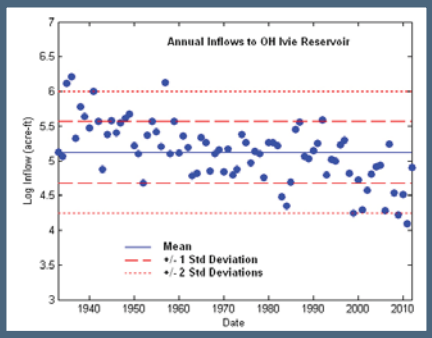
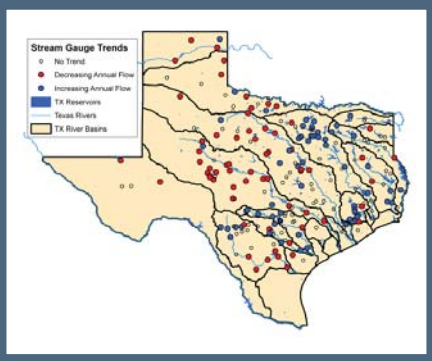
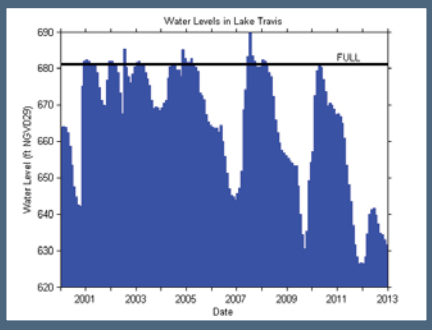
Evidence for the Need to Change the Approach to Water Planning in the Lower Colorado Basin

Part II: WAM & WMP Analyses







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June 12, 2013

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EXECUTIVE SUMMARY

The State of Texas and the Lower Colorado River Authority (LCRA) base their water planning and management on historical flow records. Inflows to the Highland Lakes have been significantly lower in recent years, causing many to wonder if the use of historical hydrology is justified for decision-making. The Central Texas Water Coalition (CTWC) commissioned a rigorous study of historical Highland Lake inflows to determine if past hydrology is a good surrogate for future hydrology in the Lower Colorado River Basin.

Findings of the study demonstrate that the average annual naturalized inflow to the Highland Lakes in recent years is, statistically, significantly lower than the average annual naturalized inflow in historical records, indicating that there has been a downward shift in the natural flow regime. Furthermore, the firm yield of the Highland Lakes, which is the starting point for water availability studies and the Lower Colorado River Basin Water Management Plan (WMP), is likely lower than the number currently being used. This is corroborated by two facts:

1. If dry conditions persist for just a few more months, the Lower Colorado Basin will be experiencing a new drought of record, and

2. Had TCEQ not issued emergency orders removing LCRA's responsibility to release interruptible water in 2012 and 2013, the combined storage in the Highland Lakes would presently be well below its historical low value, and also below the accepted threshold for defining a new drought of record.

These findings lead us to conclude that past hydrology is not a good proxy for future hydrology and that any Lower Colorado Basin WMP must be based solely upon recently observed low stream flow conditions. As such, the pending WMP, while a step in the right direction from the previous plan, is not appropriate for planning and allocation of flows in the basin and must be revised as soon as possible. The following sections provide the technical evidence that lead to CTWC's assertions, as included in this document and in CTWC's May 8th, 2013 report entitled "Evidence for the Need to Change the Approach to Water Planning in the Lower Colorado Basin."

1.0 WAM ANALYSES

This section contains a description of the WAM analyses and results that support the statements and conclusions included in Sections 1-5 of CTWC's May 8th, 2013 report (herein referred as "May 8th Report") entitled "Evidence for the Need to Change the Approach to Water Planning in the Lower Colorado Basin." Specifically this section presents analyses supporting claims that:

- LCRA's WAM modeling in support of the WMP needs to be adjusted to include inflows that occurred through 2012
- Inflows to the Highland Lakes have, on average, been significantly reduced since 1999
- Reduced Inflows will lead to a lower firm yield from the Highland Lakes if dry conditions continue into the near future
- Had the period 1940-1998 been as dry, on average, as the period 1999-2012, the firm yield of the Highland Lakes would have been much lower.

In an interoffice memorandum ("Memo") dated April 15, 2013, Dr. Kathy Alexander of the TCEQ Water Rights Permitting and Availability Section outlined her review of LCRA's modeling of water availability in support of its water management plan. In the review, TCEQ states that:

> *"LCRA's WAMs include a "no call" assumption whereby water rights above the Highland Lakes are modeled as senior to downstream rights and have access to river flows at their location irrespective of the priority dates of downstream rights." (Memo, Page 7)*

And

> *"LCRA's WAMs include an extension of the period of record for naturalized flows for some of the gauges in the lower basin below Lakes O.H. Ivie and Brownwood." (Memo, Page 7)*

TCEQ continued to say that according to TWC §11.027, LCRA's "no-call" assumption is not in accordance with TCEQ policies. In addition, as the naturalized flows used by LCRA were not extended for all locations in the Colorado Basin, TCEQ could not use LCRA's extended model to assess whether LCRA's WMP impacts any or all water right holders in the Colorado basin. To perform such an assessment, TCEQ used its officially accepted Colorado River Basin WAM model, with a period of record spanning 1940-1998.

Shown in Figure 1 are the annual naturalized inflows to the Highland Lakes as computed from WAM data per LCRA's methods. The data shown for years 1940-1998 are from the TCEQ WAM model for the Colorado River Basin, and the data from 1999-2009 are from the LCRA's extended WAM model. Data for 2010-2012 are conservatively estimated, based on USGS gauge records. The annual naturalized inflow data shown in Figure 1 are identical to that shown in Figure 2 of the May 8th Report.

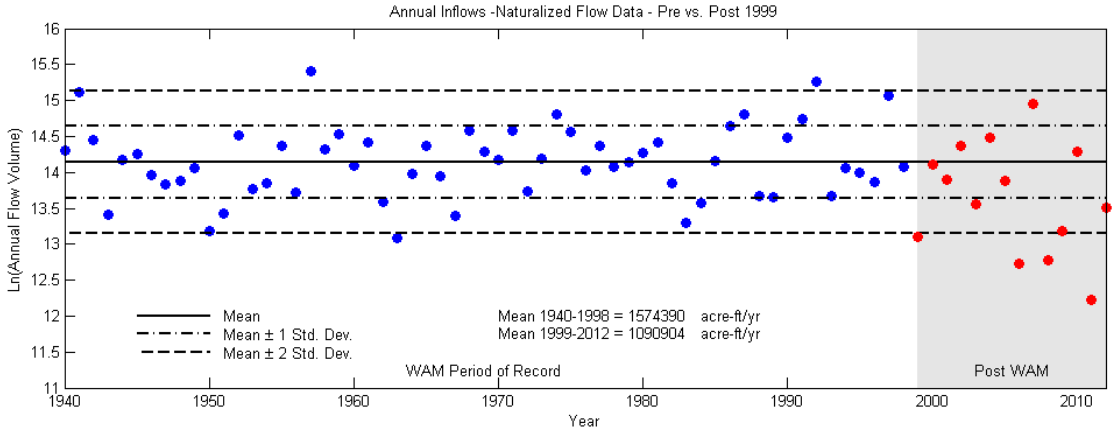


Figure A1 – Annual Total Naturalized Inflows to the Highland Lakes from 1940-2012.

The mean flows and standard deviations from the mean flows shown in Figure 1 were computed using only the TCEQ's accepted naturalized flow data for the period 1940-1998 (blue dots). For the period 1999-2012, there were 5 years in which the highland lake inflows were less than 2-standard deviations below the mean inflow for the period 1940-1998, indicating that the flows were less than the 5th-percentile flows and therefore not very likely to occur. Mean flows for the period 1999-2012 were computed to be 1,090,904 acre-ft/yr, whereas mean inflows used in TCEQ's WAM model were 1,574,390 acre-ft/yr. Thus the mean flows in the more recent time period (1999-2012) were only 69% of the mean flows used in TCEQ's WAM model. WAM modeling to assess future water reliability requires that future inflows match inflows included within the WAM period of record. Based on data from Figure 1, Highland Lake inflows post-1998 are lower than those observed in the TCEQ's WAM period of record, thereby suggesting that TCEQ's WAM should not be used to assess water availability in the Colorado River Basin.

As shown in Figure 1, post-1998 Highland Lake inflows were, on average, 31% lower than inflows pre-1998. To demonstrate the impact of these lower inflows on Highland Lake water availability, INTERA reduced the TCEQ WAM naturalized flows for the period 1940-1998 by 31%, and re-computed Highland Lake combined storage values. The results (Figure 2) indicate that with the reduced inflows, the combined storage of Lakes Buchanan and Travis would have dropped to 0 acre-ft in early 1950, and would have remained essentially empty until 1957 when the drought ended. Also shown in Figure 2 is that the combined storage values computed using the reduced naturalized flow dataset would have periodically dipped below the 600,000 acre-ft mark currently used by LCRA for signaling complete curtailment of all irrigation operations downstream from the Highland Lakes.

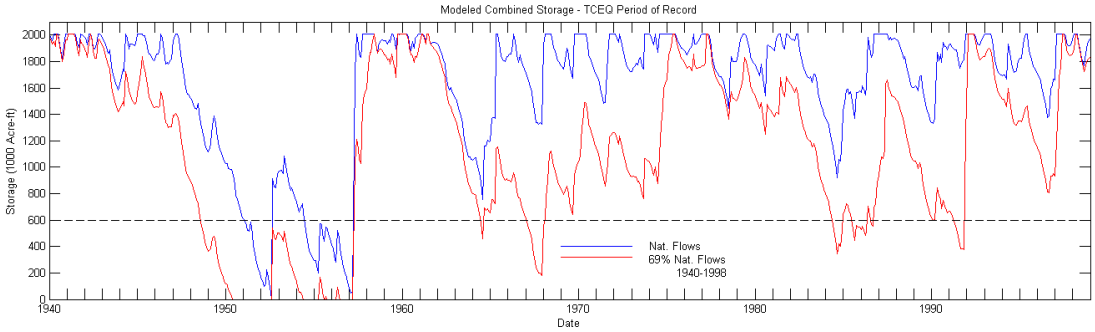


Figure 2 – Modeled Combined Storage in the Highland Lakes using TCEQ Naturalized Flows (1940-1998) and flows reduced by 31% (as observed for the period 1999-2012).

Both the TCEQ and LCRA compute the "firm yield" of the Highland Lakes in assessing water availability in the Colorado River Basin. Typically, a firm yield is the minimum quantity of water able to be withdrawn from a system on an annual basis without causing complete depletion of the system reservoir storage. For the Colorado River Basin, however, TCEQ and LCRA compute the firm yield slightly differently, as:

> *"the average annual amount of water supplied during the critical period. The critical period covers a 10.2 year period from May of 1947 through June of 1957"*
> *(Memo, Page 8)*

By this definition, the firm yield for the Highland Lakes is not the minimum annual amount of available water, but rather an average amount over the currently accepted basin drought of record. Table 1 presents computed firm yields for the Highland Lakes using data from Figure 2 as well as both definitions of firm yield (TCEQ/LCRA's method and the minimum annual available water definition). As indicated, the combined firm yield calculated by INTERA using the method and model adopted by LCRA (TCEQ WAM & period 5/47-6/57) is 473,684 acre-ft/yr, which is higher than the 439,155 acre-ft/yr yield reported by TCEQ (Memo, page 8). The reason for this yield difference was not investigated by INTERA, yet is likely due to INTERA's use of a model developed by LCRA, which differs from TCEQ's WAM model in that before performing their analysis, TCEQ "updated LCRA's WAMs to include more recent amendments to water rights in the Colorado River Basin" (Memo, Page 7).

Table 1 – Highland Lake Firm Yields computed from TCEQ & Reduced Inflow WAMs (1940-1998)

	Period 5/47-6/57	Minimum Annual Availability
TCEQ WAM (1940-1998)	473,684 acre-ft/yr	127,091 acre-ft/yr
Reduced Flows WAM (1940-1998)	297,099 acre-ft/yr	0 acre-ft/yr

As conveyed in Table 1, computing the firm yield as a minimum annually available quantity of water results in yields less than those computed as an average during the critical period. Firm yields are also reduced when modeling using the reduced flows WAM. The firm yield reduces to zero when calculated from the reduced flows WAM using the minimum annual availability approach. This signifies the fact that by reducing naturalized inflows from 1940-1998 by 31% (to match recent averaged flows), there are annual periods when the Highland Lakes would not be able to provide any water to firm or interruptible customers.

One problem with assessing the firm yield using a defined critical period is that the yield cannot be adjusted to reflect conditions observed in a new drought of record (were one to be declared in the future). In TCEQ's "Notice of an Application to Amend the LCRA Water Management Plan," TCEQ stated that complete curtailment of interruptible water releases for the Lakeside, Pierce Ranch, and Gulf Coast operations will be required when combined storage values drop below 600,000 acre-ft. TCEQ also stated that such curtailments will be implemented if the LCRA board declares a drought worse than the drought of record. From these statements, it is suggested that a combined storage value of 600,000 acre-ft is indicative of a new drought of record.

To assess the likelihood of meeting the 600,000 acre-ft combined storage criteria as the current Colorado Basin drought continues, INTERA modified the LCRA WMP WAM models (Firm Yield and 2010 Interim Demand Models) to include naturalized flow data for the years 2010-2016. As previously stated in this report, naturalized inflows to the Highland Lakes for the period 2010 through 2012 were estimated based on gauged inflows to the Highland Lakes, with adjustments made to account for the subordination of Colorado River water flowing into OH Ivie Reservoir. The annual total inflows to the Highland Lakes were then "naturalized" by multiplying the inflows by the largest ratio between measured and naturalized Highland Lake annual inflows from past records. This is a very conservative approach as it results in naturalized flows that are likely higher (wetter) than reality. To extend the naturalized flow dataset for WAM modeling, INTERA determined which year in the LCRA WMP period of record (1940-2009) had the total naturalized inflow to the Highland Lakes most similar to the naturalized annual inflow computed based on gauged records (for years 2010, 2011, and 2012). INTERA then modified the WAM-specified naturalized flows for each modeled control point according to the ratio of the total annual WAM inflow to the total annual naturalized gauged flows. For example, the total annual naturalized Highland Lake inflow for 2010 was computed to be 1,594,419 acre-ft/yr, which is nearly identical to the total naturalized inflows for 1969. Therefore in modeling 2010, INTERA used naturalized flows from 1969. No corrections were made for the seasonal pattern of flows occurring in any given year. In a similar manner, INTERA calculated naturalized flows for 2011 to be equal to 60% of the naturalized flows for 2006, and the naturalized flows for 2012 were 96% of the naturalized flows from 2003. INTERA approximated a continuing drought by modeling years 2013-2016 with are repeat of years 2006, 2008, 2006, and 2008 respectively.

WAM modeling results obtained with INTERA's extended naturalized flow dataset (1940-2016) are presented in Figure 3, along with a time-history of observed combined storage values for Lakes Buchanan and Travis from October 1942 – April 2013. Also shown on Figure 3 is the 600,000 acre-ft combined storage threshold for identifying a new drought of record.

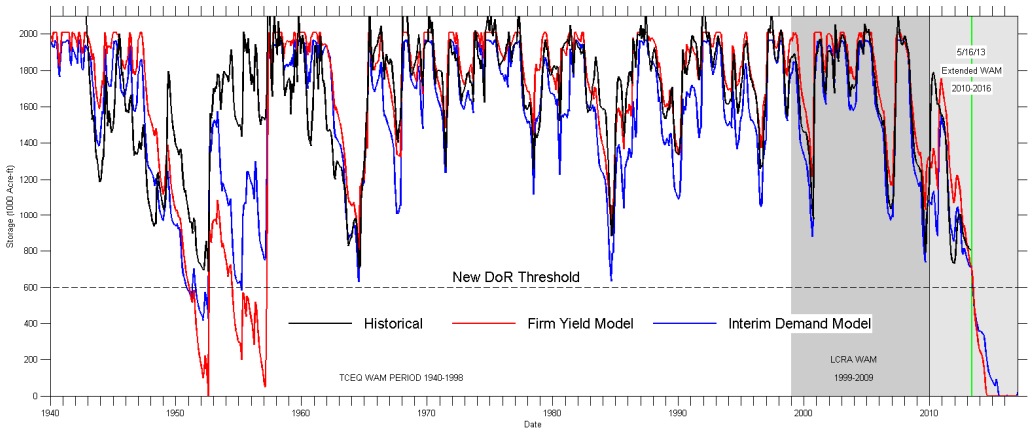


Figure 3 – Historical and WAM-modeled combined storage of Lake Buchanan and Lake Travis, using INTERA's extended 1940-2016 naturalized flows dataset.

Notable aspects of the modeling results presented in Figure 3 include:

- Large differences between modeled and historical combined storages during the 1947-1957 drought of record, with historical storages exceeding modeled levels
- Excellent agreement between historical and interim demand model storages during the 1963-1965 dry period
- Historical storages typically in between modeled storages calculated using the firm yield and interim demand models for the period from 1990-2009.

It is also notable that for both the interim-demand and firm yield models, the continued dry period from 2010 onward causes modeled combined storage to drop to zero by mid 2014, passing the 600,000 acre-ft combined storage threshold in July of 2013. INTERA notes, however, that the historical combined storage in April 2013 was approximately 100,000 acre-ft higher than the modeled combined storage at this time, suggesting perhaps that the modeled date for crossing the drought of record threshold is too early.

Figure 4 presents the results from INTERA's WAM modeling using the extended (1940-2016) naturalized flow dataset, showing the time-history of computed releases from storage in Lakes Buchanan and Travis. As shown, releases from the Firm yield model are lower outside of the dryer portions of the period of record, and tend to increase during both the current drought of record (1947-1957) and the current drought (2010-2016). The lower releases during the non-drought period reflect the fact that more water is available from the watershed below Lake Travis to meet the demands of water users. This trend is not evident in the interim demand model, however, where interruptible water releases are made for agricultural usage. Releases under both models decrease to near zero levels toward the end of the current drought period (2010-2016).

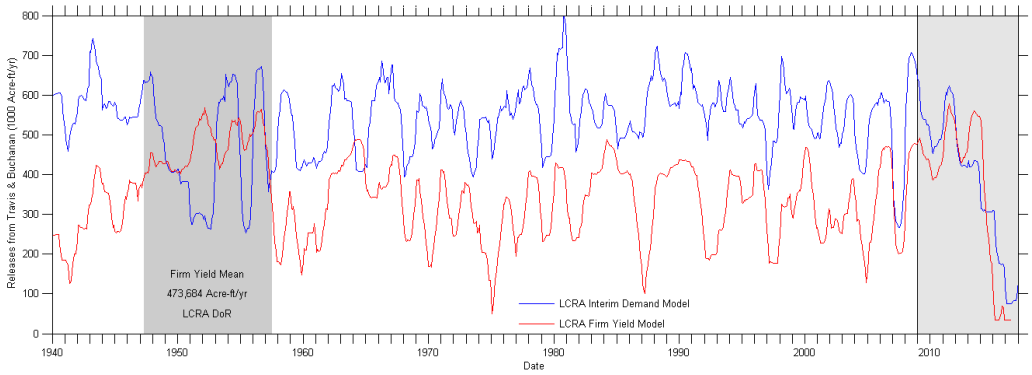


Figure 4 – Modeled Releases from Lake Travis and Lake Buchanan

In addition to the standard WAM modeling discussed above, it is possible to use existing features within the WRAP software along with existing WAM models to statistically address the likelihood of future reservoir storage conditions based on current lake levels and past hydrology. This little-used feature of WRAP is called "Conditional Reliability Modeling (CRM)," and it allows for the assessment of likely future conditions given the water management constraints implemented in the WAM model. INTERA applied CRM to the LCRA interim demand model to assess the likely combined storage level in Lake Buchanan and Travis after 4-month and 12-month periods when the initial combined storage level was set at 40%. This model scenario mimics the 2013 calendar year, in that the combined storage on January 1, 2013 was approximately 40% of the maximum combined storage for the Highland Lakes. The results of CRM, therefore, statistically demonstrate the likelihood of obtaining certain storage levels by May 1st 2013 and by December 31st, 2013, respectively.

Figure 5 presents the likelihood of exceeding a given combined storage quantity on May 1st and December 31st with lake storages at 40% on January 1st. As shown for the December 31st combined storages, there is a 25% chance that storages would decrease below the 600,000 acre-ft threshold triggering a new drought of record. However storages are likely to increase for nearly 65% of all modeled 12-month scenarios. In contrast, May 1st storages are likely to be less than January 1st storages nearly 55% of the time, yet there is an approximate 1% chance of dropping below the 600,000 acre-ft threshold for triggering a new drought of record.

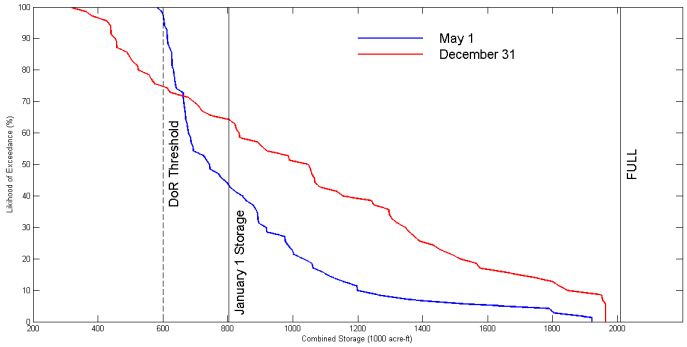


Figure 5 – Conditional Reliability Modeling Results – Likelihood of Exceedance for May 1st and December 31st Combined Storage computed using the LCRA Interim Demand WAM, assuming 40% lake storage on January 1st of each year.

2.0 PROJECTED STORAGE UNDER WMP CONDITIONS

In 2012 and 2013, LCRA was granted permission by TCEQ to manage water resources outside of the requirements stipulated in the current WMP or in the WMP that is pending approval. These "emergency orders" allowed LCRA to withhold interruptible water releases and therefore retain greater quantities of water within the Highland Lakes. As such, in 2012 and in 2013, there were not and have not been any releases of interruptible water. INTERA performed a water accounting analysis to determine what the combined storage in the Highland Lakes would be "now" (as of 5/21/2013) had emergency orders not been issued. Without the emergency orders in place, LCRA would have made interruptible water releases according to published curtailment curves. This analysis shows that under either the current or pending WMP, without emergency orders the combined storage in the Highland Lakes would drop below 500,000 acre-ft, triggering the recognition of a drought worse than the drought of record.

For this analysis, INTERA started from the combined storage value observed on January 1, 2012 and "projected" forward into the future by using the observed storage changes (without interruptible water releases) and adding releases dictated by the WMP curtailment curves. INTERA performed separate analyses using the current WMP curtailment curves and using the pending WMP curtailment curves. For each analysis, INTERA assumed that storage changes observed from 2012 to the present would have occurred in the same timing and magnitude whether or not interruptible water releases were being made. INTERA did not account for reduced evaporative losses that would occur after interruptible water releases when lake surface areas would be smaller. INTERA also assumed that 1st crop releases would be completed before May 21 of each year, and that 2nd crop releases under the current WMP curtailment curves amount to 27% of the total releases for the year. This percentage is the approximate percentage of the 2nd crop release out of the total curtailment release under the proposed WMP.

The curtailment curves in the current WMP are based entirely on the combined storage on January 1. Curtailment curves for 1st crop releases in the pending WMP are based on the maximum combined storage on January 1 or March 1 of a given year. Similarly, curtailment curves for 2nd crop releases in the pending WMP are based on the maximum combined storage on June 1 or August 1 of a given year. To determine the combined storage of Lakes Buchanan and Travis at the dates needed for this assessment, INTERA obtained lake levels from the USGS NWIS system, and converted the lake levels to storage quantities through the use of TWDB volume-elevation tables published in 2006 (for Lake Buchanan) and in 2009 (for Lake Travis). USGS NWIS data was not available for January 1, 2013, yet LCRA reported a combined storage value of 825,000 acre-ft on this date. Table 2 presents the observed combined storage values used in this analysis.

Table 2 – Observed Highland Lake Combined Storage Volumes

Date	Combined Storage (acre-ft)	Change (acre-ft) Current WMP Scenario	Change (acre-ft) Pending WMP Scenario
January 1, 2012	738,715		NA
March 1, 2012	846,359		107,644
June 1, 2012	1,028,665		182,306
August 1, 2012	964,768		-63,897
January 1, 2013	825,000	86,285	-139,768
March 1, 2013	822,782		-2,218
May 21, 2013	782,367	-42,633	-40,415

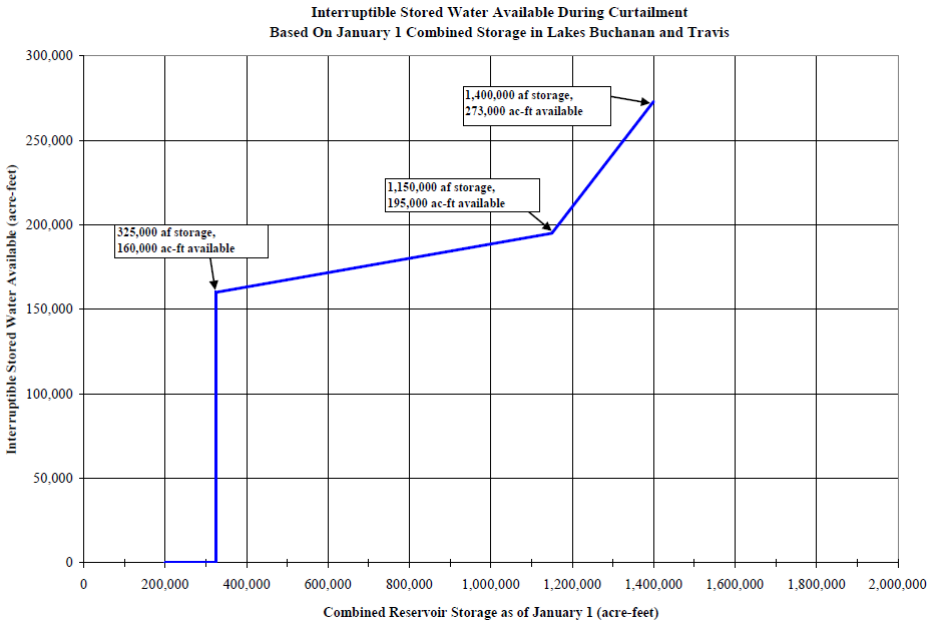


Figure 6 – Interruptible Water Curtailment Curve in the current LCRA WMP. (Source: LCRA)

Under the current WMP, interruptible releases are calculated based on the curtailment curve shown in Figure 6. With the January 1, 2012 combined storage of 738,715, the curtailment curve requires the release of 180,044 acre-ft from Highland Lake storage. Combined with the observed increase in storage from January 1, 2012 to January 1, 2013, the projected January 1, 2013 storage is calculated as:

	$Storage_{January\ 1,\ 2012}$		738,715	Acre-ft
+	$Storage\_Change_{January\ 1,\ 2012\ to\ January\ 1,\ 2013}$	+	86,285	Acre-ft
-	Interruptible Release	-	180,044	Acre-ft
	$Projected\_Storage_{January\ 1,\ 2013}$		644,956	Acre-ft

With a projected storage on January 1, 2013 of 644,956 acre-ft, the required interruptible water release is 176,635 acre-ft. This amount is the total amount to be released for both 1st crop and 2nd crop, yet only releases for 1st crop would occur before May 21, 2013. Assuming the 1st crop release is 73% of the total release, the projected 2013 1st crop release quantity is 128,944 acre-ft. Combined with the observed decrease in storage from January 1, 2013 to May 21, 2013, the projected May 21, 2013 storage is calculated as:

	$Projected\_Storage_{January\ 1,\ 2013}$		644,956	Acre-ft
+	$Storage\_Change_{January\ 1,\ 2013\ to\ May\ 21,\ 2013}$	+	-42,633	Acre-ft
-	Interruptible 1st Crop Release	-	128,944	Acre-ft
	$Projected\_Storage_{January\ 1,\ 2013}$		473,379	Acre-ft

Therefore the projected May 21, 2013 combined storage under the current WMP would be 473,379 acre-ft.

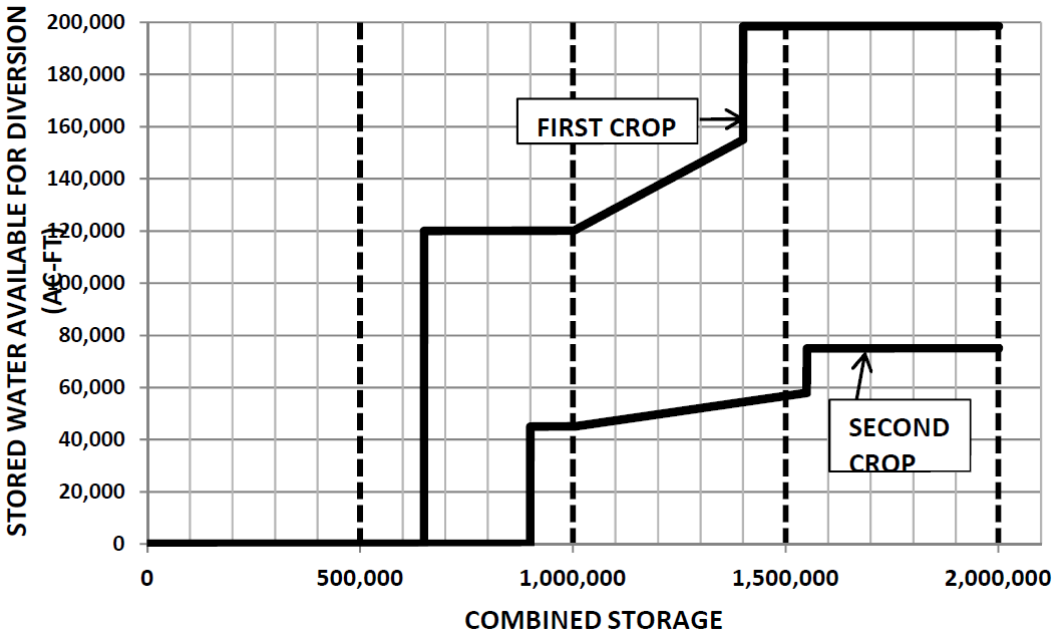


Figure 7 – Interruptible Water Curtailment Curve in the proposed LCRA WMP. (Source: LCRA)

Under the proposed WMP, interruptible releases are calculated based on the curtailment curve shown in Figure 7. With the March 1, 2012 combined storage (846,359 acre-ft) being larger than the January 1, 2012 combined storage (738,715 acre-ft), the March storage value dictates a 1st crop release of 120,000 acre-ft. Combined with the observed increase in storage from January 1, 2012 to March 1, 2012 and the observed increase in storage from March 1, 2012 to June 1, 2012, the projected June 1, 2012 storage under the proposed WMP curtailment curve is calculated as:

	$Storage_{January\ 1,\ 2012}$		738,715	Acre-ft
+	$Storage\_Change_{January\ 1,\ 2012\ to\ March\ 1,\ 2012}$	+	107,644	Acre-ft
+	$Storage\_Change_{March\ 1,\ 2012\ to\ June\ 1,\ 2012}$	+	182,306	Acre-ft
-	Interruptible 1st Crop Release	-	120,000	Acre-ft
	$Projected\_Storage_{June\ 1,\ 2013}$		908,655	Acre-ft

As the observed storage decreased between June 1, 2012 and August 1, 2012 (See Table 2), the June 1, 2012 storage would be used to calculate 2nd crop interruptible releases. With a projected storage on June 1, 2012 of 908,655 acre-ft, the required interruptible 2nd crop release is 45,000 acre-ft. Combined with the observed decrease in storage from June 1, 2012 to August 1, 2012 and the observed storage decrease from August 1, 2012 to January 1, 2013, the projected January 1, 2013 storage is calculated as:

	$Projected\_Storage_{June\ 1,\ 2012}$		908,655	Acre-ft
+	$Storage\_Change_{June\ 1,\ 2012\ to\ August\ 1,\ 2012}$	+	-63,897	Acre-ft
+	$Storage\_Change_{August\ 1,\ 2012\ to\ January\ 1,\ 2013}$	+	-139,768	Acre-ft
-	Interruptible 2nd Crop Release	-	45,000	Acre-ft
	$Projected\_Storage_{January\ 1,\ 2013}$		659,990	Acre-ft

As the observed combined storage on March 1, 2013 was less than the observed combined storage on January 1, 2013, the January 1, 2013 combined storage dictates the volume of interruptible 1st crop release. With a projected storage on January 1, 2013 of 659,990 acre-ft, the required interruptible 1st crop release is 120,000 acre-ft. Combined with the observed decrease in storage from January 1, 2013 to March 1, 2013 and the observed decrease in storage from March 1, 2013 to May 21, 2013, the projected May 21, 2013 storage is calculated as:

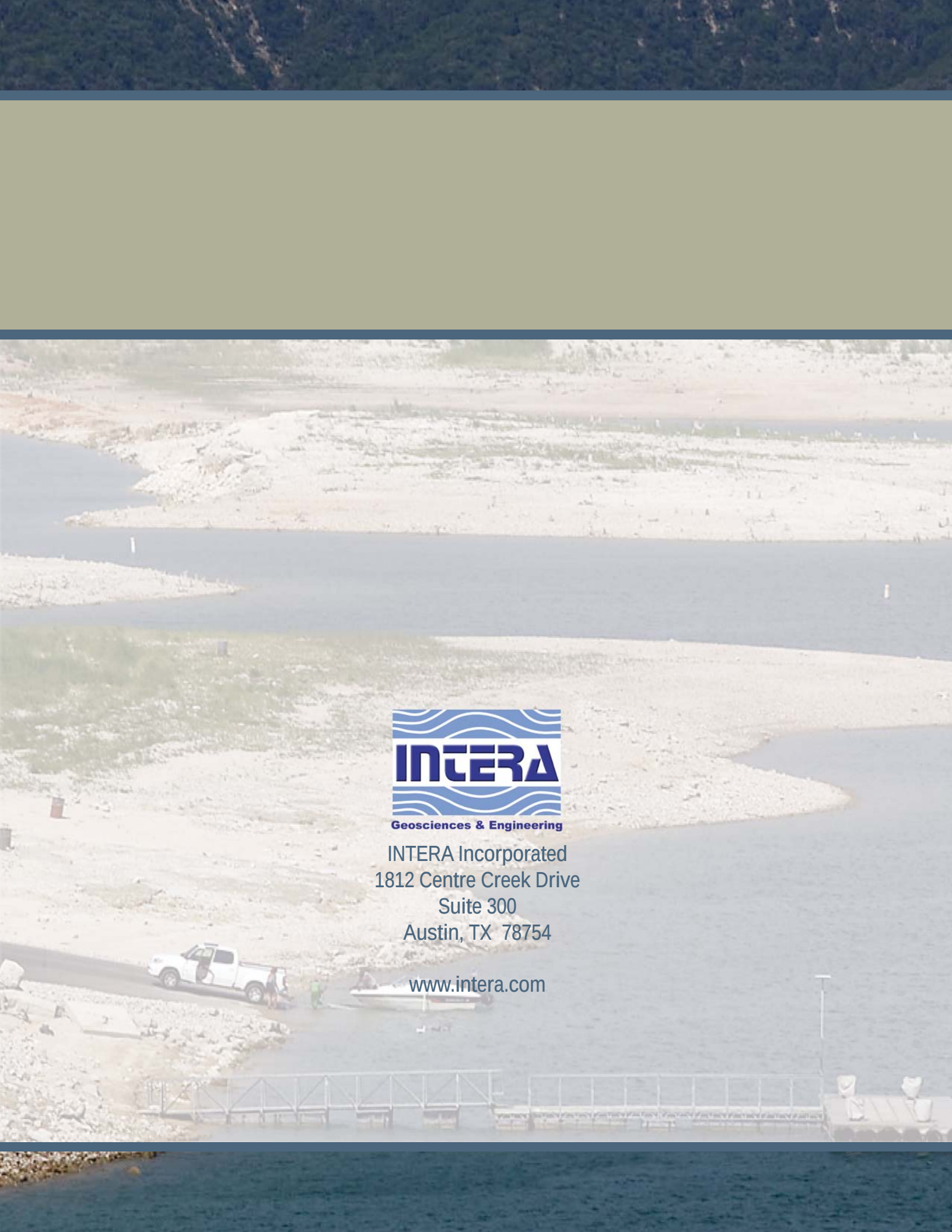
	$Projected\_Storage_{January\ 1,\ 2013}$		659,990	Acre-ft
+	$Storage\_Change_{January\ 1,\ 2013\ to\ March\ 1,\ 2013}$	+	-2,218	Acre-ft
+	$Storage\_Change_{March\ 1,\ 2013\ to\ May\ 21,\ 2013}$	+	-40,415	Acre-ft
-	Interruptible 1st Crop Release	-	120,000	Acre-ft
	$Projected\_Storage_{May\ 21,\ 2013}$		497,357	Acre-ft

Therefore the projected May 21, 2013 combined storage under the proposed WMP would be 497,357 acre-ft.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Despite the fact that LCRA has extended the TCEQ-published naturalized flow series for the 2010 WMP, the use of naturalized flows for 1940 to 2009 is not a good basis for determining future water availability in the Lower Colorado Basin. The naturalized flow dataset needs to be officially extended through to the end of 2012 and serious consideration needs to be given to the evidence presented in the May 8th report and this report that the hydrology of the basin has shifted significantly downwards. Reducing the full naturalized flow dataset by 31 percent for recalculation of the firm yield and reassessment of water availability is a possible and reasonable approach in the short term. However, we will not know how bad the current drought is or by how much the firm yield should be reduced until the drought has broken or we have a good understanding of the new hydrology of the basin. Until that time, policy-makers should take a conservative approach to water management to ensure that there remains sufficient water in the basin to meet the needs of firm customers under uncertain future conditions. In very short order, we need to revisit the data, models, techniques, triggers and rule curves for management of the Highland Lakes in order properly to deal with this changed hydrologic condition.

Neither the current nor proposed WMPs would have provided sufficient drought protection for LCRA's firm water customers during the 2012-2013 current drought. A new WMP must be developed that provides such firm water protection without the need for continual emergency orders to be issued by the TCEQ.



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