CE394K – GIS IN WATER RESOURCES
TERM PROJECT REPORT

WATER BALANCE FOR THE LOWER COLORADO RIVER AUTHORITY:
AN INVESTIGATION INTO THE ROLE OF MUNICIPAL WATER DEMAND

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EXECUTIVE SUMMARY

This report contains the details of a study into the role of municipal (i.e. residential) demand for water services on the water balance of the Lower Colorado River Basin. The report is organized into 5 sections, beginning with an introduction into water management strategies and the role of municipal demand in water management as well a description of the goals of this project. A background of the current drought conditions in the lower Colorado River Authority (LCRA) is then presented, with an explanation of the effect of population forecasts as well as description of the particular water management strategies outlined for Region K, the LCRA, in the 2012 State Water Plan prepared by the Texas Water Development Board (TWDB). An explanation of the methodology used to calculate the total water balance for the LCRA, using Geographic Information Systems (GIS) tools as well as historical records of water stored in the Highland Lakes reservoirs will then be given and the results of the water balance will be presented.

These results were then correlated to estimated population projects for the next 5 decades, until 2060, in order to anticipate the effect that technically feasible improvements and adoption of water-efficient technologies will have on supply-side infrastructure, specifically the storage of water within the Highland Lakes reservoirs within the LCRA. Conclusions were be drawn regarding any discrepancies in data collected and calculated as well as their correlation to municipal demand. Finally, future work endeavors will be presented to outline suggested areas of study based on the results.

It was found that the water levels in the Lake Buchanan and Lake Travis reservoirs, which are used to supply water to the LCRA municipalities, are heavily dependence both on hydrologic fluxes as well as demand from firm water user groups. In most cases, changes in water demand correlated to hydrologic changes, indicating the high level of dependence of municipal demand on environmental supply.

Analysis was performed to determine the required percent reduction of municipal demand for each of the scenarios outlined in the TWDB 2012 State Water Plan. Additionally, the impacts of conserved water volume associated with each scenario were applied to supply-side infrastructure in the form of effect on monthly reservoir level variation. In Lake Buchanan, conservation efforts through efficiency amplified variations in the reservoir, possibly indicating insufficient storage capacity. However, in Lake Travis, conservation efforts showed mostly no effect on required storage and sometimes decreased reservoir storage fluctuations, which is to be expected for a less volatile demand schedule.

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INTRODUCTION

History of Drought Conditions in Texas

The current drought of record for the state of Texas occurred from 1950 to 1957, characterized by extremely low rainfall, resulting in low streamflow and loss of livestock and crops. Lakes Travis and Buchanan, were built in order to store excess water during wet weather and release water in times of drought such as those experienced in the 50s. The lowest combined storage between lakes Buchanan and Travis totaled just over 600,000 acre-ft in 1952, the lakes have a combined capacity of 2.01 million acre-ft, meaning that at their lowest levels, the two lakes were approximately 30% full.

Currently, Lakes Buchanan and Travis have a combined storage representing 37% of the total capacity, approximately 750,000 acre-ft, dangerously close to the current drought of record. However, the lakes have only reached these low levels since 2011, though 5 out of the 10 lowest inflows on record into the lakes have occurred within the last decade with inflows in 2013 rivaling those of the drought on record. The LCRA classifies drought conditions worse than the drought of record as 24 months since lakes Travis and Buchanan were last full, the inflows into the lakes are equal to or less than the drought of record, and the combined storage of both lakes is less than 30% full. With two of these three criteria already satisfied, the LCRA is dangerously close to drought conditions similar to those in the 1950s.

LCRA Water Management Strategies

For the LCRA, the water from the Highland Lakes is distributed to “firm” customers such as cities, power generation plants, and industries, and “interruptible” customers, mostly comprised of agriculture demands. During times of drought, water supply is ceased for interruptible customers, however supply for firm customers must remain available. Seven reservoirs make up the highland lakes: Lake Buchanan, Inks Lake, Lake Marble Falls, Lake Lyndon B Johnson, Lake Travis, Lake Austin, and Lady Bird Lake. Of these lakes, lakes Buchanan, LBJ, Travis and Austin, provide drinking water for the LCRA, while the other lakes provide recreation, power generation, and flood control capabilities. However, lakes LBJ and Austin are kept at near constant levels at all time, in order to provide water to municipalities, while Lake Buchanan and Lake Travis are allowed to fluctuate according to hydrologic fluxes. Therefore, the changes in storage volumes of these two lakes can be taken as proxies for total water demand from firm and interruptible customers. In the event that combined storage drops below 600,000 acre-ft, service to firm customers will begin to be curtailed. However, efforts are being made to curb demand for water services by all categories of customers. Table 1 shows the breakdown of water use from the Highland Lakes, which provide approximately 39% of all water surface water withdrawals by the LCRA, according to usage category for the year of 2012. Municipal demands represent a major area for effective water management supply strategies.

Water Rights Group	*2012 Use (acre-ft)*	*% Total Demand*
Municipal	*122360*	*65.08%*
Industrial	*19133*	*10.18%*
Agricultural	*8896*	*4.73%*
Recreational and Firm Irrigation	*6338*	*3.37%*
Environmental Releases	*31285*	*16.64%*
Emergency Hydroelectric Releases	*0*	*0.00%*

Table 1: 2012 Water Use by Category

2012 TWDB State Water Plan

Every 5 years, the Texas Water Development Board develops a state water plan, outlining population and correlated water service demand projections for future decades, and comparing these projections against total water supply projections. Based on the estimated availability of water, the TWDB then recommends water management strategies on a regional basis in order to ensure adequate supplies in case of water scarcity, such as those condition facings the LCRA (Region K) now. Management strategies range from conservation and adjustment of water rights allocations to desalination and development of new storage capacity.

According to the 2012 State Water Plan, the LCRA population is expected to double by 2060. The corresponding municipal water demand is expected to increase by 73% while overall water usage is only expected to increase by approximately 21%. The disparity in water demand projections is due to large estimated decrease in demand for irrigation and large estimated increase in municipal demand, with other usage categories increasing only slightly from current usage. The water management strategies outlined for Region K are estimated to supply an additional 650,000 acre-ft of water by 2060, though **recommended** water supply strategies for Region K are only expected to provide an additional 240,000 acre-ft, while projected water needs for 2060 (the difference between current available supply and estimated demand) are expected to reach 370,000 acre-ft. This leaves 130,000 acre-ft of unmet water needs that will most likely be placed on the irrigation sector, with expected cutbacks in water allocation for irrigation use.

Role of Efficiency and Conservation in Water Supply Management Strategies

About 7% of the recommended supply volume increase is expected to come from municipal conservation, representing about 17,400 acre-ft of the estimated 240,000 acre-ft. While behavioral adjustments can create the necessary reductions in water demand, they are hard to quantify and do not provide consistent resource benefits. Adoption of demand-side efficiency technologies in the building sector however, can be estimated based on engineering economic analysis. These technologies include EnergyStar clothes washers and dishwashers, as well as ultra-low-flow (ULF) toilet fixtures, low-flow showerheads, and faucet aerators. Although a complete engineering economic analysis is beyond the scope of this project, the technically feasible adoption rate per year in order to achieve the estimated savings from conservation can be calculated.

Project Goals

This project aims to assess the feasibility of the expected water supply savings from municipal conservation efforts outlined in the recommended water management strategies for Region K in the 2012 State Water Development Board, and to assess the effects on supply side infrastructure, specifically the Highland Lakes Reservoirs. In order to accomplish this analysis, a water balance model for lakes Buchanan and Travis will be developed in order to determine the hydrologic fluxes affecting the drainage areas of each lake. This hydrologic data will be compared to historical changes in the reservoir storages from 2009 to present day in order to determine the periods of time when water was either stockpiled in the reservoir or discharged downstream for municipal consumption. Using these correlations, technically feasible water demand reductions from adoption of demand-side efficiency technologies will be estimated and the resulting impacts on total reservoir storage requirements will be determined.

METHODS

Study Areas

The Highland Lakes are a collection of seven reservoirs located in the LCRA that store and provide water for the LCRA residents. In order to assess the hydrologic fluxes associated with Lakes Buchanan and Travis, the drainage areas for each reservoir was delineated using GIS tools in ArcGIS, specifically the elevation tools provided by ESRI. Figures 1 and 2 present the LCRA (Region K) study area as well as a zoomed in view of the drainage areas associated with each reservoir. Note that there are 8 points in Figure 2. The north-most point represent the O.H. Ivie Reservoir, which was used to delineate the drainage area upstream of Lake Buchanan, and was not used in the water balance calculations.

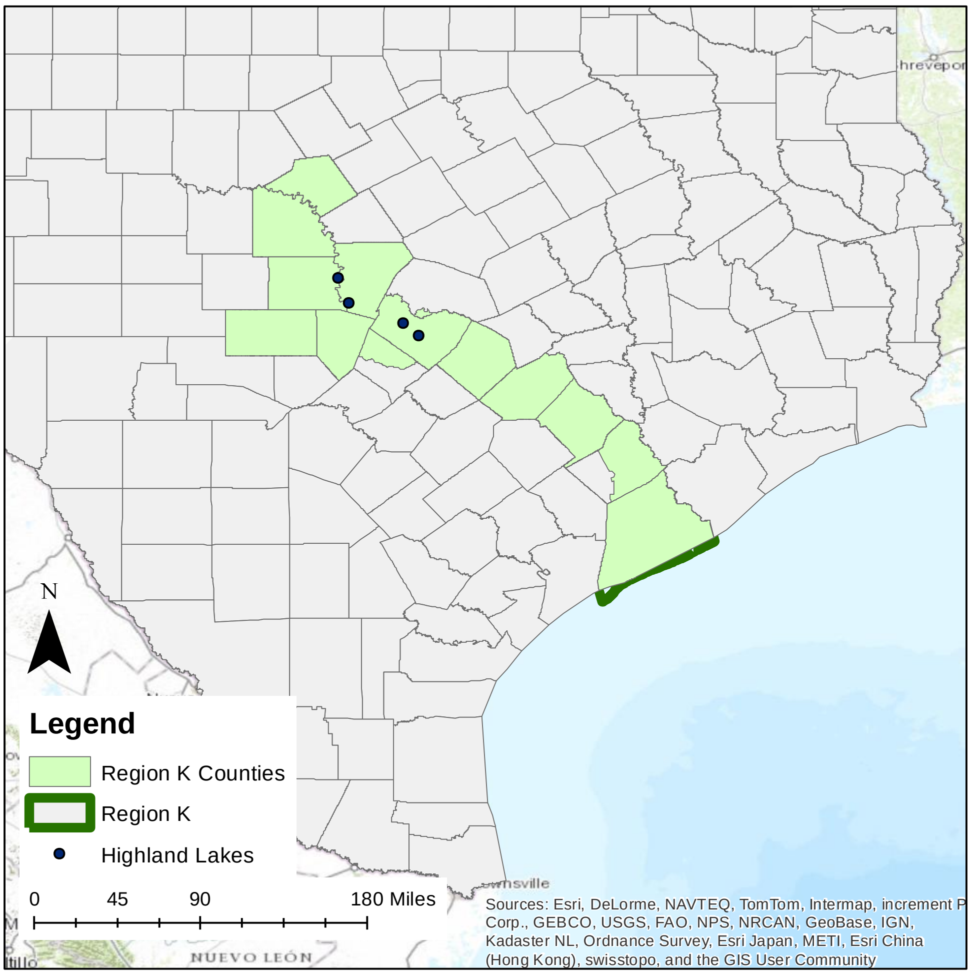

Figure 1: Region K - Lower Colorado River Authority and Highland Lakes Drinking Water Reservoirs

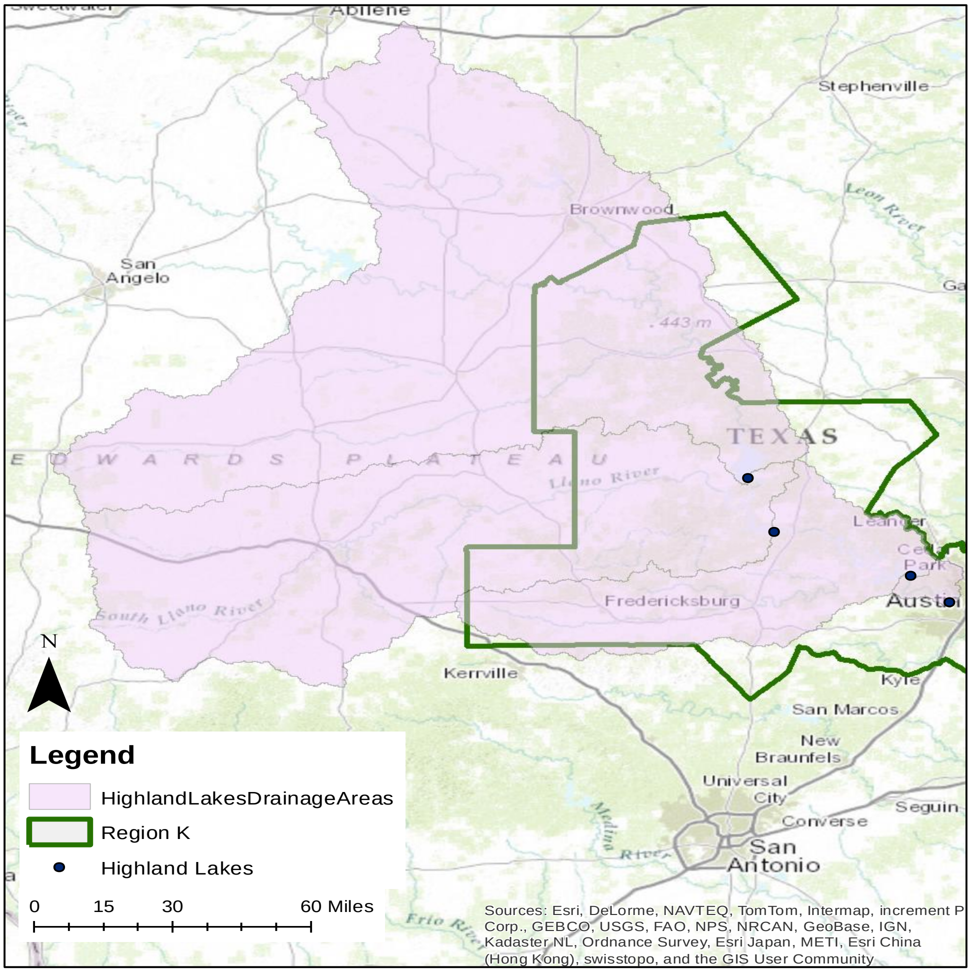

Figure 2: Highland Lakes Catchments

The drought conditions affecting Region K were first assessed using data from the World Water Online GRACE Anomaly data. The gravity anomaly associated with each month was compared to the average historic reservoir levels during that month. From the data, it is clear that the LCRA underwent severe drought conditions several times throughout the time span of 2009 to present day. Figure 3 shows the transitions from normal to drought conditions, several times throughout the course of the time area studied. Specifically, from August of 2011 to present day, the main source of water for the LCRA have shown levels less than half-full, qualifying for classification of conditions similar to the drought of record. Note that only four reservoirs are shown, these represent the reservoirs that provide drinking water to the LCRA. From north to south, the reservoirs are Lake Buchanan, Lake Lyndon B Johnson, Lake Travis, and Lake Austin. Almost all of the fluctuation in reservoir level is seen from Lake Buchanan and Lake Travis, while Lake LBJ and Lake Austin are kept near constant at all times. It is reasonable to assume that the inflow is equivalent to the outflow for the constant-level reservoirs and therefore do not reflect changes in hydrologic storage. Therefore, *Lakes Buchanan and Travis were chosen as the significant study areas for the water balance calculation.*

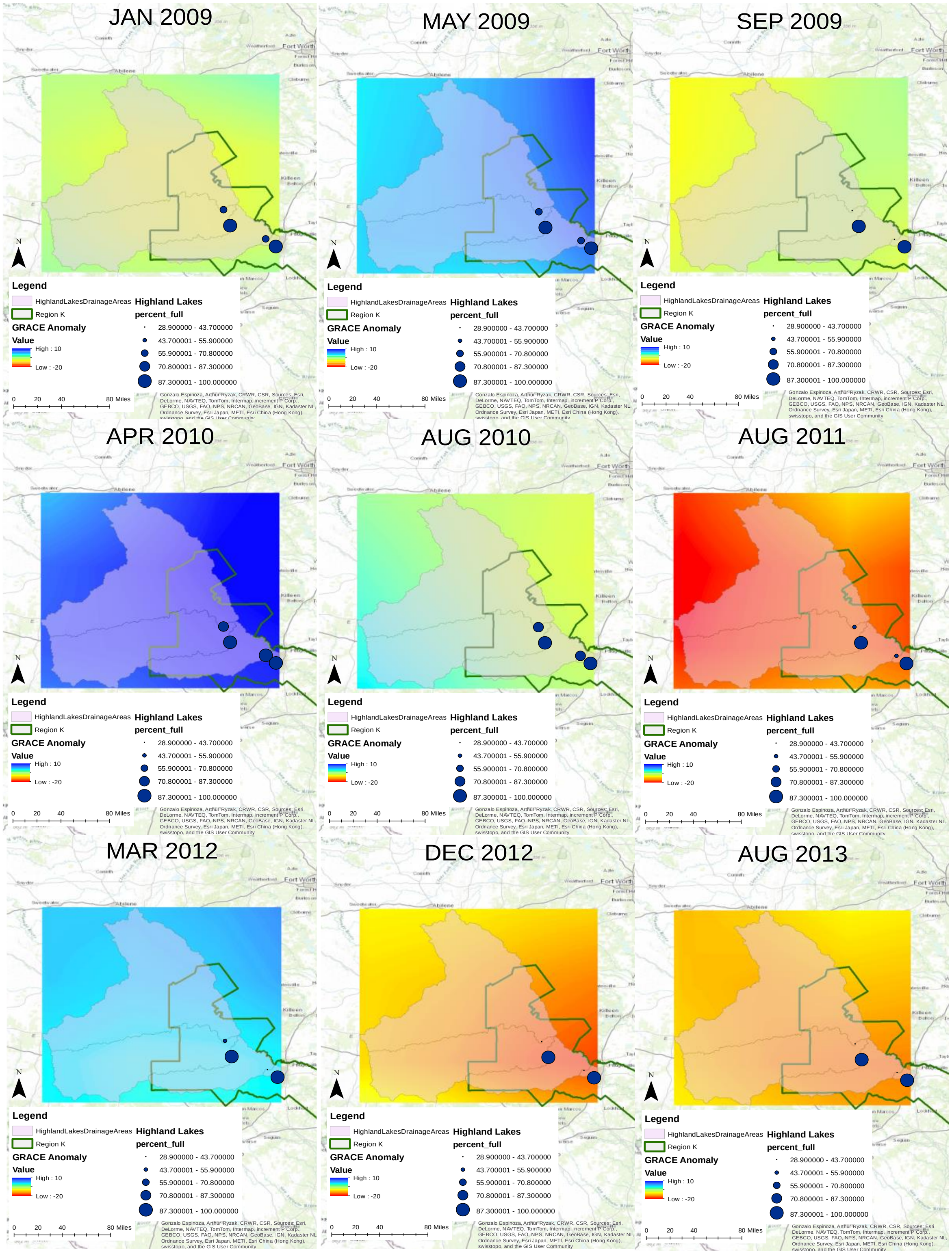

Figure 3: GRACE Anomaly and Reservoir Storages

Water Balance Methodology

NLDAS Tools

In order to calculate the hydrologic water balance, several sets of data were needed. Two separate methods were used to calculate the average monthly change in water storage for the drainage area contributing to reservoirs of study. First, tools developed by Gonzalo Espinoza-Davalos of University of Texas-Austin were used to download monthly hydrologic flux and hourly hydrologic storage data for both drainage areas on a 1/8 arcsecond grid resolution. The download process was automated using a Python script developed by Dr. David Tarboton of Utah State University, with modifications to analyze the drainage areas of interest. Once the appropriate data was downloaded, the grid data was averaged over each drainage area in order to calculate monthly changes in rainfall, snowfall, evapotranspiration, surface runoff, baseflow, plant canopy storage, soil moisture storage within the top 200 cm of the soil column, and the snow-water equivalent volume associated with each drainage area. The zonal averaging was also completed using a Python script developed by Dr. Tarboton and modified for this case study. These monthly data averages were used as the inputs into the standard formula for a water balance shown:

$$(SM + Cstor + SWE)_{T1} - (SM + Cstor + SWE)_{T2} = RF + SF - ET - Q_{base} - Q_{surface}$$

Where:

SM = Soil Moisture Storage
Cstor = Plant Canopy Storage
SWE = Snow-Water Equivalent Storage
RF = Rainfall
SF = Snowfall
ET = Evapotranspiration
Q_{base} = Baseflow
$Q_{surface}$ = Surface Runoff
T2 = beginning of month 2
T1 = beginning of month 1
*all units in mm

The results of the hydrologic water budget are presented in the Results section of this report.

Historic Reservoir Level Data

The second method used historic reservoir storage data collected by the TWDB and available at the WaterDataforTexas.org website. Although historical data was available from the beginning of operation for each reservoir, the reservoir storage from January 1st, 2009 to September 30th, 2013 was used for this analysis, in order to capture time periods before and during the current drought conditions. The daily change in storage for each reservoir was then calculated and summed over monthly intervals to determine monthly changes in recorded storage volumes. The difference between the monthly recorded storage and the hydrologic storage for the month was taken to be to total change in storage for the drainage area. Using this rationale, positive values represent time period were more water was released from the reservoir than was taken in, corresponding to a decrease in combined reservoir and drainage area storage and negative values represent time periods where more water was taken in than released, corresponding to an increase in combined reservoir and drainage area storage.

Municipal Water Usage Estimates

With the assumption that this difference represents the total water supplied or stored for the area, the volume of water used for municipal demand was estimated using the municipal percentage of total water demand presented in the first section of this report, giving the total water supplied to municipal demand sources for 2012. This total water volume was then divided by the 2012 Region K population to find a per capita water use for 2012. This per capita use could then by applied to future population projections to estimate the total municipal demand for Region K at future population estimates.

The projected municipal demands presented in the 2012 TWDB State Water Plan already incorporated savings from adoption of end-use efficiency technologies. Therefore, assuming that efficiency technology provided 100% of the water supply savings from municipal conservation, the difference between the water supply estimated in the State Water Plan and the water demand volume extrapolated from current water usage represents the estimated savings from future adoption of efficiency technologies. Finally, a first-order analysis of the impacts of the estimated water savings was conducted by comparing these volumes to the current storage capacities of Lake Buchanan and Lake Travis, to assess the suitability of current infrastructure to handle increases in storage volumes associated with decreased municipal demand.

Additionally, the effects of projected demand reductions were applied to the current reservoir storage conditions in order to determine the effect that demand reduction through adoption of efficient technologies would have on the current drought conditions and supplies.

RESULTS AND ANALYSIS

Water Balance Summaries

Using the data supplied by NOAH via the NLDAS toolbox, the monthly hydrologic fluxes for the drainage areas contributing to Lake Buchanan and Lake Travis were compared to the monthly change in storage calculated by summing soil moisture storage, plant canopy storage, and snow-water equivalent storage. The data for both catchments are compared in Figure 4.

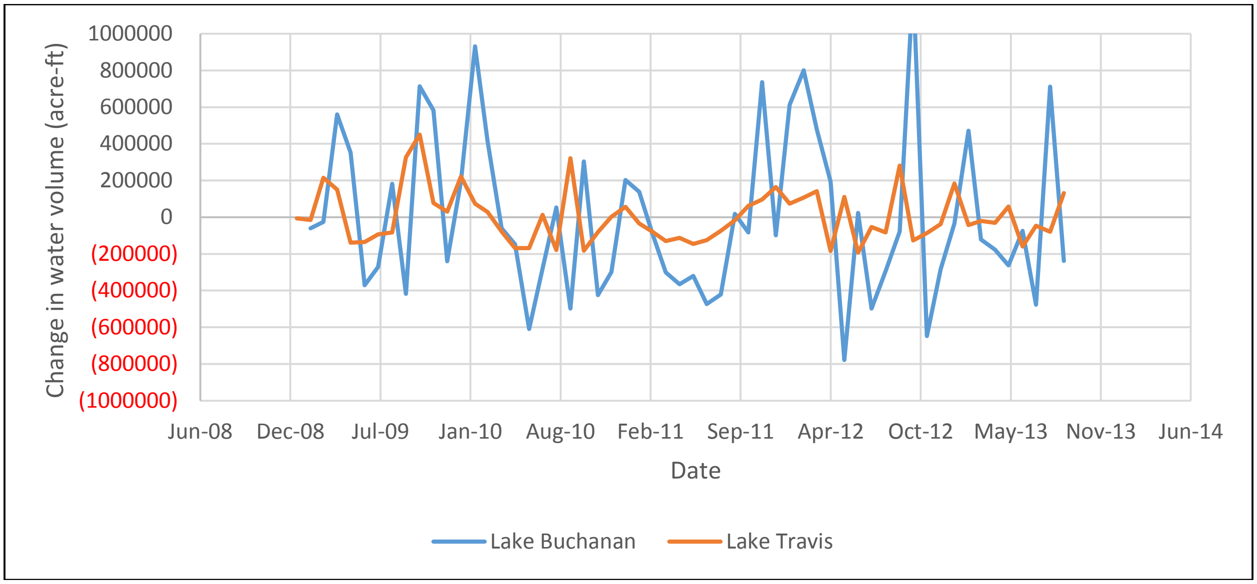

Figure 4: Monthly Changes in Hydrologic Storage

The data between the two are similar in terms of trends, however the volume of water variability is larger for Lake Buchanan, which is expected. In this graph, positive values indicate time period when inputs outweighed hydrologic losses, while the opposite is true for negative values. Note that the period from February 2011 to September 2011 shows constant losses from hydrologic flux, also shown in Figure 3. This data alone represents the hydrologic conditions affecting the catchment areas for the two main drinking water supply reservoirs in the LCRA. Figure 5 shows the historical changes in reservoir storage plotted for the same time period. Note the corresponding negative change in reservoir storage from February 2011 to September 2011. For most months, the change in reservoir storage is negative, indicating that more water was being released to customers than was being stored. Using these two relationships, an estimate for total water supplied to water service customers was created, by taking the difference between changes in reservoir storage and hydrologic fluxes.

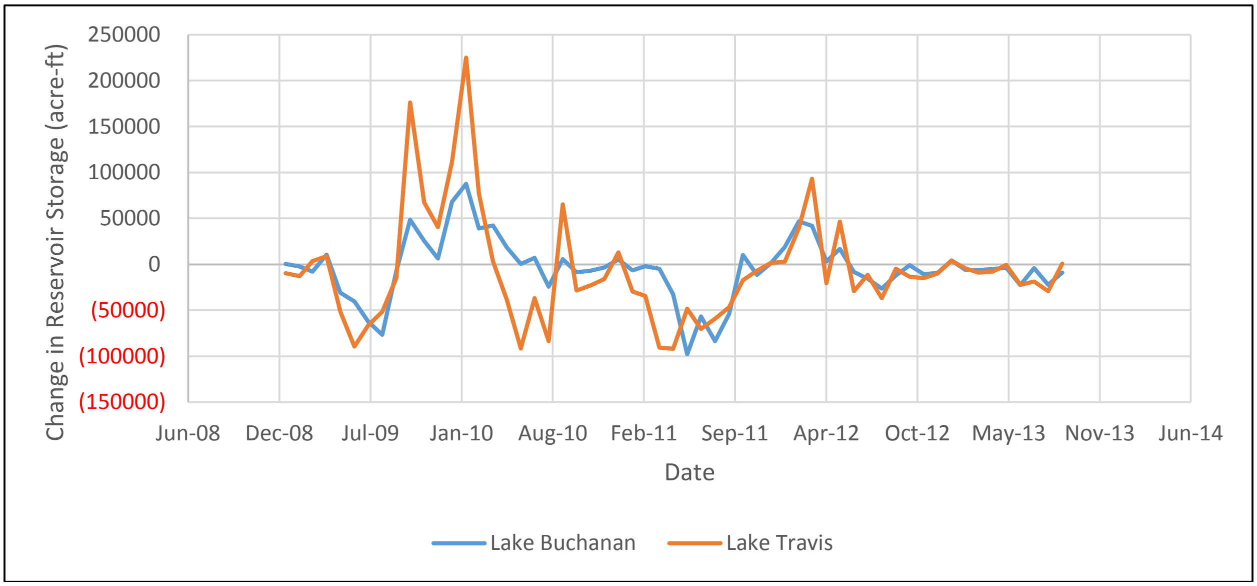

Figure 5: Monthly Changes in Reservoir Storage

The results of this calculation are found in Figure 6, showing the monthly changes in water supplied by Lakes Buchanan and Lake Travis from January 2009 to present day. In this chart, positive values represent months when more water was supplied to the LCRA than was taken from upstream sources. Negative values indicate time period when more water was taken from upstream sources than was supplied to LCRA customers. Note that the trends associated with curve are very similar to those shown in Figure 5. This is due to the scale difference between the hydrologic fluxes and the reservoir storage changes. It also indicates that the supply for water services are dependent on hydrologic fluxes of the area and the demand for water services are the main driver of reservoir levels, rather than drought storage and flood control. This notion is interesting because it indicates an area of risk associated with maintaining consistent water supply. If water demand is expected to increase and is the main factor in resulting reservoir levels, serious water scarcity implications may be ahead for the LCRA.

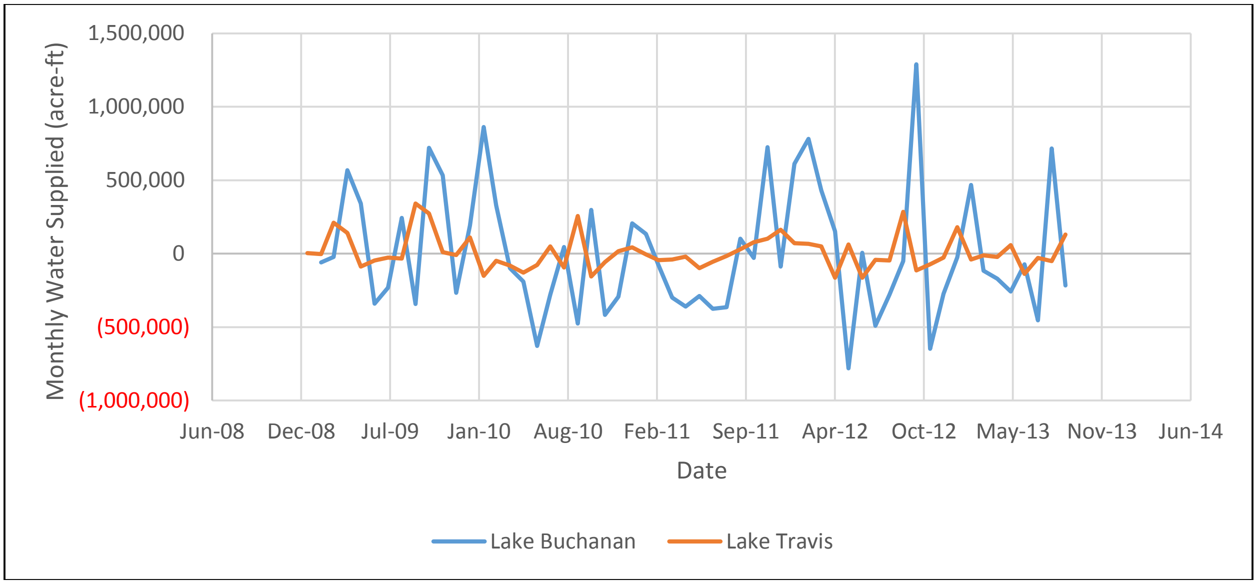

Figure 6: Monthly Water Supplied by Highland Lakes

Water Usage Estimates

The total change in hydrologic flux over the time period studied totaled just over 700,000 acre-ft, indicating net positive water supply. Meanwhile, the total change in reservoir storage totaled -270,000 acre-ft, indicating that more water was supplied to LCRA customers than was provided by hydrologic supply. In fact, the total amount of water supplied since January of 2009 was approximately 976,000 acre-ft of water, which represents almost half of the total storage capacity of the Highland Lakes!

Table 2 shows the estimated required reduction in demand needed to meet municipal conservation goals outlined in the 2012 TWDB State Water Plan. The percent growth, total demand, and required reduction in municipal demand columns were all calculated using the annual water supplied from the Highland Lakes from January 2009 to present, representing a mixture of normal and dry conditions.

Year	*Population*	*% Growth Since 2010*	*Total Demand (acre-ft)*	*Recommended Conservation (acre-ft)*	*% Demand Reduction*
2010	1412834	0%	208663.85	18498	9%
2020	1714282	21%	253185.22	169207	67%
2030	2008142	42%	296585.90	179630	61%
2040	2295627	62%	339045.05	192541	57%
2050	2580533	83%	381123.30	221622	58%
2060	2831937	100%	418253.58	241544	58%

Table 2: Population and Demand Projections

The effects of the demand projections on the reservoir storage capacity was estimated for the 2009-2013 time period. This was done by calculating the expected change in reservoir level based on the hydrologic fluxes calculated for the study period and subtracting the water supplied from each reservoir, adjusting for increase of demand due to population and decrease in demand due to conservation efforts. In this sense, the conservation efforts acted to mitigate the effects of population increase on the monthly storage changes seen in the reservoir. This analysis was completed for each population project, and is visualized for Lake Buchanan and Lake Travis in Figures 7 and 8, respectively.

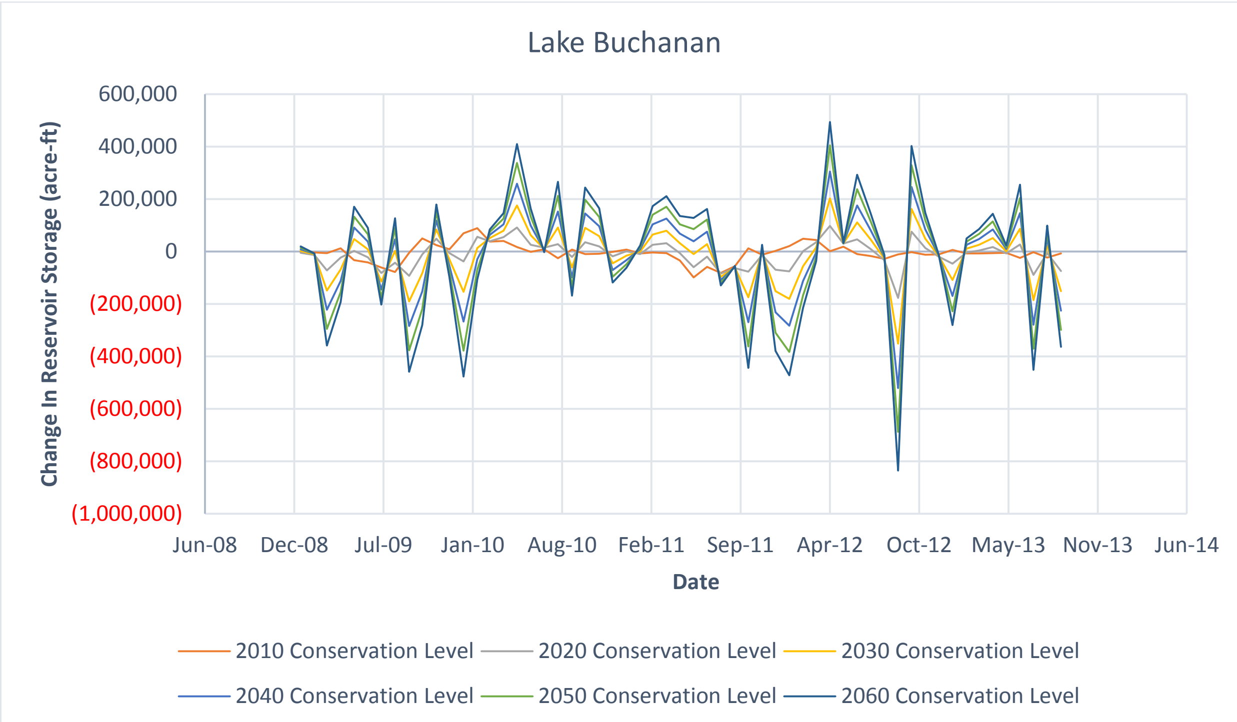

Figure 7: Monthly Change in Reservoir Storage based Conservation and Population Scenarios: Lake Buchanan

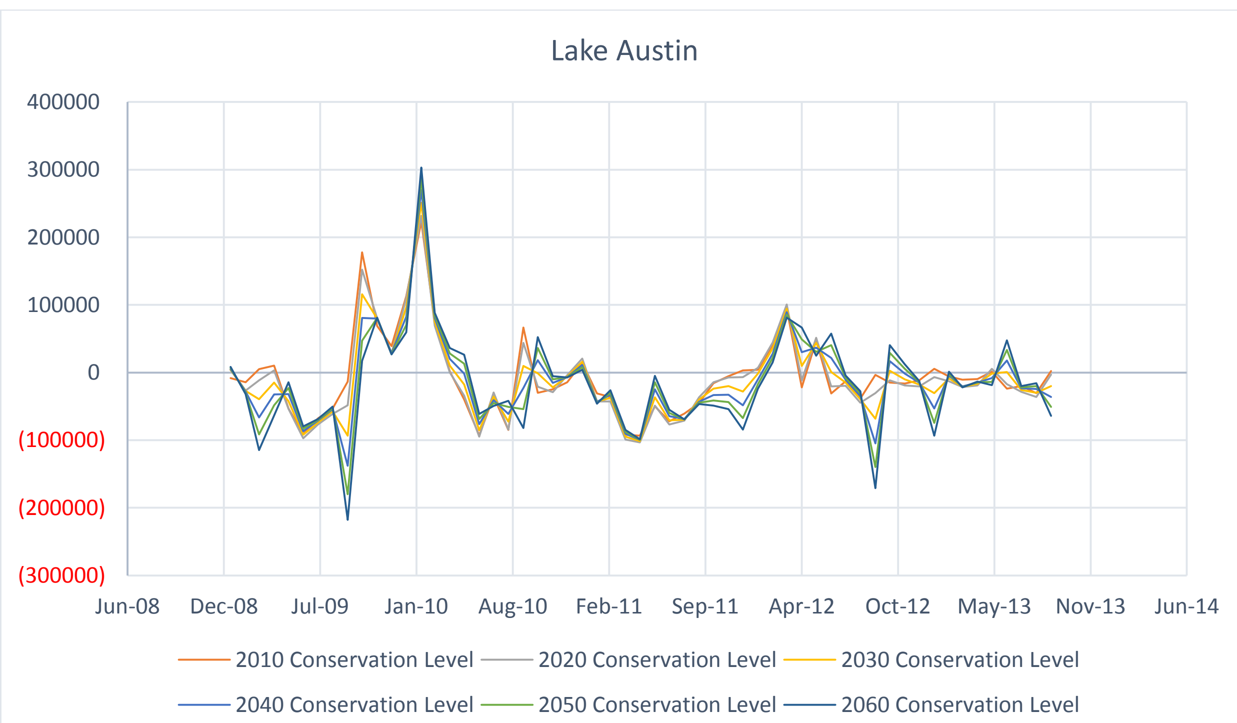

Figure 8: Monthly Change in Reservoir Storage based Conservation and Population Scenarios: Lake Buchanan

DISCUSSION AND FUTURE WORK

The wide variation in monthly storage seen for each reservoir, between scenarios, can be attributed the corresponding increase in population, and therefore water demand, as municipal demand is seen to take a larger role in total demand volume. The variation is much larger across scenarios for Lake Buchanan while the changes in Lake Travis are much closer together compared to current monthly variations. It is also interesting to note that in each scenario, conservation efforts seem to amplify storage fluctuations, which is the opposite of what would be expected. With less water demand, one would think that the reservoir level would stay more constant, given the same hydrologic fluxes. This behavior is seen in Lake Travis. In some instances, such as November of 2009, the variation in reservoir storage is seen to decrease as municipal conservation efforts increase

From this information, it is unclear what implications efficiency may have on supply-side infrastructure requirements. Due to the assumptions used as well as limited data retrieved, a sufficiently detailed analysis was not achieved. However, a first order indication into the dependency of the Highland Lakes on hydrologic conditions and water customer demand was established. This information can be used to better guide water management decisions in the LCRA. In order to truly assess the realistic impact of water efficiency technology, an engineering economic analysis would be appropriate in order to estimate realistic adoption of efficiency technology and estimate the corresponding water demand reductions.

More work can also be done to disaggregate the different demand usage category to better estimate those savings attributed to other sectors from effient technology adoptions such as industrial and power sectors.

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