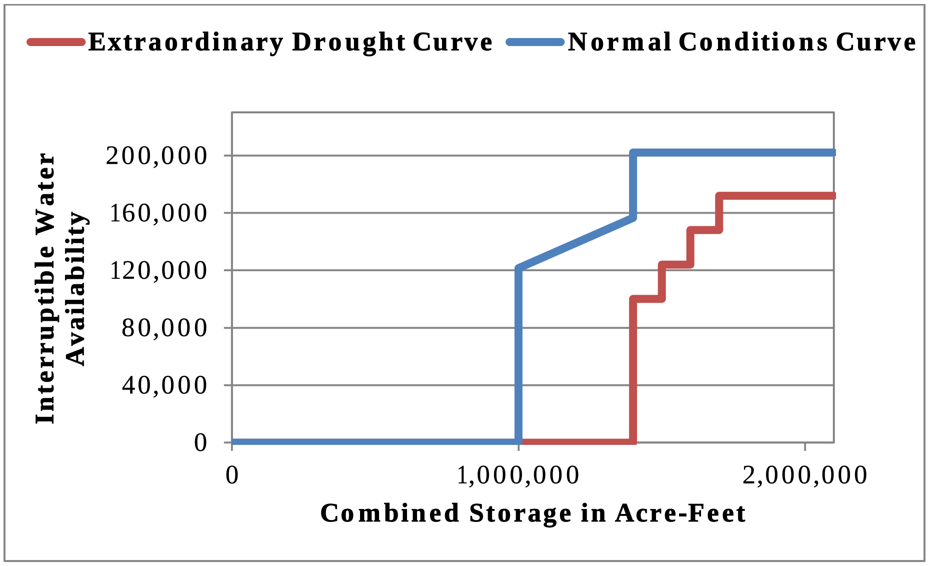


Figure 4.1.3 Comparison of the Extraordinary Drought Curtailment Curve at 1.4 MAF to the Normal Conditions Curtailment Curve at 1.0 MAF for First Crop

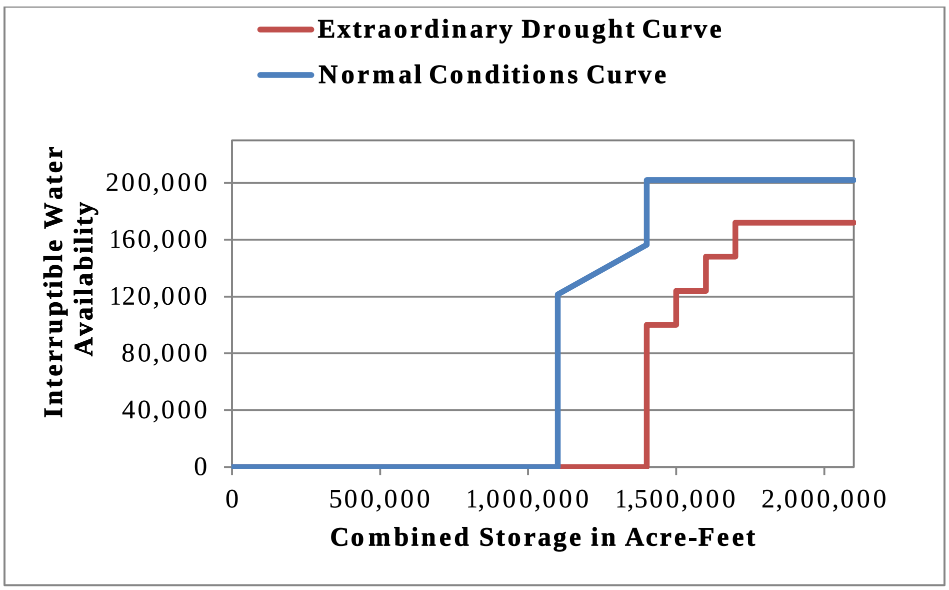


Figure 4.1.4 Comparison of the Extraordinary Drought Curtailment Curve at 1.4 MAF to the Normal Conditions Curtailment Curve at 1.1 MAF for First Crop

The proposed Extraordinary Drought Curtailment Curve would increase the combined storage level at which LCRA supplies interruptible water for the Gulf Coast, Lakeside, and Pierce Ranch Districts from the normal conditions range of 950,000 AF to 1.1 MAF to 1.4 MAF during extraordinary droughts. If the proposed Extraordinary Drought Curtailment Curve was utilized in the extraordinary drought of 2011, model results indicate over a 50% reduction in the amount of interruptible water released or passed through the Highland Lakes for these Districts.
Staff also reviewed the modeling results during the period 1950-1957 and 2011-2013 to determine an appropriate minimum level below which interruptible stored water should be

completely curtailed during extraordinary drought conditions. Based on review of years when interruptible stored water was completely curtailed or when no water was supplied for the second crop, a complete curtailment at 1.1 MAF during these type of drought conditions would provide a margin of safety for firm water customers. Furthermore, staff's review also indicates that the combined storage would also need to reach a level of at least 1.7 MAF prior to shifting to a different curtailment curve to ensure full recovery from extraordinary drought conditions.

Although previous evaluations of curtailment during the current drought produced different results, none of those previous analyses were based on or considered the updated and extended naturalized streamflows. Given that the current drought continues to persist, staff believes that use of the Extraordinary Drought Curtailment Curve (1.4 MAF) described in this section presents a reasonable approach to water management in the lower Colorado River until the current drought is over and more information is available regarding the actual duration and intensity of the current drought.

4.2 Less Severe Drought Conditions

Staff's review of the combined storage indicates that there are times during the period of record where the Extraordinary Drought Criteria would not be met but inflows were low and reservoir storage was below 1.4 MAF. These periods represent potentially developing drought conditions. During these conditions, releasing interruptible water under a curtailment curve designed for normal conditions creates the potential for interruptible releases to result in mandatory water use reductions for firm water customers. LCRA's 2012 WMP application and Drought Contingency Plan (DCP) state that at a level of 900,000 AF, LCRA and its firm customers enter Stage 2. At Stage 2, LCRA requests firm customers to implement additional drought response measures and requests that firm customers implement mandatory water use reduction measures. In order to ensure that firm demands are protected during developing drought conditions, staff looked at a curtailment curve that was lower than the Extraordinary Drought Curve and higher than the range of Normal Conditions Curtailment Curves.

Staff first reviewed a dataset of actual inflows received from LCRA in January of 2014. Staff calculated the total inflow over three month periods preceding LCRA's proposed determination dates for interruptible supply, i.e. October-December (January 1), December-February (March 1), March-May (June 1) and May-July (August 1). Staff also looked at modeled combined storage. Staff determined that a total inflow from the previous three-month period below the 33^{rd} percentile of the period of record for that three month period and a combined storage below 1.4 MAF would be indicative of time periods where drought conditions were worsening. The identified time periods are depicted in Figure 4.2.1. Staff believes the following criteria could be used to determine whether potentially developing drought conditions would require deviation from a Normal Conditions Curtailment Curve:

1. Combined storage in the Highland Lakes is below 1.4 MAF; and
2. Cumulative inflows to the Highland Lakes for the preceding three month period are below the 33^{rd} percentile for the period of record for that three month period.

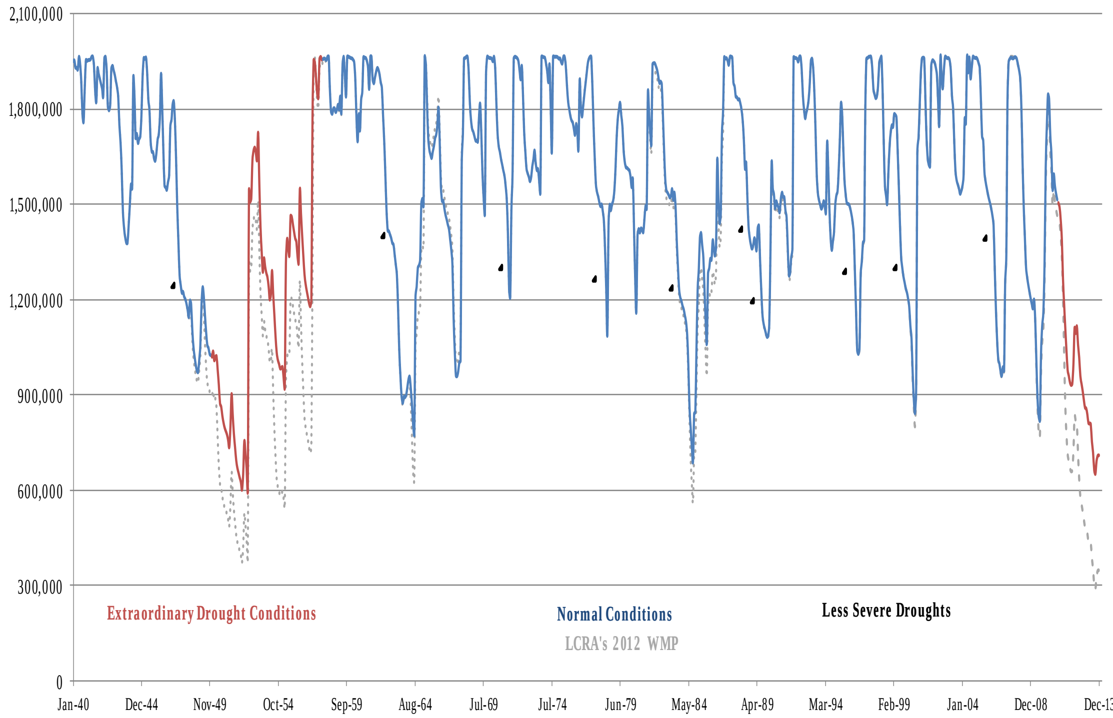


Figure 4.2.1 Combined Storage in the Highland Lakes Using Trigger Levels of 1.0 MAF under Normal Conditions and 1.4 MAF under Extraordinary Drought Conditions with Less Severe Droughts Indicated

To illustrate the effects of a Less Severe Drought Curtailment Curve, Staff used the 1958-2010 dataset with trigger levels of 1.4 MAF under Extraordinary Drought Conditions and 1.0 MAF under normal conditions as a baseline. Staff selected the period from 1963-1964 to demonstrate the effects of an intermediate curtailment curve for less severe drought conditions. Staff constructed models for the periods 1958-1962, 1963-1964 and 1965-2010, using the process described in Section 4.1. Based on the modeling results, application of the Less Severe Drought Curtailment Curve prevented the combined storage from dropping below 900,000 acre-feet during this period, as shown in Figure 4.2.2. Table 4.2.1 shows the specific numerical values for the Less Severe Drought Curtailment Curve and Figure 4.2.3 shows a graphical comparison of the Extraordinary Drought Curtailment Curve, a Less Severe Drought Curtailment Curve, and a Normal Conditions Curtailment Curve Using a Trigger Level of 1.0 MAF.

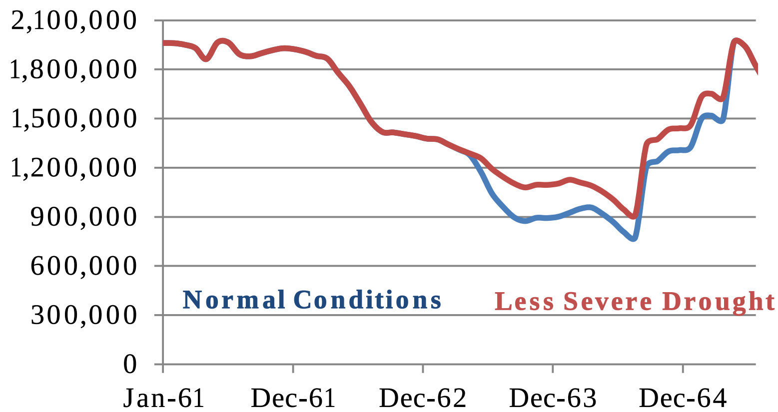


Figure 4.2.2 Comparison of Modeled Combined Storage in the Highland Lakes Under a Normal Conditions Curtailment Curve with a Trigger Level of 1.0 MAF and a Curtailment Curve for Less Severe Drought

Table 4.2.1 Less Severe Drought Curtailment Curve

First Crop	
Combined Storage Levels (acre-feet)	**Amount of Water Supplied (acre-feet)**
Below 1.1 MAF	**No stored water**
1.1 MAF – 1.199 MAF	100,000
1.2 MAF – 1.299 MAF	115,000
1.3 MAF – 1.399 MAF	130,000

Second Crop	
Below 1.1 MAF	**No stored water**
Between 1.1 and 1.4 MAF	46,000

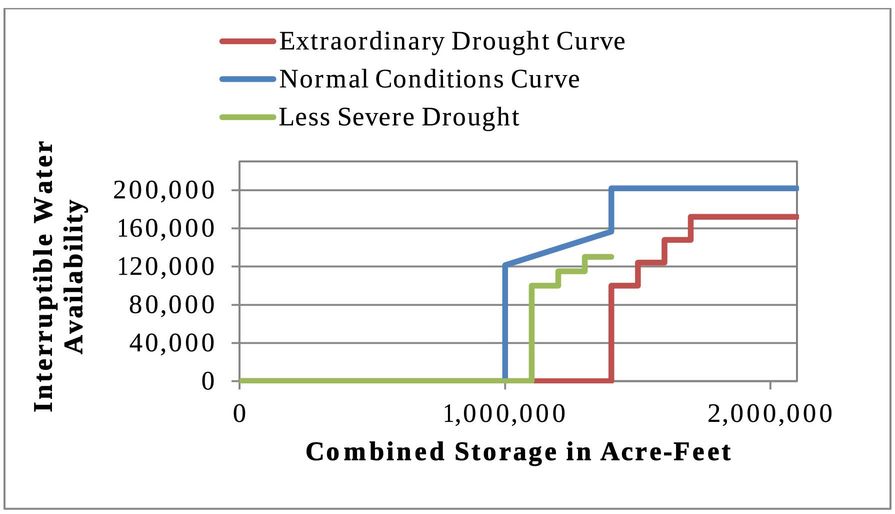
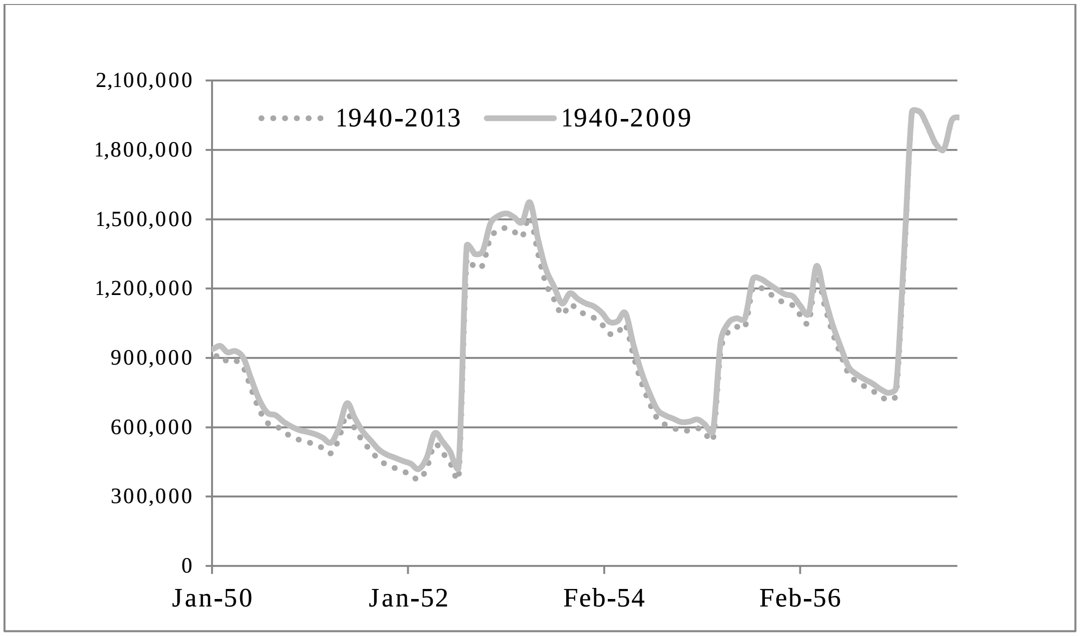


Figure 4.2.3 Comparison of the Extraordinary Drought Curtailment Curve at 1.4 MAF, the Less Severe Drought Curtailment Curve, and a Normal Conditions Curtailment Curve at 1.0 MAF

Based on the trigger levels in the Less Severe Drought Curtailment Curve and the amount of water supplied at those levels, a complete curtailment under Less Severe Drought conditions at 950,000 AF should be protective of firm demands. In addition, based on the combined storage and hydrologic variability during the 74 year period of record for the models, Less Severe Drought Curtailment could be lifted when combined storage in the Highland Lakes recovers to 1.4 MAF. As discussed in the previous section, given the persistence of the current drought, a curtailment curve that accounts for developing drought conditions is a reasonable approach to protecting firm water customers. Staff also recommends that LCRA review its DCP and examine whether additional credits could be provided for firm water customers in the event interruptible releases cause the combined storage to drop below 900,000 AF, requiring firm water customers to implement mandatory water use reductions.

4.3 Normal Conditions

Staff also evaluated the effect of the extended naturalized streamflow dataset on LCRA's proposed interim curtailment curves for the 2012 Water Management Plan under more normal conditions. Based on this evaluation, the curtailment curves in the 2012 WMP application would not be sufficient to prevent the combined storage from dropping below 600,000 AF if additional curtailment criteria, such as those discussed in Sections 4.1 and 4.2, were not included in the WMP. TCEQ's evaluation demonstrates that the WMP should include higher trigger levels under more normal conditions to protect firm water customers. The combined storage in Lakes Travis and Buchanan using 1940-2013 data, as compared to the combined storage generated based on LCRA's submittal, which used a 1940-2009 naturalized flow dataset, is shown in Figure 4.2.1. Based on the new hydrology, the 1940-2009 dataset produces higher combined storage levels in many years. The lower storage levels in the 1940-2013 dataset are the result of staff's modifications and updates to the 1940-1998 naturalized flows. Use of LCRA's Interim Demand Curtailment Curves would result in combined storage dropping to near 600,000 AF in 1964 and below 600,000 AF in 1984. This indicates that the curtailment curves for interruptible agriculture should be adjusted so that the combined storage does not drop below 600,000 AF if only a normal conditions curtailment curve is utilized. LCRA's Interim Demand Curtailment Curves also cause combined storage to drop below 600,000 AF in the 1950s and the current drought. A storage trigger level of 1.4 MAF to address those extraordinary droughts was evaluated in Section 4.1 and a Less Severe Drought curtailment curve for potentially developing drought conditions was discussed in Section 4.2.



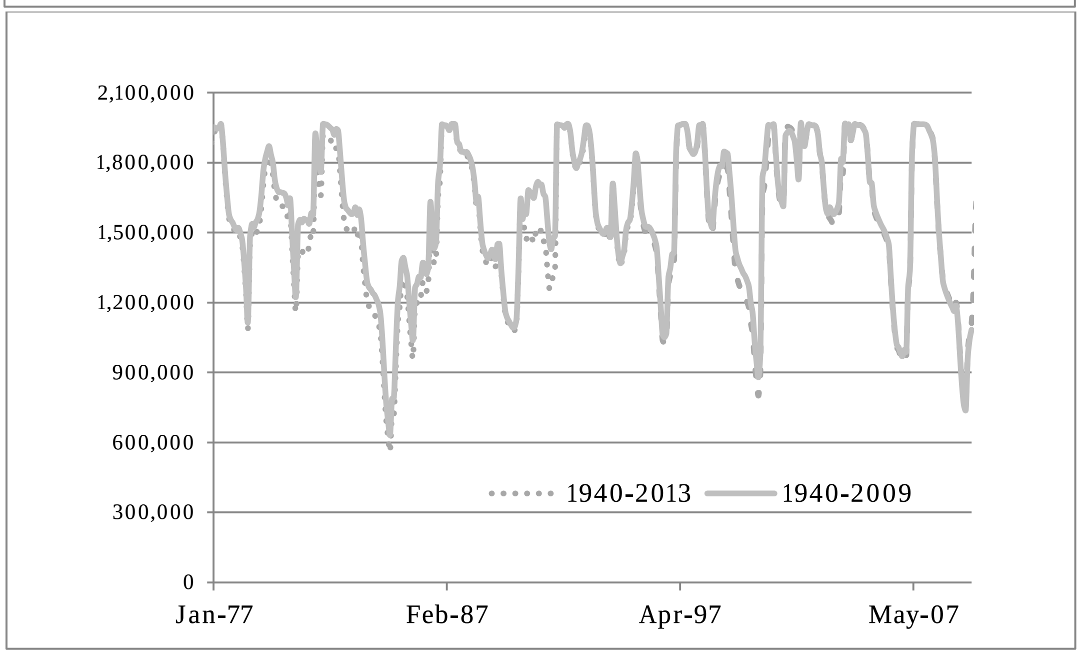


Figure 4.3.1 Selected Results of Combined Storage in Lakes Buchanan and Travis from LCRA's Interim Demand Scenario Using 1940-2009 and 1940-2013 Naturalized Flows

In light of recent drought conditions, staff's approach to adjusting the curtailment curves looked at a range of minimum combined storage levels at which LCRA would provide stored water for interruptible agriculture, except for Garwood, between 950,000 AF and 1.1 MAF. Storage levels below 950,000 AF could prevent the combined storage from dropping below 600,000 AF; however if these lower storage levels are used, combined storage at the onset of drought conditions is lower, which can affect combined storage levels during these periods of very low inflows. At combined storage levels between 1.0 and 1.1 MAF, sufficient water remains in storage to prevent the lakes from dropping below 600,000 AF during the drought of the

1950s or the current drought. Regarding the upper limit of the range, there is uncertainty regarding future run-of-river water use under senior water rights in the Colorado River below Lake Travis. For example, Corpus Christi may begin diverting its portion of Certificate 14-5434 in the near future, LCRA may be using its downstream run of river rights differently, or LCRA may begin making diversions of its senior water under Certificate 14-5476 to fill an off-channel reservoir. These demands and changes were not included in the models and LCRA would need to amend its WMP to account for those changes when they occur. **Given uncertainties regarding when these diversions and operational changes may begin, any potential impact on the amount LCRA would need to release to meet the needs of its downstream firm customers when these changes occur, and the need for a margin of safety during drought conditions, staff's opinion is that the upper limit of the range may need to be at least as high as 1.1 MAF.**

Adjustments to the amount of water supplied at each trigger level in the curtailment curve or adjustments to the higher storage trigger levels could change when and how interruptible stored water could be supplied, and these adjustments would change the amount of water remaining in Lakes Buchanan and Travis. However, staff's concerns focused on a level that would provide a margin of safety for firm water customers. Staff adjusted the curtailment curves and the level at which LCRA would cease to supply interruptible stored water to the Gulf Coast, Lakeside, and Pierce Ranch Irrigation Divisions to evaluate a range of storage levels which protect firm water customers and do not cause the combined storage to fall below 600,000 AF as a result of interruptible releases. Tables 4.3.1- 4.3.3 provide a comparison between the trigger levels and the amounts of water supplied under the LCRA's submittal and a range of curtailment curves for interruptible water supply. Figures 4.3.2 – 4.3.4 provide a comparison of LCRA's submittal and a range of curtailment curves under normal conditions for first crop. Figures 4.3.5-4.3.7 provide a comparison of LCRA's submittal and a range of curtailment curves under normal conditions for second crop.

Table 4.3.1 Comparison of LCRA's 2012 WMP Application and a Normal Conditions Curtailment Curve at 950,000 AF

First Crop			
LCRA's 2012 submittal		**Curtailment Curve at 950,000**	
Combined Storage Level (acre-feet)	**Amount of Water Supplied (acre-feet)**	**Combined Storage Level (acre-feet)**	**Amount of Water Supplied (acre-feet)**
Below 650,000	No water supplied	Below 950,000	No water supplied
650,000-999,999	121,500	950,000-999,999	121,500
1,000,000-1,399,999	121,500-156,500	1,000,000-1,399,999	121,500-156,500
Above 1,400,000	202,000	Above 1,400,000	202,000
Second (Ratoon) Crop			
LCRA's 2012 submittal			
Combined Storage Level (acre-feet)	**Amount of Water Supplied (acre-feet)**	**Combined Storage Level (acre-feet)**	**Amount of Water Supplied (acre-feet)**
Below 900,000	No water supplied	Below 1,000,000	No water supplied
900,000-999,999	46,000	1,000,000-1,549,000	46,000-59,500
1,000,000-1,549,000	46,000-59,500	Above 1,550,000	76,500
Above 1,550,000	76,500		

Table 4.3.2 Comparison of LCRA's 2012 WMP Application and a Normal Conditions Curtailment Curve at 1.0 MAF

First Crop			
LCRA's 2012 submittal		**Curtailment Curve at 1.0 MAF**	
Combined Storage Level (acre-feet)	**Amount of Water Supplied (acre-feet)**	**Combined Storage Level (acre-feet)**	**Amount of Water Supplied (acre-feet)**
Below 650,000	No water supplied	Below 1,000,000	No water supplied
650,000-999,999	121,500	1,000,000–1,399,999	121,500-156,500
1,000,000-1,399,999	121,500-156,500	Above 1,400,000	202,000
Above 1,400,000	202,000		
Second (Ratoon) Crop			
LCRA's 2012 submittal			
Combined Storage Level (acre-feet)	**Amount of Water Supplied (acre-feet)**	**Combined Storage Level (acre-feet)**	**Amount of Water Supplied (acre-feet)**
Below 900,000	No water supplied	Below 1,100,000	No water supplied
900,000-999,999	46,000	1,100,000-1,549,000	46,000-59,500
1,000,000-1,549,000	46,000-59,500	Above 1,550,000	76,500
Above 1,550,000	76,500		

Table 4.3.3 Comparison of LCRA's 2012 WMP Application and a Normal Conditions Curtailment Curve at 1.1 MAF

First Crop			
LCRA's 2012 submittal		**Curtailment Curve at 1.0 MAF**	
Combined Storage Level (acre-feet)	**Amount of Water Supplied (acre-feet)**	**Combined Storage Level (acre-feet)**	**Amount of Water Supplied (acre-feet)**
Below 650,000	No water supplied	Below 1,100,000	No water supplied
650,000-999,999	121,500	1,100,000–1,399,999	121,500-156,500
1,000,000-1,399,999	121,500-156,500	Above 1,400,000	202,000
Above 1,400,000	202,000		
Second (Ratoon) Crop			
LCRA's 2012 submittal			
Combined Storage Level (acre-feet)	**Amount of Water Supplied (acre-feet)**	**Combined Storage Level (acre-feet)**	**Amount of Water Supplied (acre-feet)**
Below 900,000	No water supplied	Below 1,150,000	No water supplied
900,000-999,999	46,000	1,150,000-1,549,000	46,000-59,500
1,000,000-1,549,000	46,000-59,500	Above 1,550,000	76,500
Above 1,550,000	76,500		

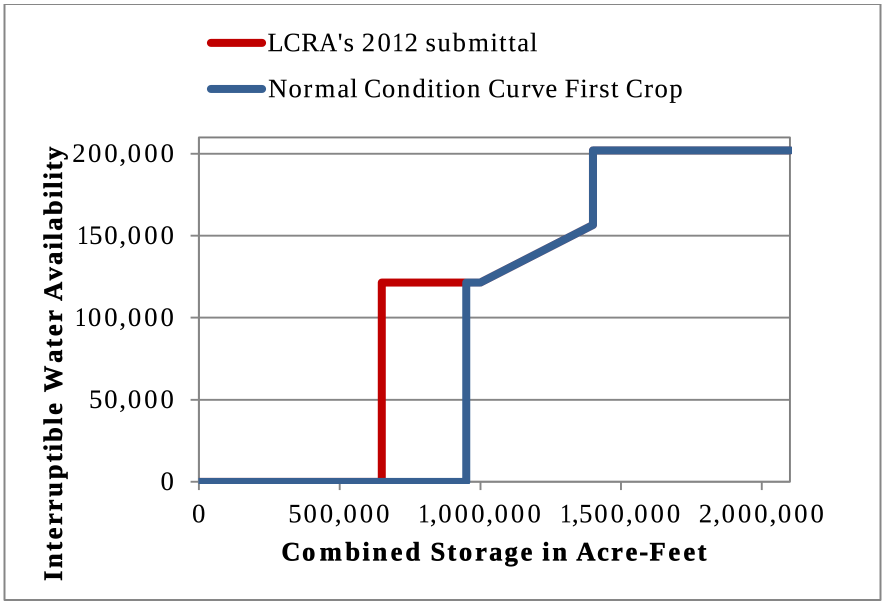


Figure 4.3.2 Comparison of LCRA's 2012 WMP Submittal Using a Normal Conditions First Crop Curtailment Curve at 950,000 AF

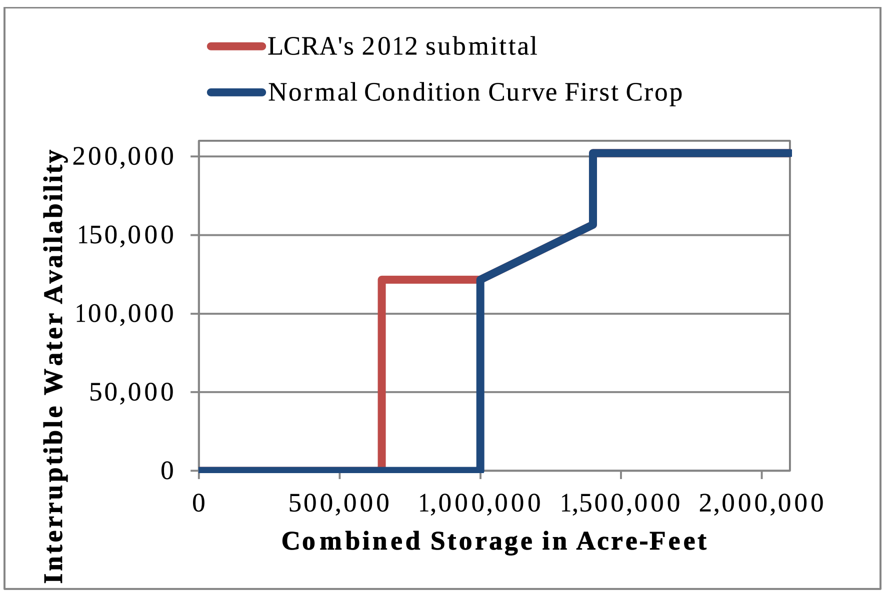


Figure 4.3.3. Comparison of LCRA's 2012 WMP Submittal Using a Normal Conditions First Crop Curtailment Curve at 1.0 MAF

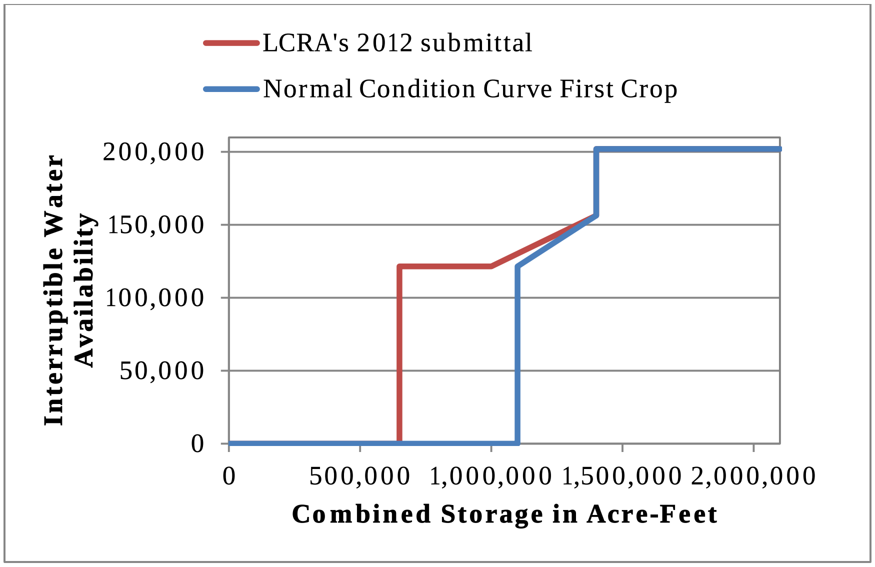


Figure 4.3.4 Comparison of LCRA's 2012 WMP Submittal Using a Normal Conditions First Crop Curtailment Curve at 1.1 MAF

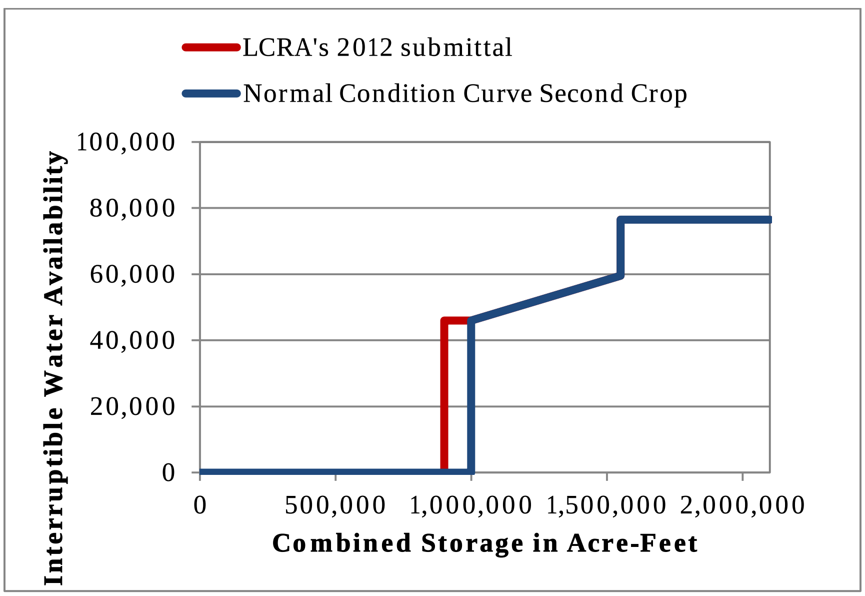


Figure 4.3.5 Comparison of LCRA's 2012 WMP Submittal Using a Normal Conditions Second Crop Curtailment Curve Based on a First Crop Curtailment at 950,000 AF

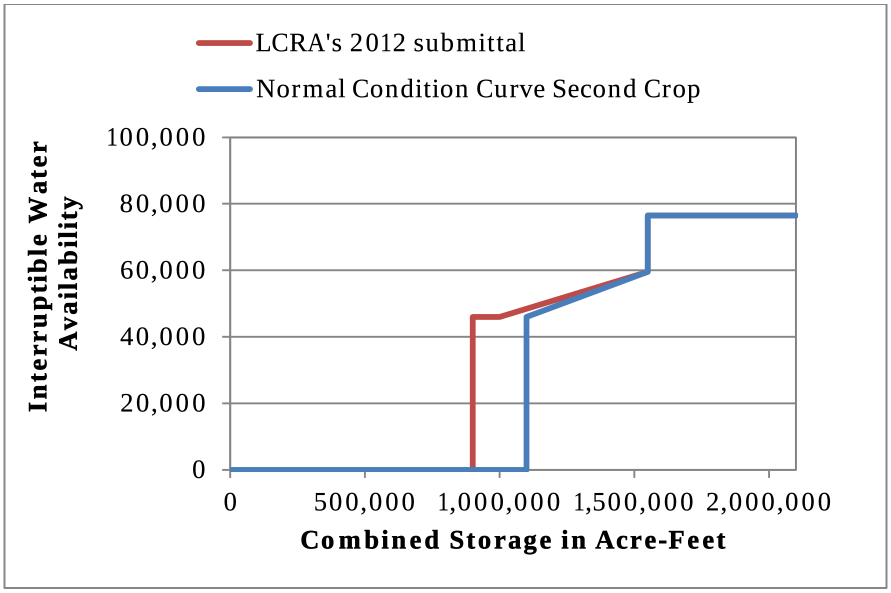


Figure 4.3.6 Comparison of LCRA's 2012 WMP Submittal Using a Normal Conditions Second Crop Curtailment Curve Based on a First Crop Curtailment at 1.0 MAF

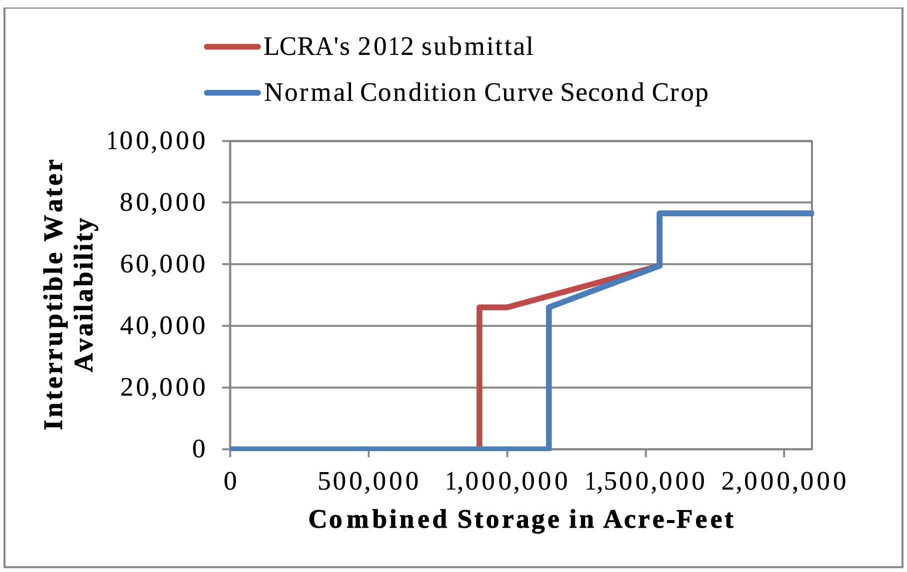


Figure 4.3.7 Comparison of LCRA's 2012 WMP Submittal Using a Normal Conditions Second Crop Curtailment Curve Based on a First Crop Curtailment at 1.1 MAF

In addition to a range of adjusted curtailment curves, staff also reviewed the level at which LCRA would cease supplying stored water to interruptible agriculture under normal conditions. LCRA's 2012 WMP application proposes that this level be set at 600,000 AF, the point at which LCRA would begin pro-rata curtailment of firm customers. After reviewing storage declines in the 1950s and 2012-2013, when stored water releases for interruptible agriculture were completely curtailed, staff's opinion is that a higher combined storage level for complete curtailment of interruptible agriculture would be more reasonable. At a level of 900,000 AF, LCRA and its firm customers enter Stage 2 of LCRA's Drought Contingency Plan. At Stage 2, LCRA requests that firm customers implement additional drought response measures by implementing mandatory water use reduction measures. Therefore, a minimum level of between 900,000 AF and 950,000 AF would provide a margin of safety to address increases in firm demands until such time as LCRA has enough information to amend the WMP to fully and completely account for the current drought, although further adjustment may be needed at the upper end of this range.

4.3 Combined Firm Yield

LCRA's 2012 WMP application provides a definition for the combined firm yield that is used in and only applicable to its WMP:

> **combined firm yield of Lakes Buchanan and Travis**: the calculated firm yield of Lakes Buchanan and Travis when operated as a system, incorporating LCRA's agreements and operating assumptions regarding calls on the upper basin;

Staff used LCRA's firm yield model, which assumes natural priority by watershed ("no call" assumption). This assumption allows water rights in the Upper Colorado Basin above O.H. Ivie Reservoir to divert available streamflow irrespective of their relative priority with respect to lower basin water rights, although they maintain their priority dates with respect to one another. Regarding the "no call" assumption, some of LCRA's agreements with upstream water rights are included in specific water rights and some are not. In addition, pursuant to TWC §11.027, all water rights in a river basin are subject to water rights that are senior to them. Therefore, staff's modeling in this section is only for the purpose of determining whether LCRA's combined firm yield estimate is adequate and not for the purpose of determining whether a change in the combined firm yield would affect other water rights in the basin.

Staff performed a simulation using LCRA's firm yield model and the extended naturalized streamflow dataset. Based on the new hydrologic data, LCRA's firm yield diversion components were not 100% reliable. The water right identifiers for the components of the combined firm yield are: 11405715002, 11405730001, 11405790001, 11204007001, 11405677001, 61405482001C, 61405480001, 61405473001, 61405474001, 61405437001BU, 61405471005RMBU, 61405471005LMBU, and 61405489003MBU. The Colorado River Basin WAM includes a water right record (61405482001C) which represents the amount of LCRA's firm yield that is not accounted for under other water rights. Staff iterated the diversion amount on this record in increments of 500 AF until all of the diversion components of the combined firm yield calculation were 100% reliable. Note that some of the combined firm yield components represent LCRA's releases to its firm water customers and the amount supplied to these customers is variable.

Staff's analysis indicates that the critical period for the drought of the 1950s, calculated from when the reservoirs were last full to the month in which they refill, is approximately eleven years – May of 1946 to June of 1957. Staff calculated the annual amount supplied during the critical period and determined that the combined firm yield is less than the amount LCRA previously calculated. The combined firm yield for the 1950s drought is now approximately 431,982 AF.

Staff also estimated a hypothetical combined firm yield based on current drought conditions using the period from September 2007 to December 2013. The purpose of this estimation is to review the potential impact of current drought conditions on the combined firm yield. The results of this calculation should not be construed as a new combined firm yield. Any determination of whether the combined firm yield should be changed based on current drought conditions cannot be completed until Lakes Buchanan and Travis completely refill because the duration of the current drought is not known. Based on the current drought, staff estimates that the hypothetical combined firm yield for the period from 2007 to 2013 is 432,191 AF. Based on model results using the extended naturalized flow dataset, the 1950s drought is still the limiting factor in determining the combined firm yield; however, this could change if current drought conditions persist or intensify.

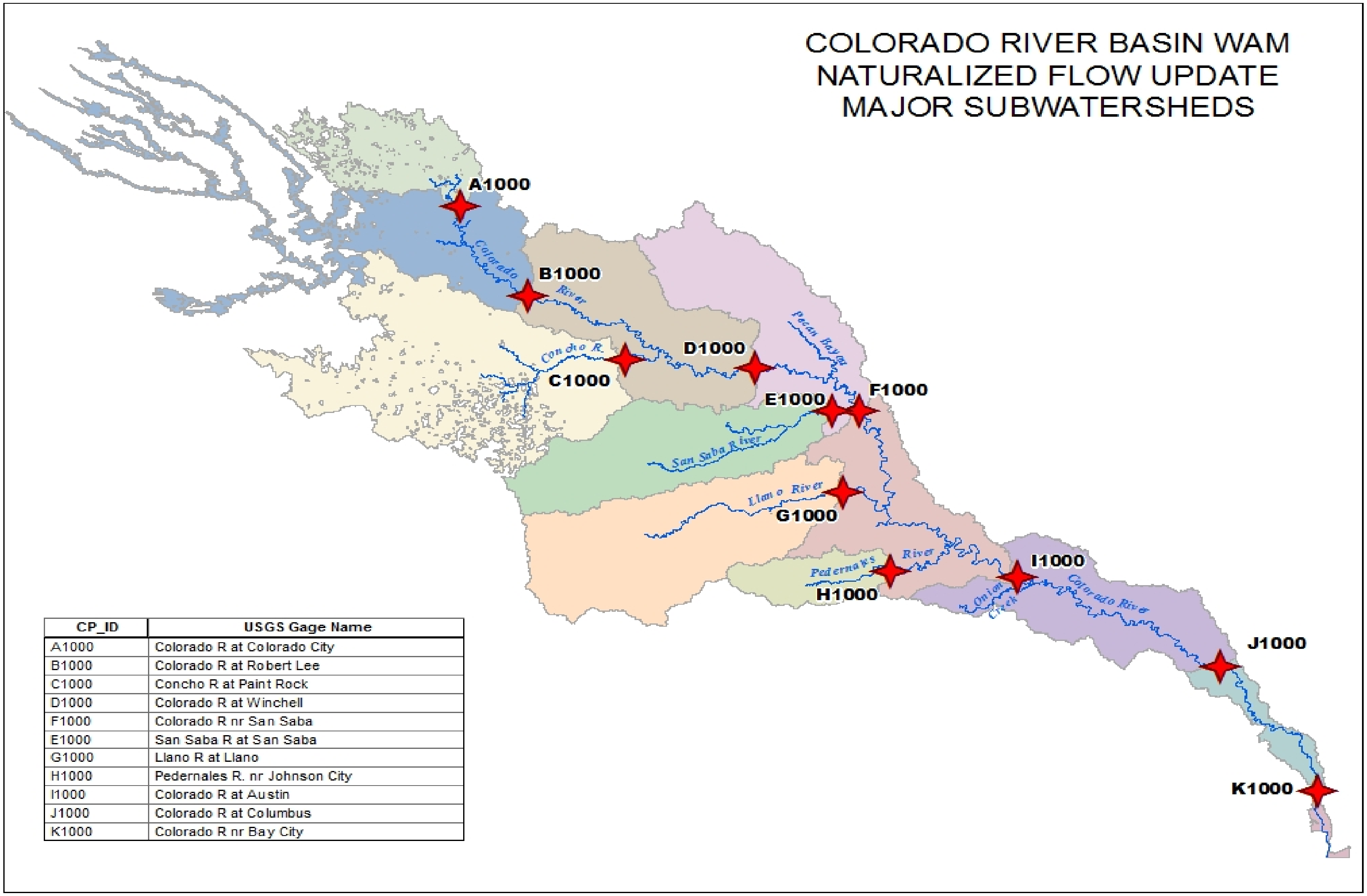
5.0 Conclusion

TCEQ performed an intensive and detailed modification of the 1940-1998 naturalized streamflows and updated these streamflows to extend the period of record from 1940-2013. This was an important and useful exercise because using these updated flows in modeling LCRA's WMP identified areas where LCRA's 2012 WMP submittal could be improved. Based on this evaluation, the curtailment curves in the 2012 WMP application would not be sufficient to account for the extraordinary drought conditions experienced in the current drought or the drought of the 1950s. In addition, LCRA's 2012 WMP submittal would not be sufficient to provide a margin of safety for firm water customers during less severe droughts. TCEQ's evaluation of potential curtailment curves under drought conditions demonstrates that the WMP should include a more robust and comprehensive drought management regime during drought conditions, with higher curtailment curves and reductions in the amount of interruptible water supplied under those conditions.

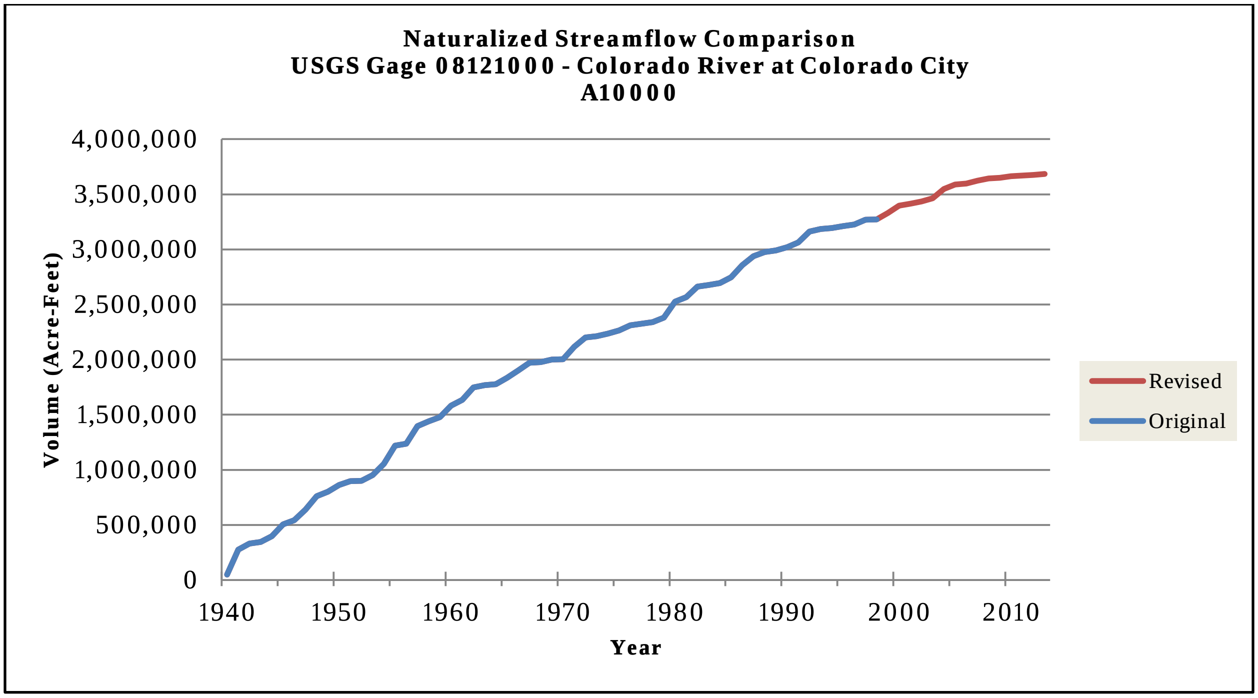
TCEQ evaluated a curtailment level of 1.4 MAF under extraordinary drought conditions, a less severe drought curtailment curve for developing drought conditions, and a range of curtailment curves for more normal conditions. LCRA's 2012 submittal already includes checking combined storage multiple times throughout a year to determine how much water could be supplied for interruptible agriculture in the lower basin. However, based on TCEQ's evaluation, using a more robust and comprehensive approach to water management in the lower Colorado River Basin would allow LCRA more flexibility to consider changing conditions under its WMP, likely reducing the need for multiple Emergency Orders. The comprehensive drought management regime described herein, with separate curtailment curves for extraordinary droughts, less severe droughts, and more normal conditions, could be a very important component that enhances flexibility in managing water supply during drought conditions under LCRA's WMP.

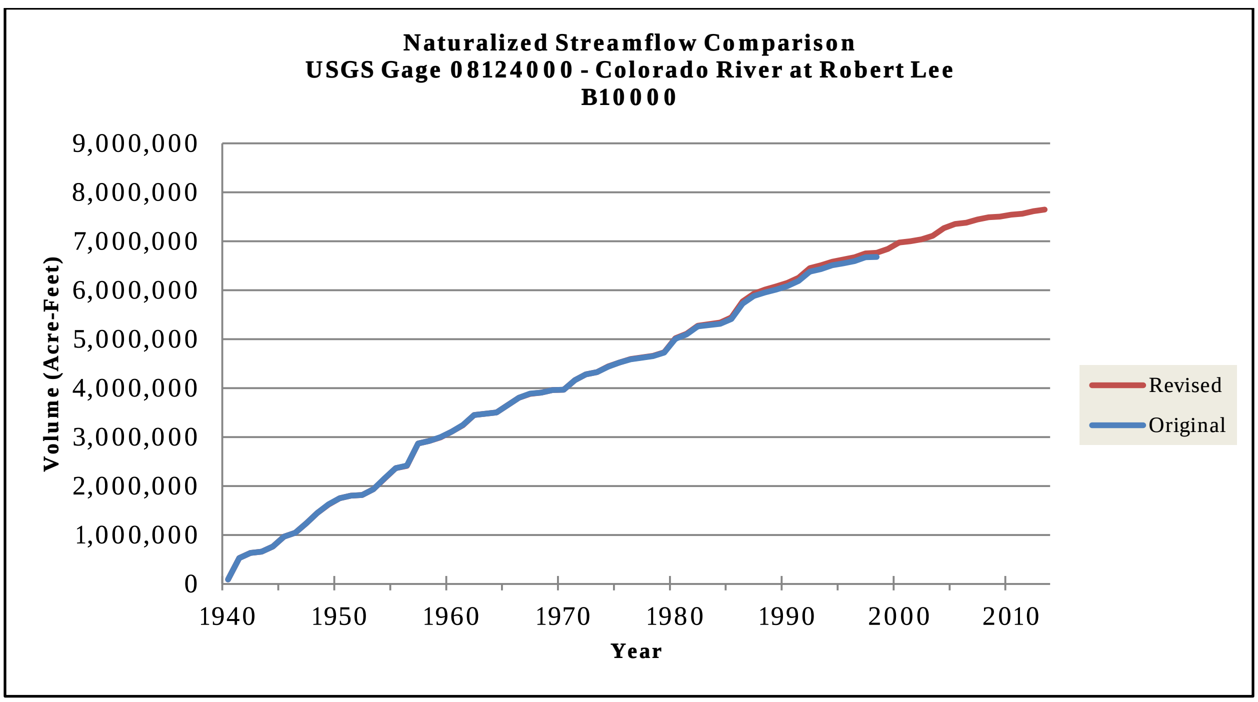
Appendix A

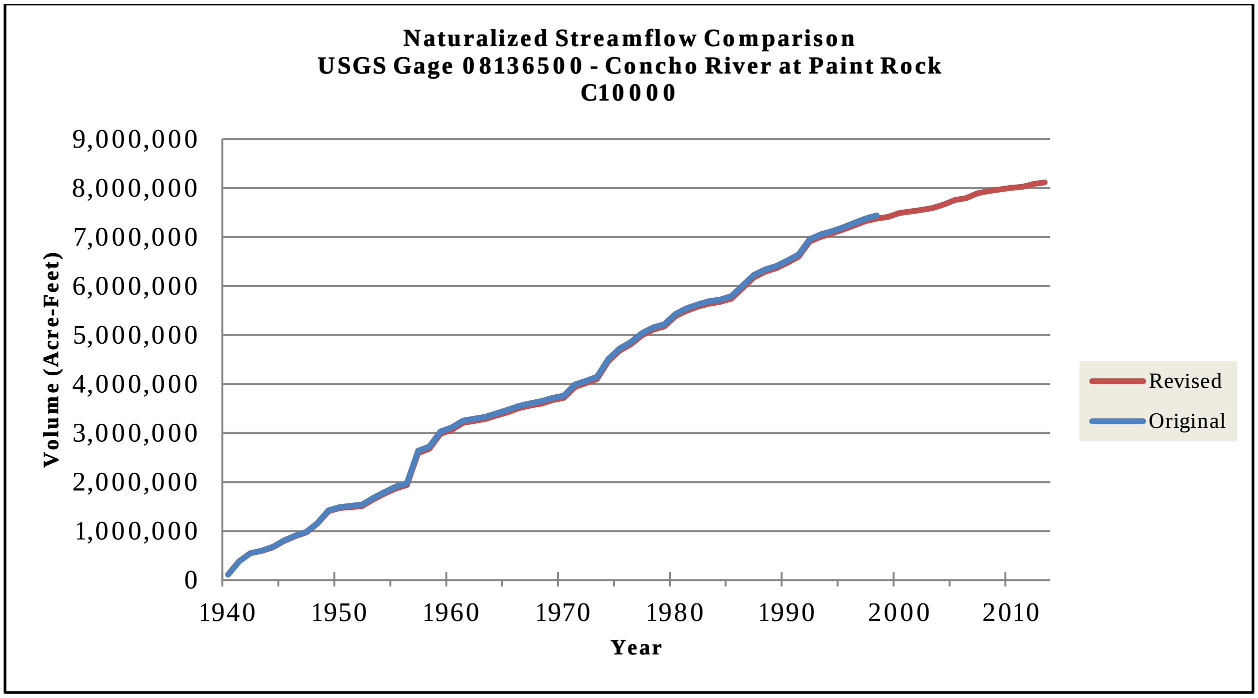
COMPARISON PLOTS OF
ORIGINAL NATURALIZED STREAMFLOWS
WITH UPDATED NATURALIZED STREAMFLOWS

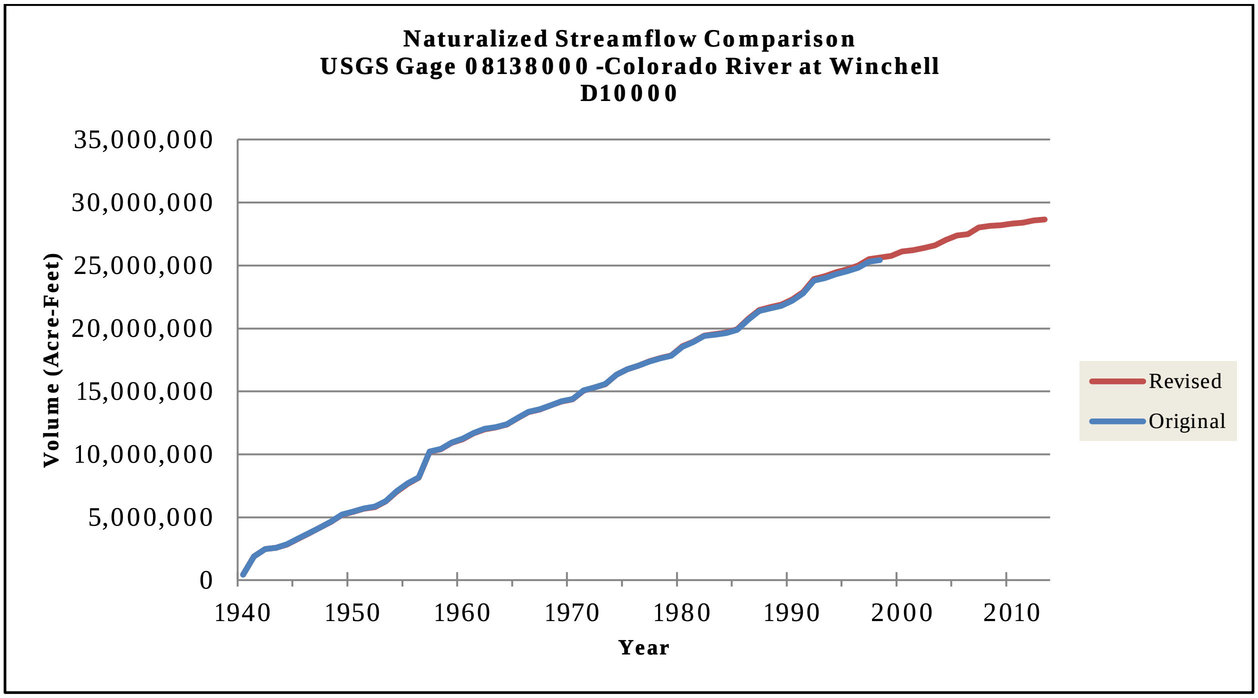


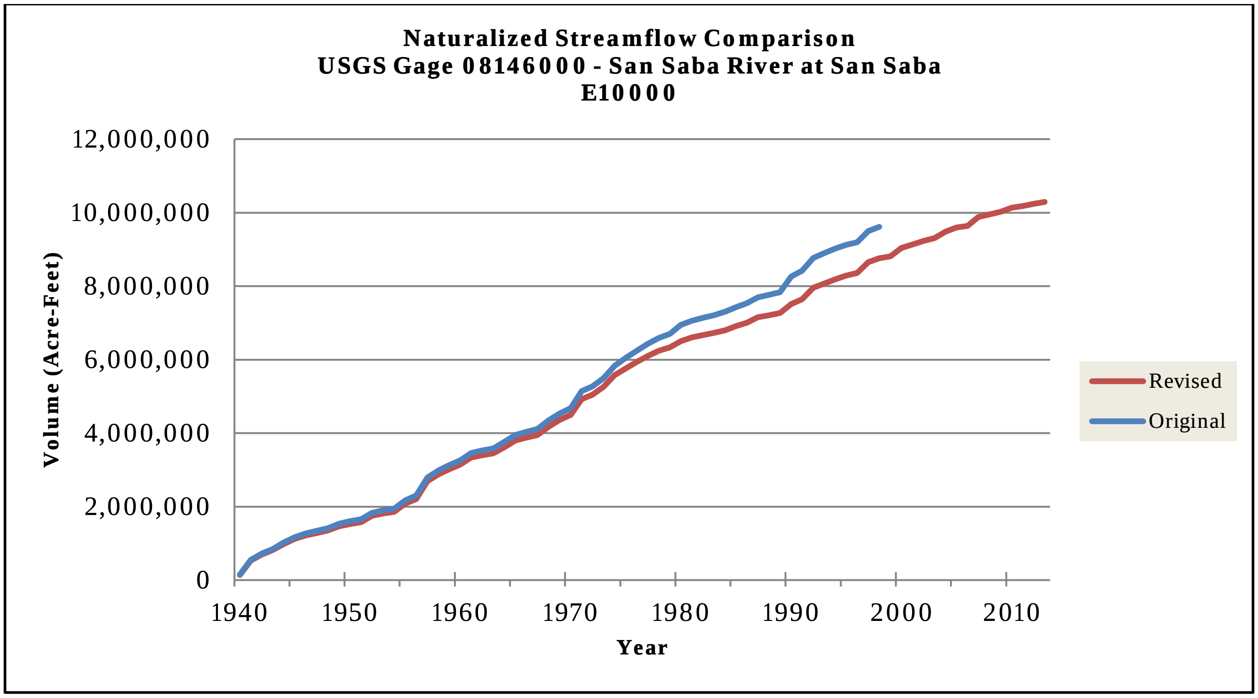
CP_ID	USGS Gage Name
A1000	Colorado R at Colorado City
B1000	Colorado R at Robert Lee
C1000	Concho R at Paint Rock
D1000	Colorado R at Winchell
F1000	Colorado R nr San Saba
E1000	San Saba R at San Saba
G1000	Llano R at Llano
H1000	Pedernales R. nr Johnson City
I1000	Colorado R at Austin
J1000	Colorado R at Columbus
K1000	Colorado R nr Bay City

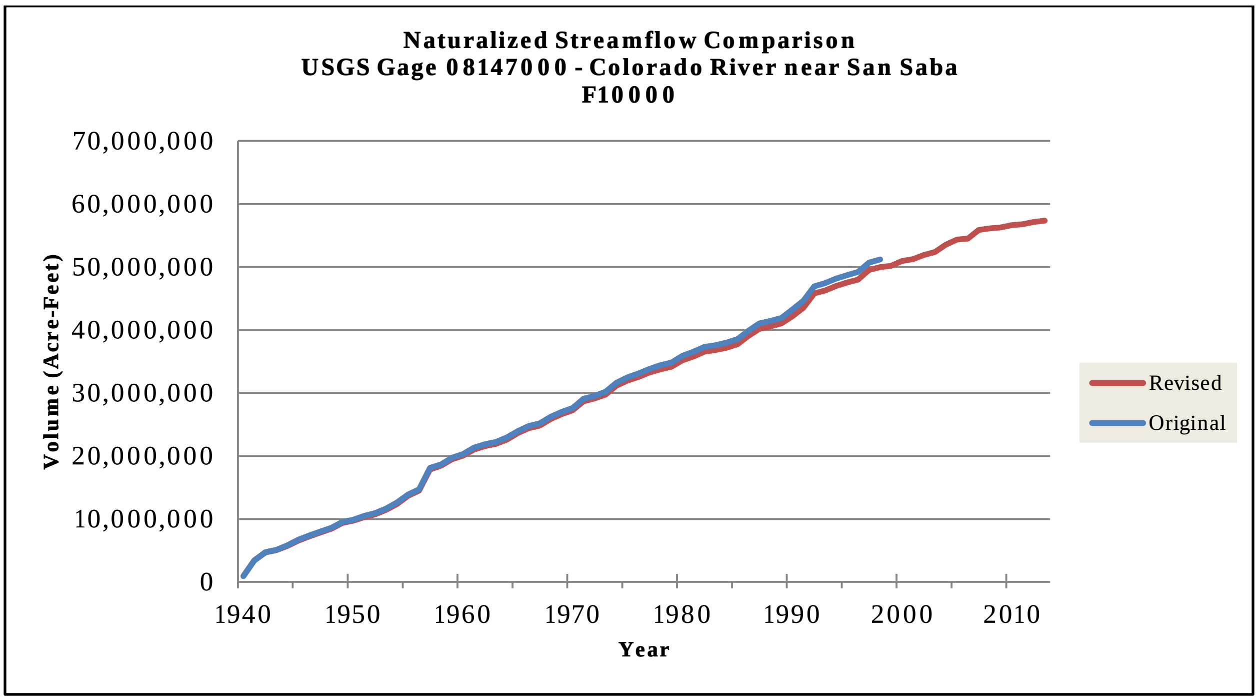

Naturalized Streamflow Comparison
USGS Gage 08121000 - Colorado River at Colorado City
A10000
Volume (Acre-Feet)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original


Naturalized Streamflow Comparison
USGS Gage 08124000 - Colorado River at Robert Lee
B10000
Volume (Acre-Feet)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original

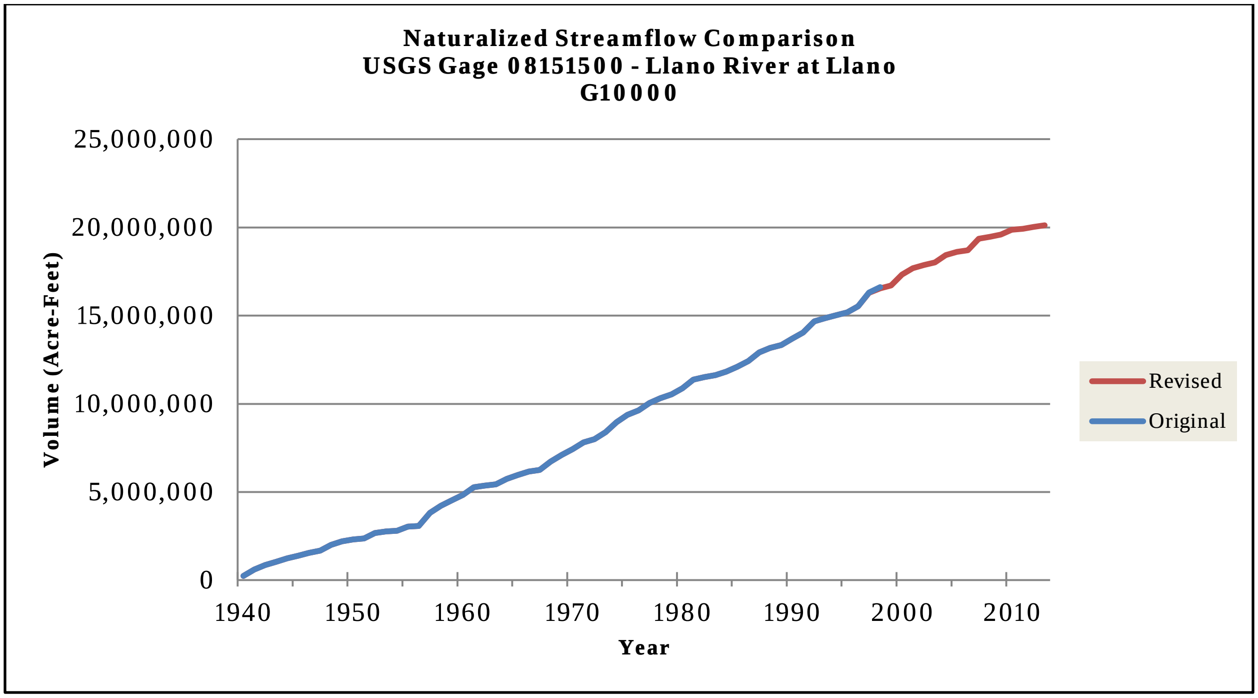

Naturalized Streamflow Comparison
USGS Gage 08136500 - Concho River at Paint Rock
C10000
Volume (Acre-Feet)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original

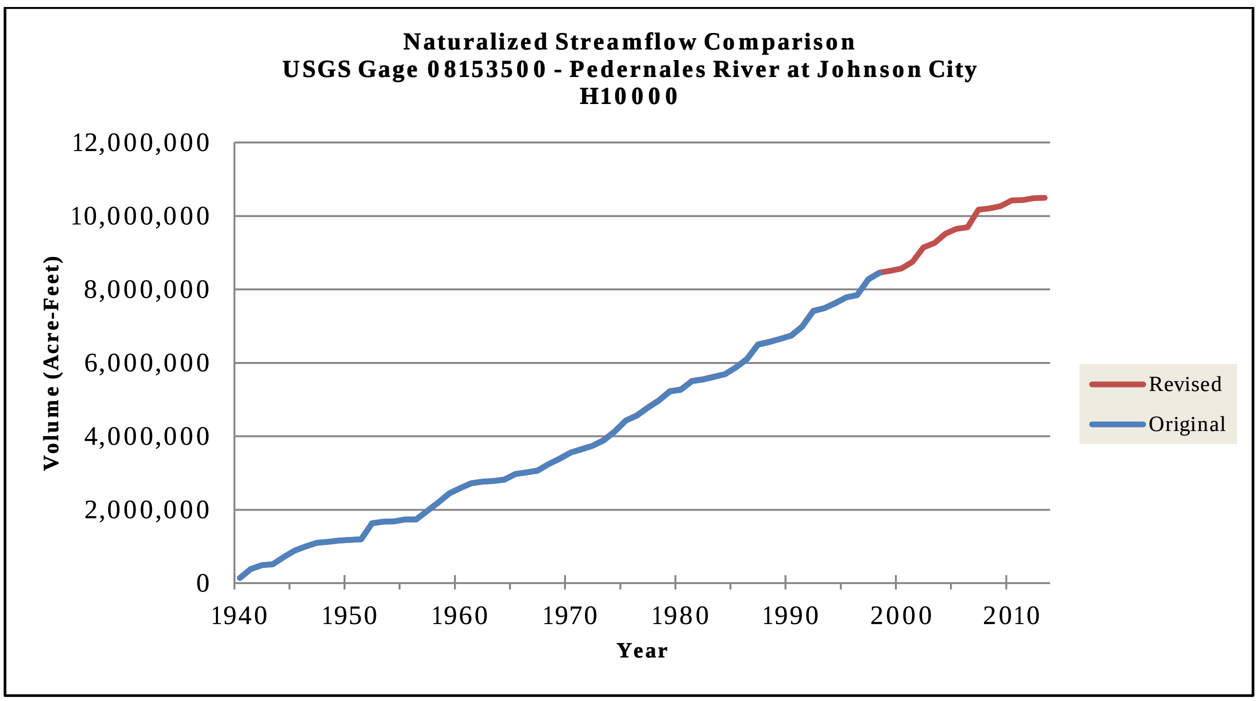

Naturalized Streamflow Comparison
USGS Gage 08138000 -Colorado River at Winchell
D10000
Volume (Acre-Feet)
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original

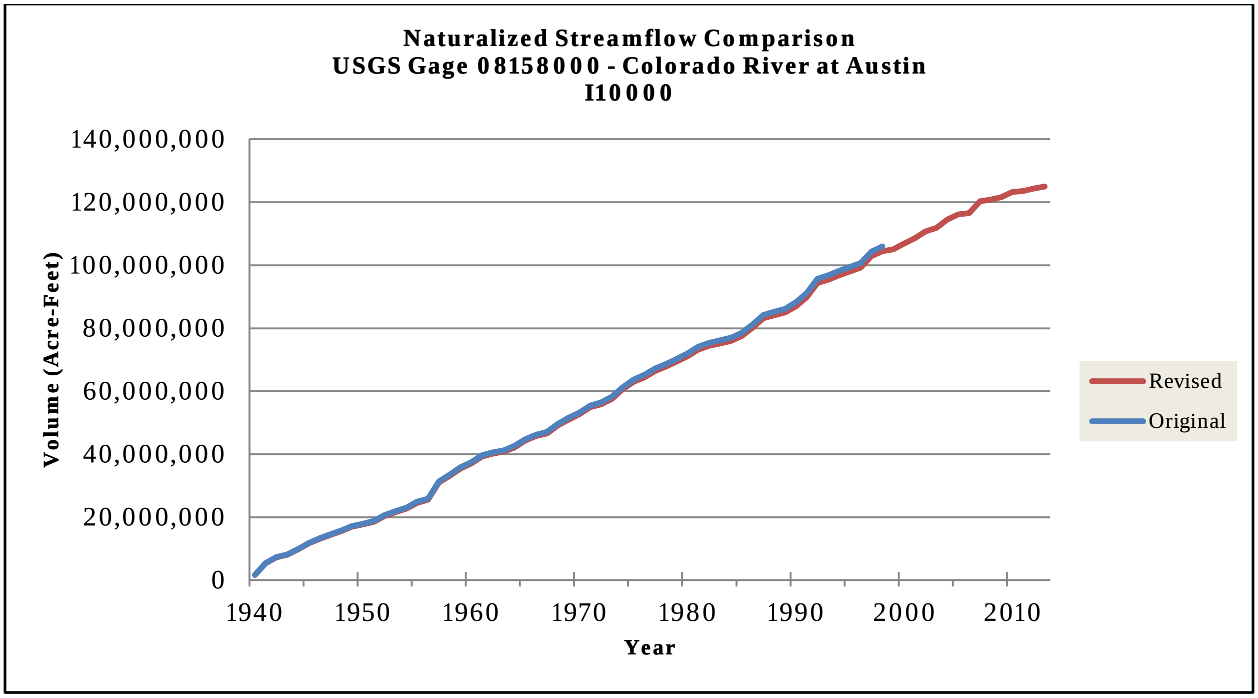


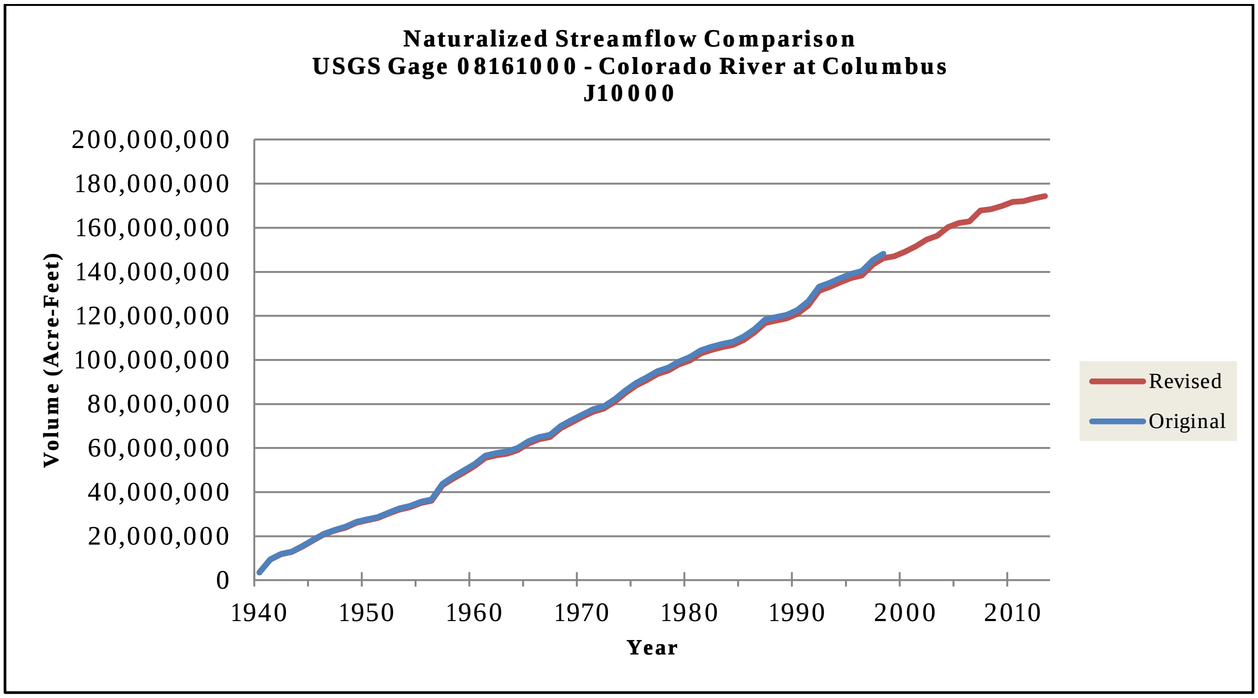


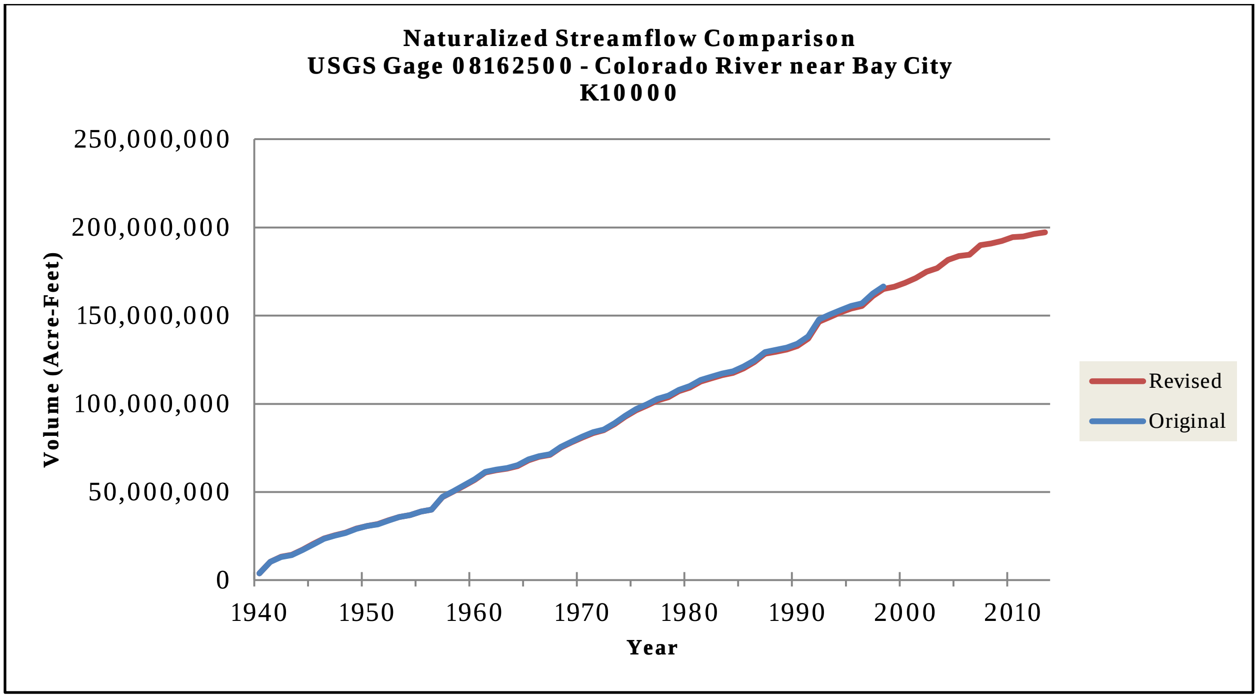
**The differences in naturalized streamflows at E10000 and F10000 above are the result of revisions to the springflow dataset as discussed in Section 3.2 of this report.


Naturalized Streamflow Comparison
USGS Gage 08151500 - Llano River at Llano
G10000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
Volume (Acre-Feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original


Naturalized Streamflow Comparison
USGS Gage 08153500 - Pedernales River at Johnson City
H10000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Volume (Acre-Feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original


Naturalized Streamflow Comparison
USGS Gage 08158000 - Colorado River at Austin
I10000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
Volume (Acre-Feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original


Naturalized Streamflow Comparison
USGS Gage 08161000 - Colorado River at Columbus
J10000
200,000,000
180,000,000
160,000,000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
Volume (Acre-Feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original


Naturalized Streamflow Comparison
USGS Gage 08162500 - Colorado River near Bay City
K10000
250,000,000
200,000,000
150,000,000
100,000,000
50,000,000
0
Volume (Acre-Feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Revised
Original