Coastal Bend Regional Water Planning Area

2011 Regional Water Plan

Study 4
Water Quality Modeling of Regional Water Supply System to Enhance Water Quality and Improve Industrial Water Conservation

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Water Quality Modeling of Regional Water Supply System to Enhance Water Quality and Improve Industrial Water Conservation
(Final)

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Table of Contents

List of Figures

Figure **Page**

List of Acronyms

CCR	Choke Canyon Reservoir
CCR/LCC	Choke Canyon Reservoir/Lake Corpus Christi System
CCWSM	Corpus Christi Water Supply Model
ft-msl	Feet-Mean Sea Level
LCC	Lake Corpus Christi
SH	State Highway
SWQM	Surface Water Quality Monitoring
TCEQ	Texas Commission on Environmental Quality
TWDB	Texas Water Development Board
TDS	Total Dissolved Solids
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey

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Executive Summary

The City of Corpus Christi (City) and its customers rely on surface water supplies from Choke Canyon Reservoir (CCR), Lake Corpus Christi (LCC), the Calallen Pool, and Lake Texana. In the 2006 Coastal Bend Regional Water Plan (2006 Plan) it was shown that during drought conditions, lower CCR water levels result in higher concentrations of TDS. Previous studies by the United States Geological Survey (USGS) and others have indicated a significant increase in the concentration of dissolved minerals in the Lower Nueces River between Mathis and the Calallen Dam. Historical water quality data show chloride concentrations at the Calallen Pool are on average 2.5 times the chloride concentrations for water released from Lake Corpus Christi. Five water quality measurement events occurred at several locations downstream of LCC to the Calallen Dam between 1960 and 1987 and showed that, on average, about 60 percent of the increase in chlorides occurs upstream of the Calallen Pool and about 40 percent of the increase occurs within the Pool.[1] Potential sources of minerals to the Calallen Pool include saltwater intrusion, groundwater seepage, and upstream sources of contamination from abandoned wells in adjacent oil fields and gravel washing operations. The source of the increase in mineral concentrations has not been conclusively determined.

The Corpus Christi Water Supply Model (CCWSM) is the regional water supply model used for representations of the primary water supplies in the Coastal Bend Region and is capable of simulating the multi-basin water supply operations of CCR, LCC (including reservoir pass-through for the Nueces Estuary), Lake Texana, and potential future water supplies such as the Garwood Project on the Lower Colorado River. In this study, a water quality component was added to the CCWSM to simulate chloride and TDS levels at the three water supply reservoirs and the Calallen Pool for a hydrologic period from 1934 to 2003. If Garwood Project supplies from the Lower Colorado River are added to the supply system in the future, then the model could be updated to include Garwood Project water quality and impacts on the system. If the Garwood supplies are delivered via a canal or pipeline into West Mustang Creek to Lake Texana for transmission through the Mary Rhodes Pipeline, then the Garwood Project supplies being diverted through Lake Texana would likely have raw water quality that is the same as the

[1] Coastal Bend Regional Water Planning Group and HDR Engineering, "2006 Regional Water Plan", January 2006.

existing Lake Texana water quality simulated in the CCWSM. If a different delivery option of the Garwood Project or different supply is being integrated into the CCR/LCC/Lake Texana System, then the CCWSM water quality database could be updated to simulate the future supply based on historical data for the source water (as available).

The CCWSM enhanced with the water quality database is capable of simulating chlorides and TDS for the existing CCR/LCC/Lake Texana system for various potential reservoir operating conditions. There are five municipal and industrial water supply intakes in the Calallen Pool area that have reported chlorides and TDS fluctuations. By using the CCWSM to evaluate the effects of various reservoir operations upon quality of water of the Calallen Pool, overall water quality of the Calallen Pool can be stabilized and the reliability of regional water supplies can be increased which will reduce water consumption and treatment costs. For example, poor raw water quality causes more water to be used in industrial cooling towers; therefore improvements to water quality will directly support industrial water conservation.

The calibrated CCWSM was used to evaluate four reservoir operating scenarios to determine the impacts to reservoir and Calallen Pool water quality, including: (1) variable trigger levels for water delivery from CCR to LCC, (2) safe versus firm yield, (3) constant versus a seasonal monthly delivery pattern from Lake Texana, and (4) monthly variable LCC trigger levels for water delivery from CCR.

For simulations with variable trigger levels for water delivery from CCR to LCC (Scenario 1), the higher trigger level of 86 ft-msl showed lower median chloride levels in CCR. There were no significant impacts to LCC, Calallen Pool, or Lake Texana water quality with variable trigger levels. For the safe versus firm yield evaluation (Scenario 2), median chloride levels increased about 13% and 10% for CCR and Calallen Pool, respectively, with safe yield analyses. There were no significant impacts to LCC and Lake Texana water quality attributable to safe or firm yield operations. For the seasonal versus monthly delivery pattern from Lake Texana (Scenario 3), no significant changes were reported to CCR, LCC, Calallen Pool, or Lake Texana water quality. With monthly variable LCC trigger levels in the summer (83 ft-msl) as compared to a constant LCC trigger level at 74 ft-msl (Scenario 4), median chloride levels decreased about 5% in CCR. There were no significant impacts to LCC, Calallen Pool, or Lake Texana water quality for monthly variable LCC triggers as compared to constant trigger levels.

1.0 Introduction

1.1 Background

The City of Corpus Christi (City) and its customers rely on surface water supplies from Choke Canyon Reservoir (CCR), Lake Corpus Christi (LCC), the Calallen Pool, and Lake Texana. The City provides water supplies, either directly or indirectly, through other wholesale water providers to meet over 85 percent of the municipal and industrial water demand in the region. Water releases from CCR and streamflow from the Nueces River provide inflows to LCC, which provides water supplies directly to local water users and to water supply intakes downstream at the Calallen Pool. Water supplies from Lake Texana are blended with Nueces River supplies at the O.N. Stevens Water Treatment Plant prior to being treated and delivered to the City and its customers.

The 2001 and 2006 Coastal Bend Regional Water Plans include substantial discussion of Nueces River water quality concerns and, more specifically, impacts on water consumption, especially for manufacturing users. Higher concentrations of TDS and chlorides occur in CCR and near water supply intakes located downstream of LCC in the Lower Nueces River near Calallen, especially during drought conditions and low streamflow events. Raw water quality fluctuations impact water treatment for drinking water supplies. Water with lower TDS and chlorides supports conservation and more efficient use of water supplies, especially in industrial cooling water towers where higher quality water allows water to be recycled more times prior to being discharged.

1.2 Need for Study and Project Objectives

The Corpus Christi Water Supply Model[1] (CCWSM) is a multi-basin water supply model that includes operations of CCR, LCC (including reservoir pass-through for the Nueces Estuary), Lake Texana, and potential future water supplies from the Lower Colorado River (i.e. Garwood water). For the 2006 Coastal Bend Regional Water Plan (2006 Plan), the model was updated to include hydrologic conditions for the drought of the 1990's through 2001, which extended the hydrologic time period from 1934 to 2003.

[1] Previously referred to as the Lower Nueces River Basin Bay and Estuary Model.

Factors that contribute to poor water quality during droughts include: longer retention time of water in reservoir storage which increases mineral concentrations as a result of evaporation, reduced inflows to reservoirs, high evaporative losses, and low streamflow in the Lower Nueces River related to reduced rainfall and releases from the Choke Canyon Reservoir/ Lake Corpus Christi (CCR/LCC) system. Prior to this study, the CCWSM did not have the capability to provide information related to water quality. By incorporating a water quality component in the CCWSM, the CCR/LCC/Lake Texana/Lower Colorado River system can now be simulated to better manage water quality. Additionally, the CCWSM can be used to evaluate water management strategies to reduce water quality impacts to regional water supplies and provide more efficient use of water supplies.

2.0 Description of Study

The CCWSM was updated to include TDS and chloride concentrations for Lake Texana, LCC, and the Calallen Pool to simulate historic TCS and chloride concentrations of water at the Calallen Pool for hydrologic conditions from 1934 to 2003. For example, with this study, the model has enhanced user capability to calculate TDS and chloride concentrations for the 1934 to 2003 simulation period for any reservoir operation plan. With funding provided by the U.S. Army Corps of Engineers (USACE) Nueces Feasibility Study, the model was updated to include similar water quality calculations for CCR. The results from CCR analysis are included in this report courtesy of the USACE to simulate the entire regional water supply system.

3.0 Methodology and Approach

A water quality analysis was performed using Texas Commission on Environmental Quality (TCEQ) Surface Water Quality Monitoring (SWQM) data and United States Geological Survey (USGS) data to evaluate long-term stream flow and water quality trends. The TCEQ water quality sampling points and locations of USGS streamflow measurements are shown in Figures 3-1 and 3-2 for the Nueces River and Lake Texana watersheds, respectively. Due to limited availability of TDS data, a relationship between TDS and chlorides was developed to calculate TDS loads to the reservoir systems.

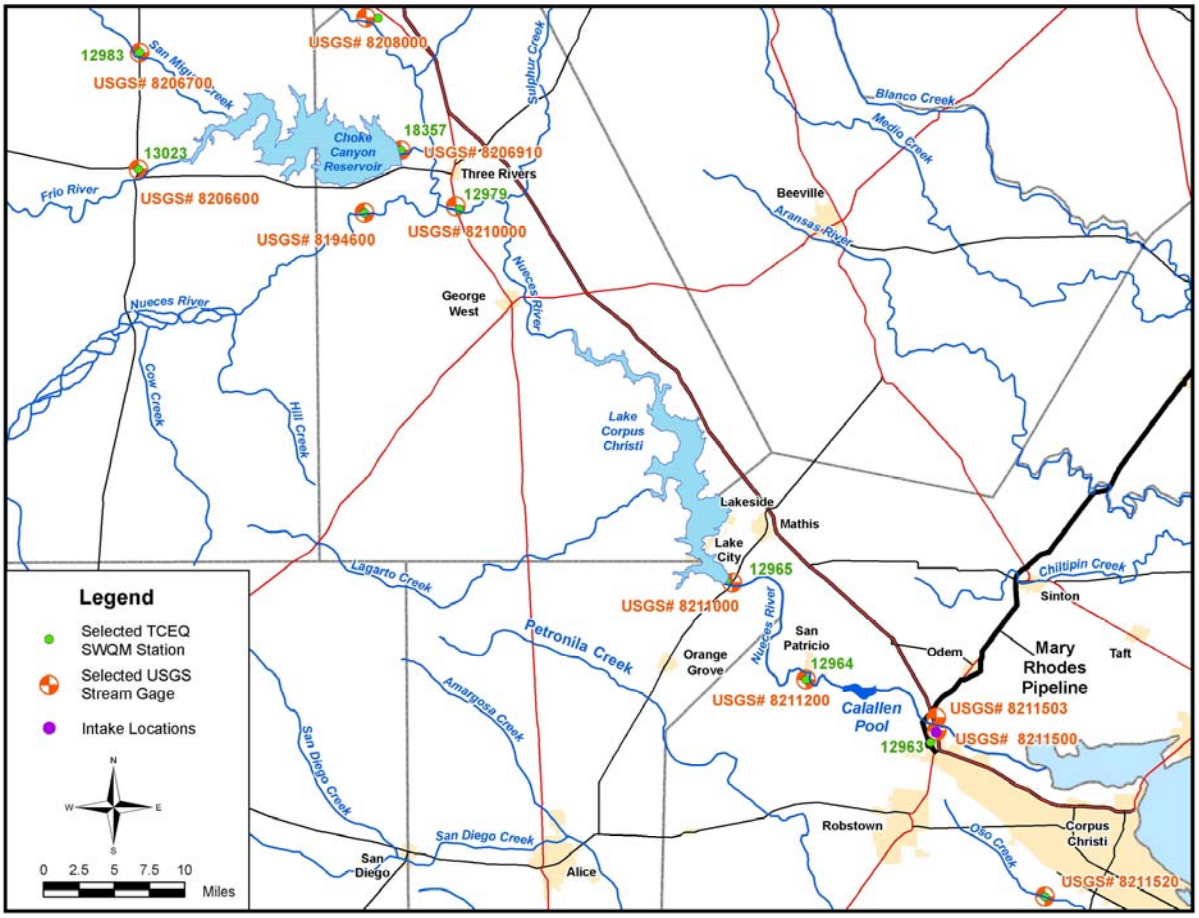


Figure 3-1 Water Quality Sampling Points and Locations of USGS Gages in the Nueces River Basin

The CCR water quality analysis considered available data for San Miguel Creek at SH16 north of Tilden and the Frio River at Tilden. Based on a regression analysis which compared historic inflow and chloride levels, the water quality for each of the two inflow sources to CCR was determined to be similar. On average, inflow from the Frio River accounts for 82% of inflow to CCR and was therefore used to calculate water quality loading to CCR. There were 171 chloride and streamflow measurements collected on the Frio River (at Tilden) over a time period from January 1976 to June 2007. These data were used to determine water quality loading to CCR using the following equation:

Reservoir Load = Flow x Constituent concentration (mg/L)

The equation stated above was also used to determine reservoir loadings for LCC and Lake Texana, as described below.

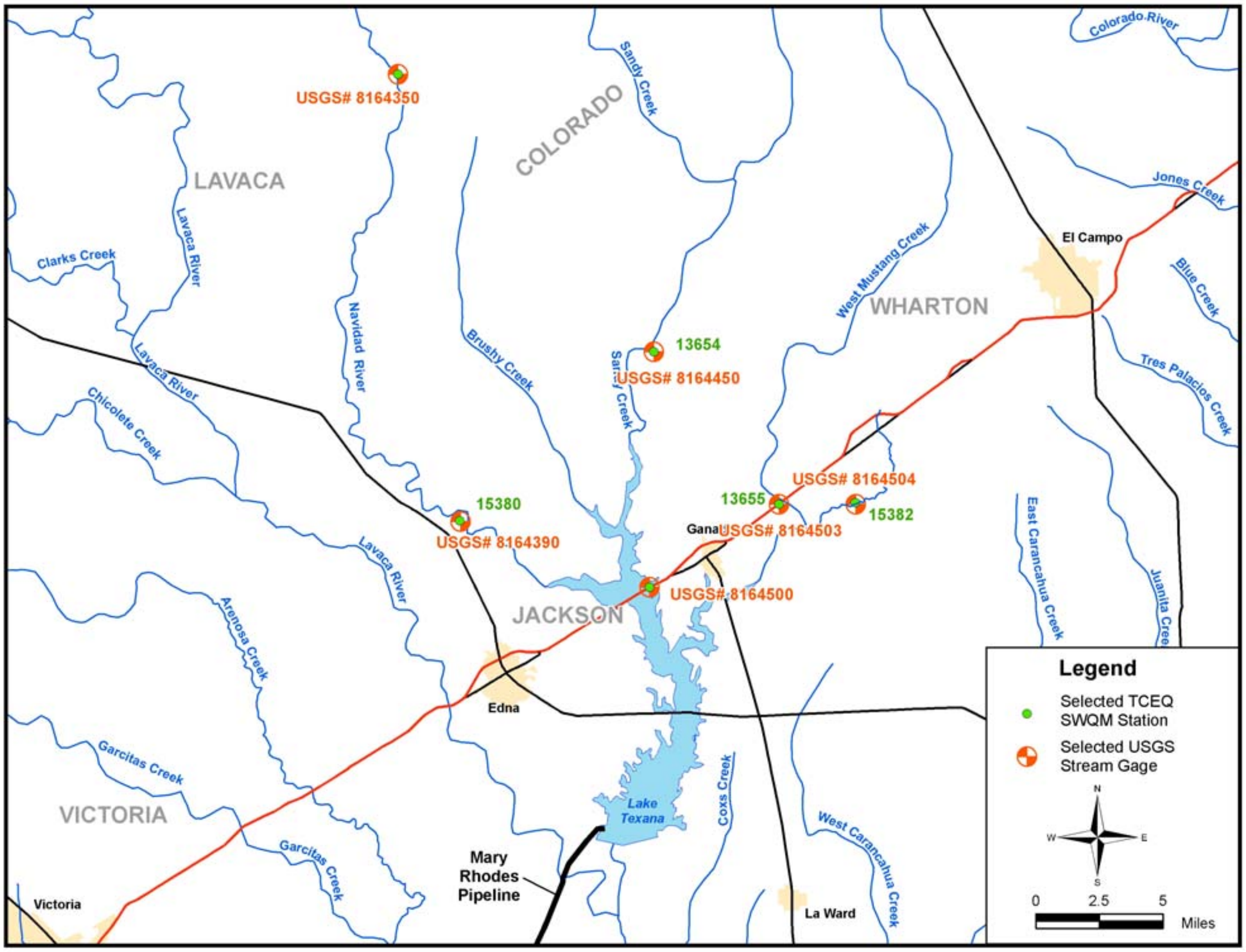


Figure 3-2. Water Quality Sampling Points and Locations of USGS Gages above Lake Texana

LCC water quality was calculated based on water quality recorded at the streamflow gage site located at the Nueces River near Three Rivers. The 436 water quality and streamflow measurements were limited to include only data collected after CCR was constructed (1987) to be most representative of current conditions. The resulting 198 chloride and streamflow measurements from June 1987 to June 2007 were used to develop an inflow water quality regression relationship for LCC.

Water quality at the Calallen Pool was calculated using a different approach which considers groundwater seepage into the Lower Nueces River. Based on previous studies by the USGS, Atlee Cunningham, and the Texas Water Development Board (TWDB), groundwater inflow from the Gulf Coast Aquifer becomes a contributing influence upon both quantify and quality of stream flow downstream of LCC. Water quality loadings into the Calallen Pool were calculated by taking water quality measurements of LCC releases and adding a groundwater quality component. The model was updated to include the capability of including the volume and concentration of groundwater contribution. Based on previous studies, groundwater inflow was estimated to average 8 cfs with a chloride concentration of 1,170 mg/L and a TDS concentration of 2,900 mg/L.

For water supplies in the Lavaca-Navidad River Basin, water quality at Lake Texana was calculated based on inflows from the following contributing tributaries: Navidad River near Edna, Sandy Creak near Ganado, and West Mustang Creek (Figure 3-2). These three tributaries contribute about 93% of total flow to Lake Texana, on average. There were 241 chloride and streamflow measurements collected for the three tributaries over a time period from November 1981 to April 2007 that were used to determine water quality loading to Lake Texana.

The water quality sampling locations used to model the water quality of CCR, LCC, and Lake Texana are summarized in Table 3-1. Figure 3-3 shows the relationship of chloride loading to inflows for CCR, LCC, and Lake Texana. The chloride loadings for each reservoir based on historical data are as follows:

$$y = 0.4154x^{0.8979} \text{ (for CCR)}$$

$$y = 0.5613x^{0.728} \text{ (for LCC)}$$

$$y = 0.1001x^{0.8871} \text{ (for Lake Texana)}$$

Where x = total flow (acft/day) and y = chloride loadings (tons/day).

For regression analyses, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates observed data. An R^2 value of 1.0 indicates that the regression line perfectly fits the observations. As shown in Figure 3-3, the R^2 values for CCR, LCC, and Lake Texana range from 0.78 to 0.87 and were determined to be suitable for modeling estimated reservoir loadings.

The City has an existing, interbasin transfer permit for supplies from the Lower Colorado River (Garwood Project) and is considering delivery of potential supplies via a canal or pipeline into West Mustang Creek and ultimately Lake Texana. These raw water supplies could then be withdrawn from Lake Texana and transported through the Mary Rhodes Pipeline to the

Table 3-1.
Data Sources for Water Quality Analysis

Name	ID	Reservoir Watershed
Frio River at Tilden	TCEQ SWQM ID #13023 USGS 08206600	Choke Canyon
Navidad River at Jackson CR 401	TCEQ SWQM ID #15380 USGS 08164390	Lake Texana
Sandy Creek at FM 710	TCEQ SWQM ID #13654 USGS 08164450	Lake Texana
West Mustang Creek at US 59	TCEQ SWQM ID #13655 USGS 08164503	Lake Texana
Nueces River on US 281 South of Three Rivers	TCEQ SWQM ID #12979 USGS 08210000	Corpus Christi

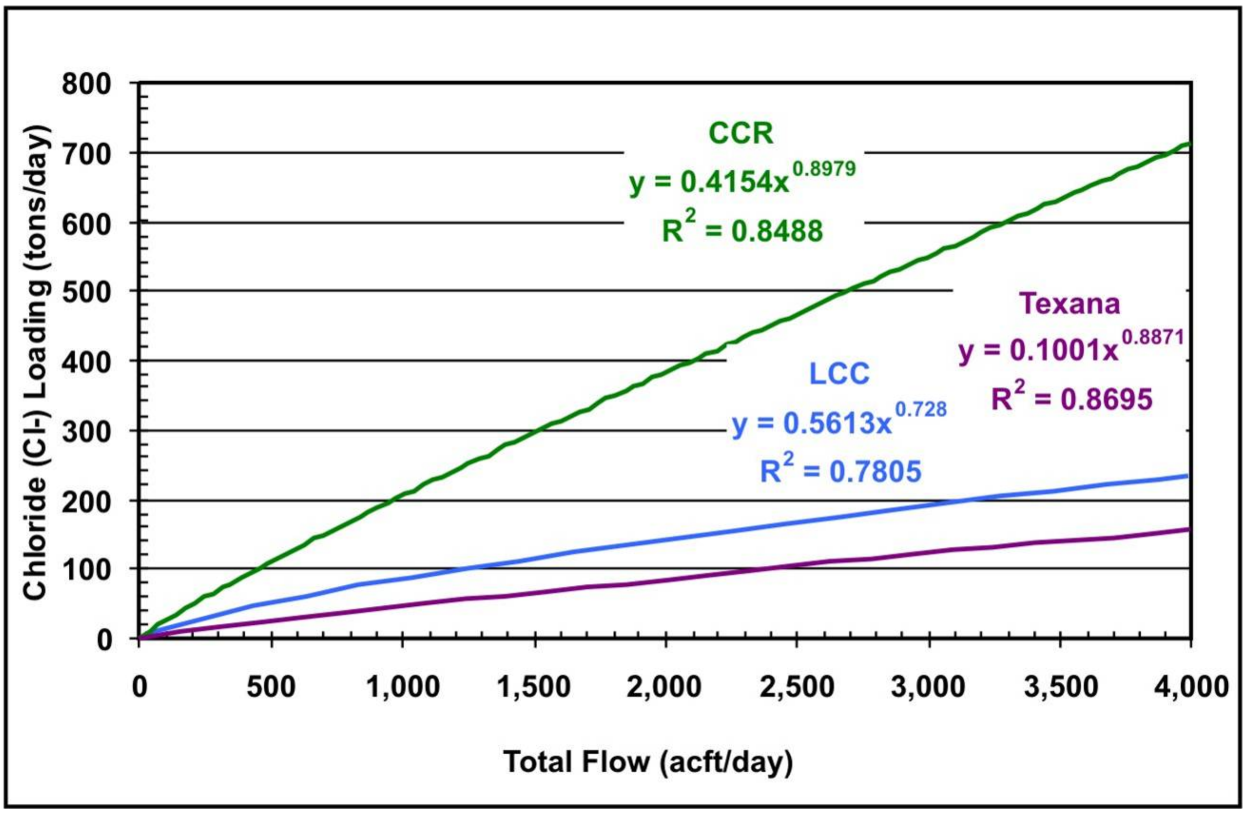


Figure 3-3. Chloride Loading of Inflows into CCR, LCC, and Lake Texana

O.N. Stevens Water Treatment Plant at Calallen. If delivered in this manner, the Garwood Project supplies being diverted through Lake Texana would likely have raw water quality that is the same as the existing Lake Texana water quality, which is currently simulated in the CCWSM. If a different delivery option of the Garwood Project or different supply is being integrated into the CCR/LCC/Lake Texana System, then the CCWSM water quality database would need to be updated to simulate the water quality of the future supply based on data for the source water (as available).

A daily-based regression equation for chlorides was applied to estimates of daily reservoir inflows and summed to monthly values to match monthly flows in the CCWSM. The results provided estimates of the monthly loadings into CCR, LCC, and Lake Texana. A mass balance analysis was then completed based on the CCWSM results and considered inflows, evaporation, and reservoir spills and diversions to provide a resulting reservoir water quality. A standard assumption of instantaneous mixing of the inflow loading in the reservoir was made.

Due to the limited availability of TDS data, a method for estimating TDS concentrations was developed using the available chloride and TDS data. The data revealed a good relationship between TDS and chlorides for each reservoir. This relationship was applied to the chloride data available at inflow locations to each reservoir (Table 3-1) to approximate the TDS concentrations for the corresponding sample dates.

The equations used to estimate TDS concentrations based on chloride data are as follows:

$$y = 2.7121x + 215.23 \text{ (for CCR)}$$

$$y = 2.3813x + 161.89 \text{ (for LCC)}$$

$$y = 3.0948x + 71.896 \text{ (for Lake Texana)}$$

Where x = chlorides concentrations (mg/L) and y = TDS concentrations (mg/L).

The relationships of TDS and chlorides for CCR, LCC, and Lake Texana are shown in Figure 3-4. R^2 values range between 0.9699 and 0.9801 indicating excellent relationships.

4.0 Model Calibration

The CCWSM uses monthly loading data to simulate the mass balance of the water quality constituents within each reservoir for each month during the 1934 to 2003 hydrologic time period. Chloride and TDS at the three reservoirs were calibrated to available historical data using reservoir operations and demands that generally matched the prevailing system operations during the time the historical data were compiled. Calibration for the Calallen Pool involved adjusting the groundwater flow and water quality at that node in the model.

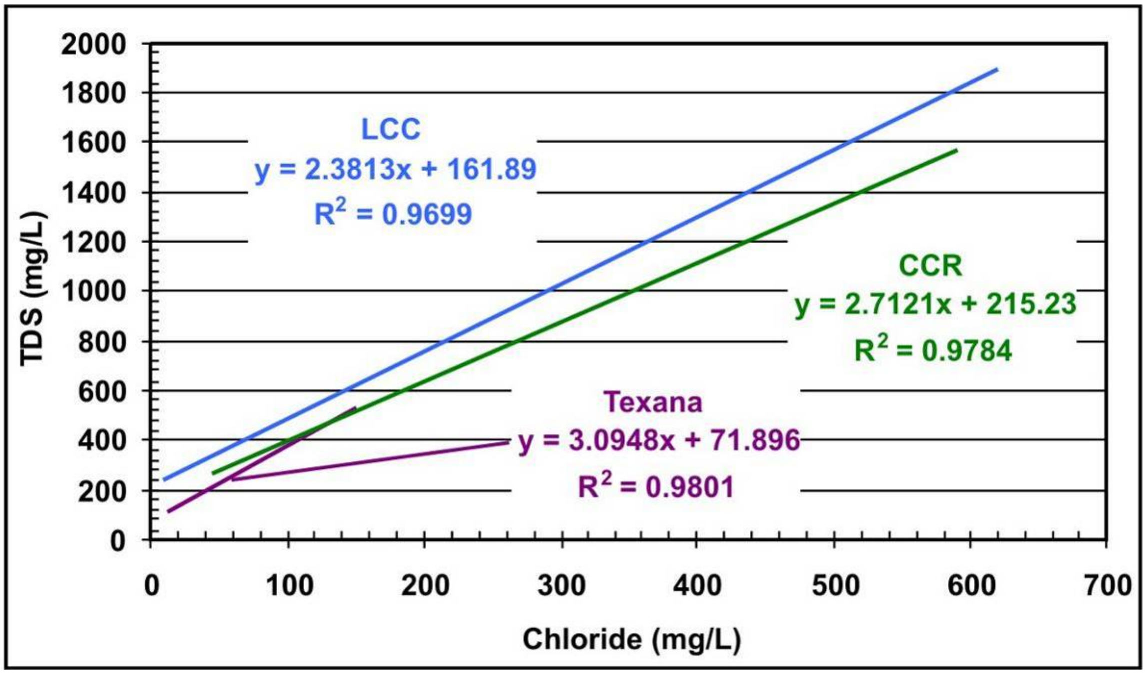


Figure 3-4. Relationship of Total Dissolved Solids (TDS) and Chlorides

Due to the complexity of modeling the conservative constituents[2] of such a large system, the loadings do not always match water quality data. This issue is addressed by an additional calibration of the model. A factor is applied to the time series of loading data and adjusted either up or down and allows the user to calibrate the model to a better match of historical conditions within the reservoirs.

The goal of the calibration procedure was to develop a "good fit" for the statistical values between the 75th and 25th percentile by using the median values as the calibration target. Successive iterations of the model were executed until the medians between the historical and modeled values matched to within 1%. After this was achieved, the model was considered "calibrated." Generally, there was good calibration for 25%, average, median, and 75% hydrologic conditions for the modeled period of record. The minimum and maximum concentrations were not well replicated due to complexities in the natural environment that extend beyond current modeling capabilities. In the future, adding monthly variability to account for a groundwater inflow component may provide better calibration for these extreme conditions. A more detailed explanation and the results of the calibration procedures by reservoir and water quality constituent can be found in Appendix A.

[2] Conservative constituents are defined as water quality parameters that do not interact with other water quality parameters. TDS and chlorides are conservative constituents.

Using the calibrated model, the water quality reservoir concentration can be user-specified for the first month of model simulation. For all other months, the previous month's reservoir concentration and present month's loading is used to calculate the resulting reservoir concentration. The model uses this method to simulate the historical hydrological period from January 1934 to December 2003. The calibrated model was then used to evaluate changes in reservoir water quality to identify preferable reservoir operating practices.

5.0 Study Results

As discussed in the previous sections, the CCWSM was updated to enable water quality modeling for chlorides and TDS at CCR, LCC, and Lake Texana. The model also estimates water quality at the Calallen pool, based on the quality of the water being released from LCC and groundwater that enters the Lower Nueces River. This capability allows for the evaluation and analysis of various operating scenarios focusing on the impacts of the resulting water quality in the reservoirs.

5.1 Reservoir Operating Scenario Evaluation

Four reservoir operating scenarios were evaluated using the CCWSM to include:

- Scenario 1 – Variable LCC trigger levels for water delivery from CCR to LCC,
- Scenario 2 – Safe versus firm system yield,
- Scenario 3 – Constant versus seasonal delivery pattern of supply from Lake Texana, and
- Scenario 4 – Monthly variable LCC trigger levels for water delivery from CCR to LCC.

As expected, the four operating scenarios did not include significant change to Lake Texana results since the operations of the CCR/LCC/Lake Texana system and delivery of Lake Texana water supplies through the Mary Rhodes Pipeline does not affect water quality of Lake Texana in an appreciable amount. Only the chloride results for CCR, LCC, and the Calallen Pool are presented in the main body of the report. Appendix B includes TDS results for all four scenarios. Appendix C includes chloride results for Lake Texana for all four scenarios. Appendix D contains time-series figures for chloride and TDS water quality constituents by scenario for CCR, LCC, Calallen Pool, and Lake Texana.

Unless otherwise noted all scenarios are modeled with a specific set of operating assumptions. These base assumptions include the following:

- Lake Texana seasonal demand of 41,840 acft/yr with interruptible water of 12,000 acft/yr.
- Safe yield reserve storage of 75,000 acft.
- Fixed system demand of 175,000 acft/yr.
- Modified Phase IV operating policy.[3]
- 2010 reservoir sedimentation conditions.
- LCC stabilization level set to 74 ft-msl.

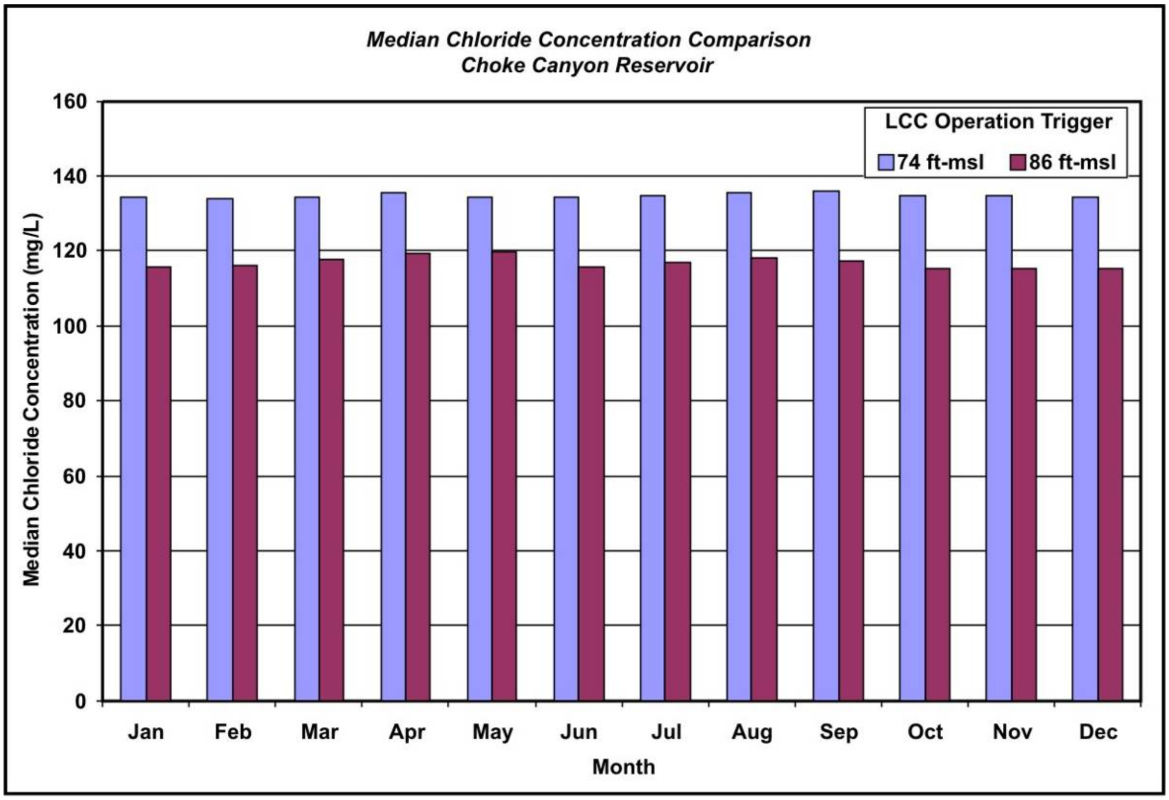
5.2 Scenario 1 – Water Quality Results from Varying Trigger Levels in LCC

The model is capable of simulating the reservoir system with a variety of operating assumptions. One of these assumptions is the LCC lake level which triggers water supply releases from CCR. This level is typically set at 74 ft-msl for most operating scenarios based on the current, modified Phase IV operating policy. For this series of model runs, the trigger level was varied to evaluate the impacts of modifying the LCC lake level on water quality of the reservoirs. The LCC trigger levels of 80 and 86 ft-msl were selected to model trigger levels that are significantly higher than current operations, which were likely to provide the most notable impact in model run results.

The figures below show the chloride results for this scenario at CCR, LCC, and Calallen Pool. As expected, there is no appreciable change in the water quality at Lake Texana associated with varying trigger levels in LCC. Figure 5-1 shows that a higher trigger level in LCC causes a reduction in the concentration of chlorides in CCR. This is because CCR makes more frequent releases in this scenario. With a lower trigger level in LCC, median chloride levels increase on average about 15% in CCR.

For LCC, a different trend is reported, as shown in Figure 5-2. There is some slight variation as the trigger levels are changed, but because LCC has such a large watershed, the water supply releases from CCR do not greatly influence the resulting water quality in LCC except during extreme hydrologic events (less than 10% occurrence) when a higher trigger level

[3] Phase IV operating policy is the maximum yield policy intended to apply to the system when water user demand exceeds 200,000 acft annually. Under Phase IV policy, the system is operated such that (1) when LCC water surface elevation is at or below 76 ft-msl and water surface elevation in CCR is *above* 155 ft-msl, releases are made from CCR to maintain LCC at 76 ft-msl; and (2) when LCC water surface is at or below 76 ft-msl and water surface elevation in CCR is *below* 155 ft-msl, LCC is allowed to draw down to its minimum elevation and CCR releases are made only to meet water supply shortages. During the mid-1990s in response to drought conditions, the City modified the Phase IV policy revising LCC's target elevation from 76 ft-msl to 74 ft-msl.



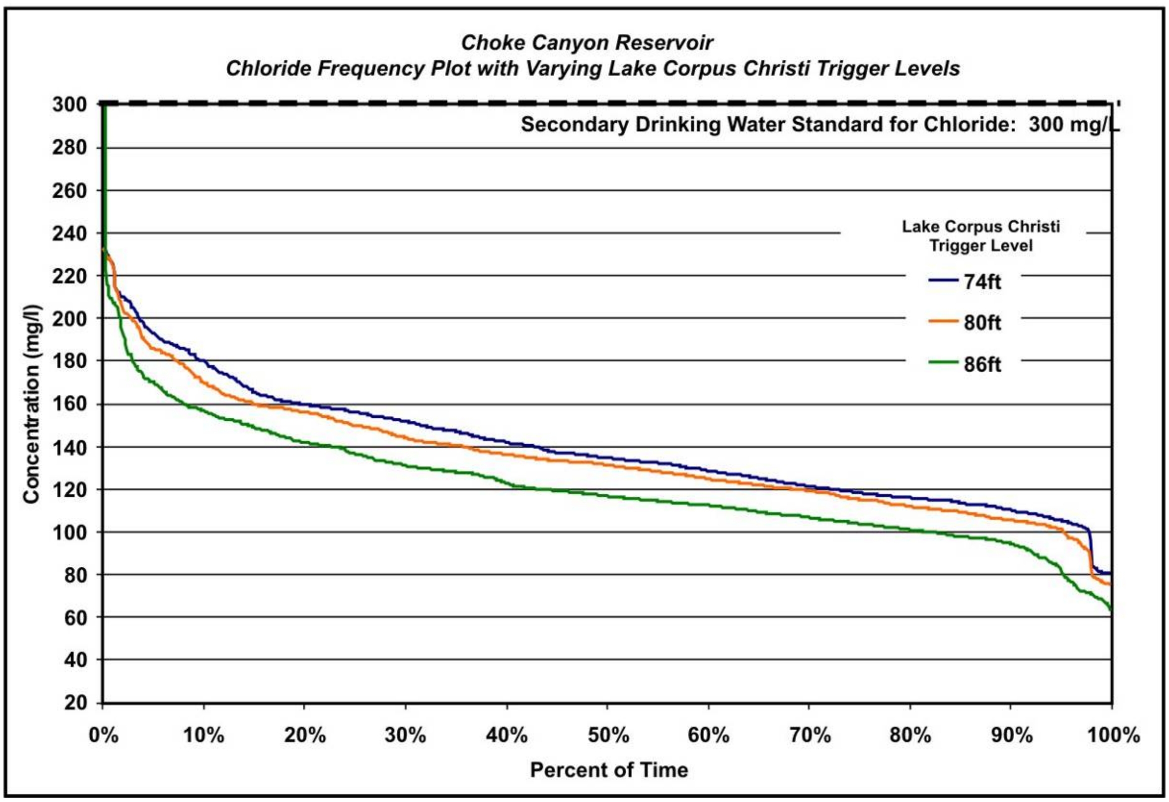
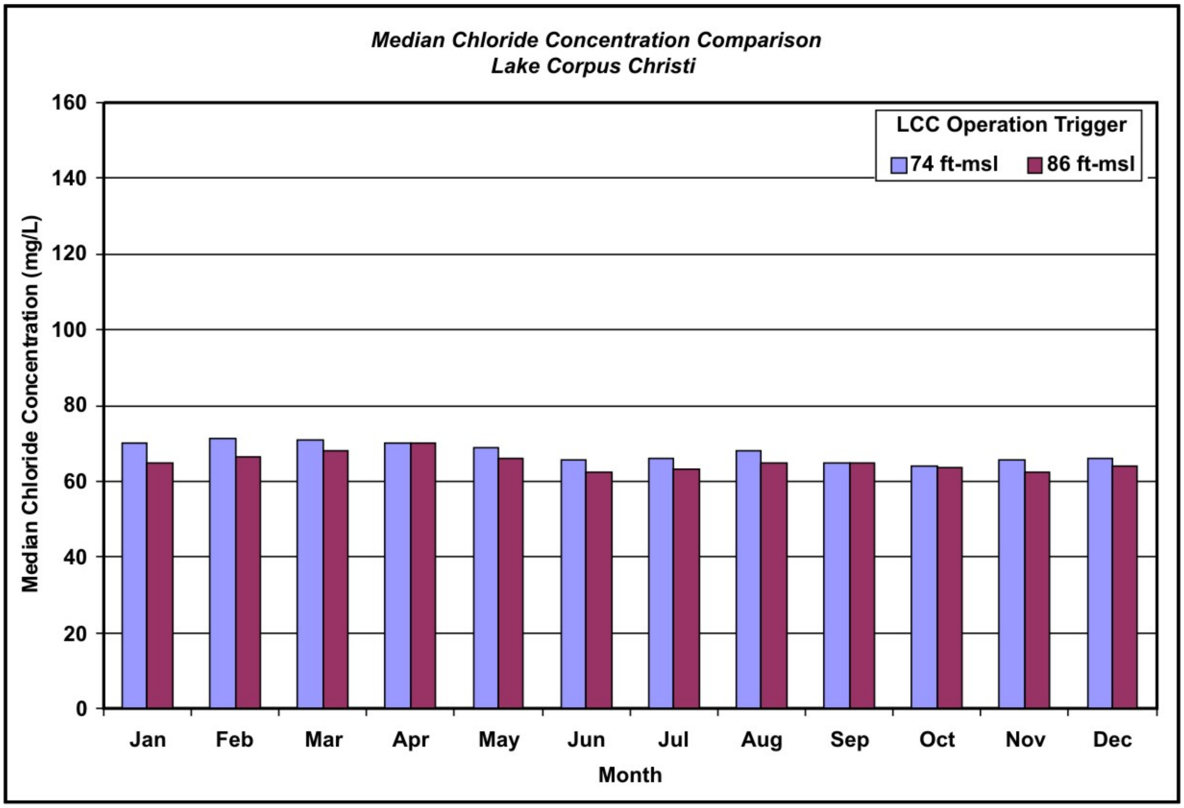


Figure 5-1. Impacts of Chloride Levels at CCR by Varying LCC Trigger Levels (Scenario 1)



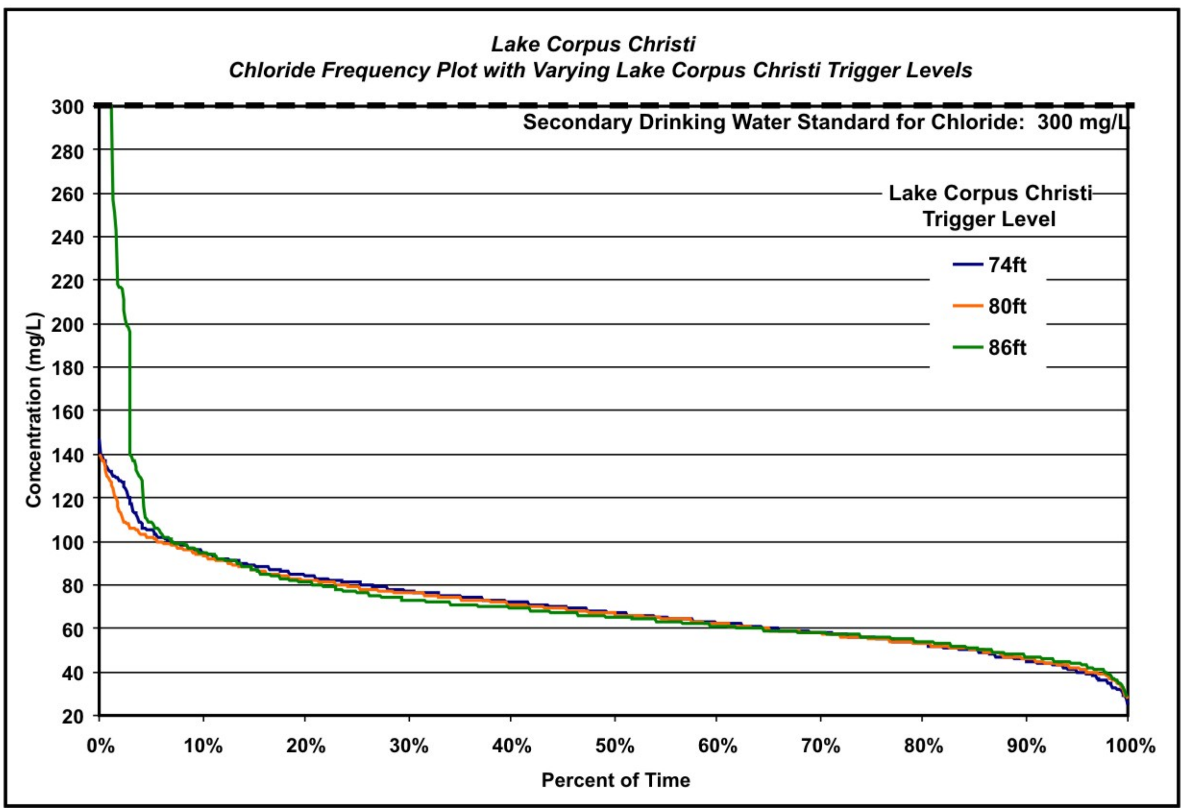


Figure 5-2. Impacts of Chloride Levels at LCC by Varying LCC Trigger Levels (Scenario 1)

in LCC causes an increase in the concentration of chlorides in LCC. This is likely attributable to poorer water quality being released from CCR more often during drier events with a higher trigger level in LCC. Water quality at the Calallen pool trends are very similar to that in LCC, as shown in Figure 5-3. Monthly median chloride levels at Calallen Pool range from 30% to 100% higher than median chloride levels at LCC, primarily attributable to a larger groundwater inflow component downstream of LCC. Similar trends exist for the TDS concentrations at these reservoirs as shown in Appendix B.

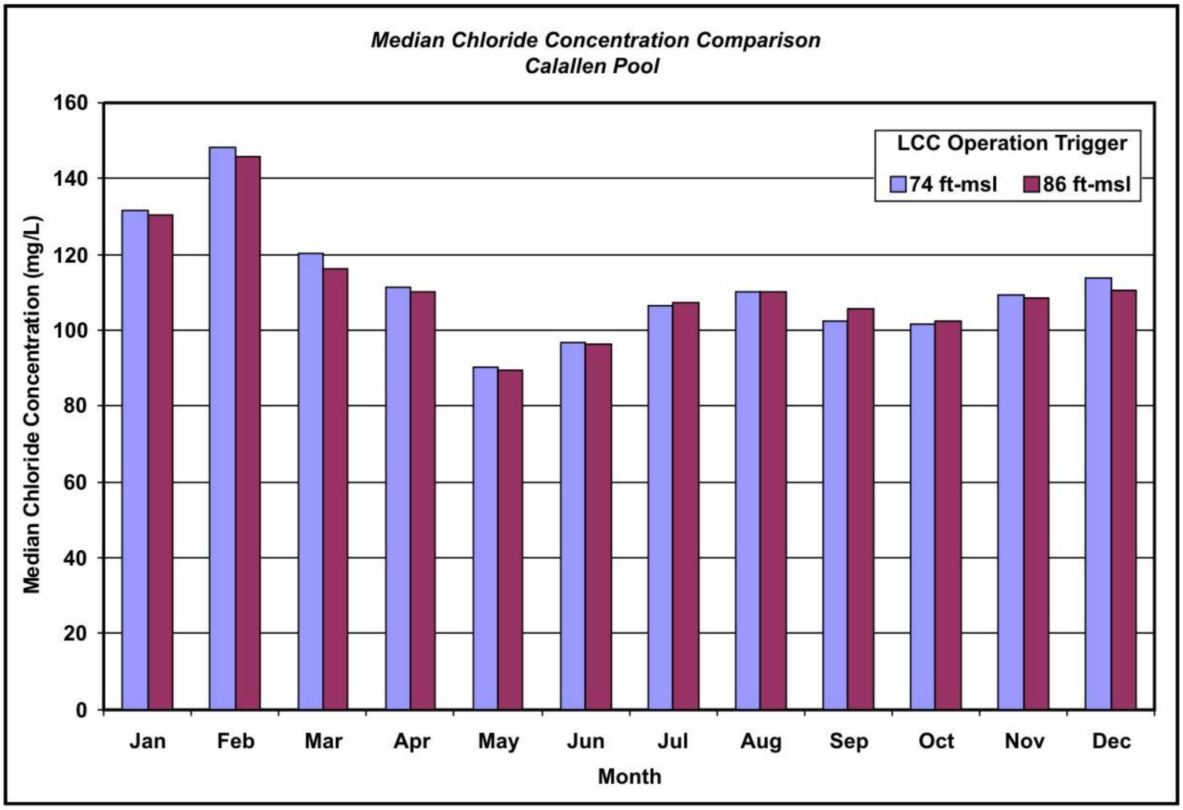
5.3 Scenario 2 – Water Quality Results Safe versus Firm Yield

The CCWSM model can be used to simulate the yield of the system under a variety of operating scenarios. This yield can either be a firm or a safe yield. Firm yield supply is the amount of water that can be reliability supplied during the worst historical drought, or drought of record, and does not leave any remaining storage in the worst month. The safe yield leaves a user specified storage reserve in the reservoirs. Safe yield supply represents a more conservative approach to determining annual availability in an area where the severity of droughts is uncertain.

Figures 5-4, 5-5, and 5-6 show the chloride results for this scenario at CCR, LCC, and Calallen Pool. For CCR, the firm yield simulations result in a lower chloride concentration than the safe yield simulation as shown in Figure 5-4. This is a result of the higher demand on CCR during the firm yield analysis. The median chloride level increases about 10% in CCR with safe yield. As shown in Figure 5-5, the difference in median chloride concentrations at LCC shows no significant changes with safe yield versus firm yield operations. About 20% of the time, LCC would be expected to have slightly lower chloride concentrations with safe yield operation. The operation of the reservoir systems results in similar depletions from LCC so the change in water quality concentration at LCC is minimized. As shown in Figure 5-6, firm yield operations would be expected to reduce median chlorides about 10% in Calallen Pool as compared to safe yield.

5.4 Scenario 3 – Water Quality Results with Constant versus Seasonal Lake Texana Delivery Pattern

The model has the ability to simulate the base Lake Texana delivery amount (41,840 acft/yr) either on a uniform, constant pattern or a seasonal pattern that reflects a summer peaking signature. Figure 5-7 compares the two patterns with the annual amount prorated on a monthly basis (as a percentage of total annual).



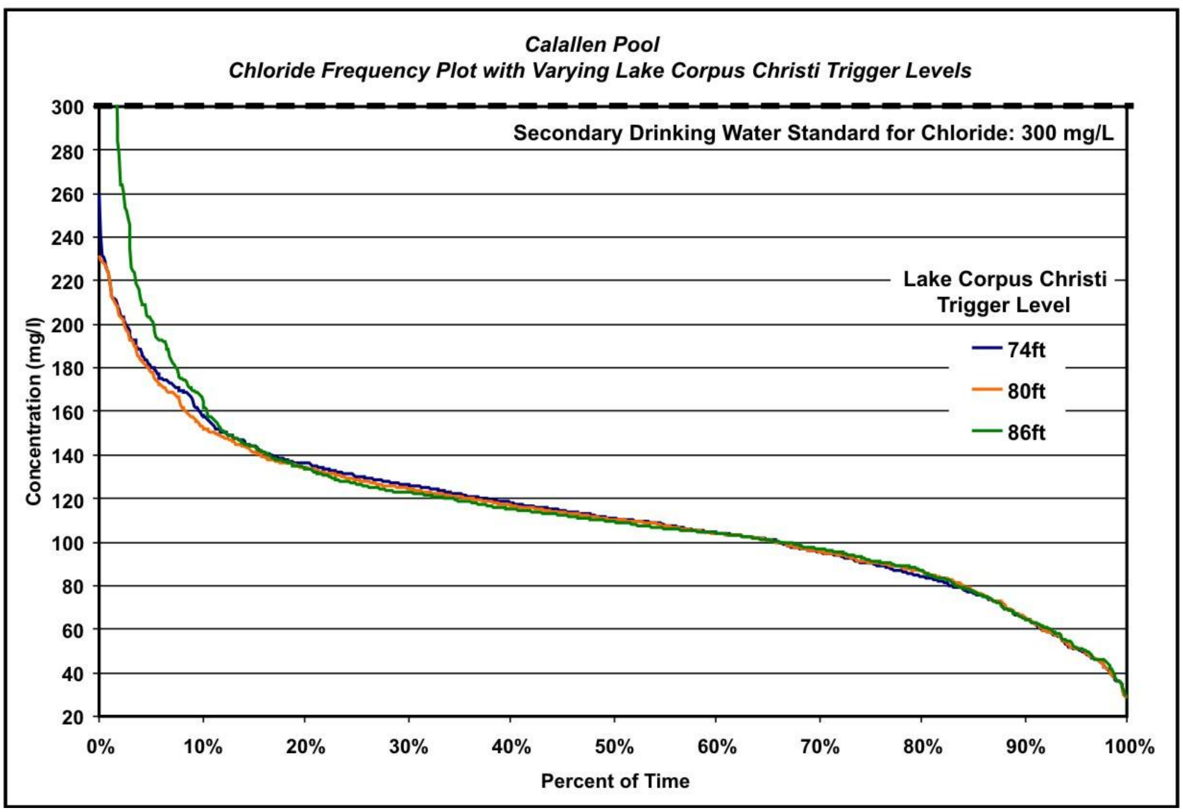
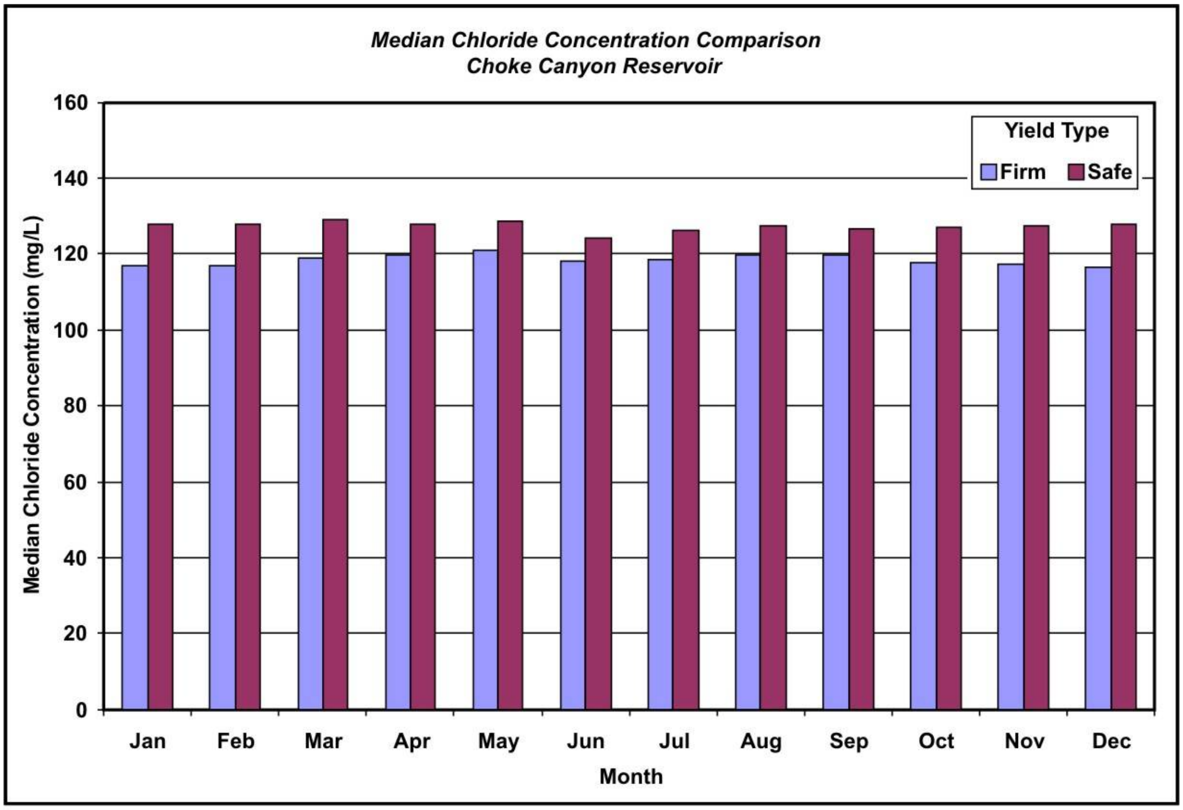


Figure 5-3. Impacts of Chloride Levels at Calallen Pool by Varying LCC Trigger Levels (Scenario 1)



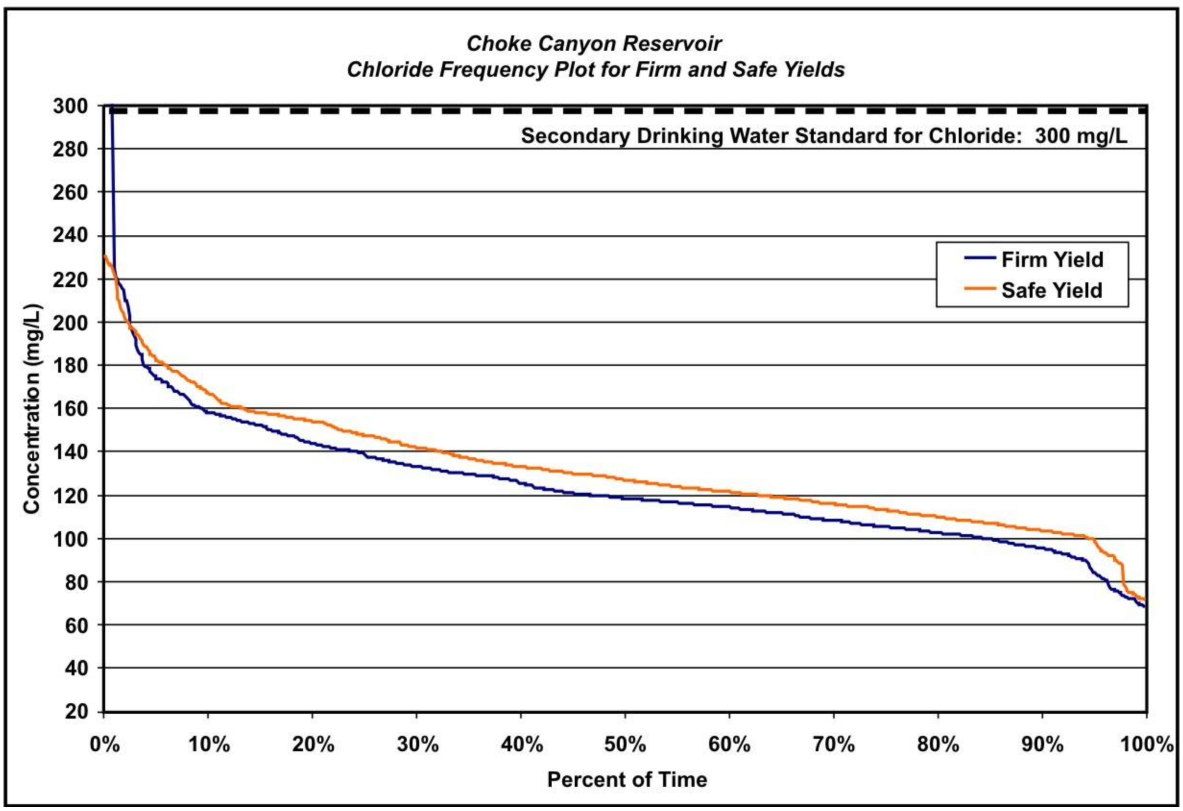
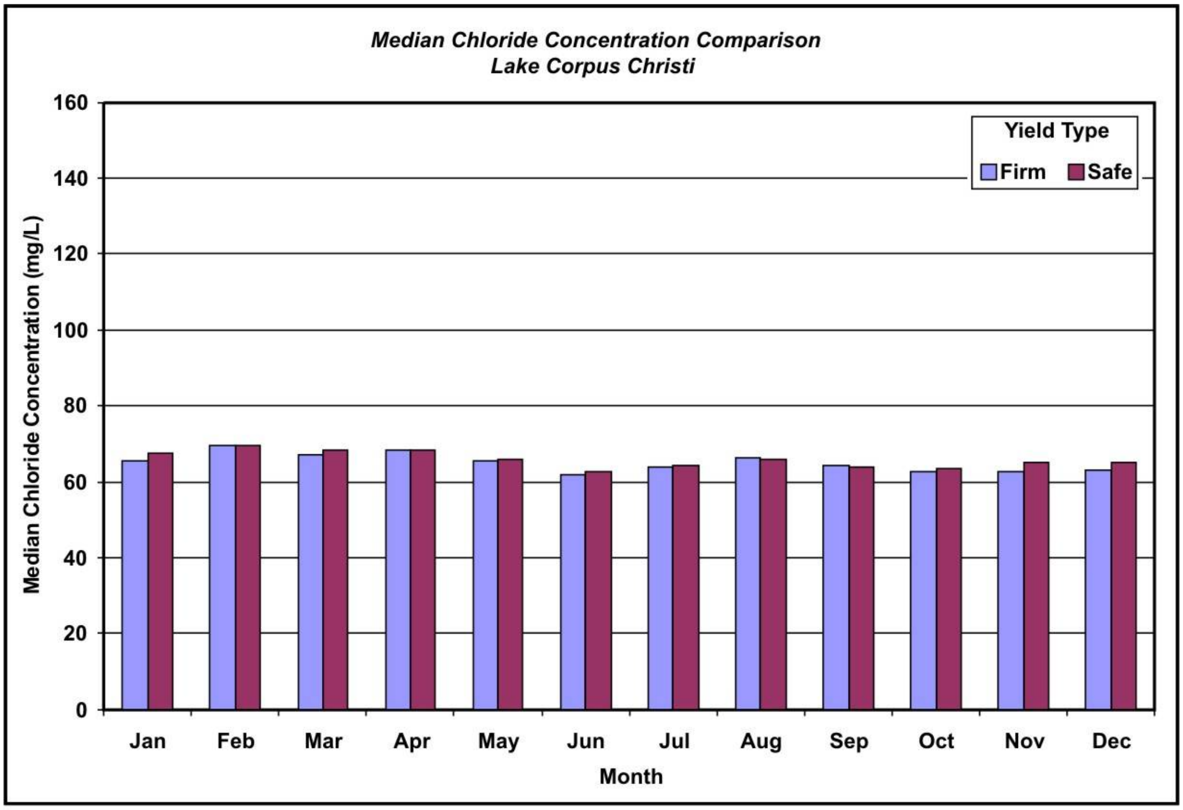


Figure 5-4. Impacts of Chloride Levels at CCR With Firm versus Safe Yield (Scenario 2)



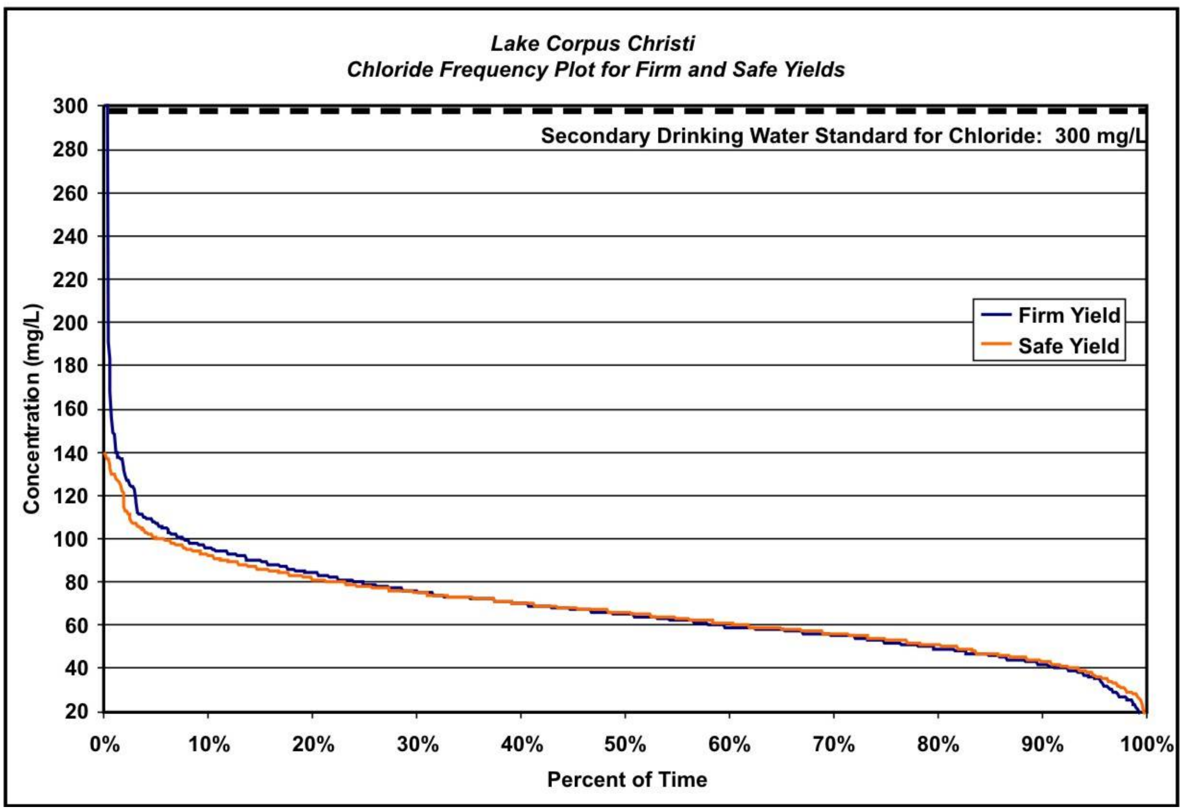
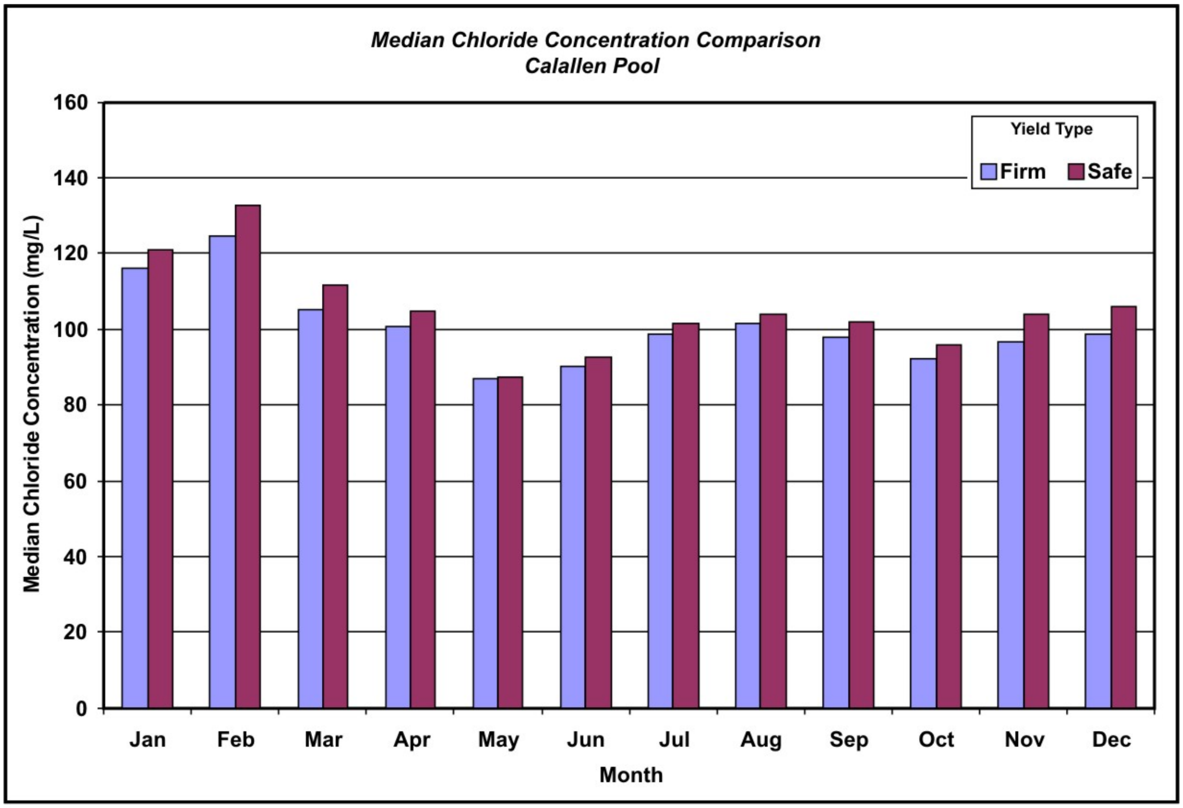


Figure 5-5. Impacts of Chloride Levels at LCC With Firm versus Safe Yield (Scenario 2)



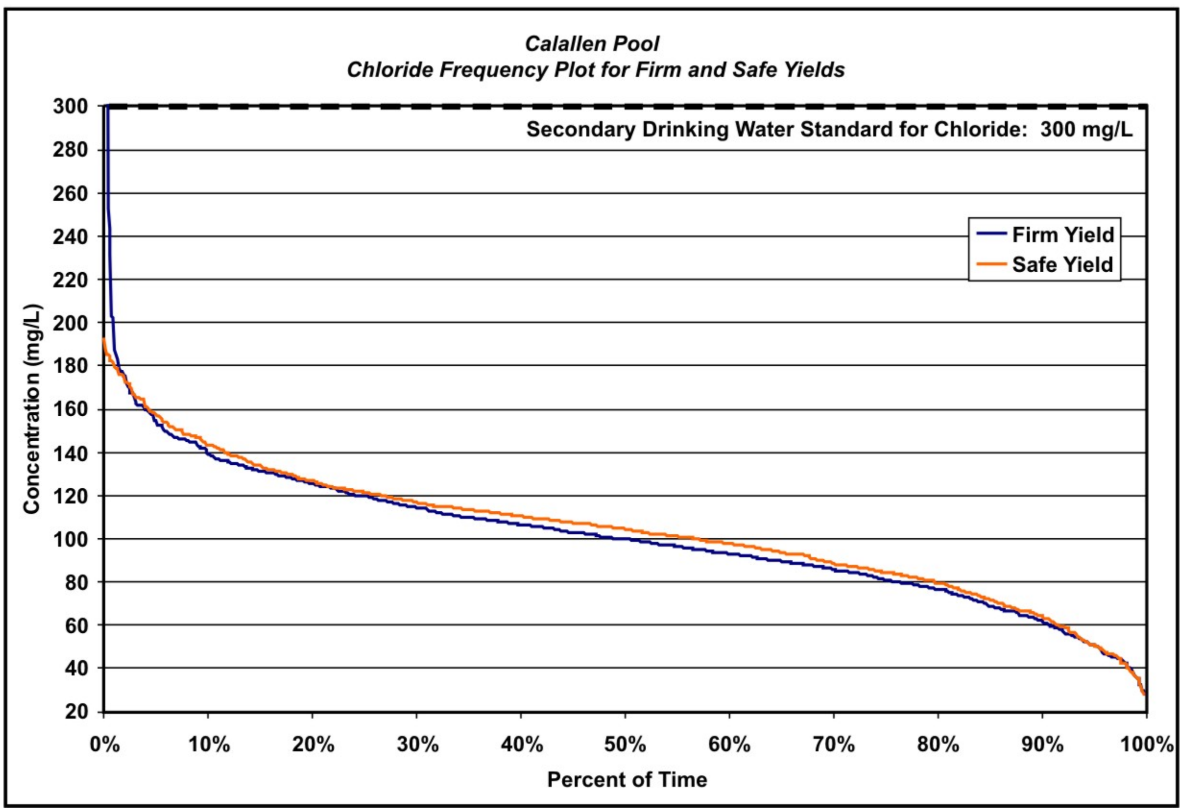


Figure 5-6. Impacts of Chloride Levels at Calallen Pool With Firm versus Safe Yield (Scenario 2)

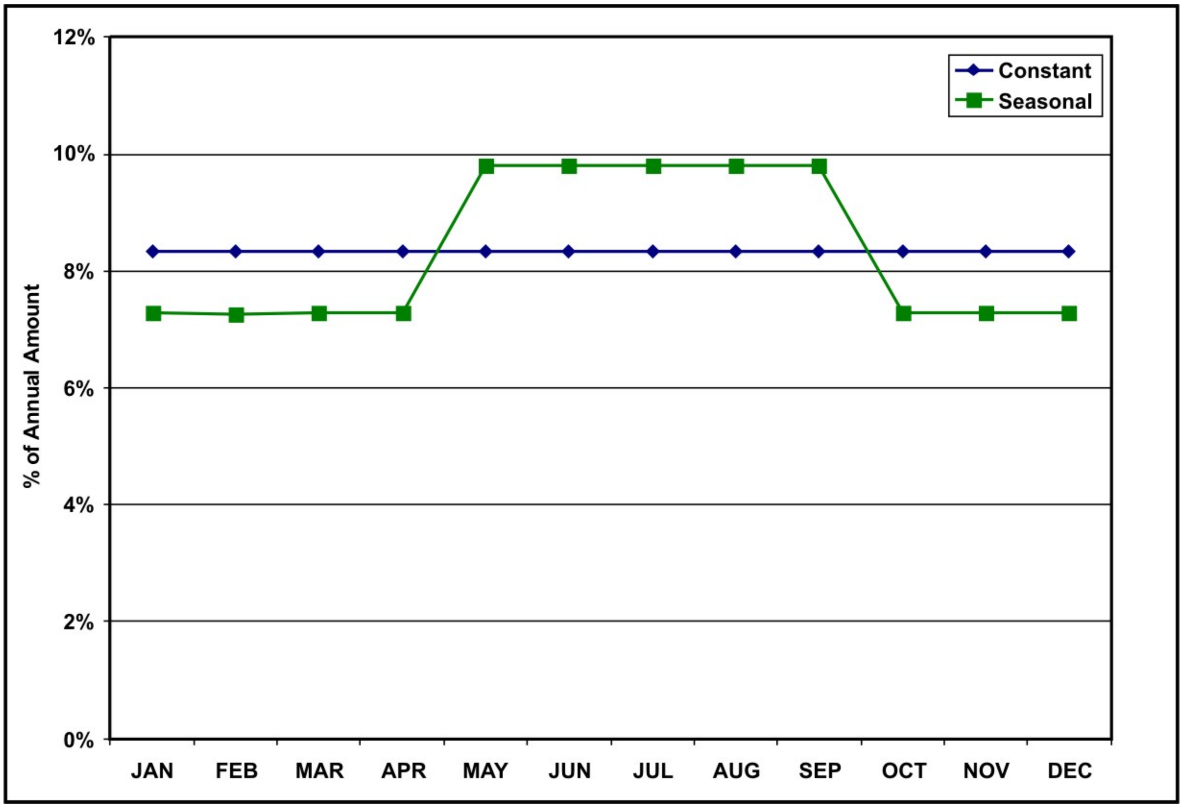
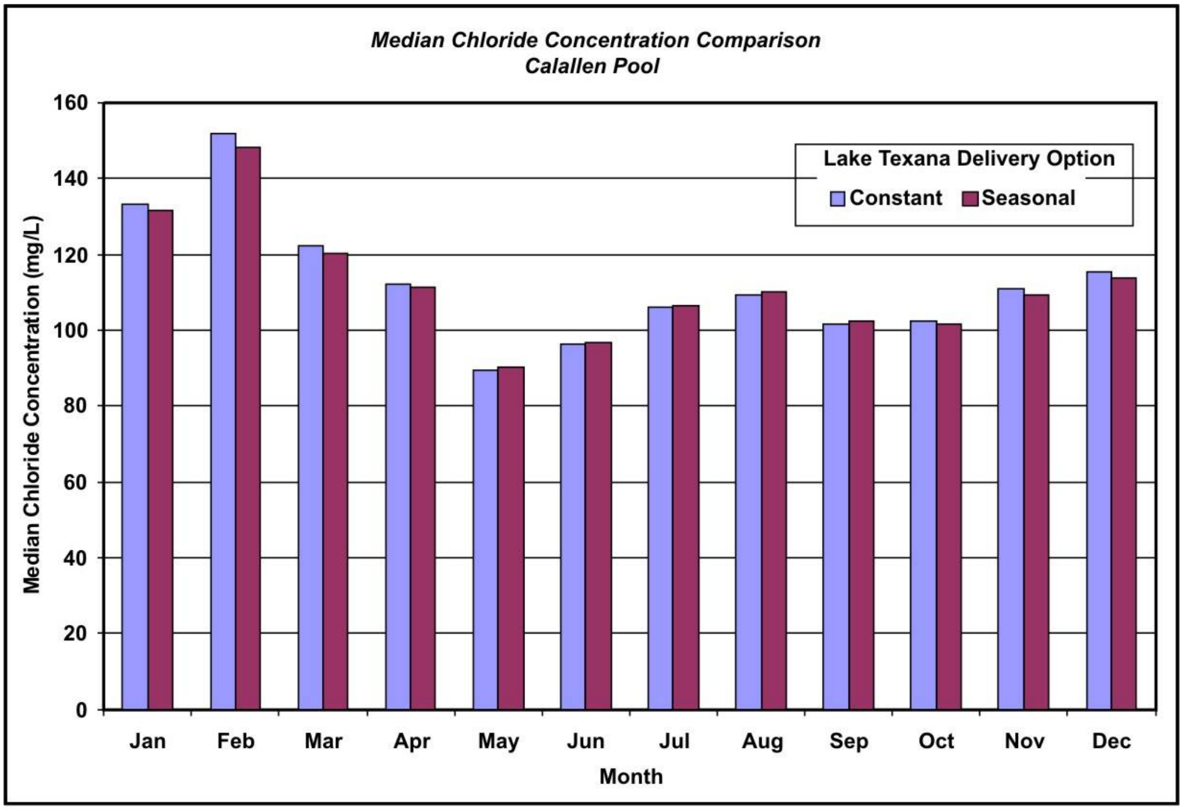


Figure 5-7. Model Simulated Constant Versus Seasonal Monthly Delivery Pattern from Lake Texana

There were no appreciable changes in water quality for CCR, LCC, or Lake Texana by changing the Lake Texana delivery pattern. As shown in Figure 5-8 for Calallen Pool, there are no significant changes in water quality concentration with constant versus seasonal deliveries. The differences between the two simulations are relatively minor when considering the water quality components. Changing the pattern of delivery from Lake Texana does not involve significant enough volumes to change the resulting water quality in CCR and LCC reservoirs.

5.5 Scenario 4 – Water Quality Results with Monthly Variable LCC Trigger Levels for Water Delivery from CCR

The final scenario involves varying monthly LCC trigger levels for delivering water supply releases from CCR. The standard assumption is that this trigger is set to 74 ft-msl, however the model has the ability to vary this trigger level by month. The trigger level from October to April was set at 74 ft-msl with the summer months of May through September set at a trigger level of 83 ft-msl as shown in Figure 5-9. This configuration allows for more water



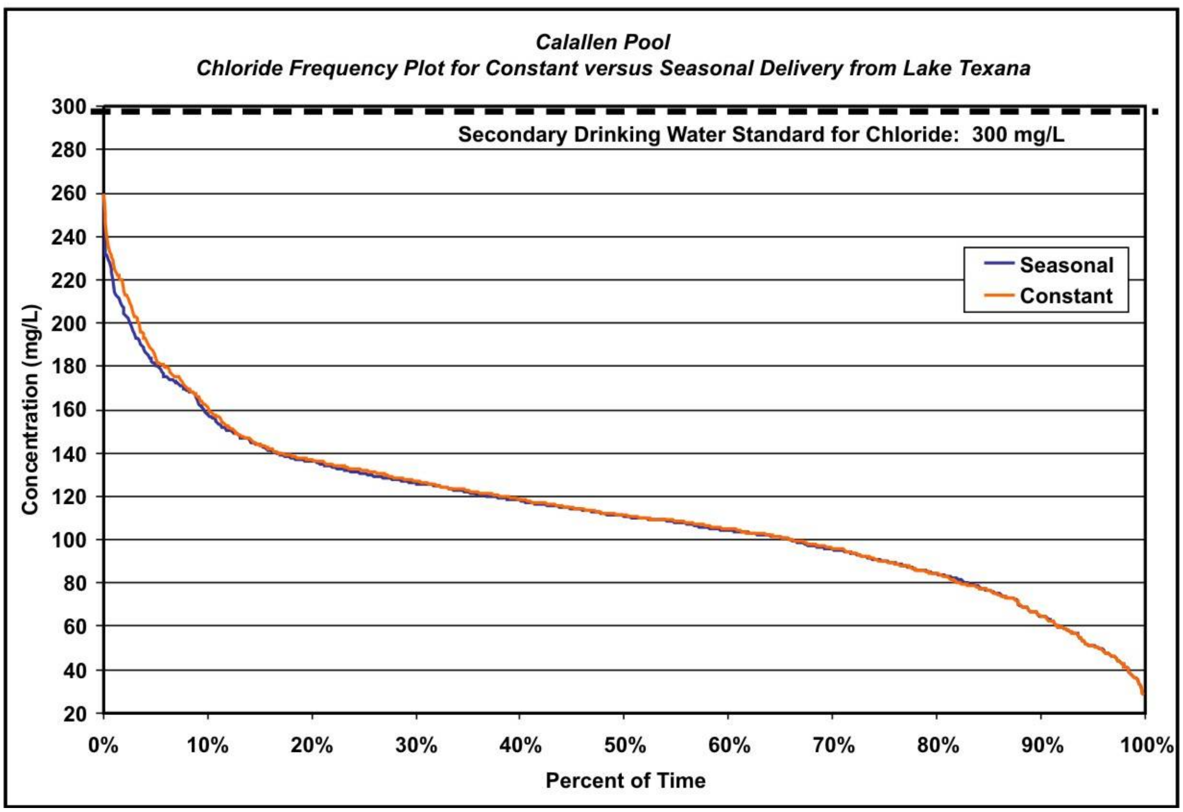


Figure 5-8. Impacts of Chloride Levels at Calallen Pool
With Constant versus Season Delivery Patterns from Lake Texana (Scenario 3)

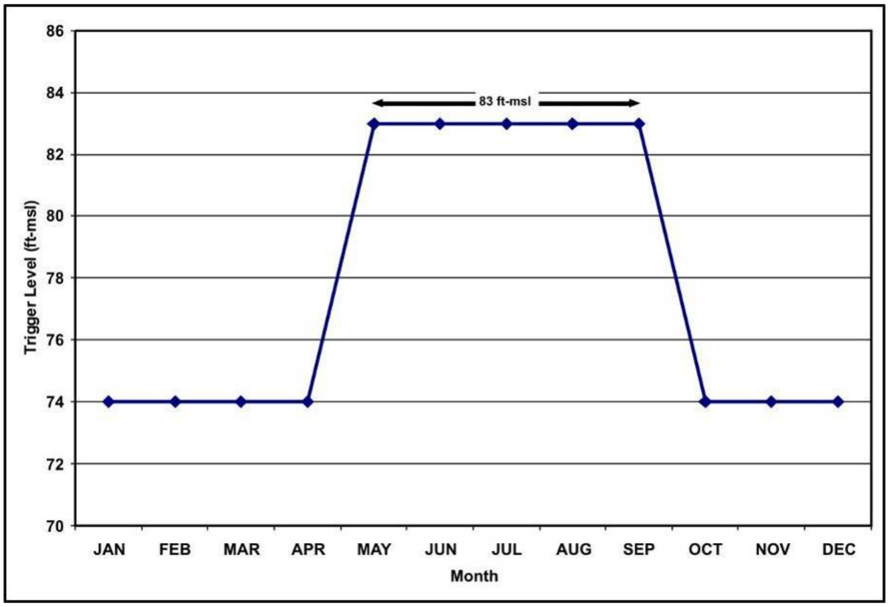
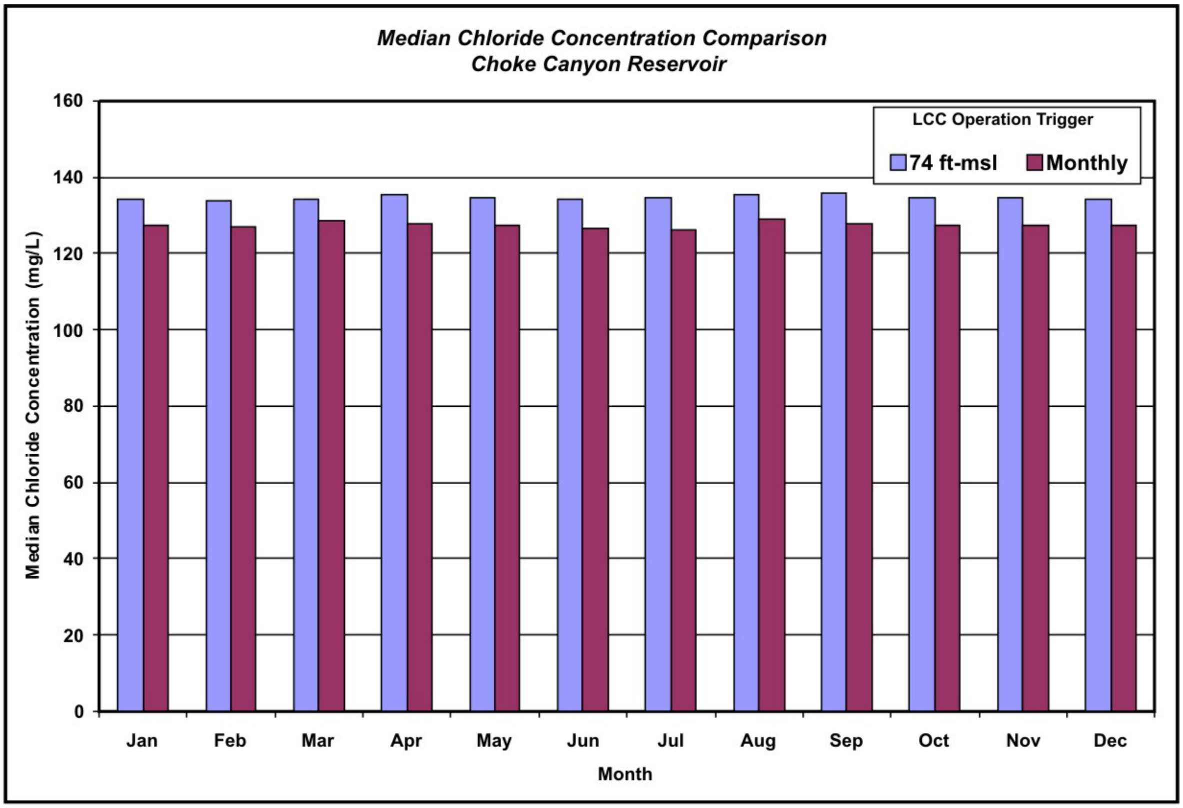


Figure 5-9. Model Simulated Variable LCC Trigger Levels

supply releases from CCR during the summer months to keep LCC at a higher lake level during these times. During summer months, more water would be stored in LCC as compared to current operations. This could enhance recreational activities on LCC.

The figures below show the chloride results for CCR, LCC, and Calallen Pool. There are some minor variations in water quality for the monthly variable trigger scenario as compared to the constant monthly trigger of 74 ft-msl. As shown in Figure 5-10, median chloride levels decrease in CCR (about 5%) with monthly variable LCC targets as compared to the constant target. For LCC and Calallen Pool, there are minimal changes in water quality associated with constant or monthly delivery pattern for LCC as shown in Figure 5-11 and 5-12. Generally, the water quality is better or the same with the monthly variable trigger scenario as with the constant trigger level scenario. About 30% of the time, chlorides in LCC and Calallen Pool would be expected to be slightly less with monthly variable triggers than with constant triggers due to more frequent filling of LCC from CCR with higher triggers during the summer months.



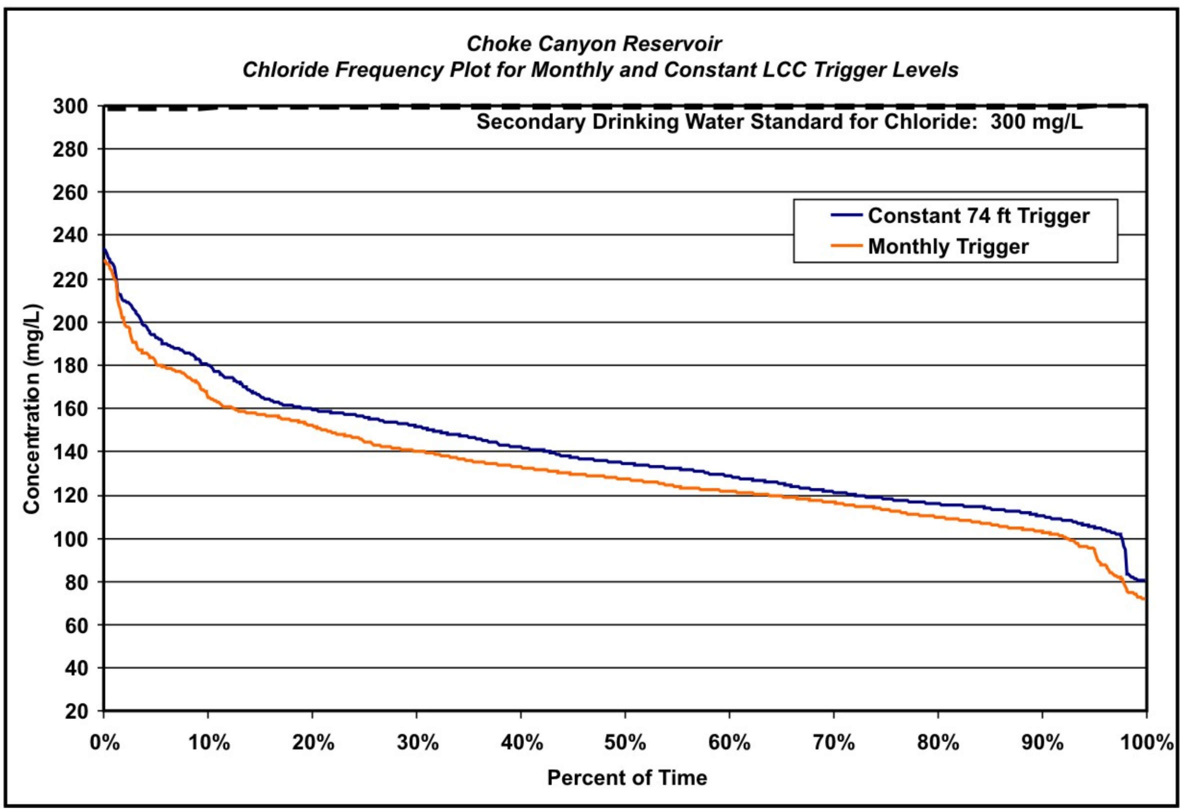
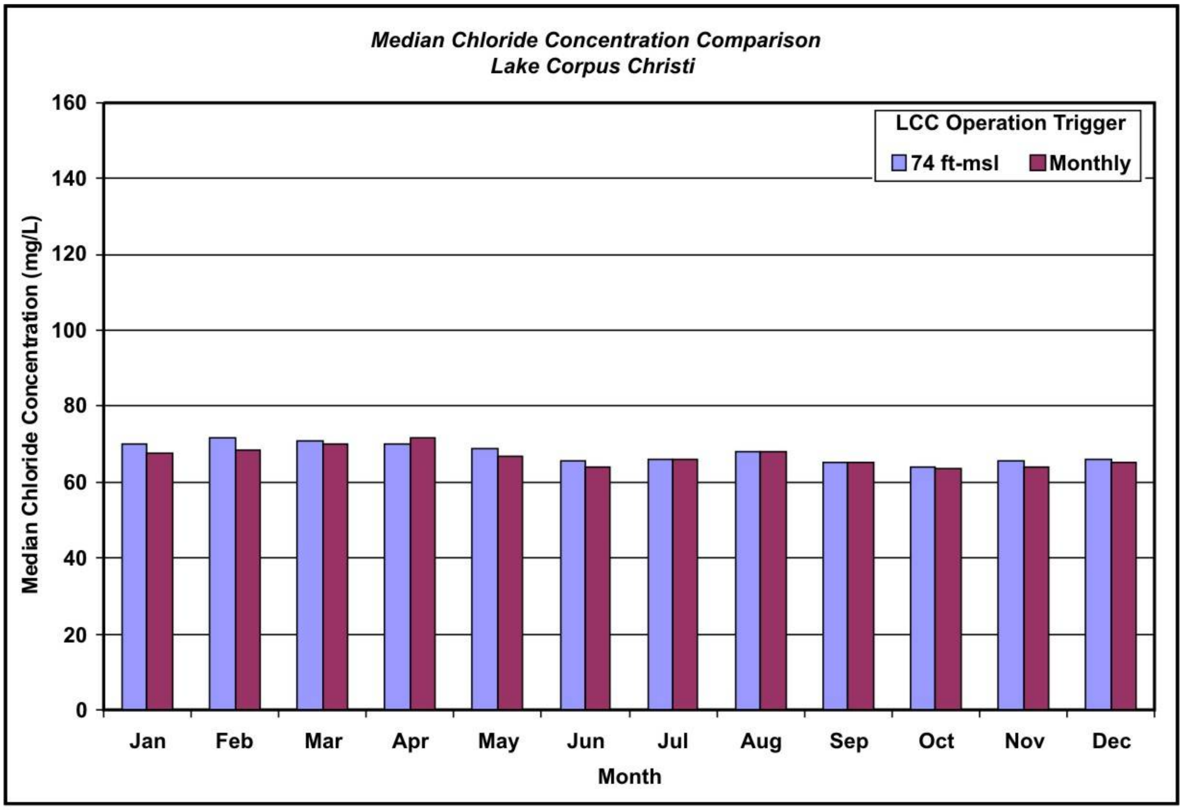


Figure 5-10. Impacts of Chloride Levels at CCR With Monthly Variable LCC Trigger Levels (Scenario 4)



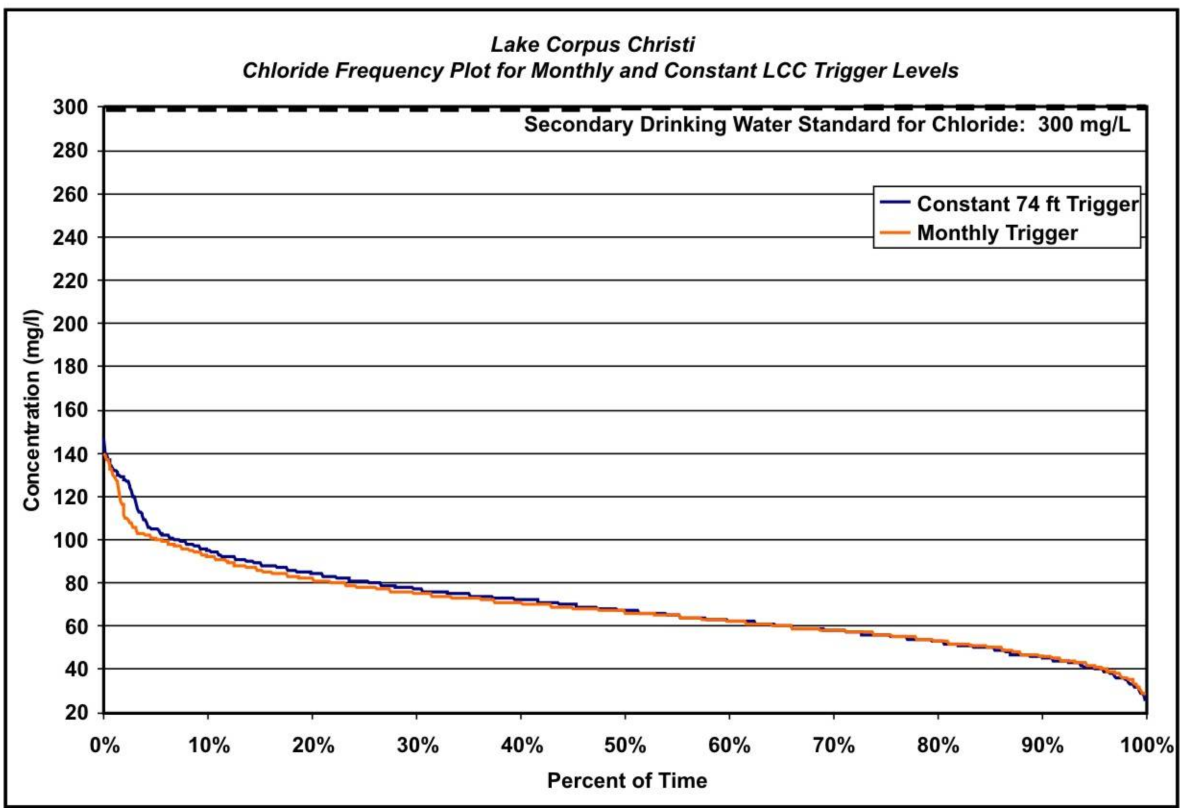
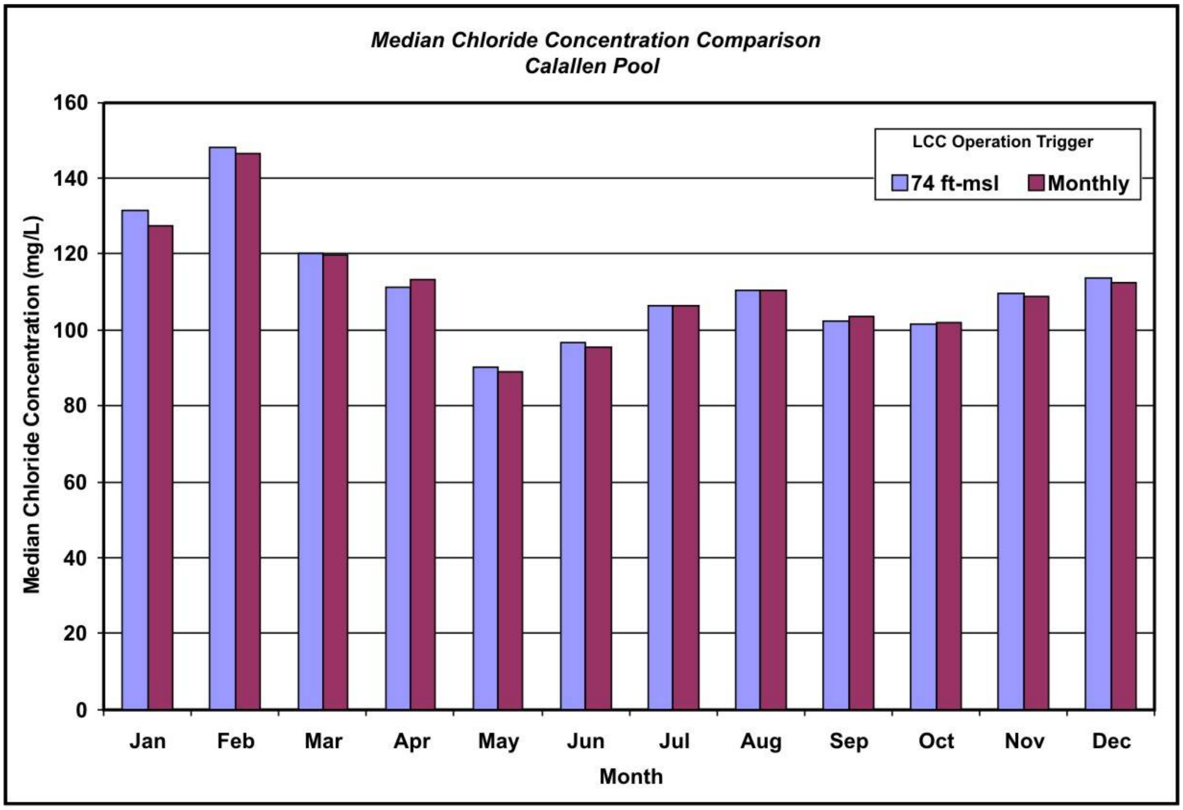


Figure 5-11. Impacts of Chloride Levels at LCC With Monthly Variable LCC Trigger Levels (Scenario 4)



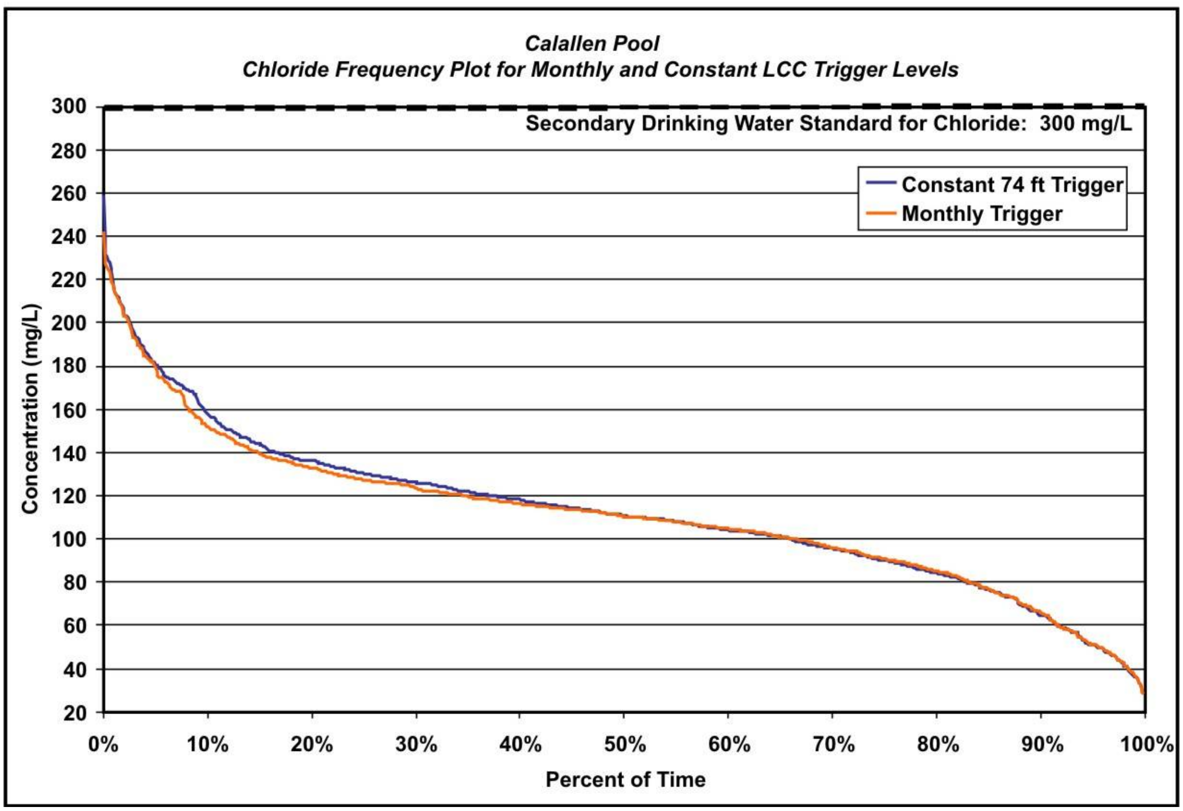


Figure 5-12. Impacts of Chloride Levels at Calallen Pool With Monthly Variable LCC Trigger Levels (Scenario 4)

6.0 Evaluation Summary

The Corpus Christi Water Supply Model (CCWSM) was enhanced to allow for a water quality evaluation of chlorides and TDS concentrations in existing regional surface water supplies including CCR, LCC (including reservoir pass-through for the Nueces Estuary), Lake Texana, and potential future water supplies from the Lower Colorado River. The City has an existing, interbasin transfer permit for supplies from the Lower Colorado River (Garwood Project) and is considering delivery of potential supplies via a canal or pipeline into West Mustang Creek and ultimately Lake Texana. These raw water supplies could then be withdrawn from Lake Texana and transported through the Mary Rhodes Pipeline to the O.N. Stevens Water Treatment Plant. If delivered in this manner, the Garwood Project supplies being diverted through Lake Texana would likely have raw water quality that is the same as the existing Lake Texana water quality, which is currently simulated in the CCWSM. If a different delivery option of the Garwood Project or different supply is being integrated into the CCR/LCC/Lake Texana System, then the CCWSM water quality database would need to be updated to simulate the water quality of the future supply based on historical data for the source water (as available) using the method and approach described in Section 3.0.

Prior to this study, the CCWSM was used as a water supply model to simulate a hydrologic time period from 1934 to 2003 and did not have a water quality component.

This study integrated a water quality database into the model. The calibrated CCWSM is capable of modeling monthly water quality for historical hydrologic period from 1934 to 2003 and is a tool for evaluating water supplies and water supply alternatives for the Coastal Bend Region. There was good calibration for 25%, average, median, and 75% conditions. With this model enhancement, the CCR/LCC/Lake Texana system can be simulated for both water supply and water quality. This new feature can be used to manage water quality, and thereby support selection of water management strategies that will reduce water quality impacts to regional water supplies and allow more efficient use of water supplies.

The CCWSM enhanced with the water quality database is capable of simulating chlorides and TDS for the existing CCR/LCC/Lake Texana system for various potential reservoir operating conditions. There are five municipal and industrial water supply intakes in the Calallen Pool area, where chlorides and TDS fluctuations have been reported. By using the CCWSM to evaluate the effects of various reservoir operations upon quality of water of the Calallen Pool, overall water quality of the Calallen Pool can be stabilized and the reliability of regional water supplies can be increased which will reduce water consumption and treatment costs. Poor raw water quality causes more water to be used in industrial cooling towers; therefore improvements to water quality will directly support industrial water conservation.

Four reservoir operating scenarios were evaluated using the CCWSM including: variable trigger levels for water delivery from CCR to LCC, safe versus firm yield, constant versus seasonal monthly delivery pattern from Lake Texana, and monthly variable LCC trigger levels for water delivery from CCR.

For simulations with variable trigger levels for water delivery from CCR to LCC (Scenario 1), the higher trigger level of 86 ft-msl showed lower median chloride levels in CCR. There were no significant impacts to LCC, Calallen Pool, or Lake Texana water quality with variable trigger levels.

For the safe versus firm yield evaluation (Scenario 2), median chloride levels increased about 13% and 10% for CCR and Calallen Pool, respectively, with safe yield analyses. There were no significant impacts to LCC and Lake Texana water quality attributable to safe or firm yield operations.

For the seasonal monthly delivery pattern (versus constant) from Lake Texana (Scenario 3), no significant change was reported to CCR, LCC, Calallen Pool, or Lake Texana water quality.

With monthly variable LCC trigger levels in the summer (83 ft-msl) as compared to a constant LCC trigger level at 74 ft-msl (Scenario 4), median chloride levels decreased about 5% in CCR. There were no significant impacts to LCC, Calallen Pool, or Lake Texana water quality for this simulation.

Based on the results of the four operating scenarios which show minimal impacts to water quality for LCC and Calallen Pool where regional water supply intakes are located, no changes to reservoir operations are recommended at this time for water quality.

7.0 Texas Water Development Board Report Formalities

This report was prepared in accordance with the approved Scope of Work pursuant to TWDB Contract No. 0704830699. The preliminary draft report was posted in October 2008 on the Nueces River Authority website for Regional Water Planning Group and public comment. All draft report comments were addressed. The draft report was approved by the Coastal Bend RWPG on November 13, 2008 and submitted to the TWDB on December 23, 2008.

The TWDB provided comments on the draft report in March 2009. The Coastal Bend RWPG approved responses to the TWDB comments on March 12, 2009. A copy of TWDB comments on the draft study report and written summary of how the final report addresses these comments is provided in Appendix E.

Appendix A
Model Calibration Approach and Results

Model Calibration Approach

As discussed in Section 4.5 of the report, the CCWSM water quality parameters were calibrated using historical water quality data for the three primary reservoirs simulated in the model. Calibration for the three reservoirs is necessary due to the regression methods used in developing the loading data and the sheer complexity of modeling a complex mass balance of the conservative constituents of a reservoir system. The calculated loadings, when simulated in the model using operating assumptions that closely matched the prevailing system operations during the time the historical data were being collected, need to be adjusted in order to statistically approximate the actual water quality concentrations measured in the reservoir.

The adjustment is applied to the time series of loadings data at the time the data are read into by the model. The adjustment factor is a user entered value located in the primary input file for the model.

Historical water quality and flow were measured in-stream at the following locations and used to develop chloride loadings into each of the three reservoirs.

Nueces River Bridge on US 281 South of Three Rivers (used to calculate chloride loadings into LCC)–

1987-2007 for chlorides (198 samples); 1981-2004 for TDS (21 samples)

Frio River at SH16 in Tilden (used to calculate chloride loadings into CCR)–

1976-2007 for chlorides (171 samples); 1981-2004 for TDS (19 samples)

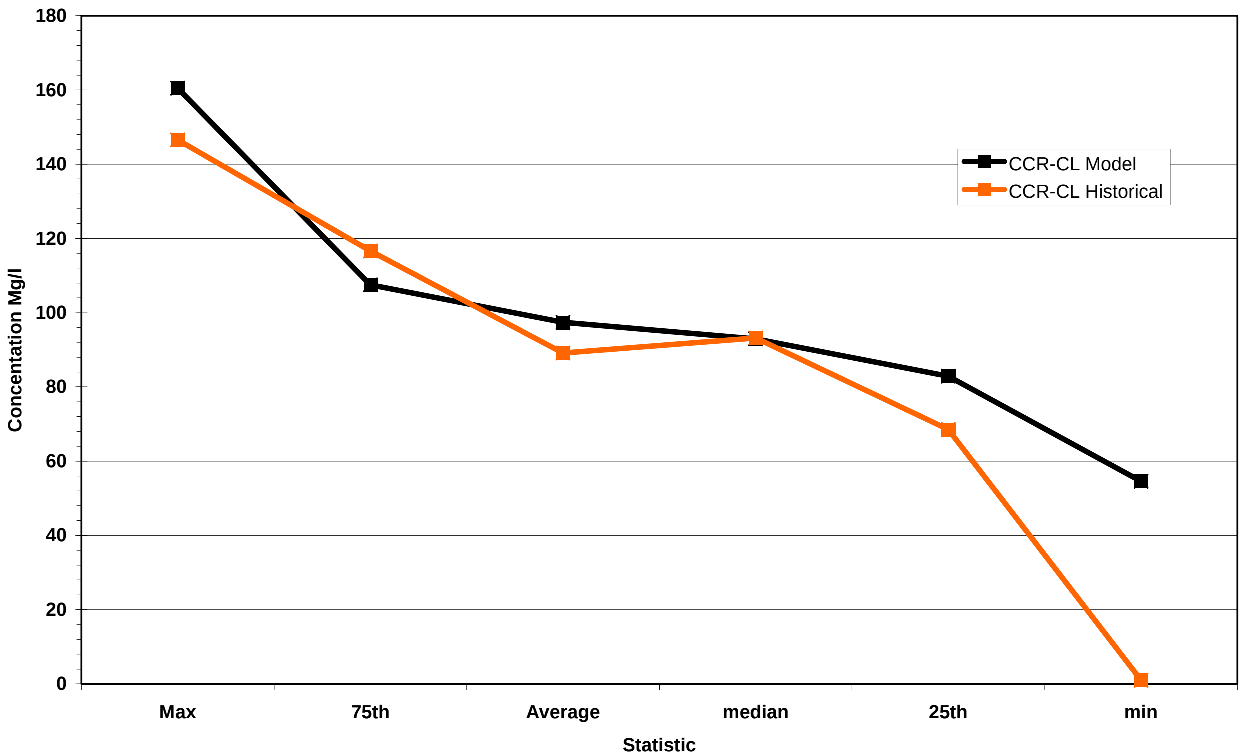
Navidad River near Edna, Sandy Creek near Ganado, and West Mustang Creek (used to calculate chloride loadings into Lake Texana)–

1981-2007 for chlorides (241 samples); 1982-1983 for TDS (10 samples)

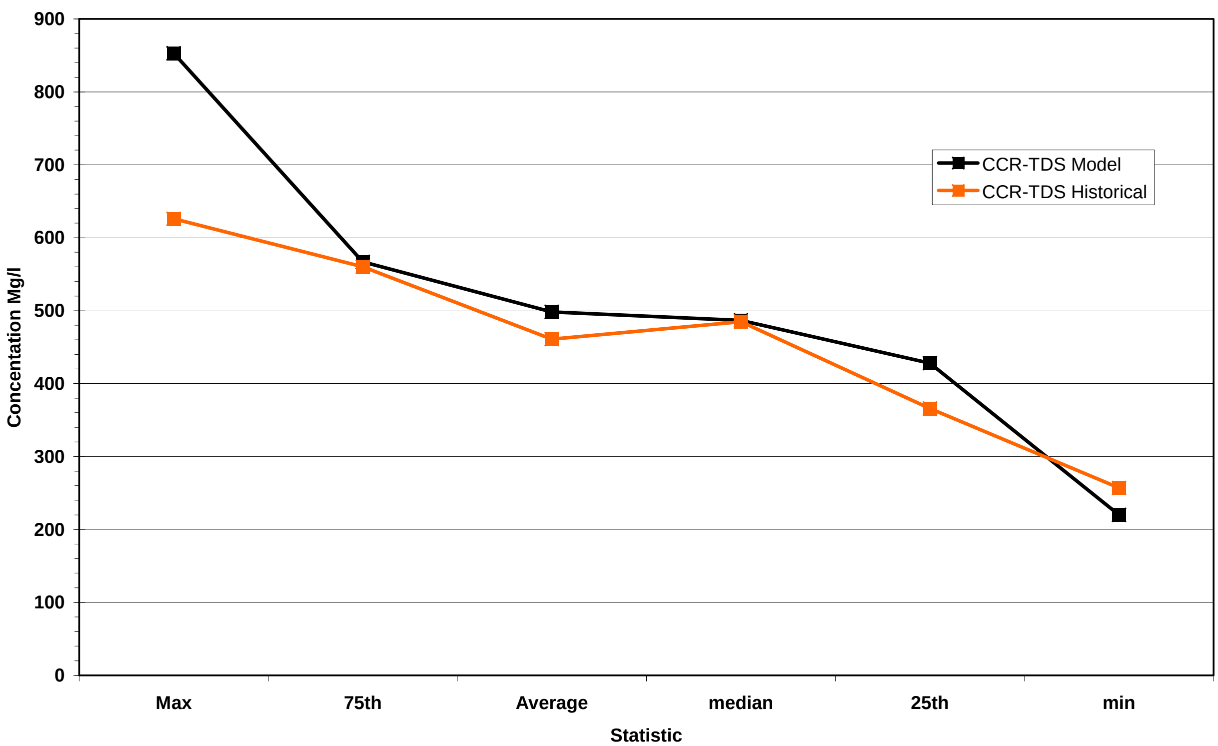
The model was run with a 1.0, or no adjustment on the loading factors, the results were summarized and compared to the actual historic data. The actual “real world” reservoir system is considerably complex with many different interactions occurring on a daily basis. Since the model cannot fully account for these daily interactions, adjustment factors were added to the water quality code during model calibration to adjust monthly loading values for each reservoir to “fine tune” the model and achieve a statistical best fit to historical water quality data. The water quality adjustment factors for CCR and Lake Texana were adjusted down to achieve the best fit, while these values were adjusted higher for LCC. Successive iterations of the model were executed with adjustments applied to model-simulated water quality values until the medians between the historical and model matched to within 1%. After this was achieved, the model was considered "calibrated." The goal of the calibration procedure was to develop a "good fit" for the statistical values between the 75th and 25th percentile by using the median value as the calibration target. The following graphs show the results of the final calibration. These final adjustment values were then used for all additional simulations of the model for the various alternatives analysis.

For Calallen Pool, the CCWSM shows discrete, monthly water quality values rather than continuous, long term simulated results that it shows for reservoirs. There are two contributing factors which impact water quality in the Nueces River at Calallen Pool: (1) natural, groundwater inflow from the Gulf Coast Aquifer, and (2) man-made periodic discharges of salty water likely from sand and gravel operations. The water quality within Calallen Pool also fluctuates according to seasonal changes and extreme hydrologic events (such as prolonged droughts or wet periods) which are challenging to simulate in a monthly time-step model. As discussed in Section 3.0, the groundwater inflow volume and water quality for Calallen Pool for the CCWSM were estimated based on results published by Atlee Cunningham and USGS studies for average conditions, which are 8 cfs with chloride concentration of 1,170 mg/L and total dissolved solids concentration of 2,900 mg/L. There were no adjustment factors applied to the model for Calallen Pool. As shown in the attached figure which compares historical and modeled values, the model under-predicts chloride concentrations for the time period from about 1978 through 1984. This could be partially attributable to the differences between actual reservoir operations during that time (pre-Agreed Order provisions) versus the model simulation which reflects current operations with modified Phase IV reservoir operating policy (for CCR water supply releases to LCC) and 2001 TCEQ Agreed Order provisions. After 1984, the modeled and historical chloride measurements have better correlation.

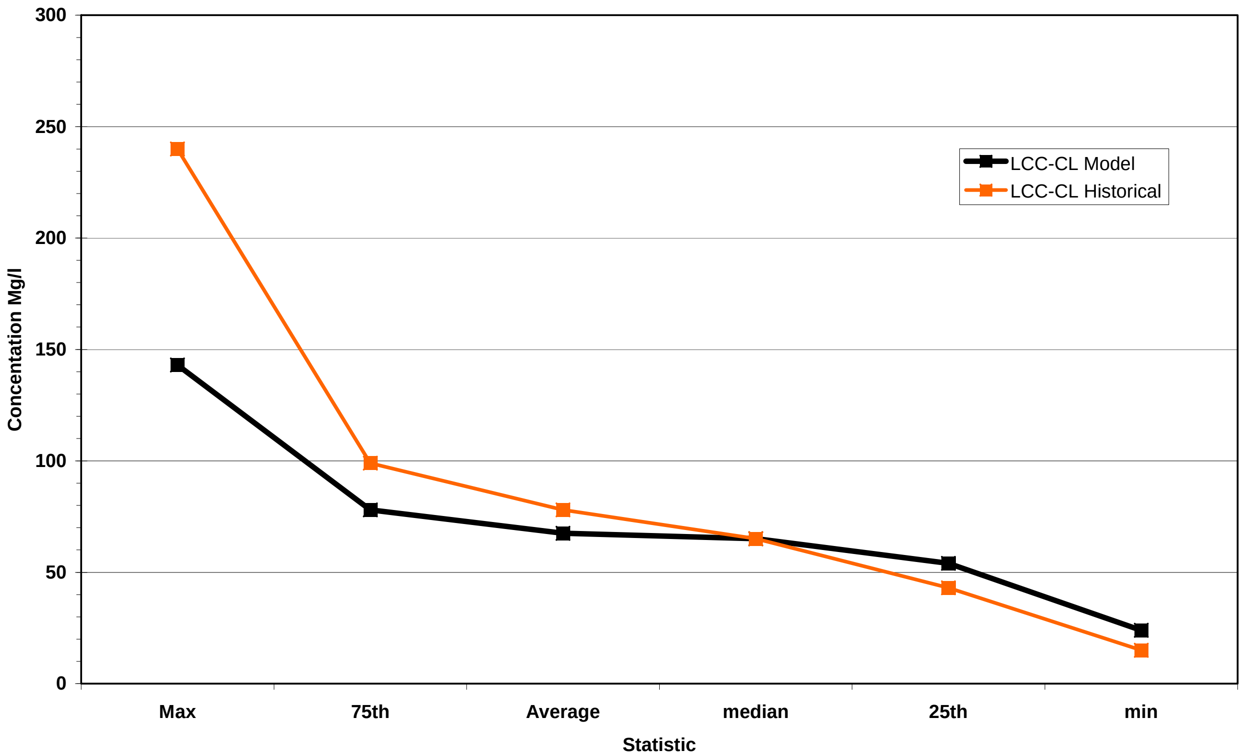
During Phase II development of the 2011 Plan, the CCWSM will be reviewed for LCC and the Calallen Pool as part of Task 4C (Evaluation of Strategies for Management of Water Supply and Operation of LCC to Improve Water Quality) to account for seasonal and/or annual variation in groundwater inflow and chloride/tds concentration which could improve the correlation between measured and historical measurements at Calallen Pool.



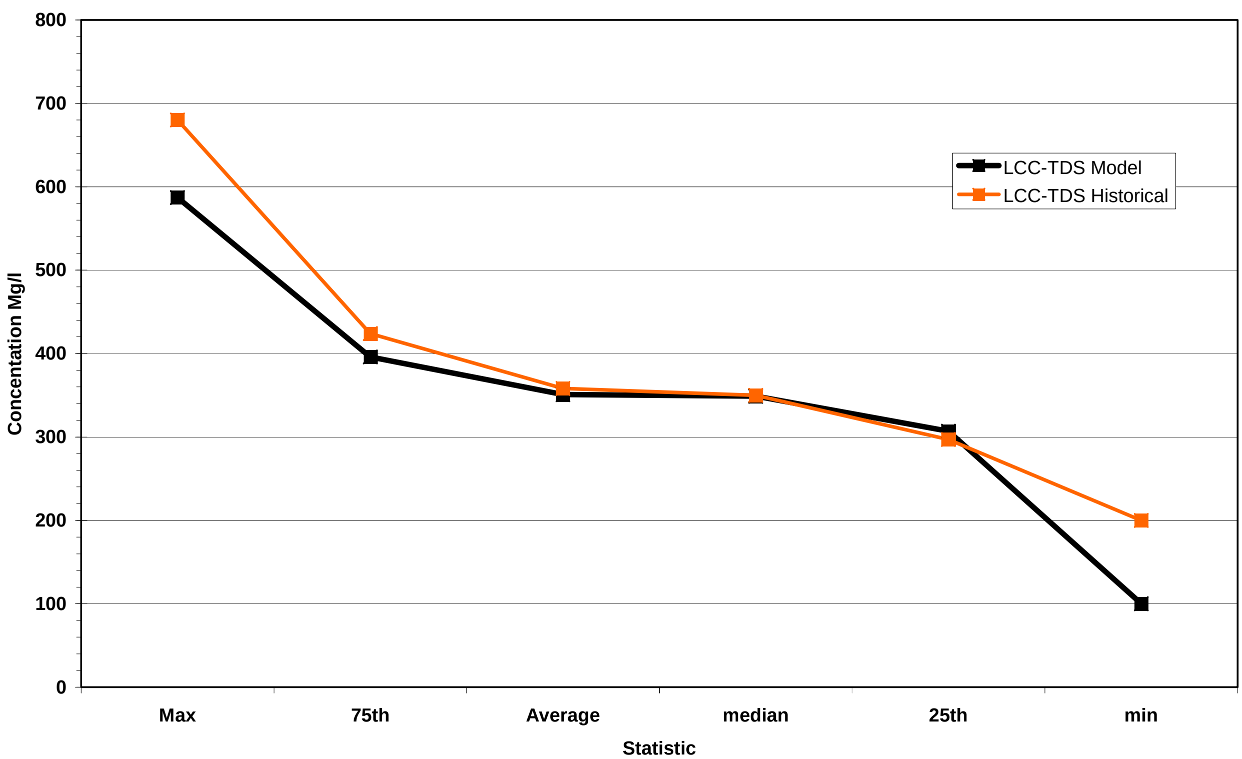
Calibrated Model Results: CCR Long Term Model Statistics for Chlorides



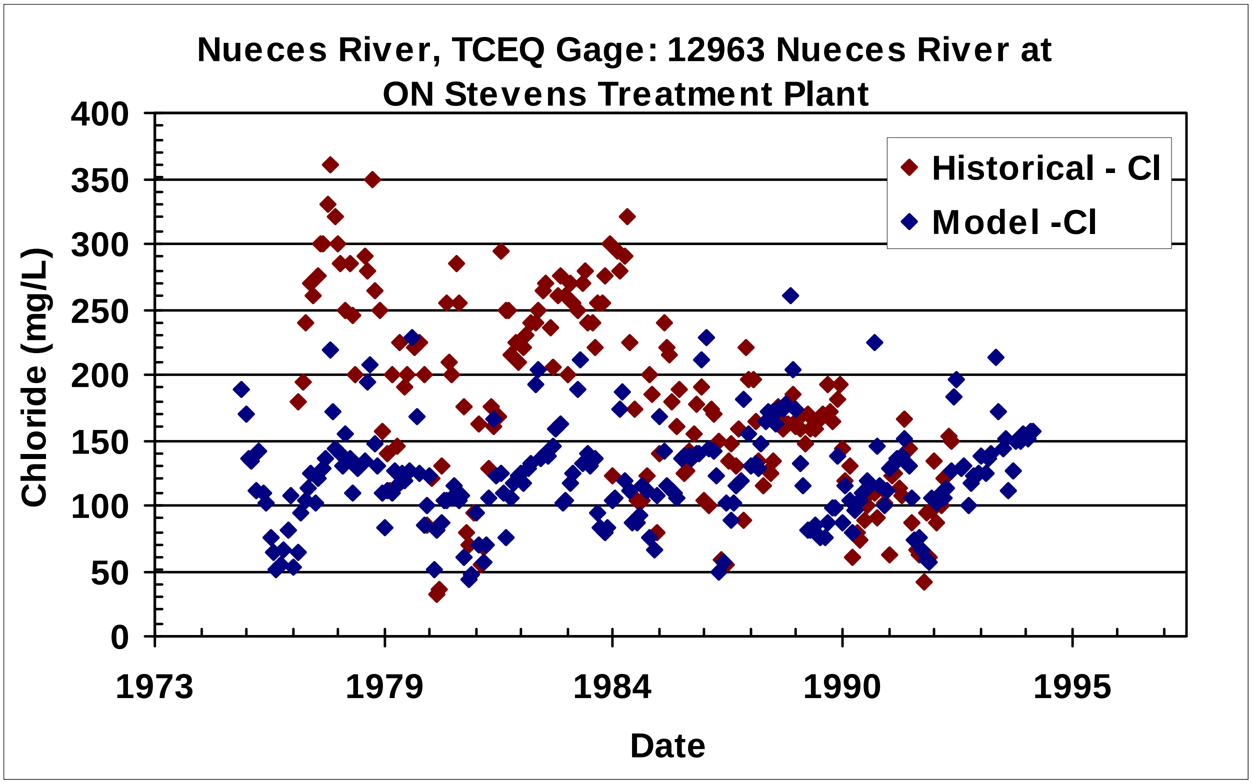
Calibrated Model Results: CCR Long Term Model Statistics for Total Dissolved Solids



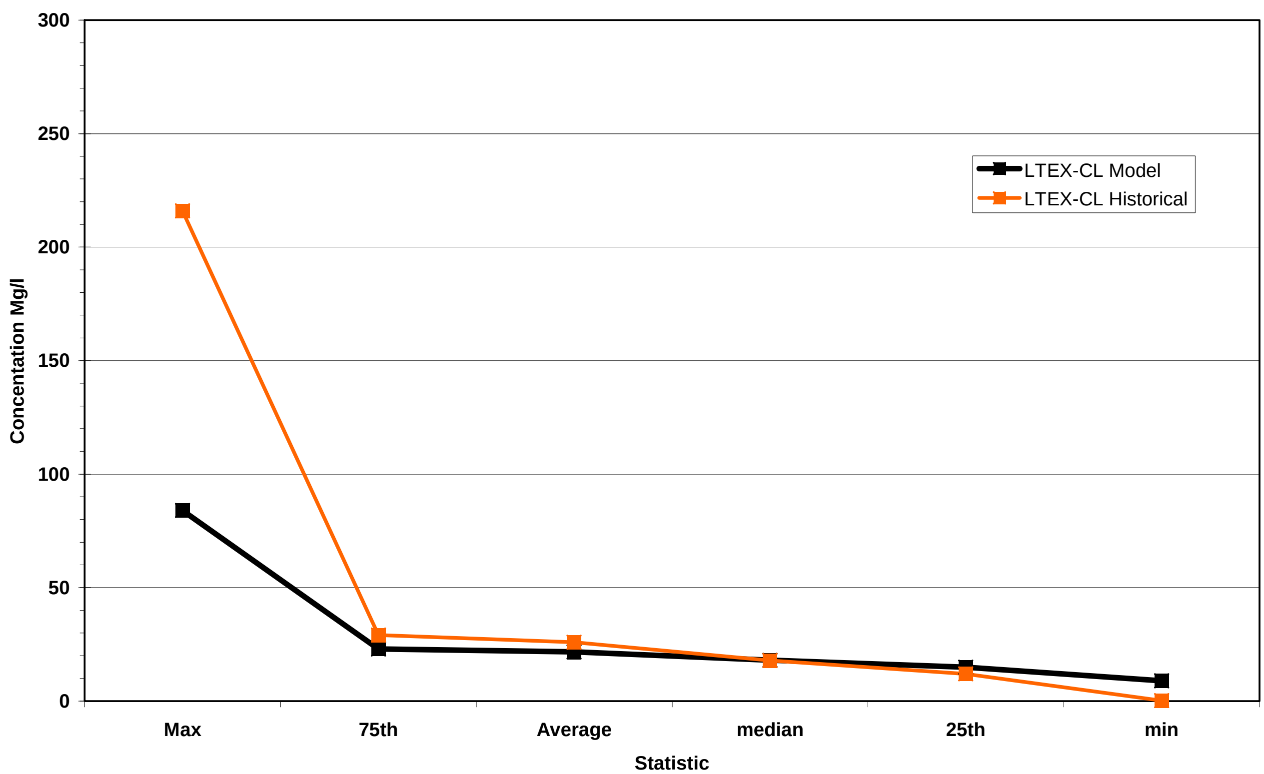
Calibrated Model Results: LCC Long Term Model Statistics for Chlorides



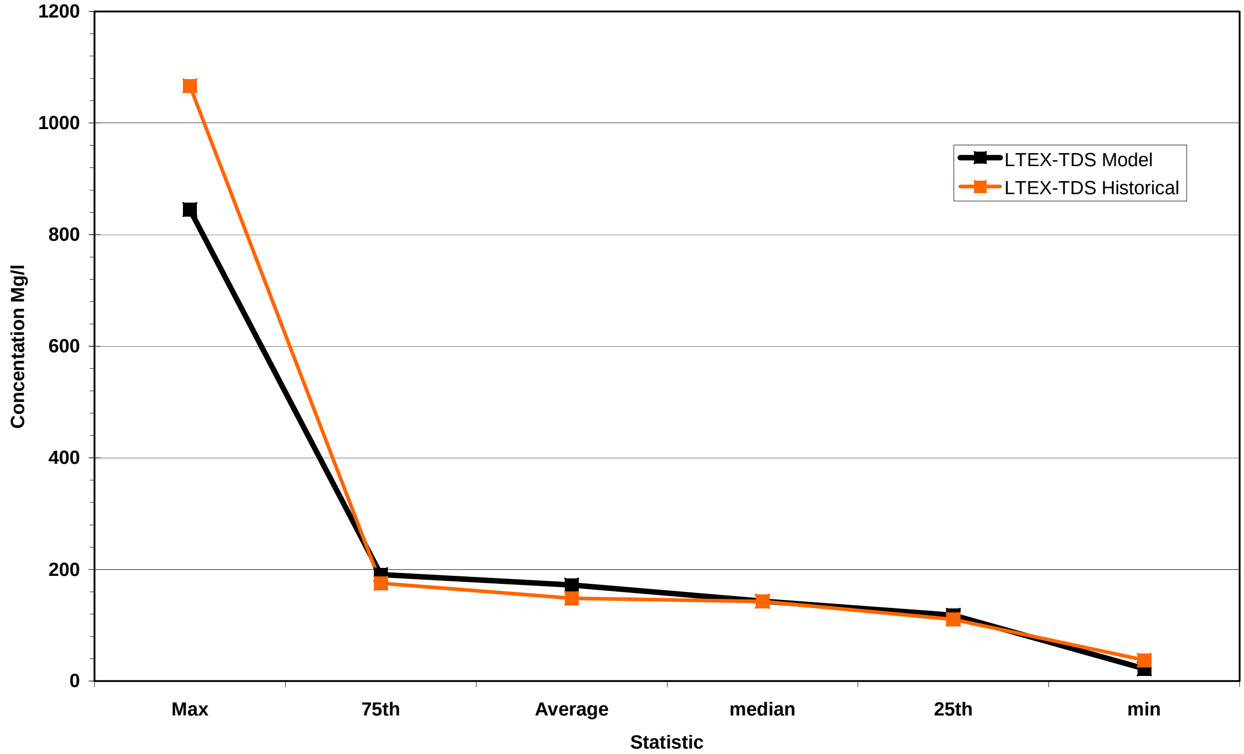
Calibrated Model Results: LCC Long Term Model Statistics for Total Dissolved Solids



Comparison of Historical Chloride Measurements to Calibrated Model Simulated Values



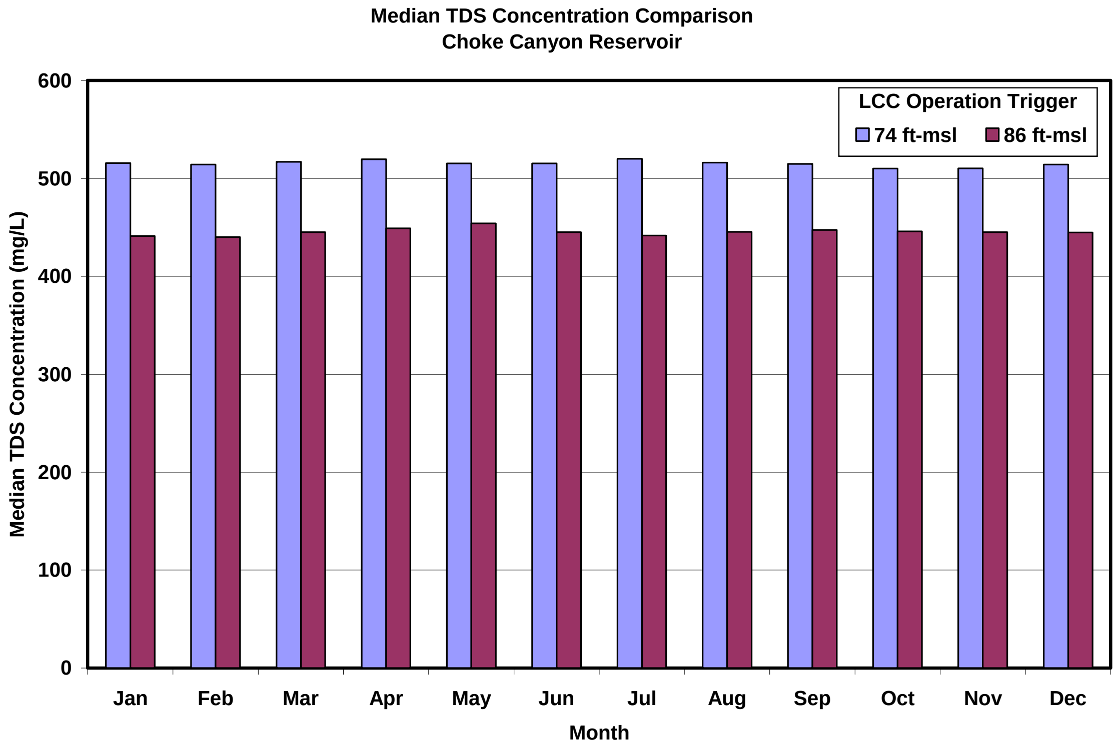
Calibrated Model Results: Lake Texana Long Term Model Statistics for Chlorides

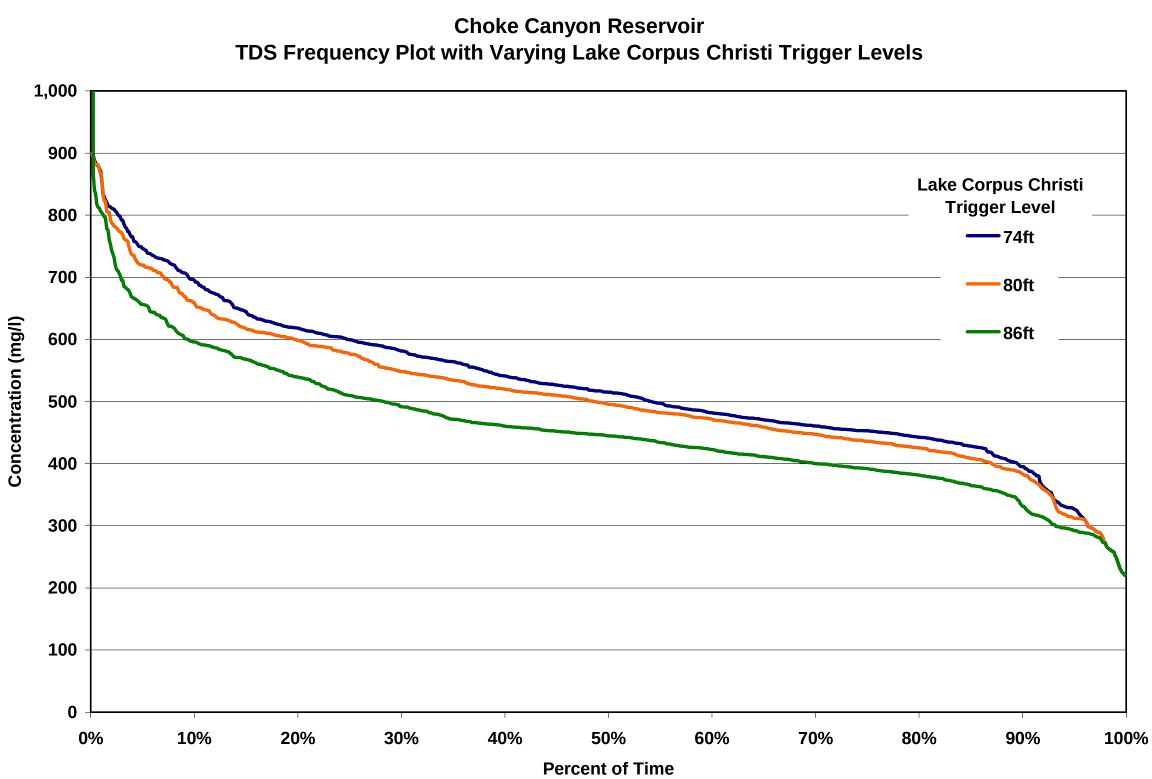


Calibrated Model Results: Lake Texana Long Term Model Statistics for Total Dissolved Solids

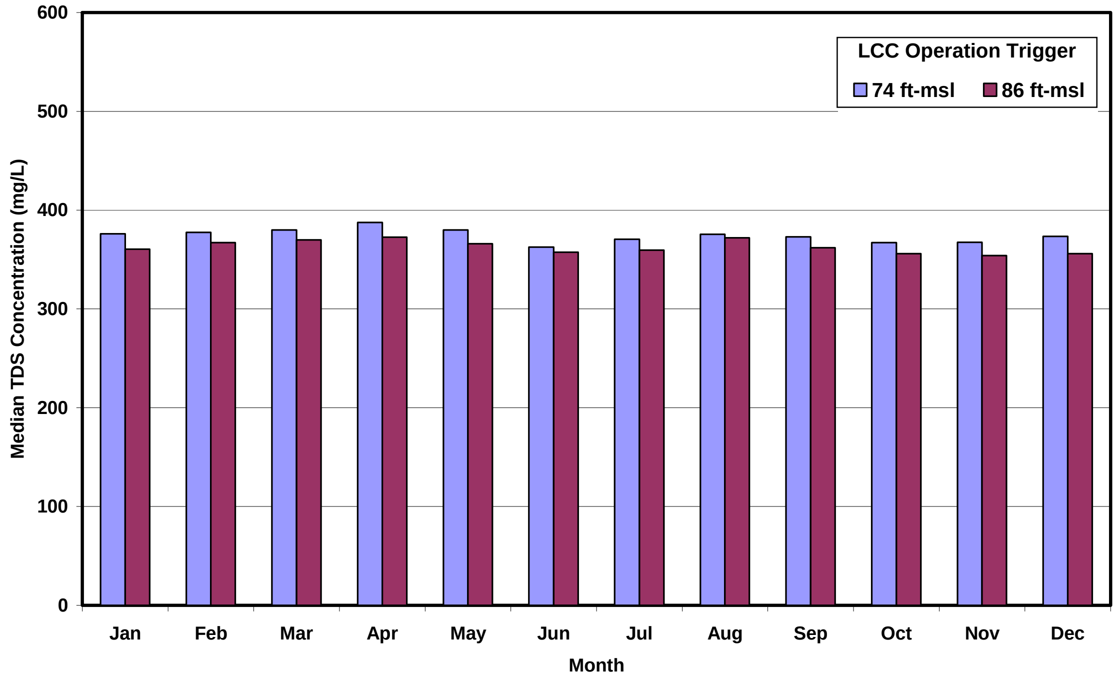
Appendix B
Total Dissolved Solids Results (by Scenario)

Attachment B-1:
Variable LCC trigger level for water delivery from CCR to LCC (Scenario 1)

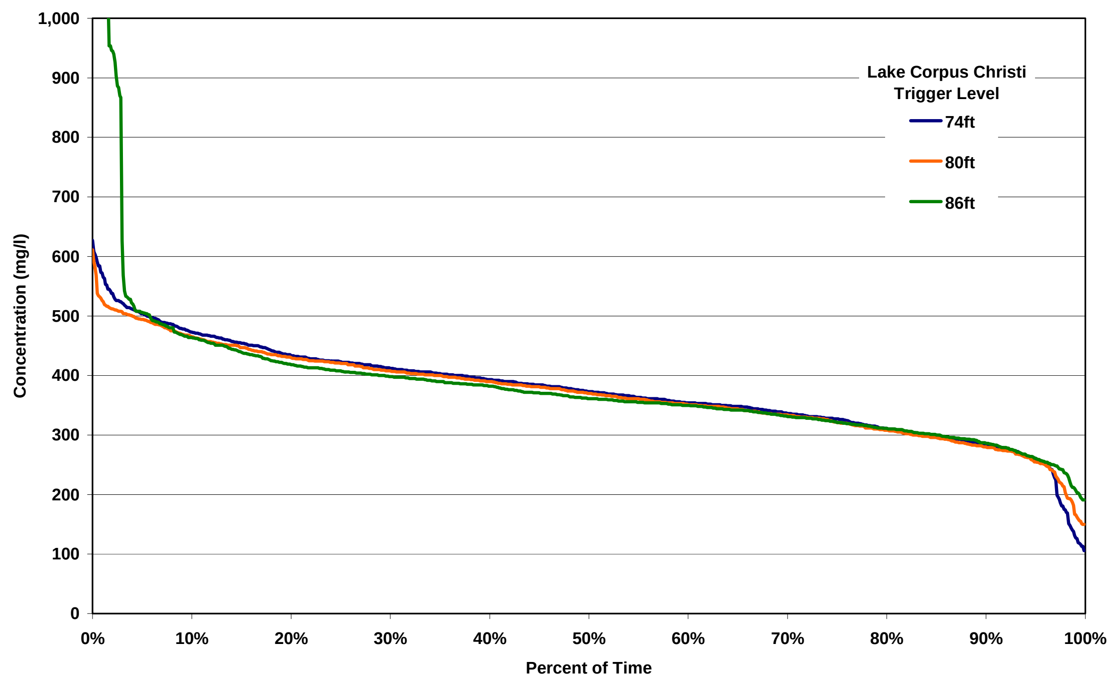

Median TDS Concentration Comparison
Choke Canyon Reservoir
LCC Operation Trigger
74 ft-msl
86 ft-msl
Median TDS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

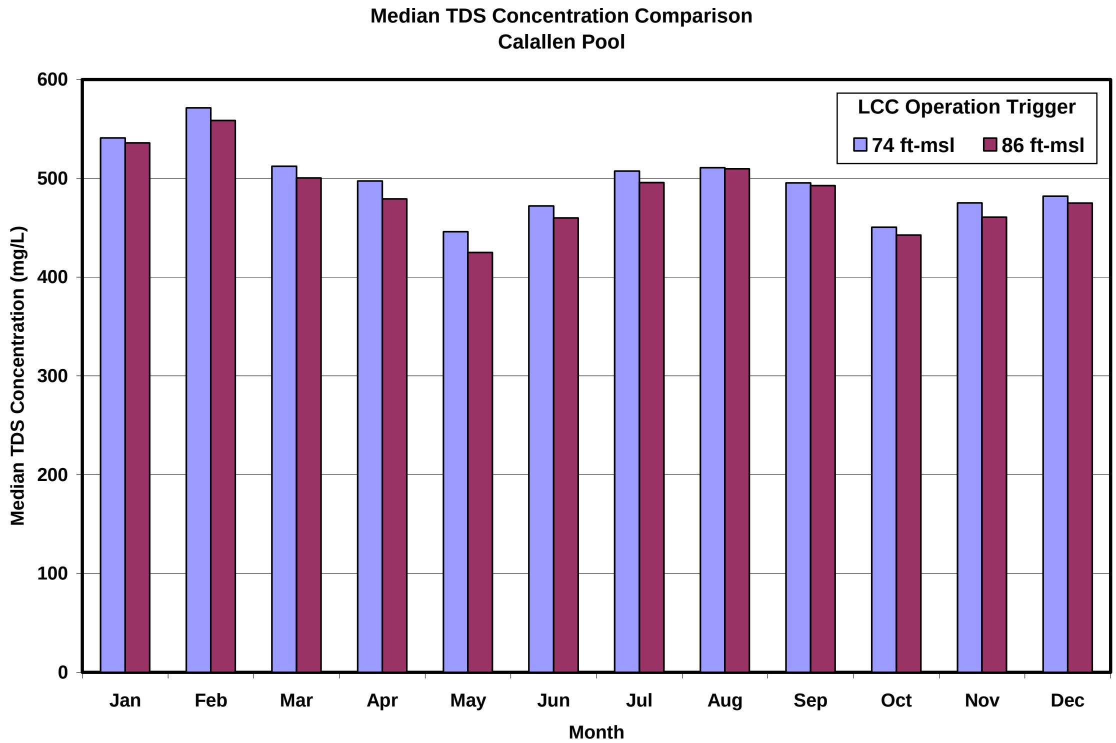

Choke Canyon Reservoir
TDS Frequency Plot with Varying Lake Corpus Christi Trigger Levels
Lake Corpus Christi
Trigger Level
74ft
80ft
86ft
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

Median TDS Concentration Comparison
Lake Corpus Christi

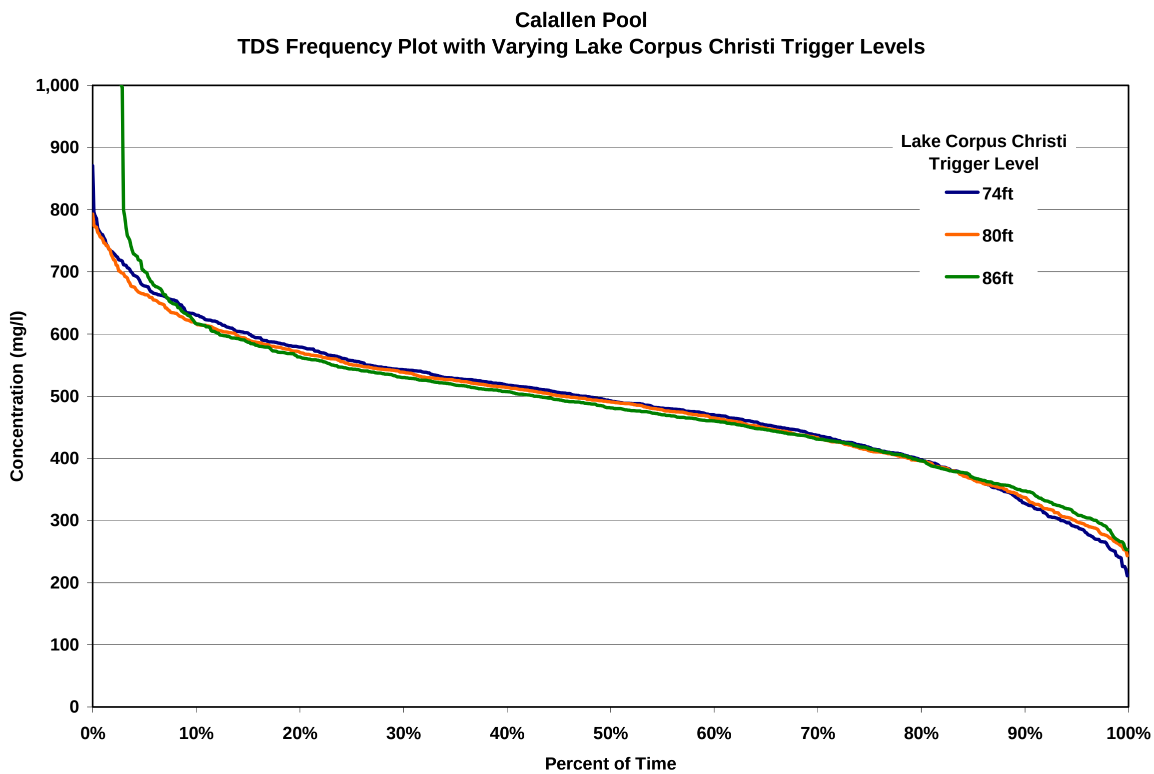


Lake Corpus Christi
TDS Frequency Plot with Varying Lake Corpus Christi Trigger Levels

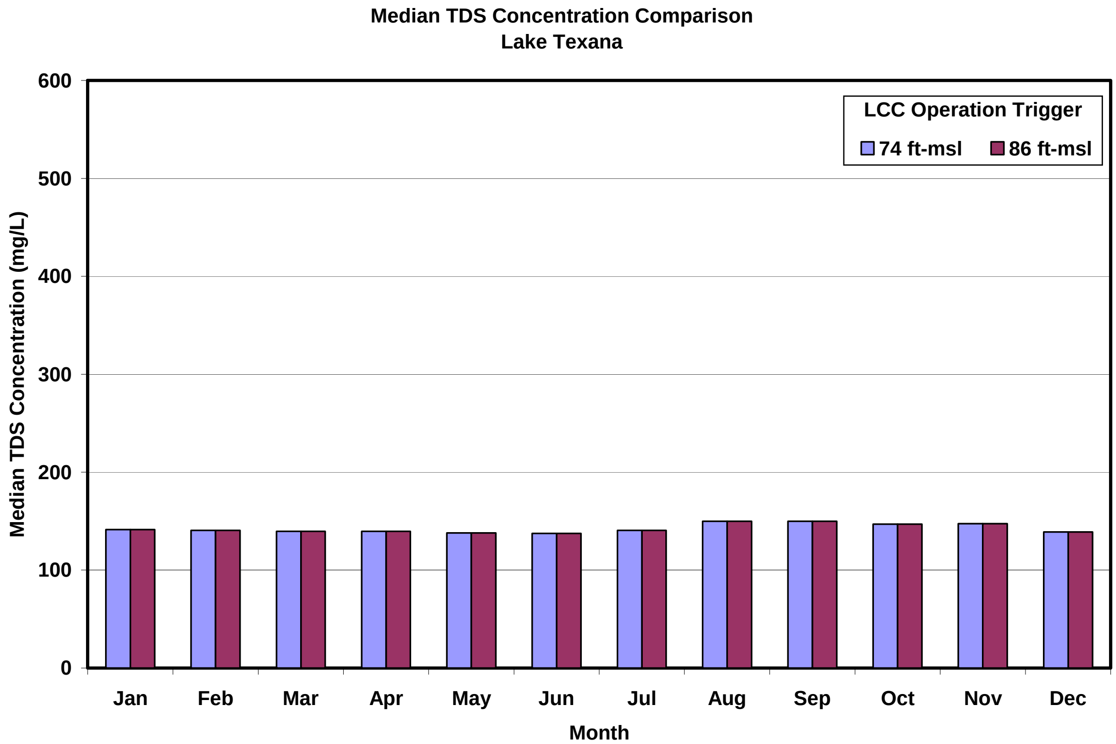


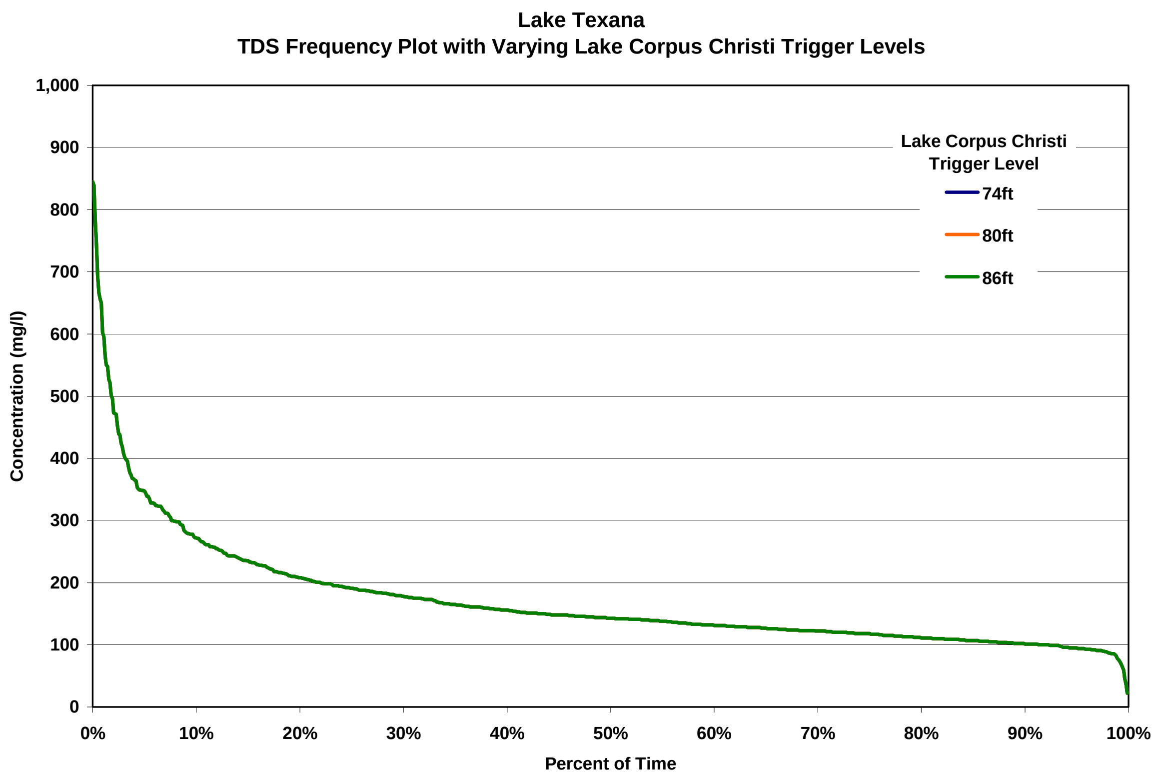


Median TDS Concentration Comparison
Calallen Pool
LCC Operation Trigger
74 ft-msl
86 ft-msl
Median TDS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

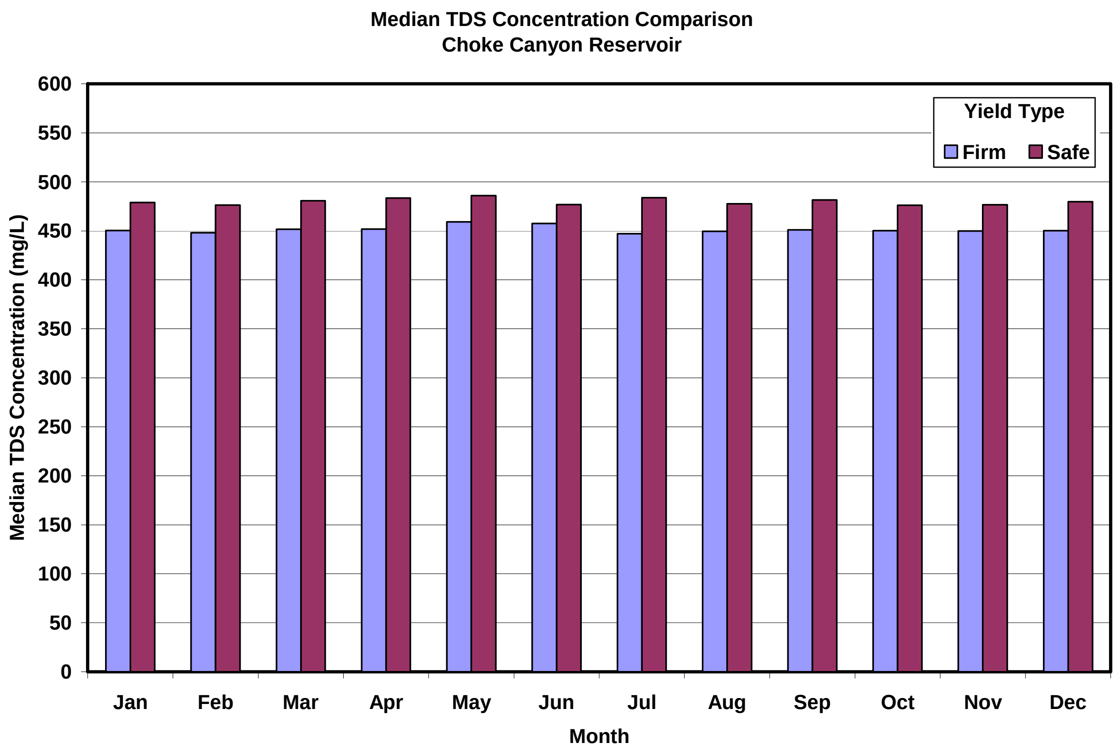


Calallen Pool
TDS Frequency Plot with Varying Lake Corpus Christi Trigger Levels
Lake Corpus Christi Trigger Level
74ft
80ft
86ft
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

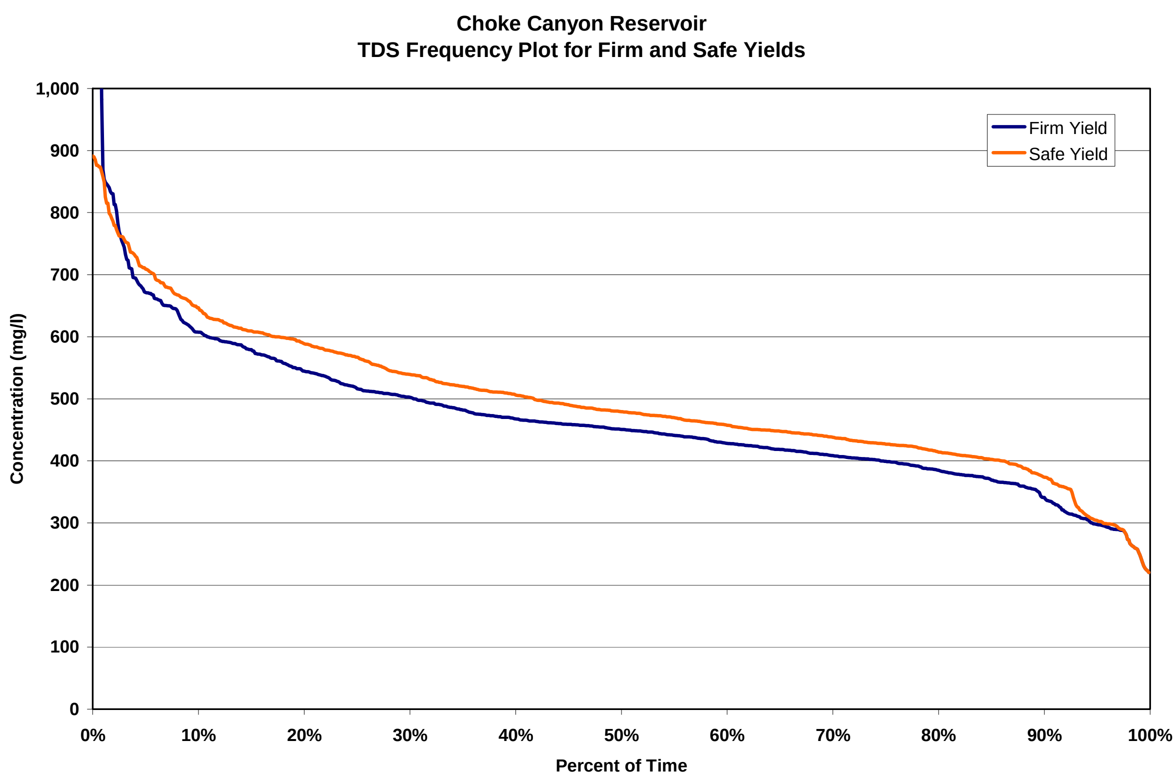

Median TDS Concentration Comparison
Lake Texana
Median TDS Concentration (mg/L)
LCC Operation Trigger
74 ft-msl
86 ft-msl
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Lake Texana
TDS Frequency Plot with Varying Lake Corpus Christi Trigger Levels
Concentration (mg/l)
Lake Corpus Christi Trigger Level
74ft
80ft
86ft
0
100
200
300
400
500
600
700
800
900
1,000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

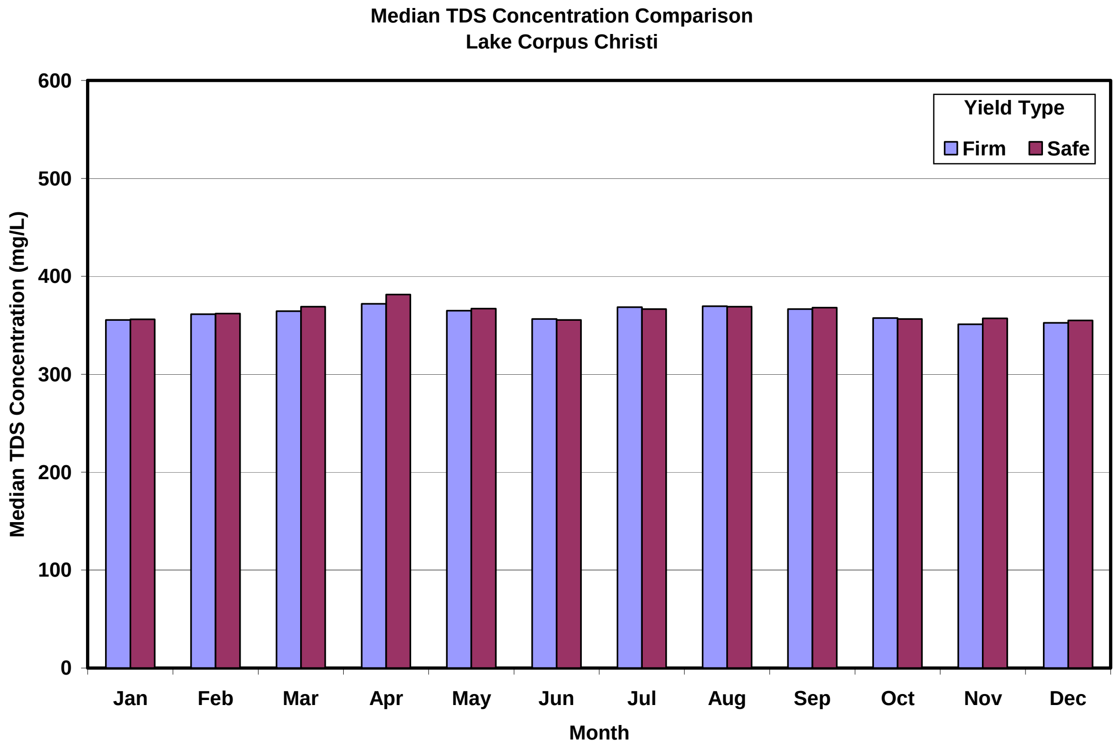
Attachment B-2:
Safe versus Firm System Yield
(Scenario 2)

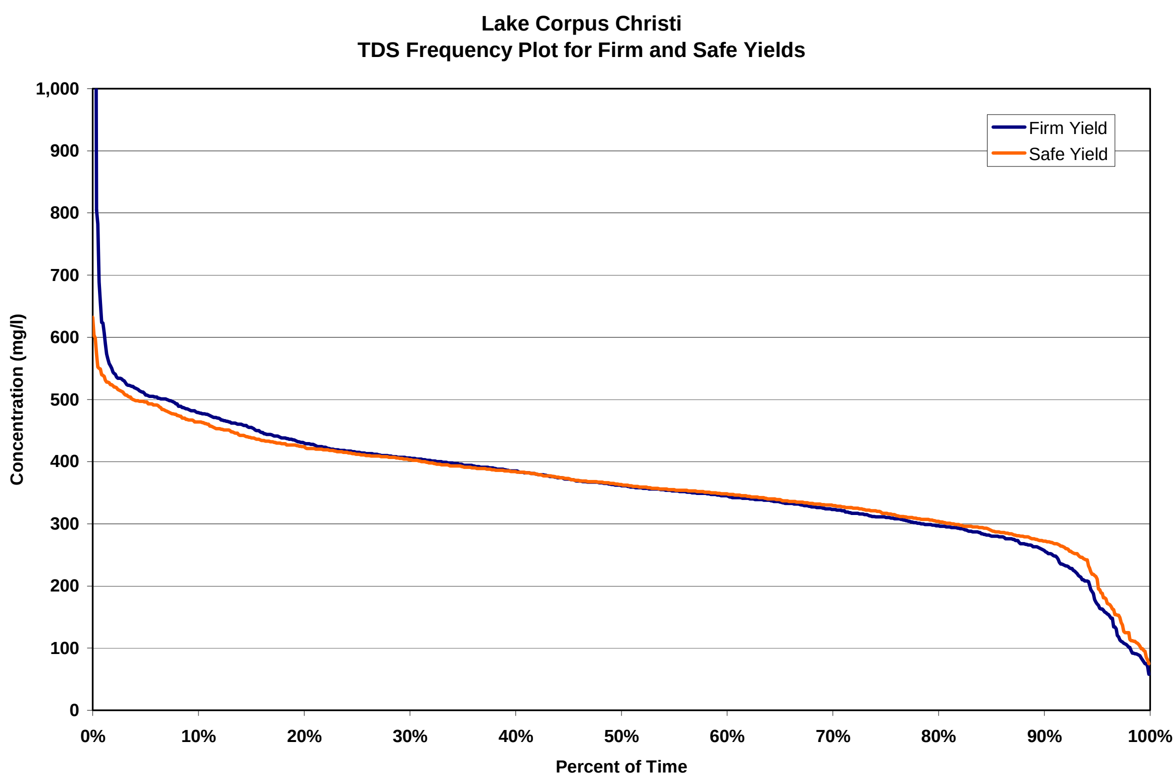


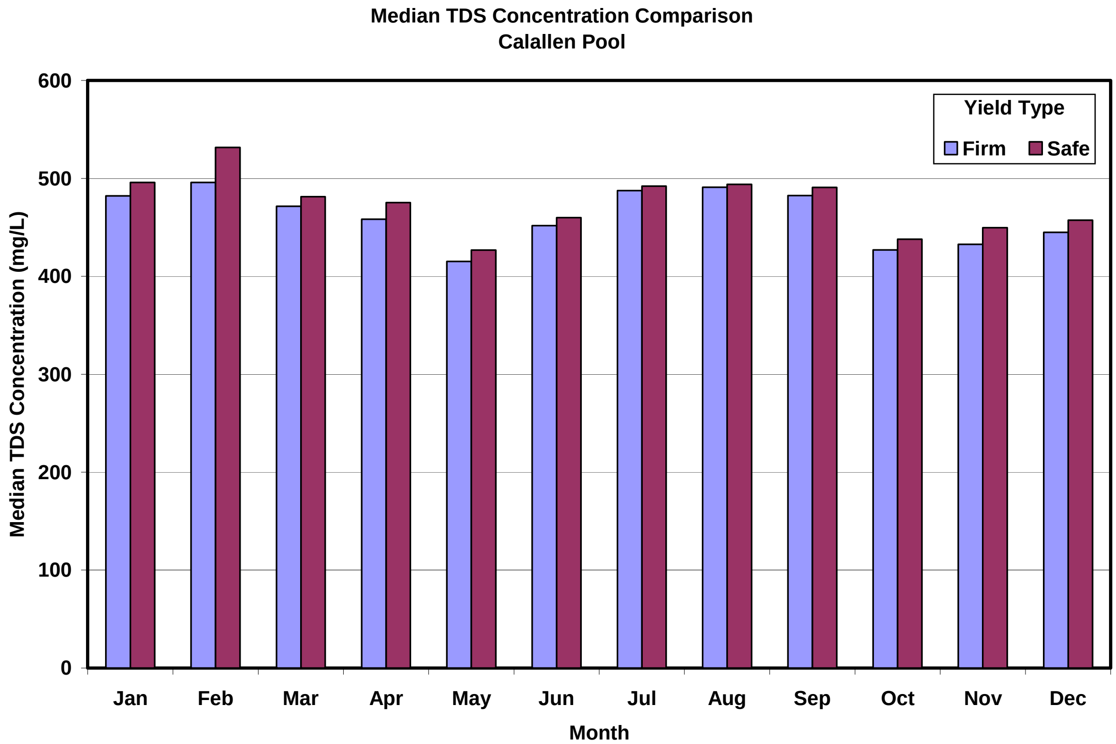
Median TDS Concentration Comparison
Choke Canyon Reservoir
Yield Type
Firm
Safe
Median TDS Concentration (mg/L)
600
550
500
450
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month



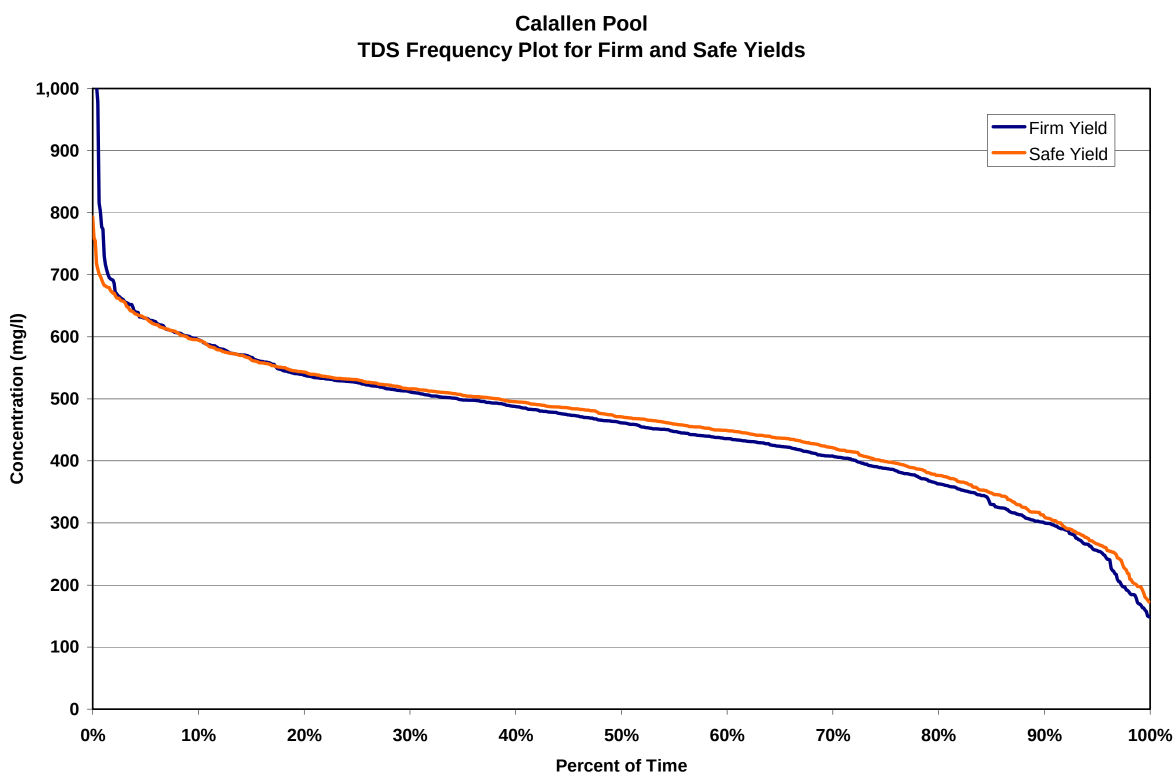
Choke Canyon Reservoir
TDS Frequency Plot for Firm and Safe Yields
Firm Yield
Safe Yield
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time


Median TDS Concentration Comparison
Lake Corpus Christi
Yield Type
Firm
Safe
Median TDS Concentration (mg/L)
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

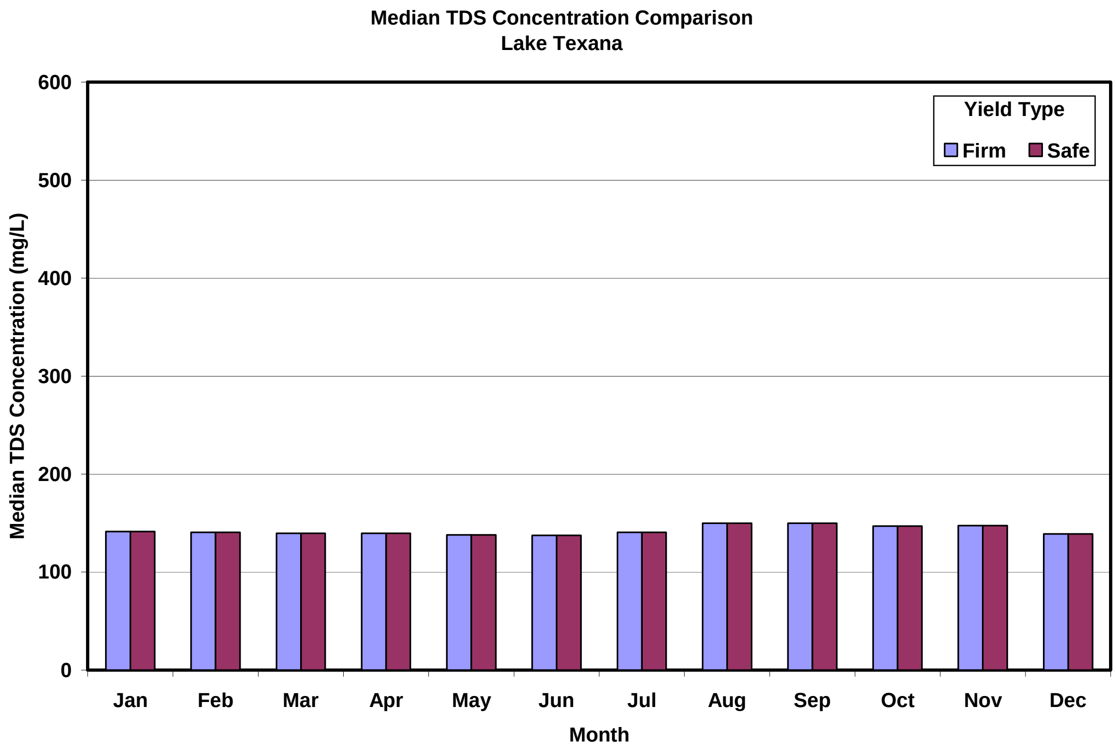

Lake Corpus Christi
TDS Frequency Plot for Firm and Safe Yields
Firm Yield
Safe Yield
Concentration (mg/l)
0
100
200
300
400
500
600
700
800
900
1,000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

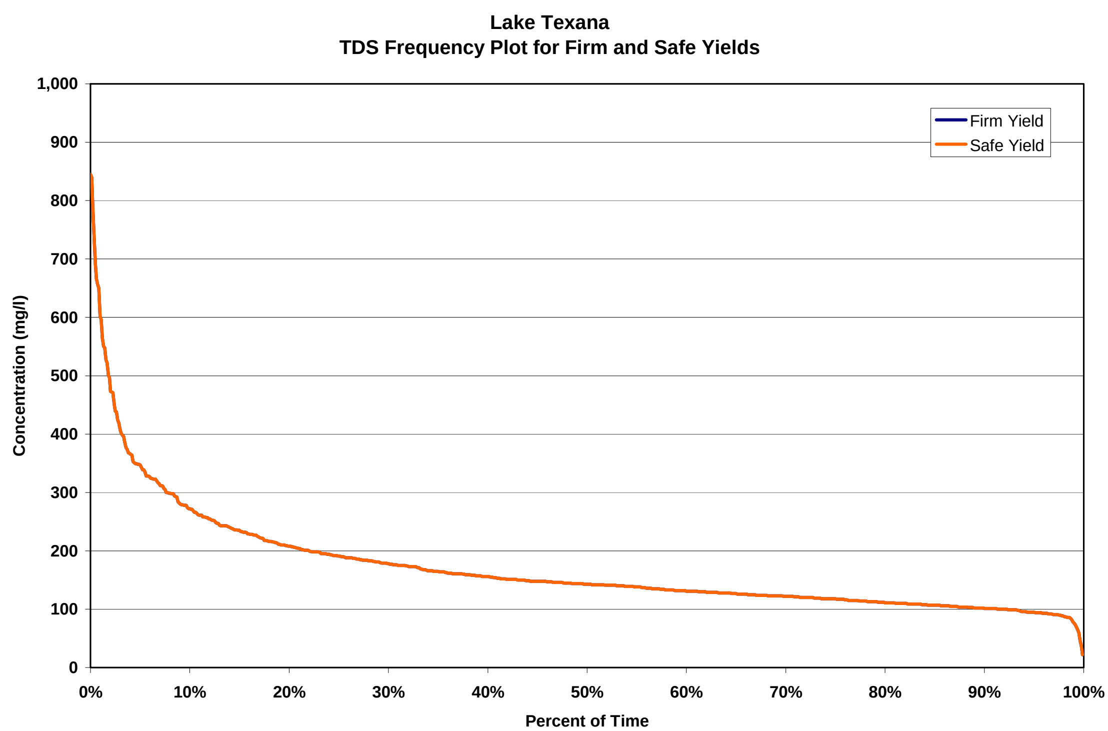


Median TDS Concentration Comparison
Calallen Pool
Median TDS Concentration (mg/L)
0
100
200
300
400
500
600
Yield Type
Firm
Safe
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

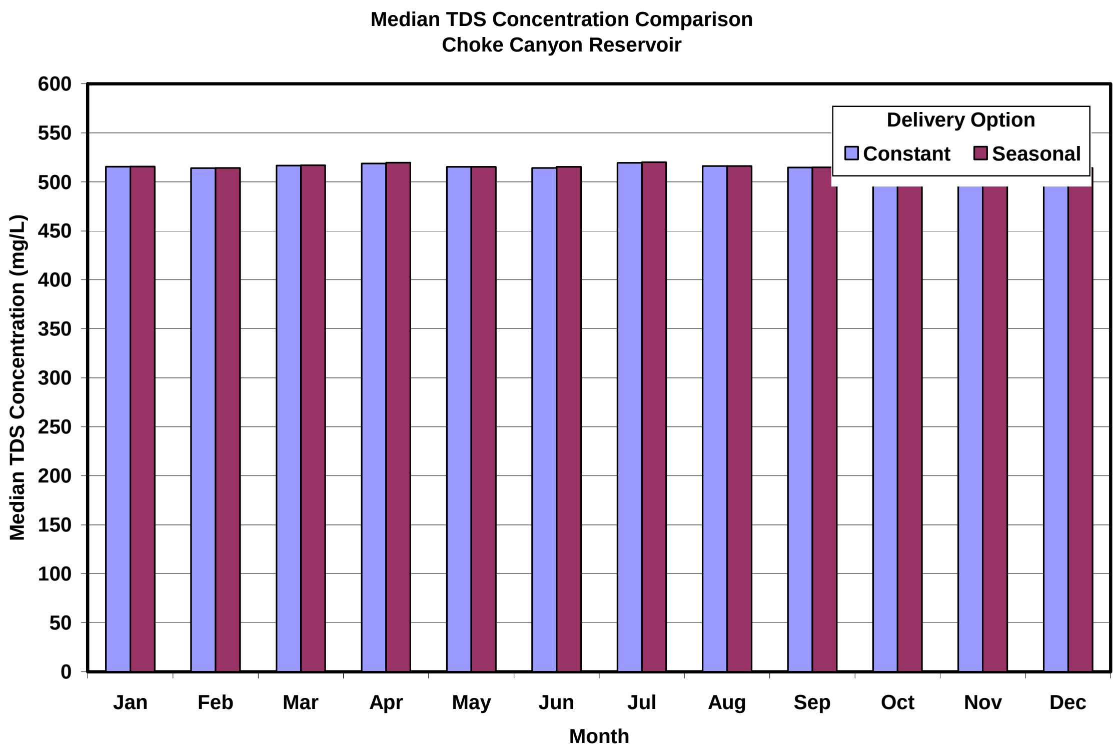


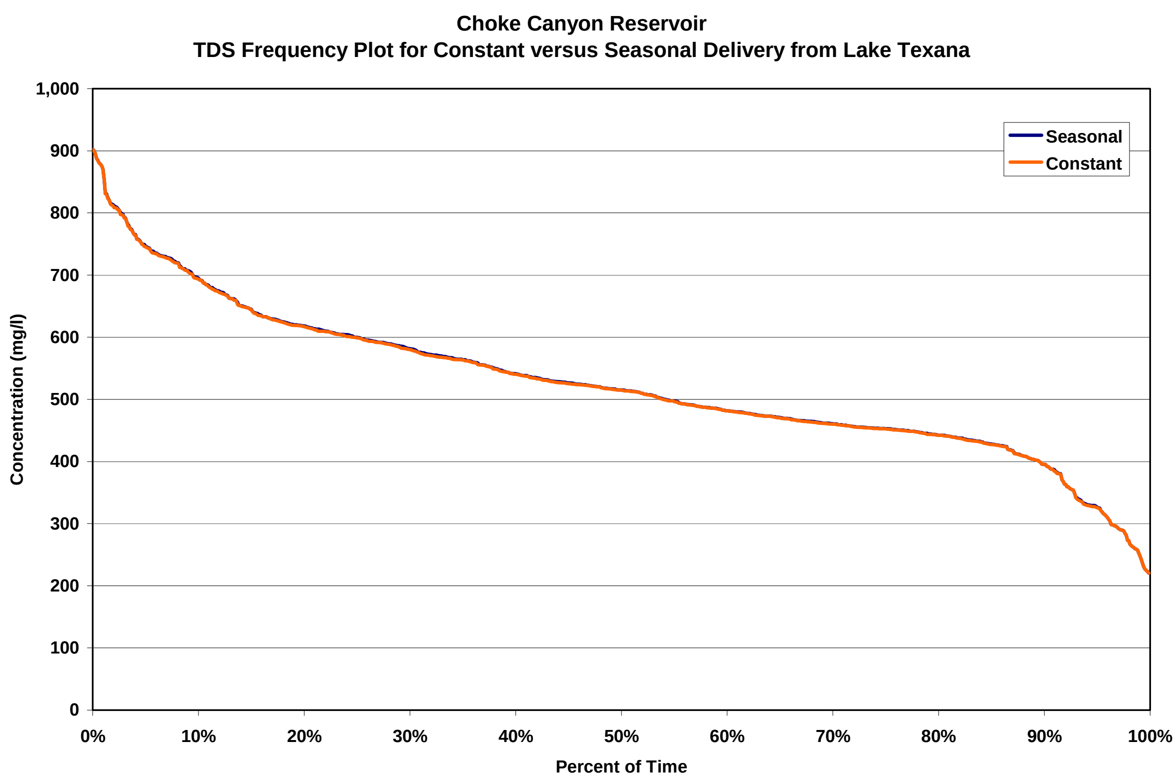
Calallen Pool
TDS Frequency Plot for Firm and Safe Yields
Concentration (mg/l)
0
100
200
300
400
500
600
700
800
900
1,000
Firm Yield
Safe Yield
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

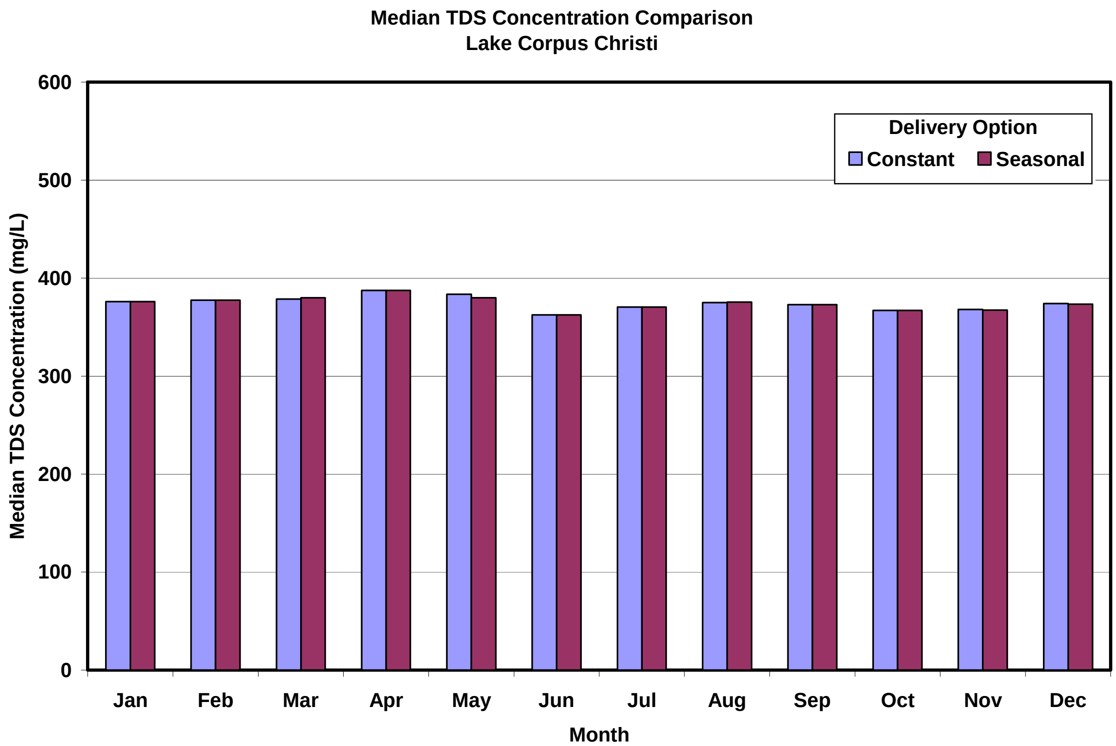

Median TDS Concentration Comparison
Lake Texana
Yield Type
Firm
Safe
Median TDS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Lake Texana
TDS Frequency Plot for Firm and Safe Yields
Firm Yield
Safe Yield
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

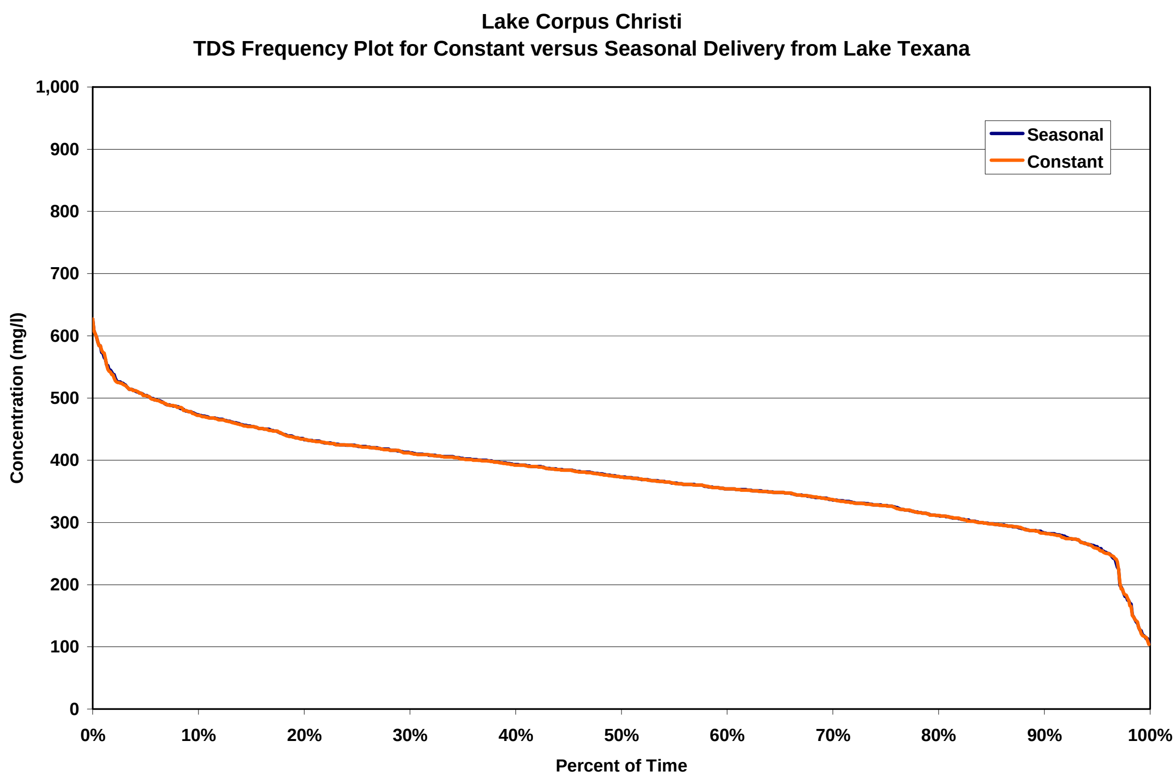
Attachment B-3:
Constant versus Seasonal Delivery Pattern
of Supply from Lake Texana
(Scenario 3)


Median TDS Concentration Comparison
Choke Canyon Reservoir
Median TDS Concentration (mg/L)
600
550
500
450
400
350
300
250
200
150
100
50
0
Delivery Option
Constant
Seasonal
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

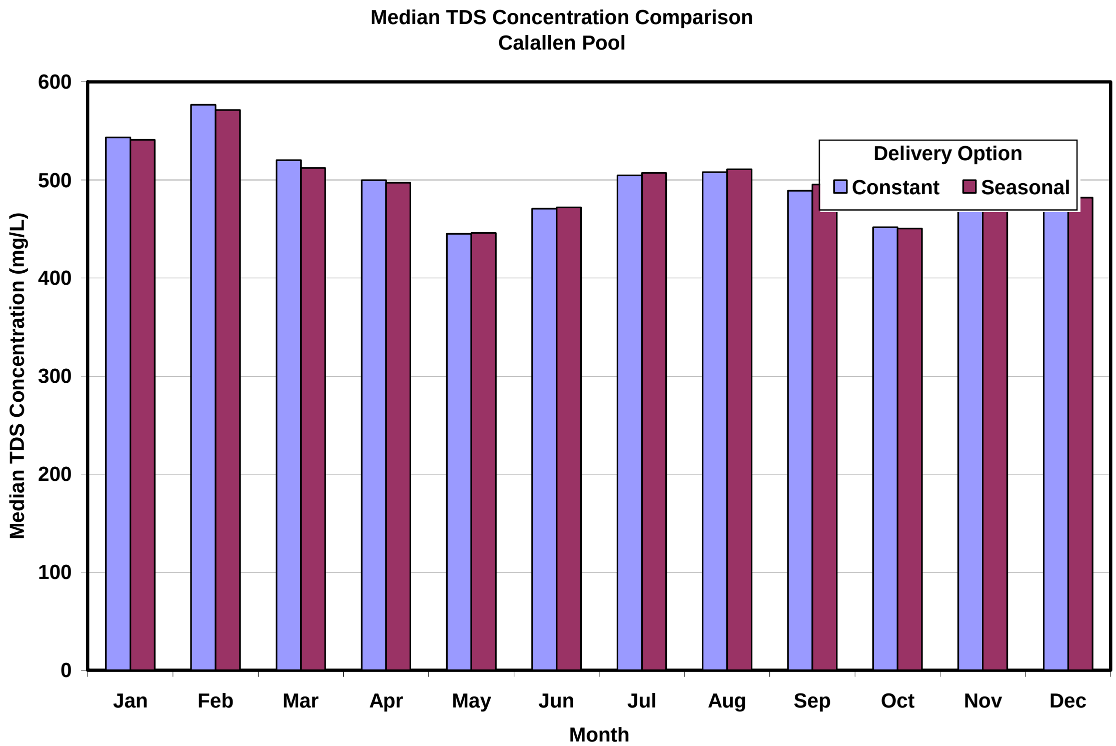

Choke Canyon Reservoir
TDS Frequency Plot for Constant versus Seasonal Delivery from Lake Texana
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
Seasonal
Constant
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time



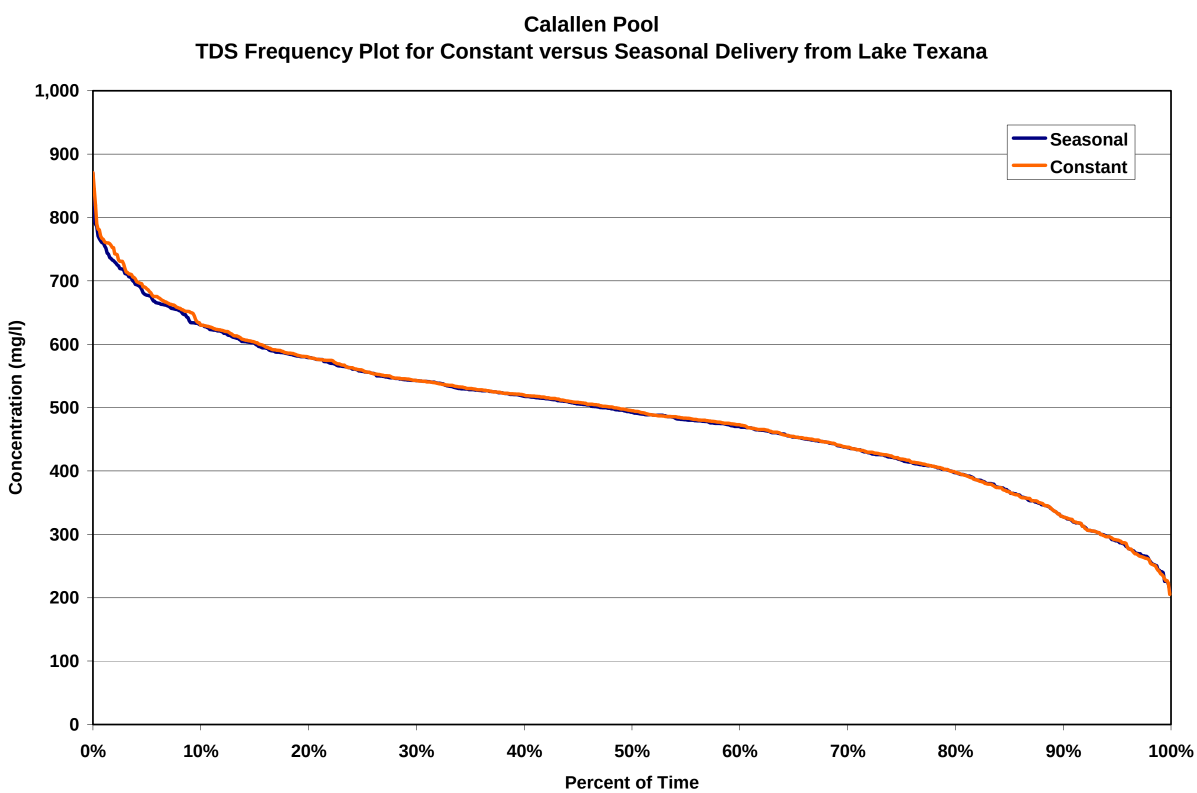
Median TDS Concentration Comparison
Lake Corpus Christi
Delivery Option
Constant
Seasonal
Median TDS Concentration (mg/L)
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month



Lake Corpus Christi
TDS Frequency Plot for Constant versus Seasonal Delivery from Lake Texana
Seasonal
Constant
Concentration (mg/l)
0
100
200
300
400
500
600
700
800
900
1,000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

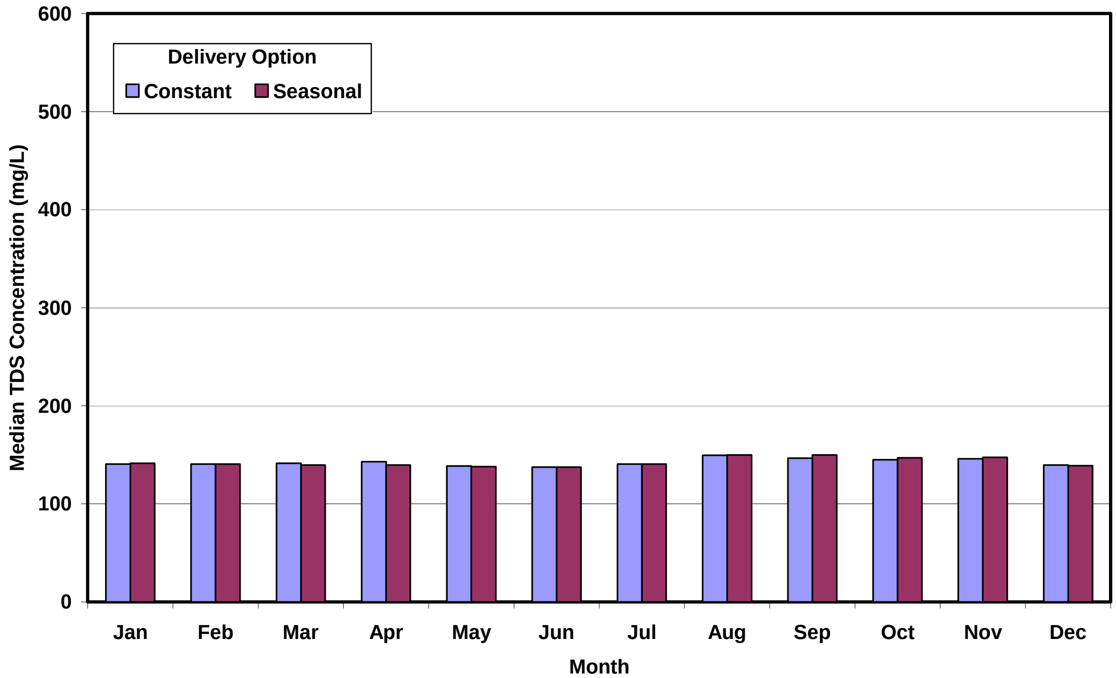


Median TDS Concentration Comparison
Calallen Pool
Median TDS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Delivery Option
Constant
Seasonal

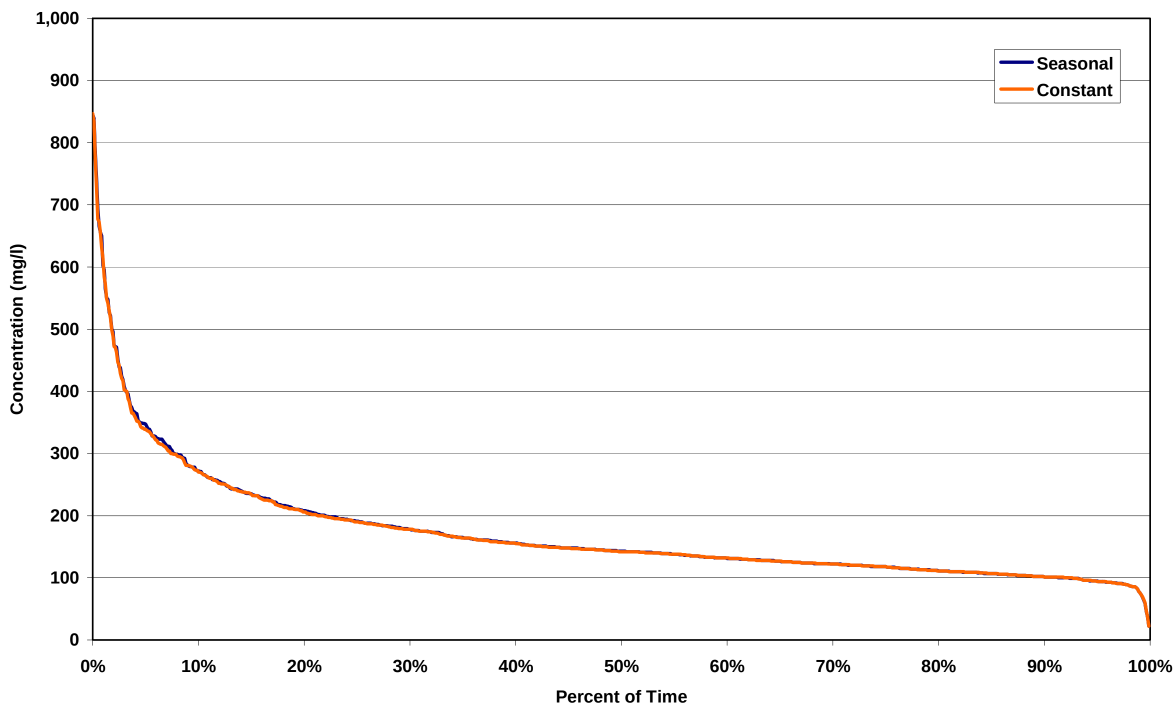


Calallen Pool
TDS Frequency Plot for Constant versus Seasonal Delivery from Lake Texana
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time
Seasonal
Constant

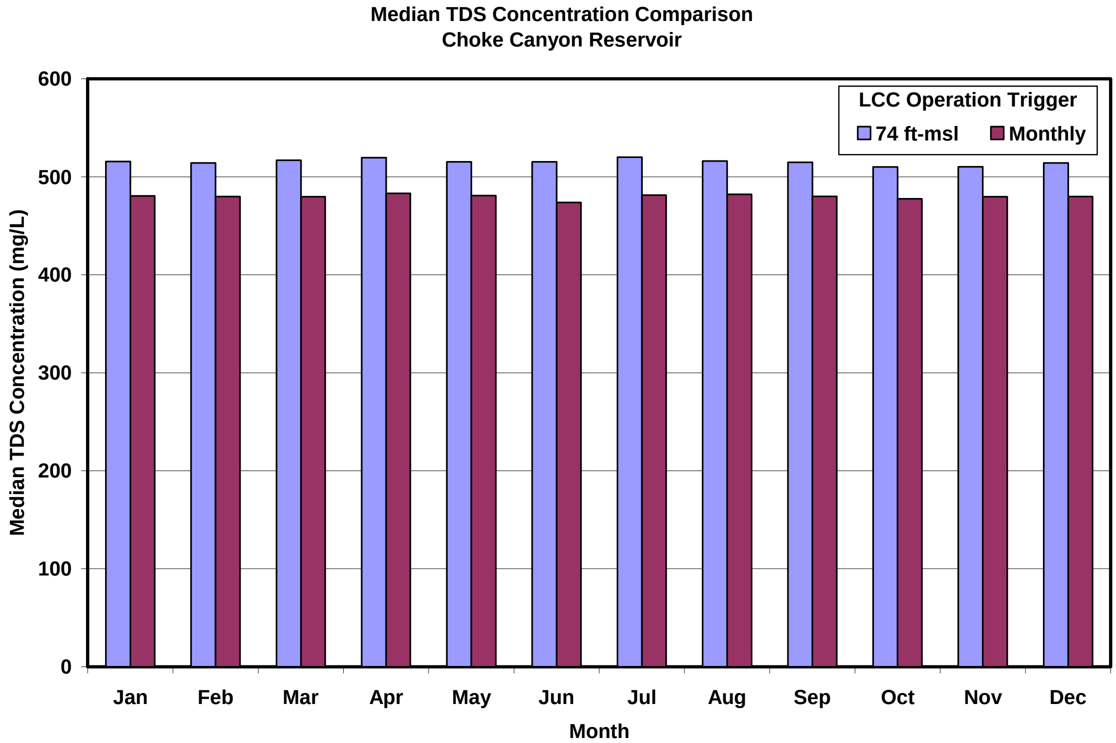
Median TDS Concentration Comparison
Lake Texana



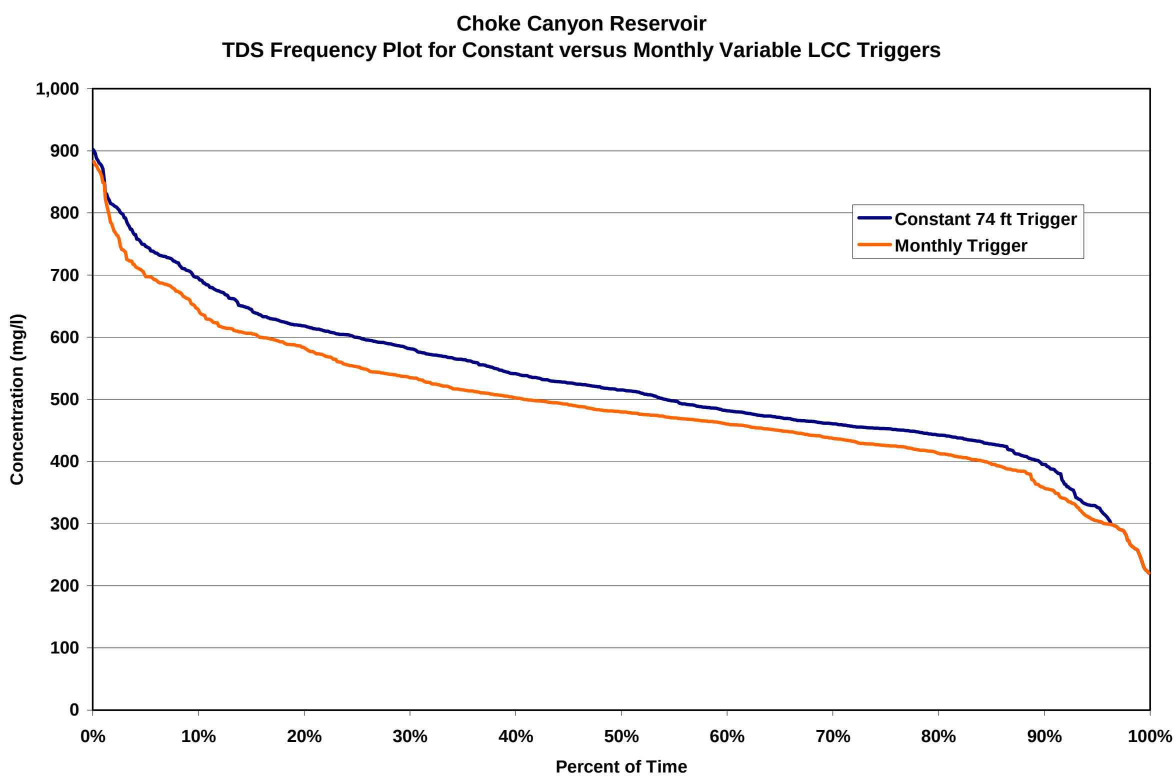
Lake Texana
TDS Frequency Plot for Constant versus Seasonal Delivery from Lake Texana



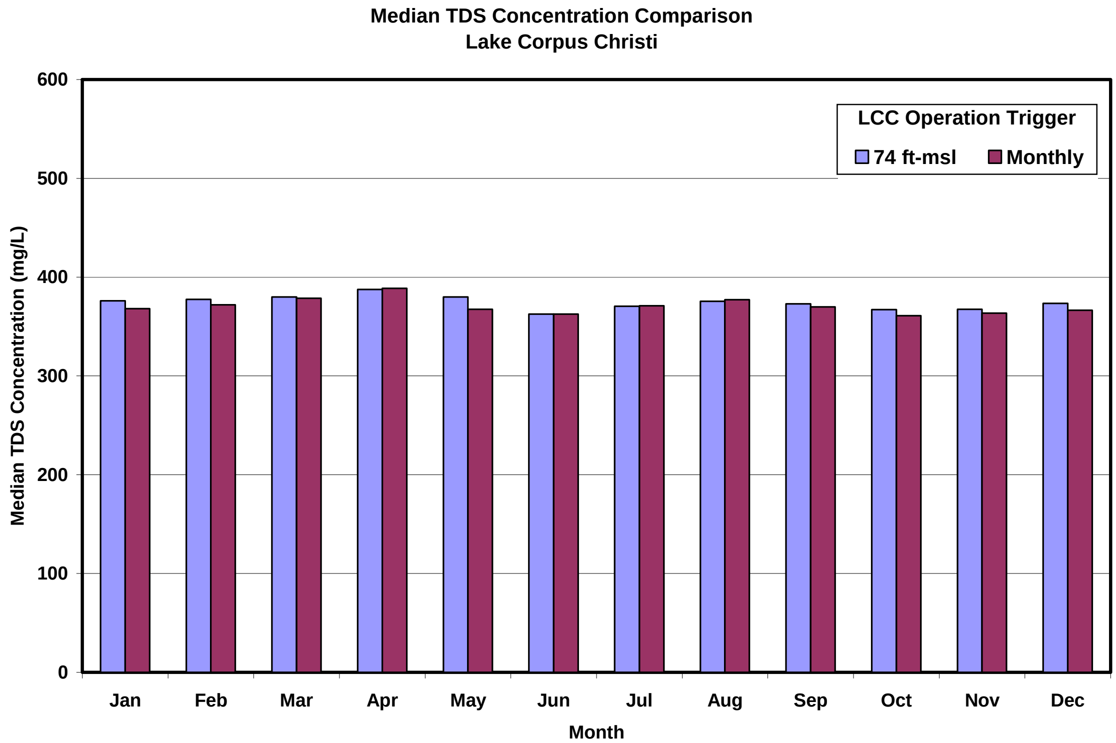
Attachment B-4:
Monthly Variable LCC Trigger Level for Water Level Delivery from CCR to LCC (Scenario 4)

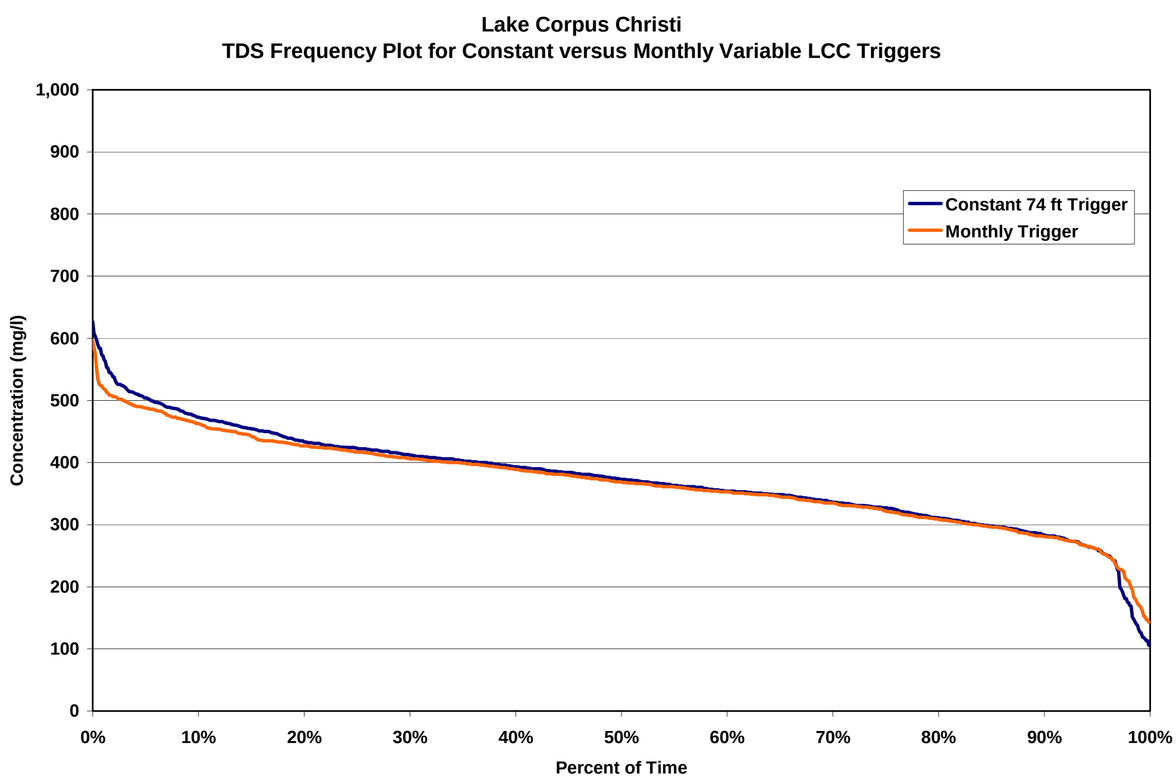


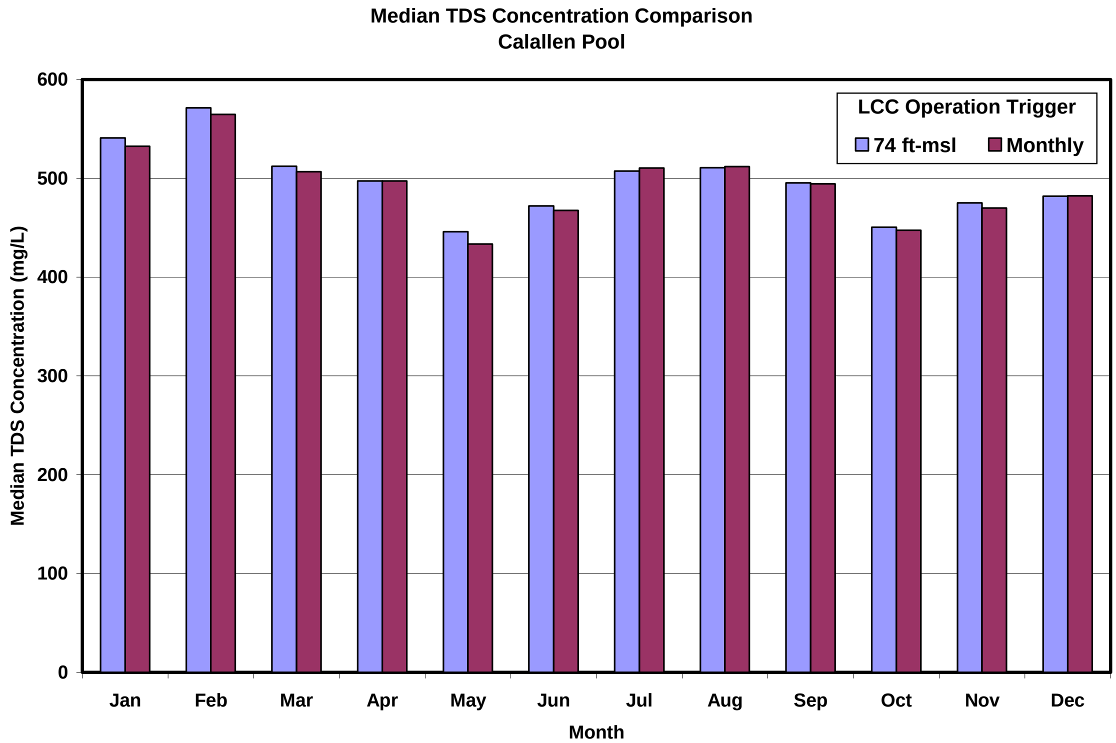
Median TDS Concentration Comparison
Choke Canyon Reservoir
LCC Operation Trigger
74 ft-msl
Monthly
Median TDS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

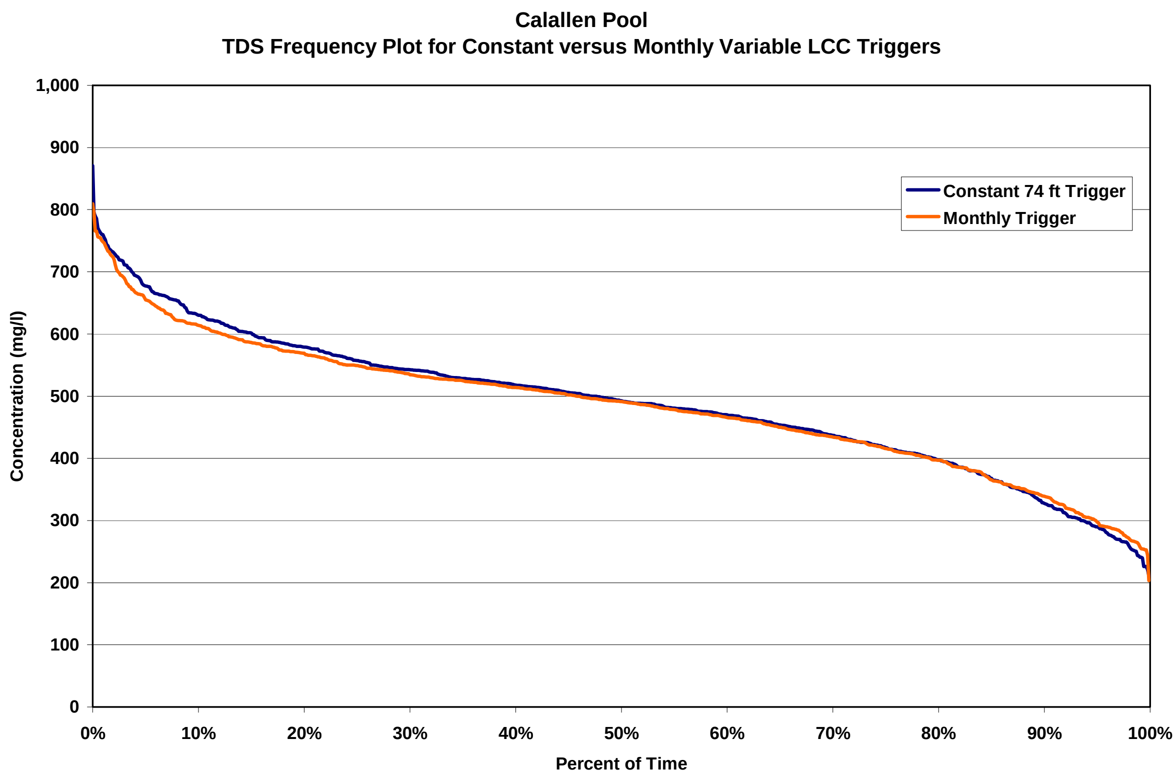


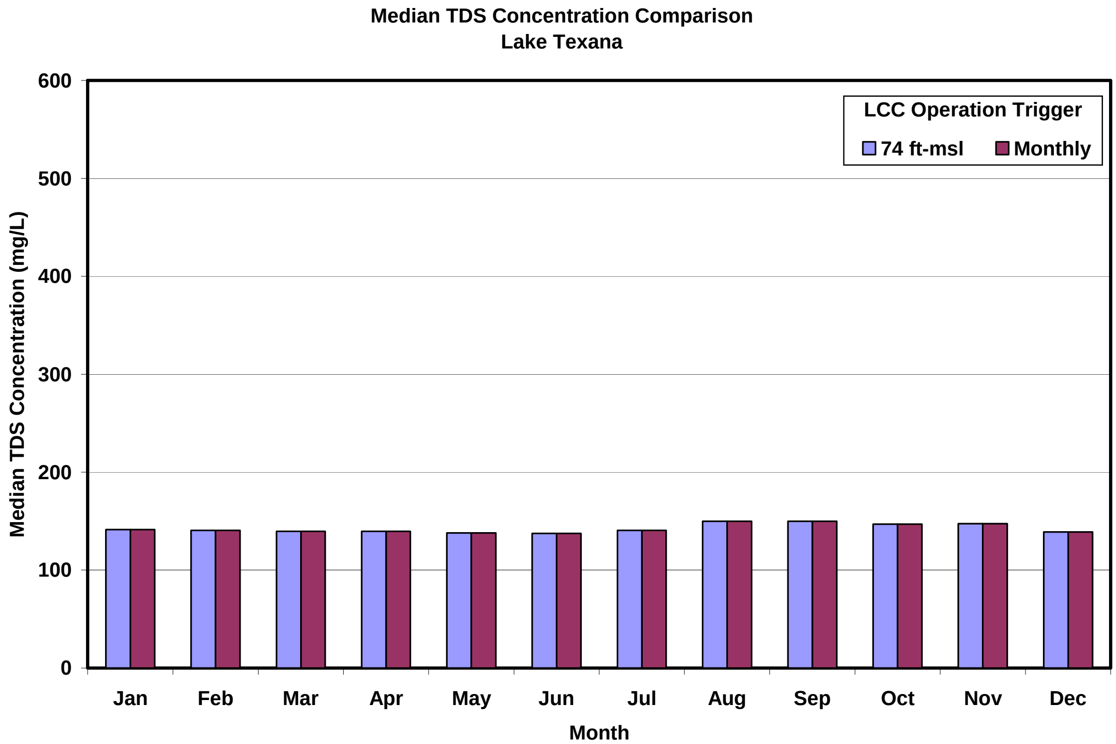
Choke Canyon Reservoir
TDS Frequency Plot for Constant versus Monthly Variable LCC Triggers
Constant 74 ft Trigger
Monthly Trigger
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time


Median TDS Concentration Comparison
Lake Corpus Christi
LCC Operation Trigger
74 ft-msl
Monthly
Median TDS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

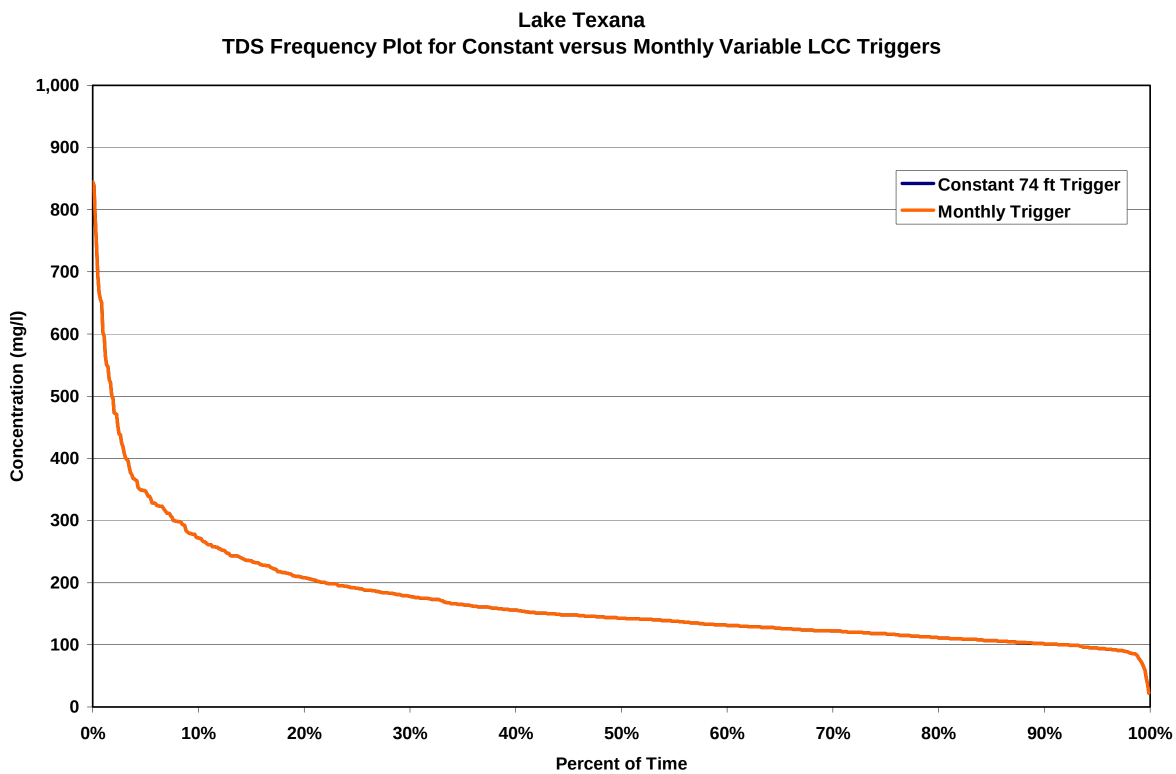

Lake Corpus Christi
TDS Frequency Plot for Constant versus Monthly Variable LCC Triggers
Constant 74 ft Trigger
Monthly Trigger
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time


Median TDS Concentration Comparison
Calallen Pool
LCC Operation Trigger
74 ft-msl
Monthly
Median TDS Concentration (mg/L)
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Calallen Pool
TDS Frequency Plot for Constant versus Monthly Variable LCC Triggers
Constant 74 ft Trigger
Monthly Trigger
Concentration (mg/l)
0
100
200
300
400
500
600
700
800
900
1,000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time



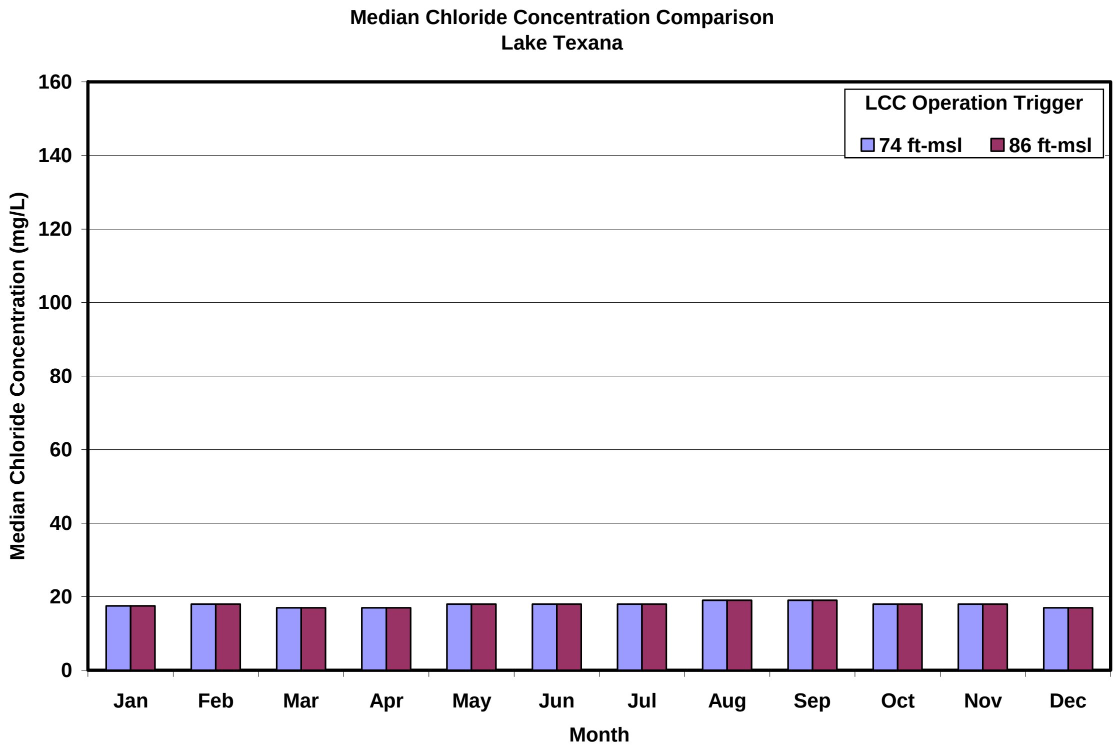
Median TDS Concentration Comparison
Lake Texana
LCC Operation Trigger
74 ft-msl
Monthly
Median TDS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

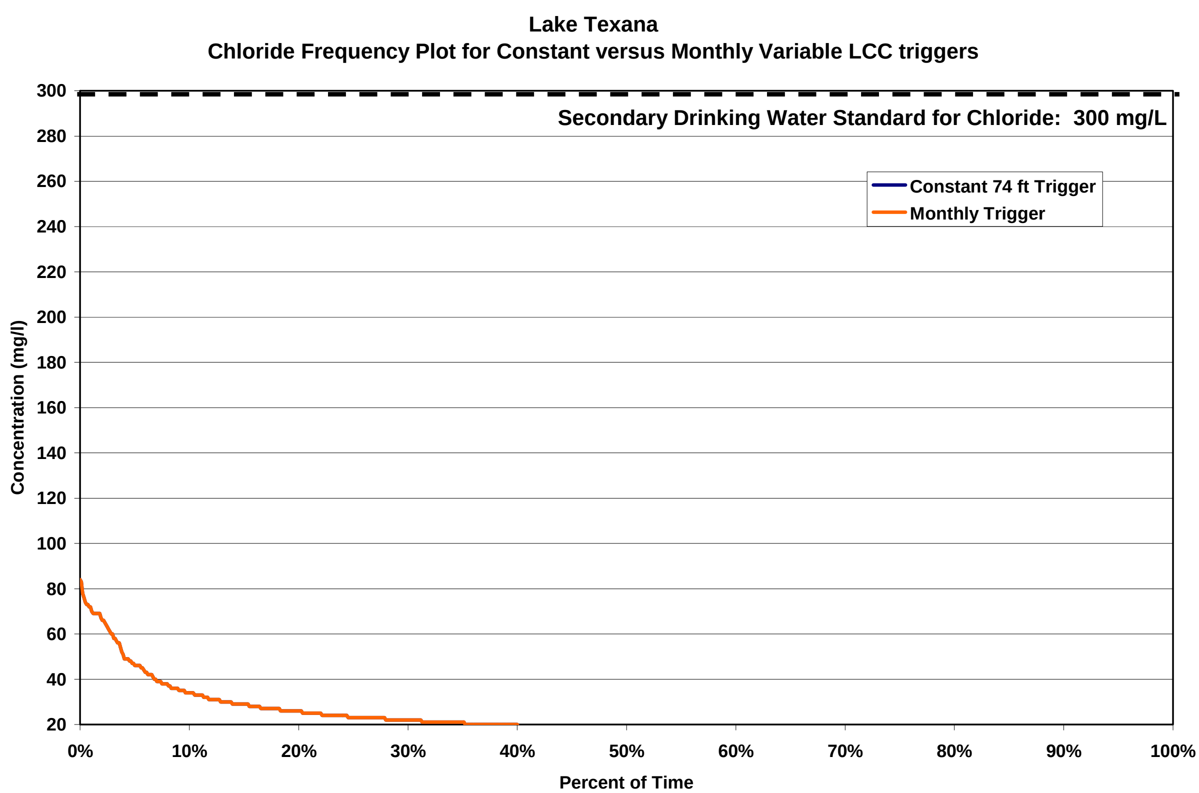


Lake Texana
TDS Frequency Plot for Constant versus Monthly Variable LCC Triggers
Constant 74 ft Trigger
Monthly Trigger
Concentration (mg/l)
1,000
900
800
700
600
500
400
300
200
100
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

Appendix C
Median Chloride and Frequency Distribution Plots for Lake Texana
(by Scenario)

Attachment C-1:
Variable LCC trigger level for water delivery from CCR to LCC
(Scenario 1)


Median Chloride Concentration Comparison
Lake Texana
LCC Operation Trigger
74 ft-msl
86 ft-msl
Median Chloride Concentration (mg/L)
0
20
40
60
80
100
120
140
160
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Lake Texana
Chloride Frequency Plot for Constant versus Monthly Variable LCC triggers
Secondary Drinking Water Standard for Chloride: 300 mg/L
Constant 74 ft Trigger
Monthly Trigger
Concentration (mg/l)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

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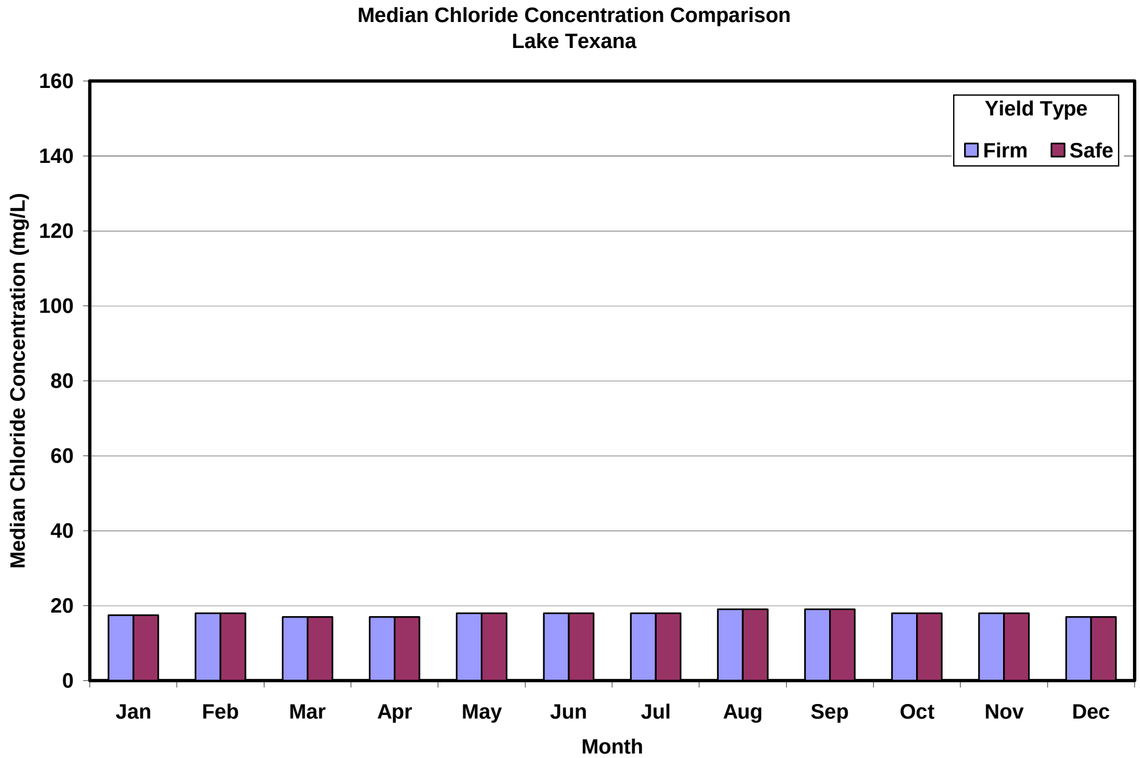
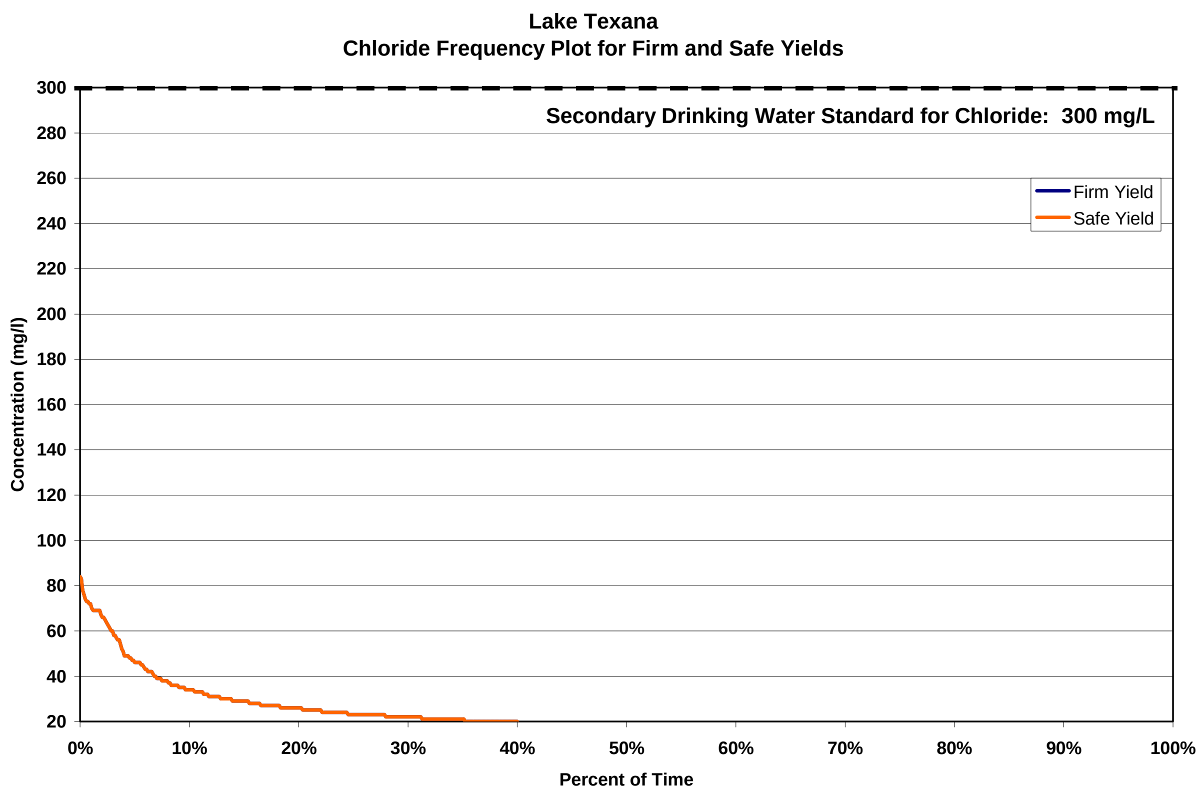
Attachment C-2:
Safe versus firm system yield (Scenario 2)


Median Chloride Concentration Comparison
Lake Texana
Yield Type
Firm
Safe
Median Chloride Concentration (mg/L)
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Lake Texana
Chloride Frequency Plot for Firm and Safe Yields
Secondary Drinking Water Standard for Chloride: 300 mg/L
Firm Yield
Safe Yield
Concentration (mg/l)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

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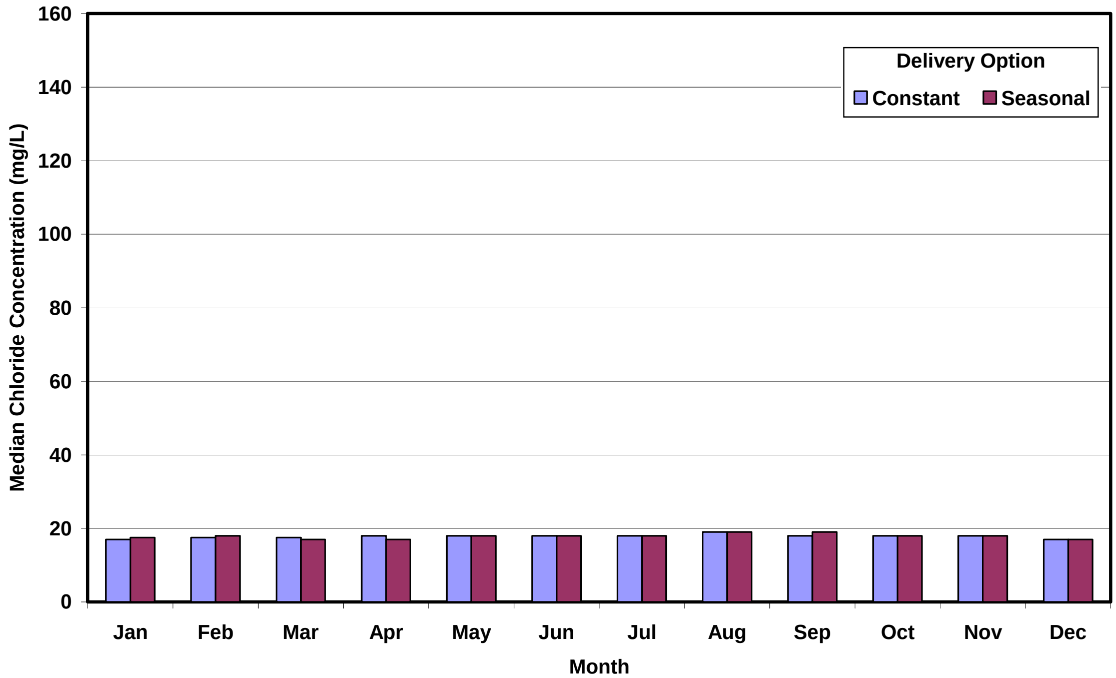
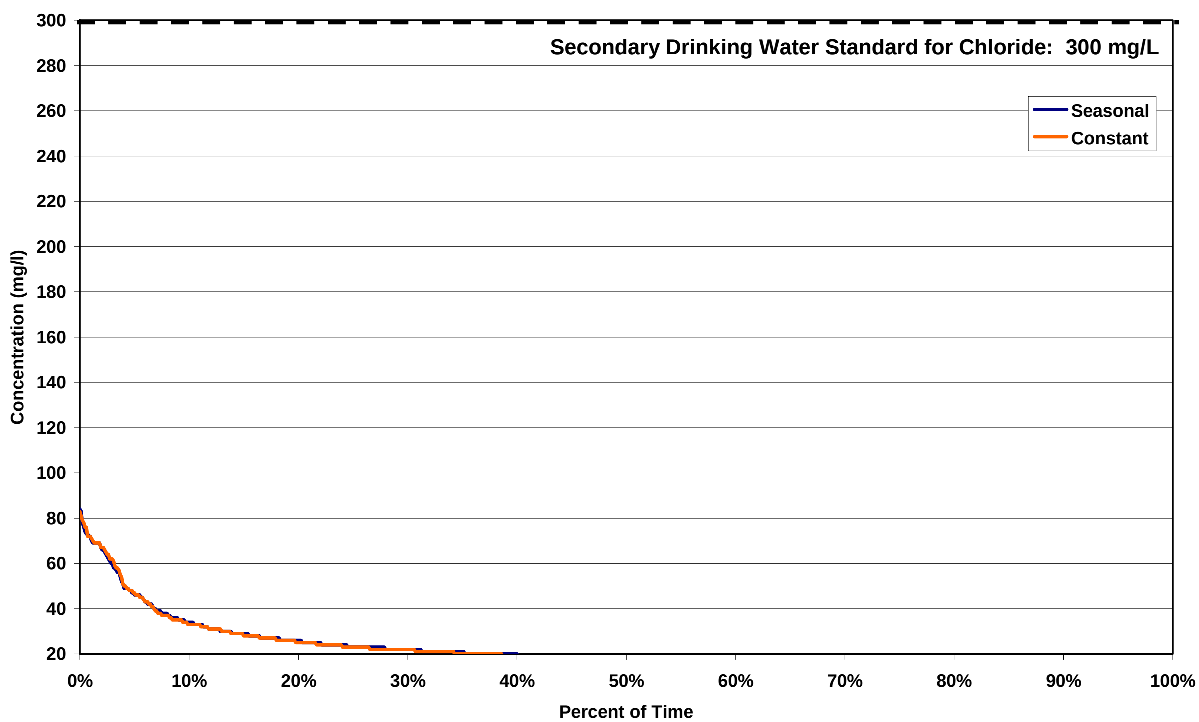
Attachment C-3:
Constant versus seasonal delivery pattern of supply from Lake Texana (Scenario 3)

Median Chloride Concentration Comparison
Lake Texana



Lake Texana
Chloride Frequency Plot for Constant versus Seasonal Delivery from Lake Texana



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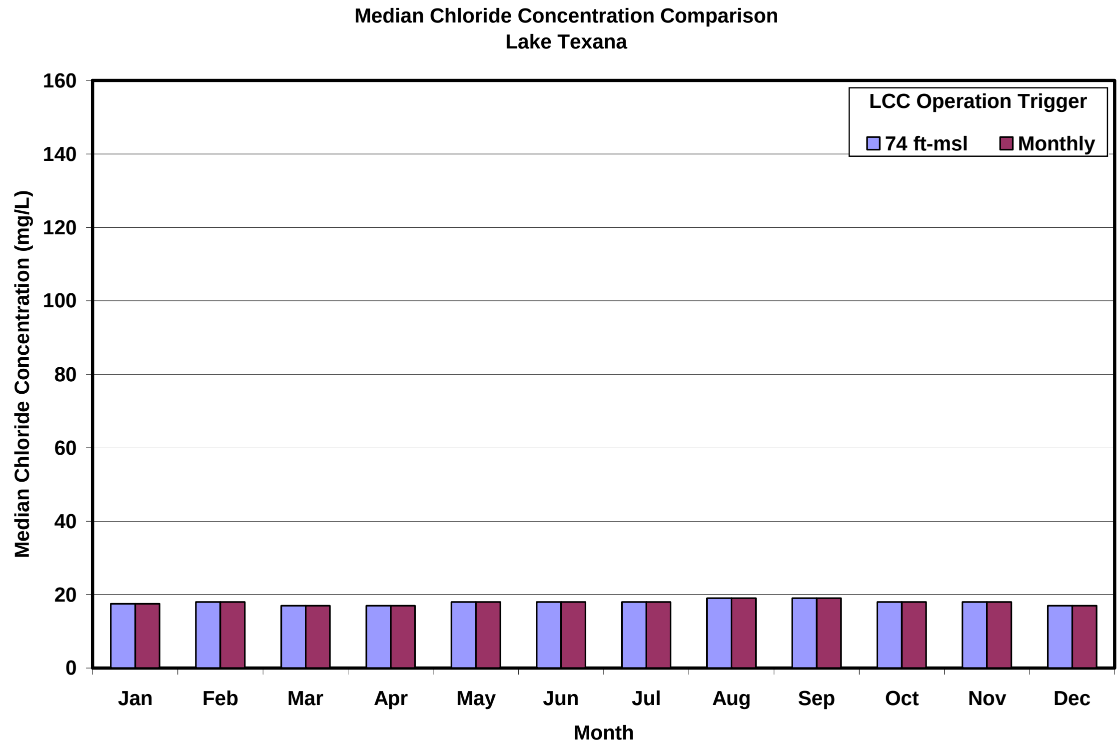
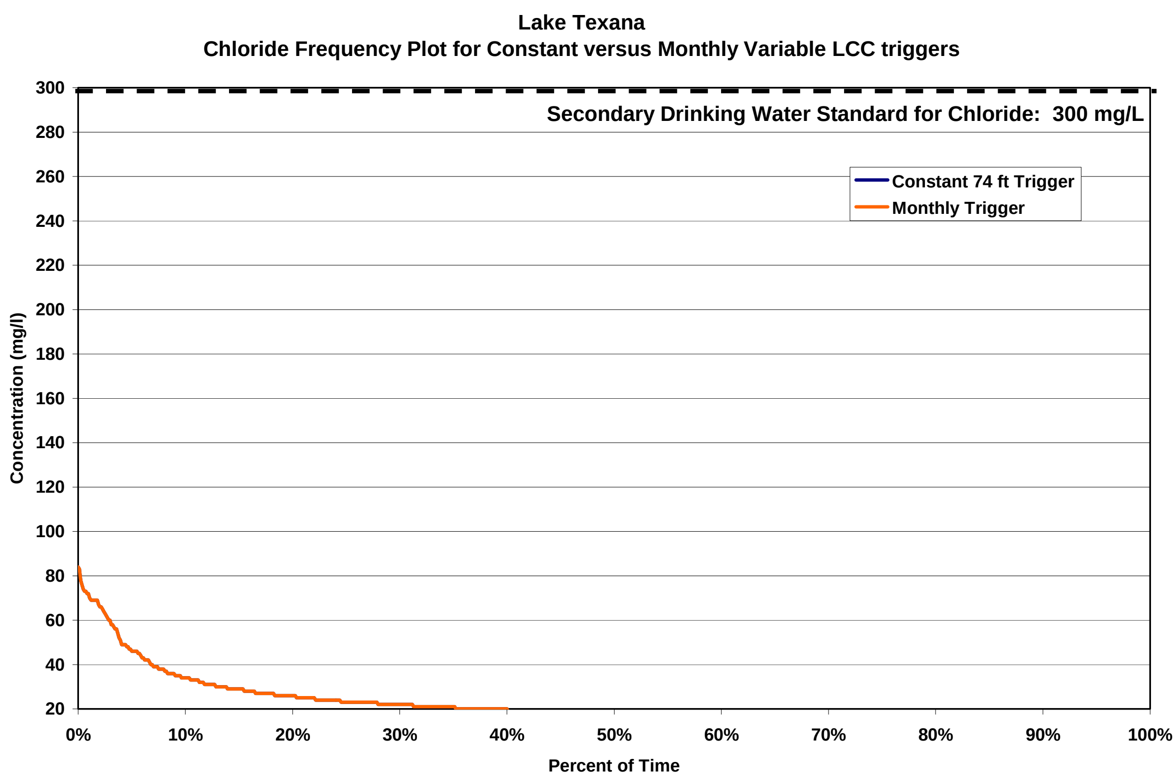
Attachment C-4:
Monthly variable LCC trigger level for water level delivery from CCR to LCC (Scenario 4)



Median Chloride Concentration Comparison
Lake Texana
LCC Operation Trigger
74 ft-msl
Monthly
Median Chloride Concentration (mg/L)
160
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month



Lake Texana
Chloride Frequency Plot for Constant versus Monthly Variable LCC triggers
Secondary Drinking Water Standard for Chloride: 300 mg/L
Constant 74 ft Trigger
Monthly Trigger
Concentration (mg/l)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time

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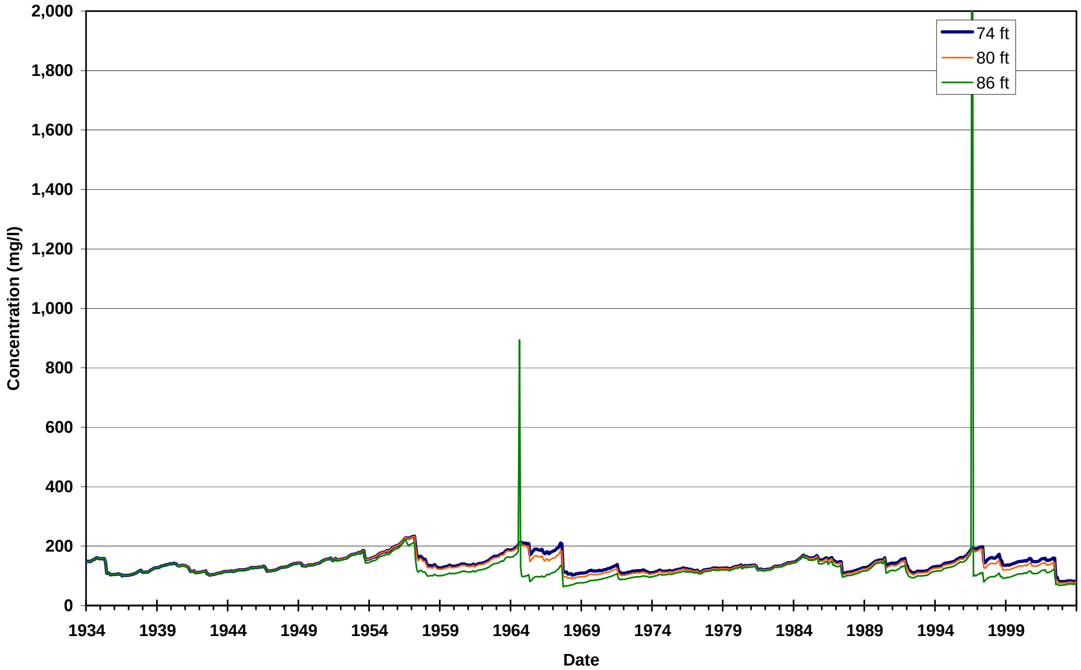
Appendix D

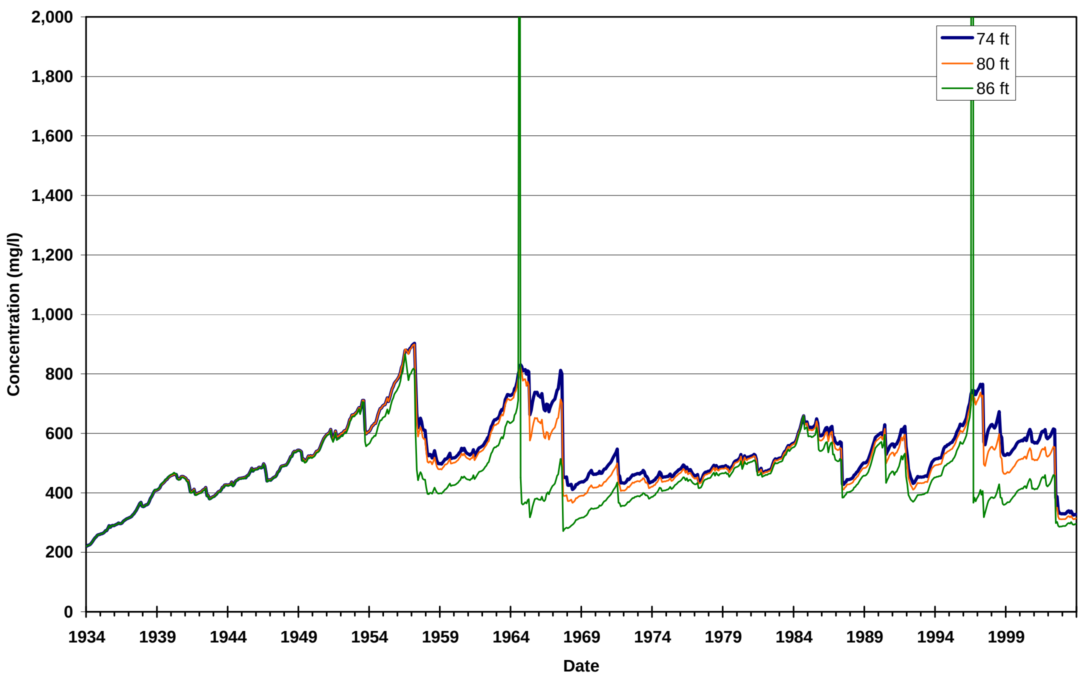
Time Series Chloride and Total Dissolved Solids Figures for CCR, LCC, Calallen Pool, and Lake Texana (by Scenario)

Attachment D-1:
Variable LCC trigger level for water delivery from CCR to LCC (Scenario 1)

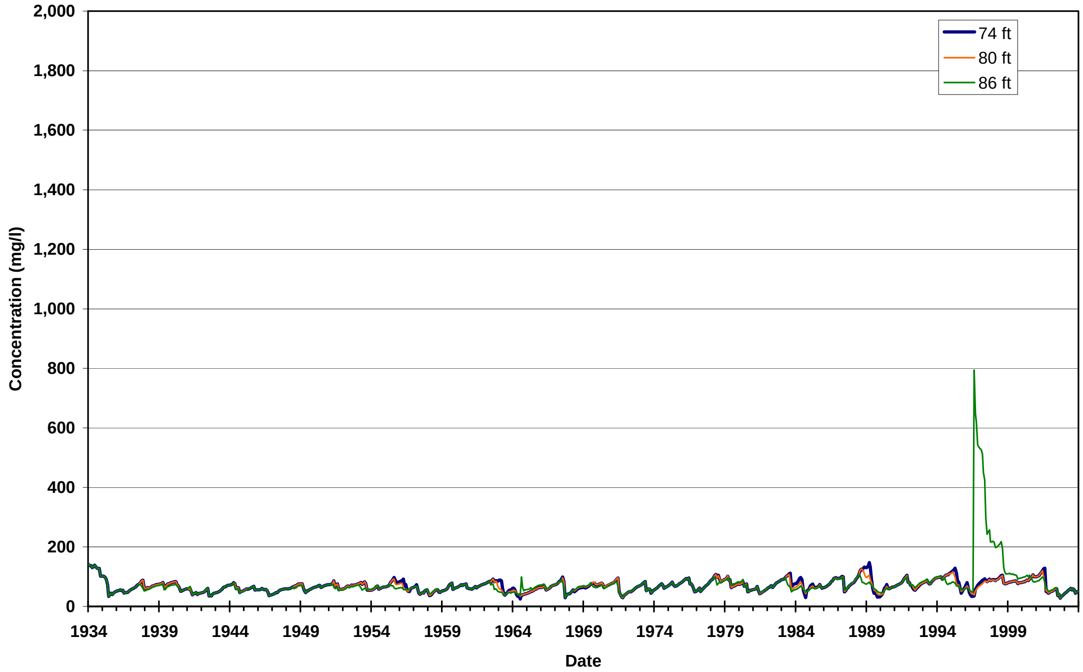
Choke Canyon Reservoir
Chloride Time Series with Varying Lake Corpus Christi Trigger Levels



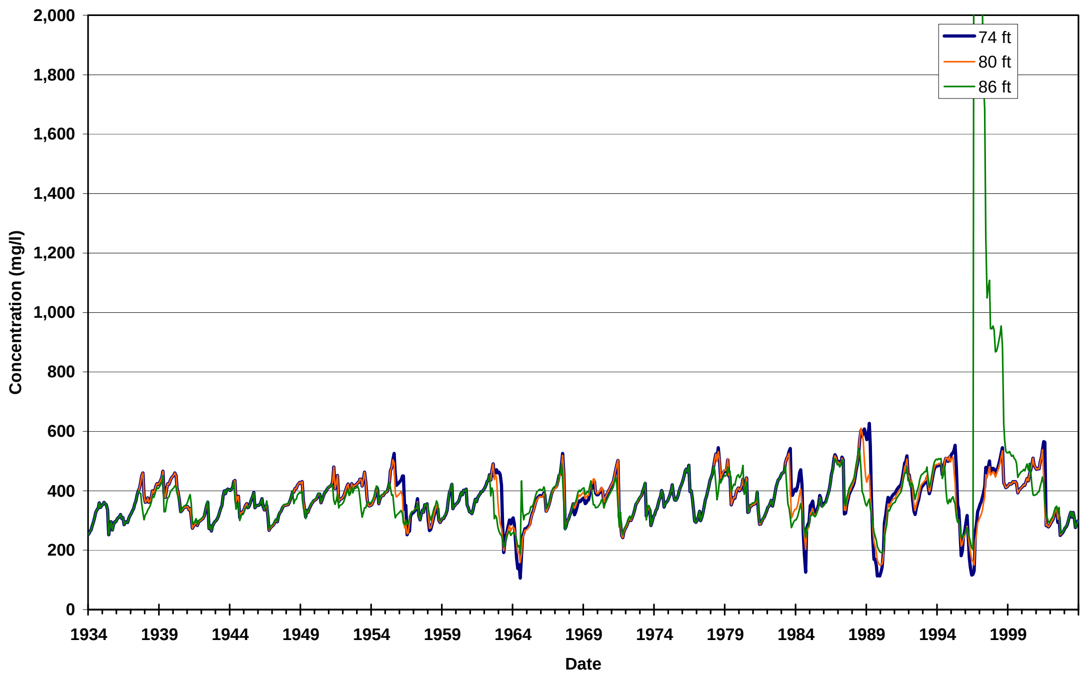
Choke Canyon Reservoir
TDS Time Series with Varying Lake Corpus Christi Trigger Levels

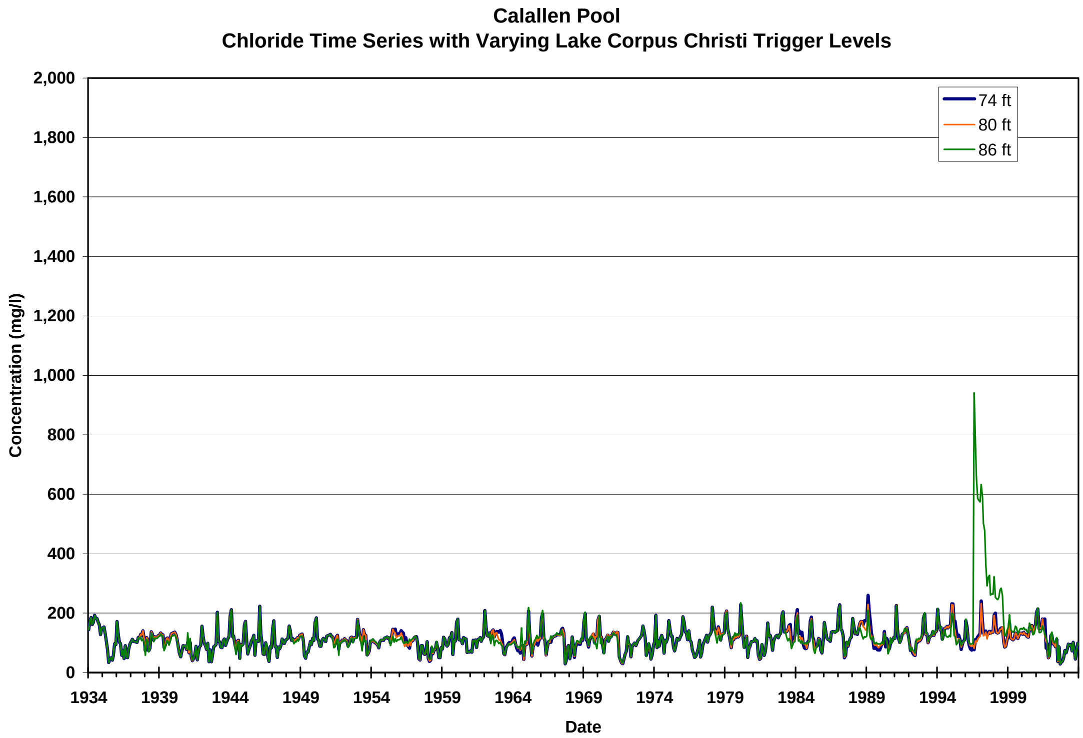


Lake Corpus Christi
Chloride Time Series with Varying Lake Corpus Christi Trigger Levels

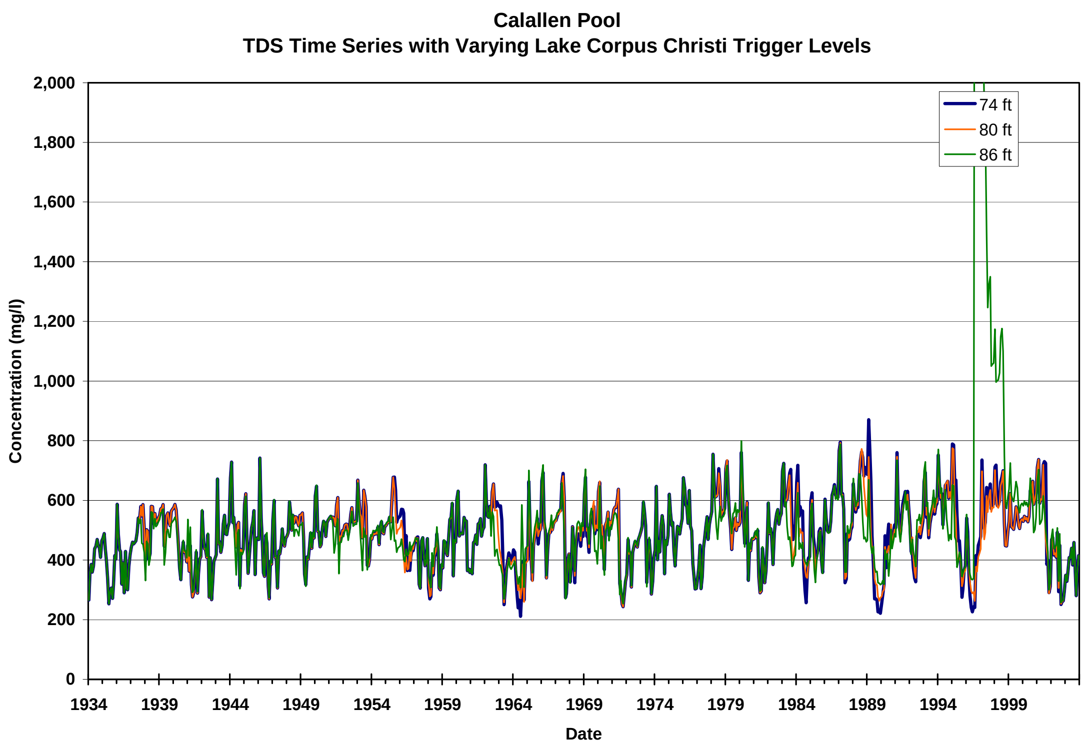


Lake Corpus Christi
TDS Time Series with Varying Lake Corpus Christi Trigger Levels



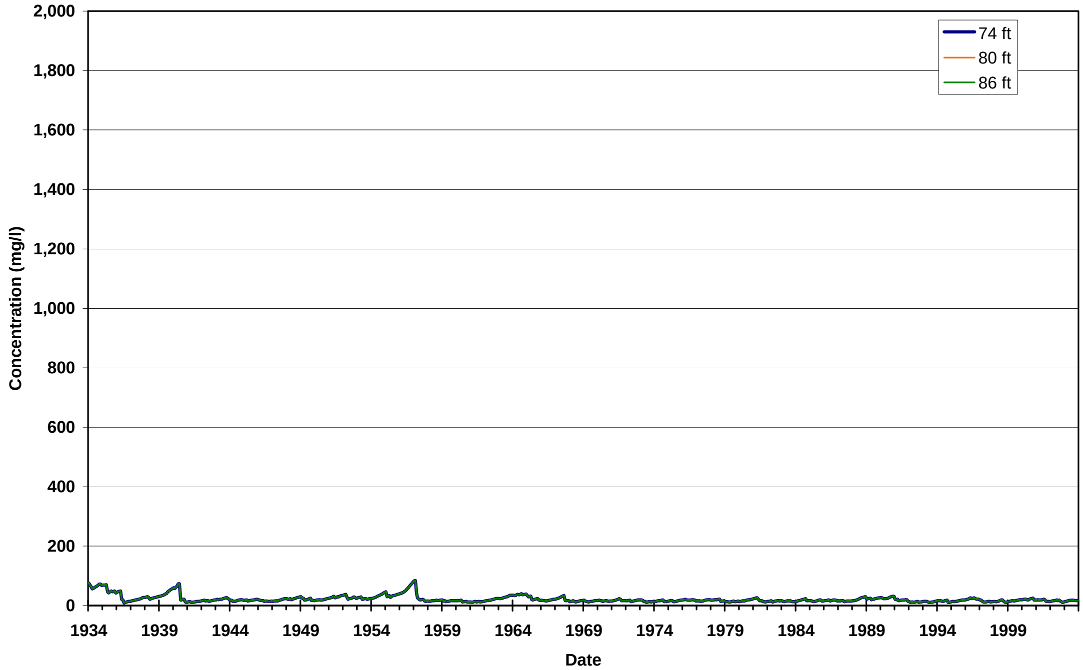


Calallen Pool
Chloride Time Series with Varying Lake Corpus Christi Trigger Levels
Concentration (mg/l)
Date
74 ft
80 ft
86 ft
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999

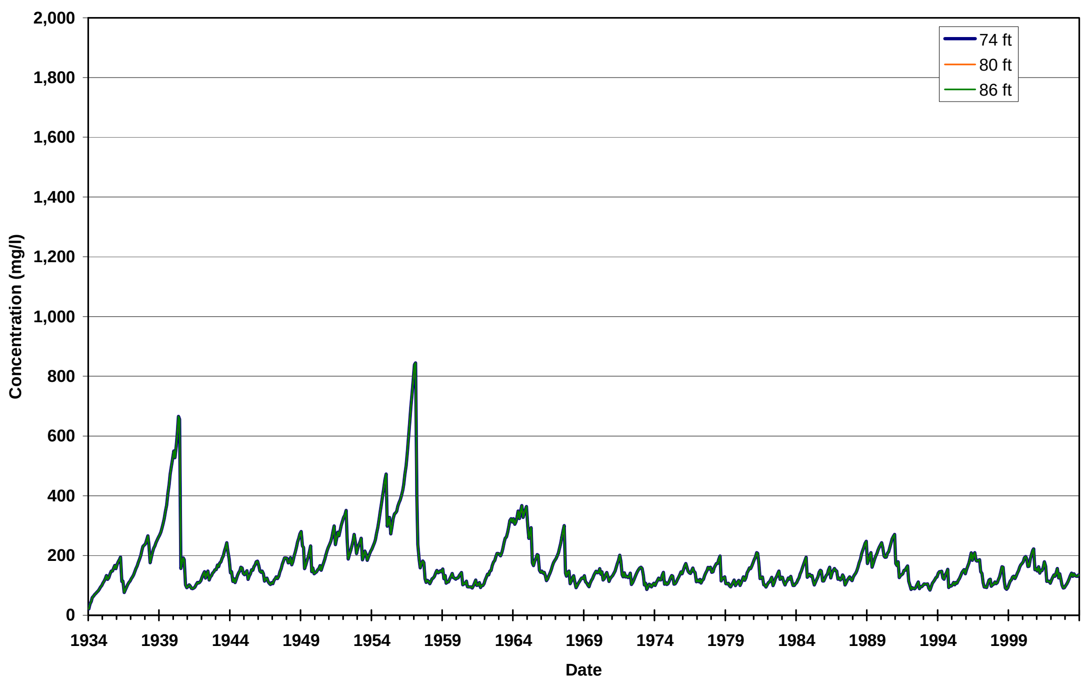


Calallen Pool
TDS Time Series with Varying Lake Corpus Christi Trigger Levels
Concentration (mg/l)
Date
74 ft
80 ft
86 ft
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999

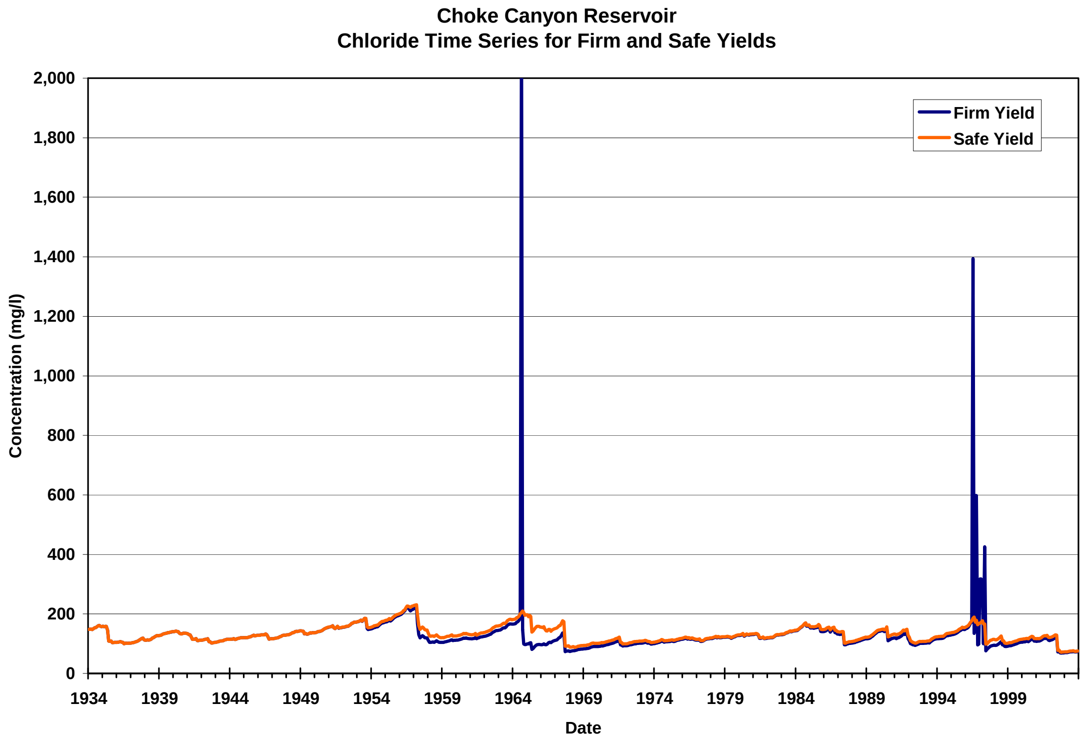
Lake Texana
Chloride Time Series with Varying Lake Corpus Christi Trigger Levels

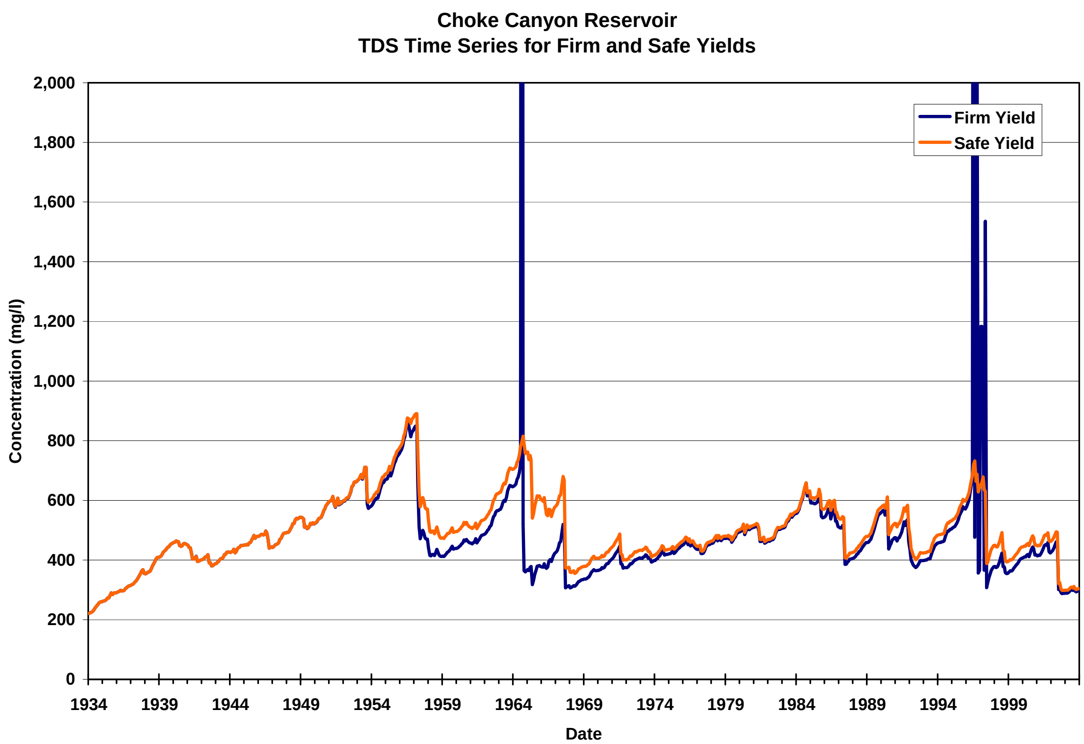


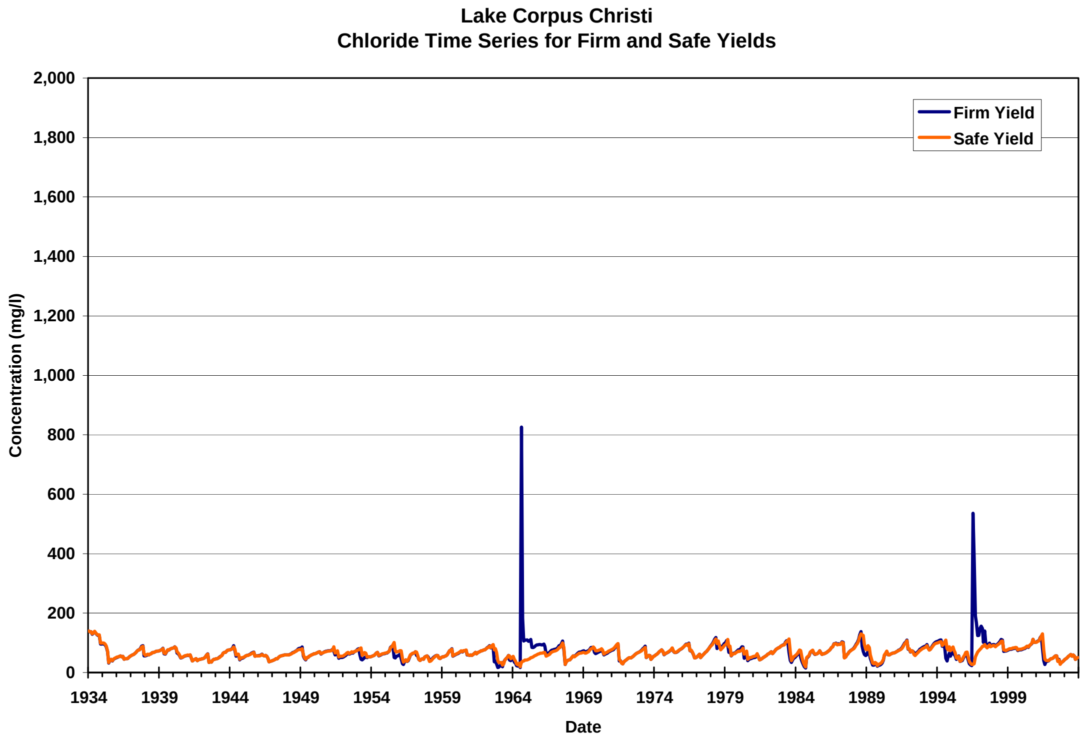
Lake Texana
TDS Time Series with Varying Lake Corpus Christi Trigger Levels

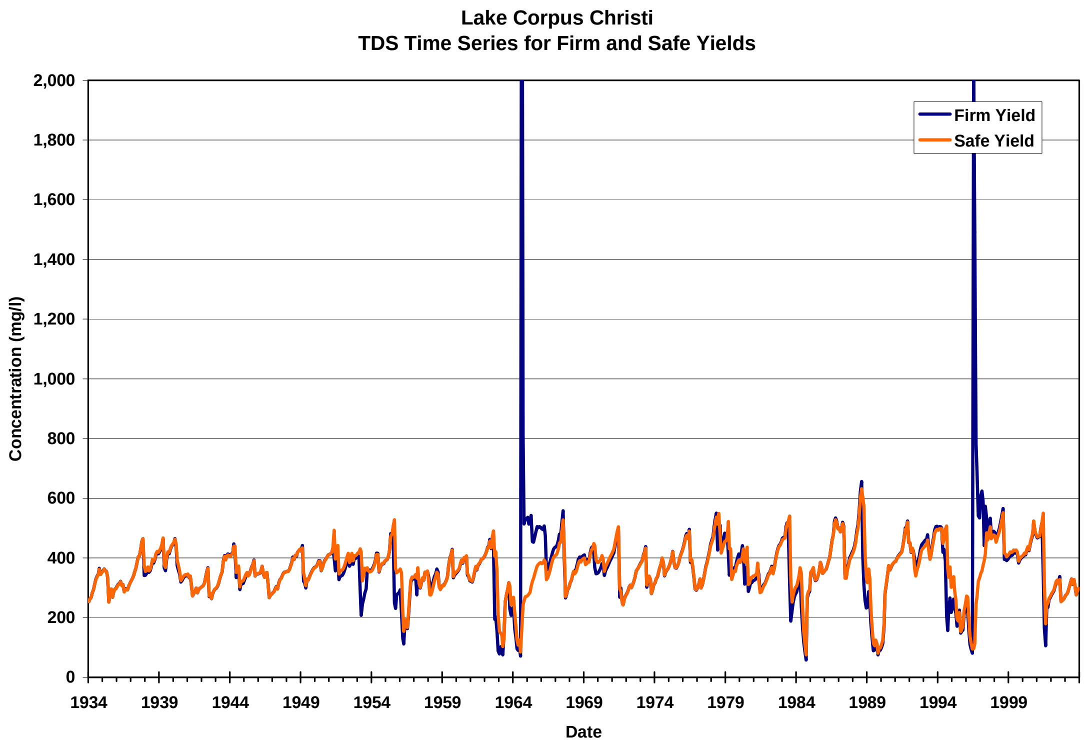


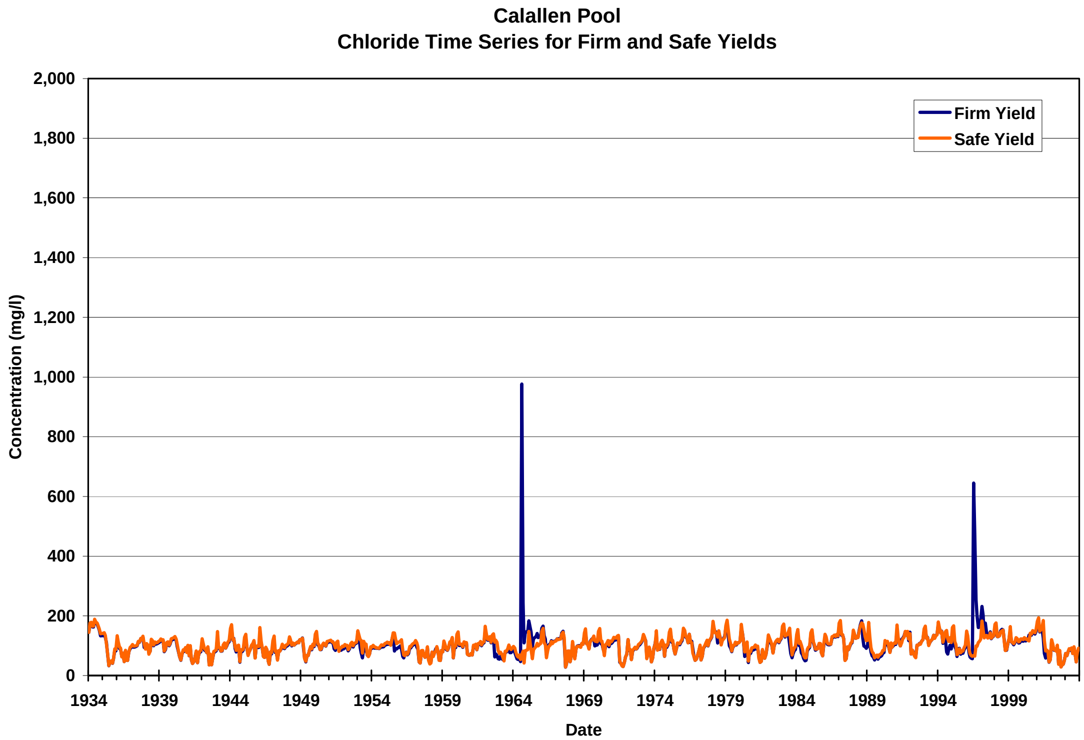
Attachment D-2:
Safe versus firm system yield (Scenario 2)

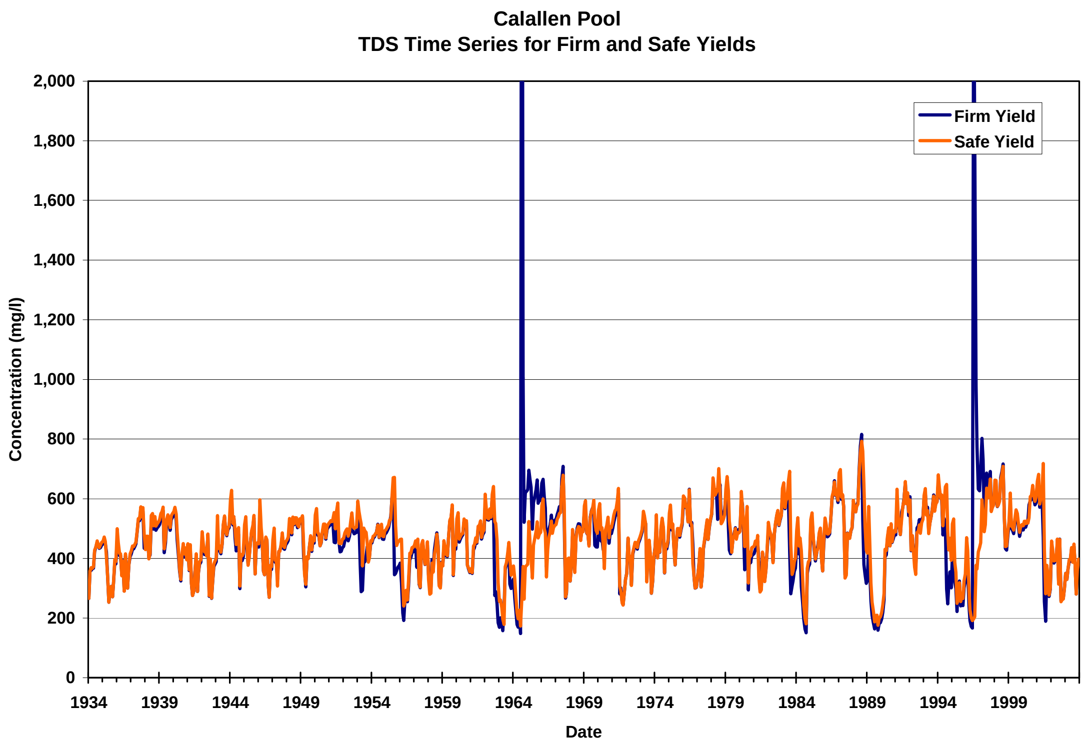

Choke Canyon Reservoir
Chloride Time Series for Firm and Safe Yields
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date
Firm Yield
Safe Yield

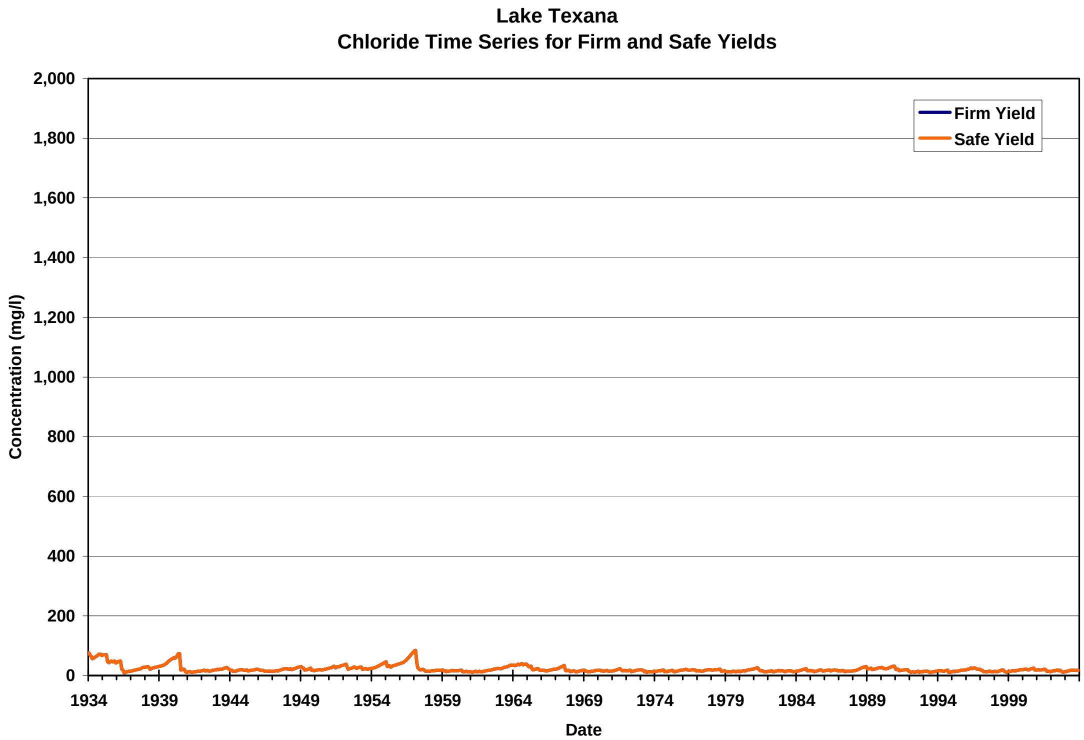

Choke Canyon Reservoir
TDS Time Series for Firm and Safe Yields
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date
Firm Yield
Safe Yield

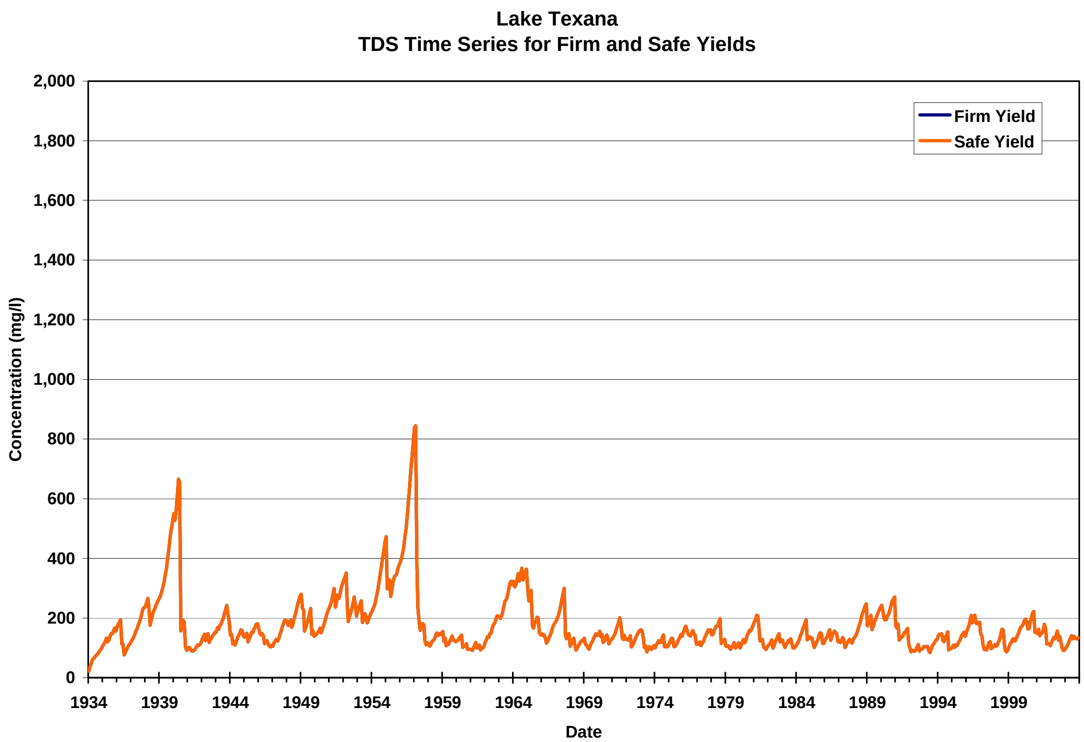

Lake Corpus Christi
Chloride Time Series for Firm and Safe Yields
Firm Yield
Safe Yield
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date


Lake Corpus Christi
TDS Time Series for Firm and Safe Yields
Firm Yield
Safe Yield
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date


Calallen Pool
Chloride Time Series for Firm and Safe Yields
Concentration (mg/l)
Date
Firm Yield
Safe Yield
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999

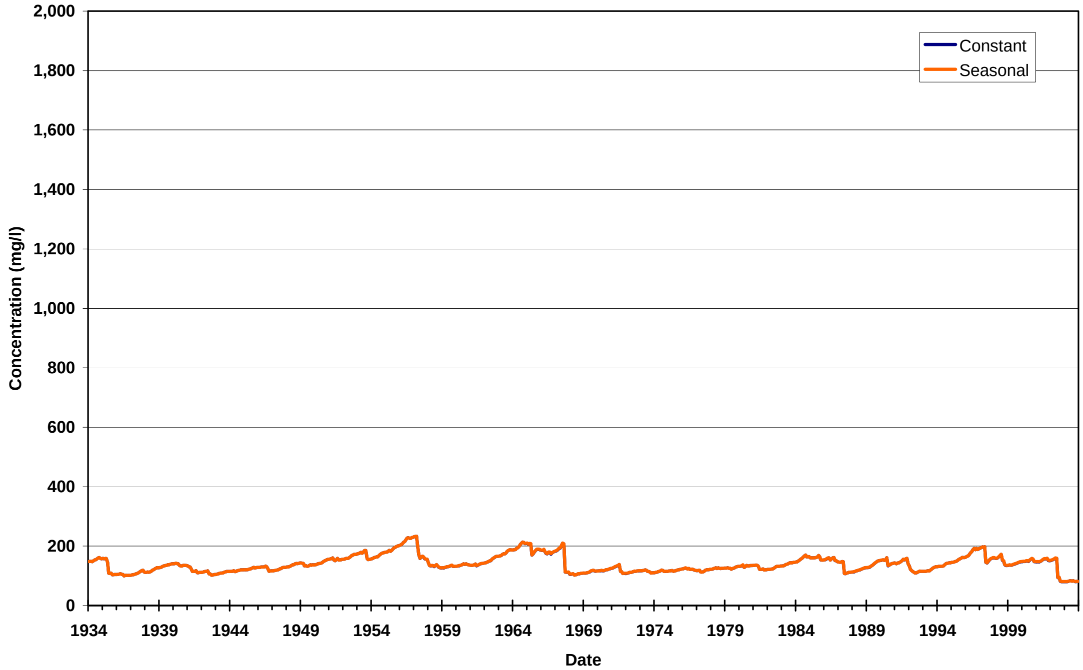

Calallen Pool
TDS Time Series for Firm and Safe Yields
Concentration (mg/l)
Date
Firm Yield
Safe Yield
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999


Lake Texana
Chloride Time Series for Firm and Safe Yields
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Firm Yield
Safe Yield
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date

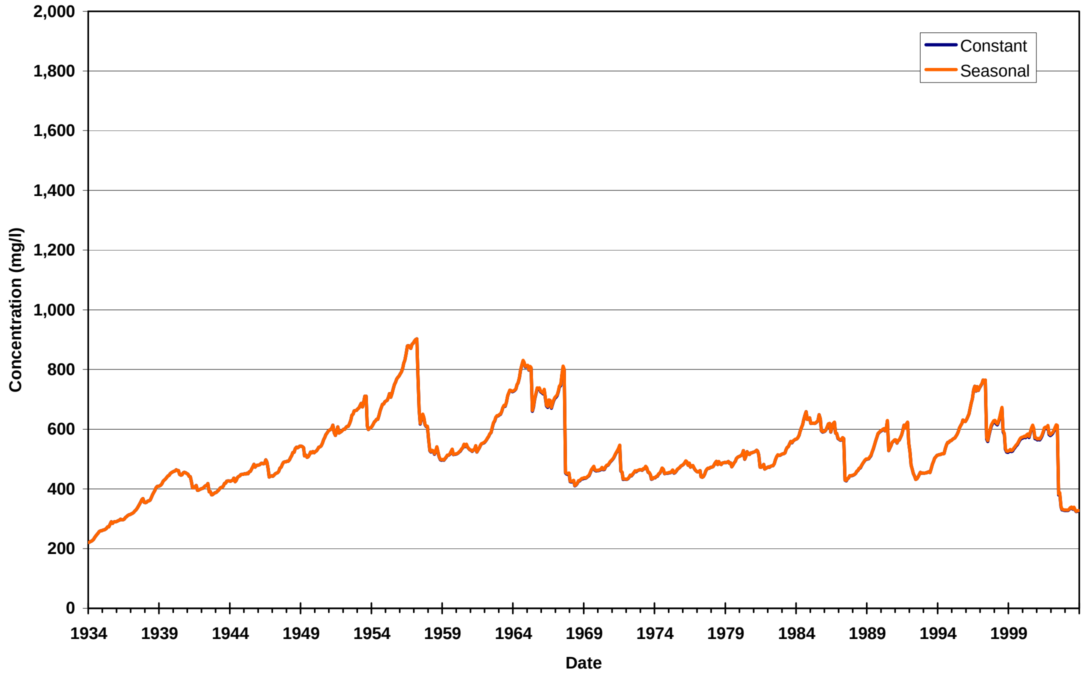

Lake Texana
TDS Time Series for Firm and Safe Yields
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Firm Yield
Safe Yield
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date

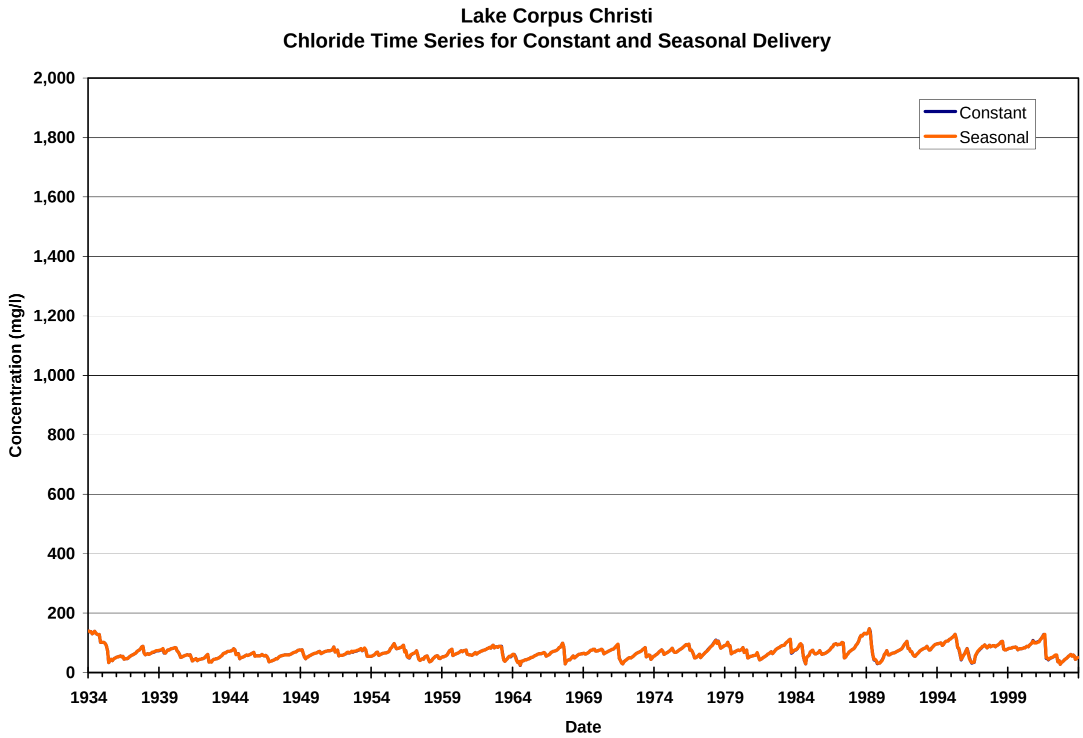
Attachment D-3:
Constant versus seasonal delivery pattern of supply from Lake Texana (Scenario 3)

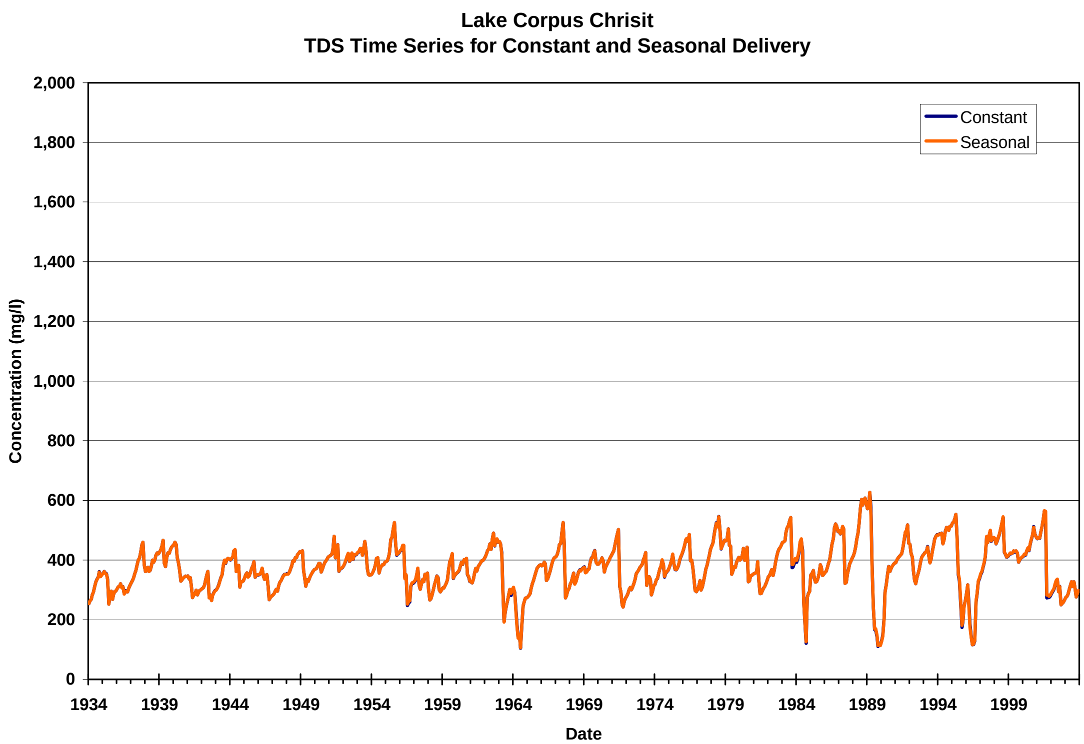
Choke Canyon Reservoir
Chloride Time Series for Constant and Seasonal Delivery



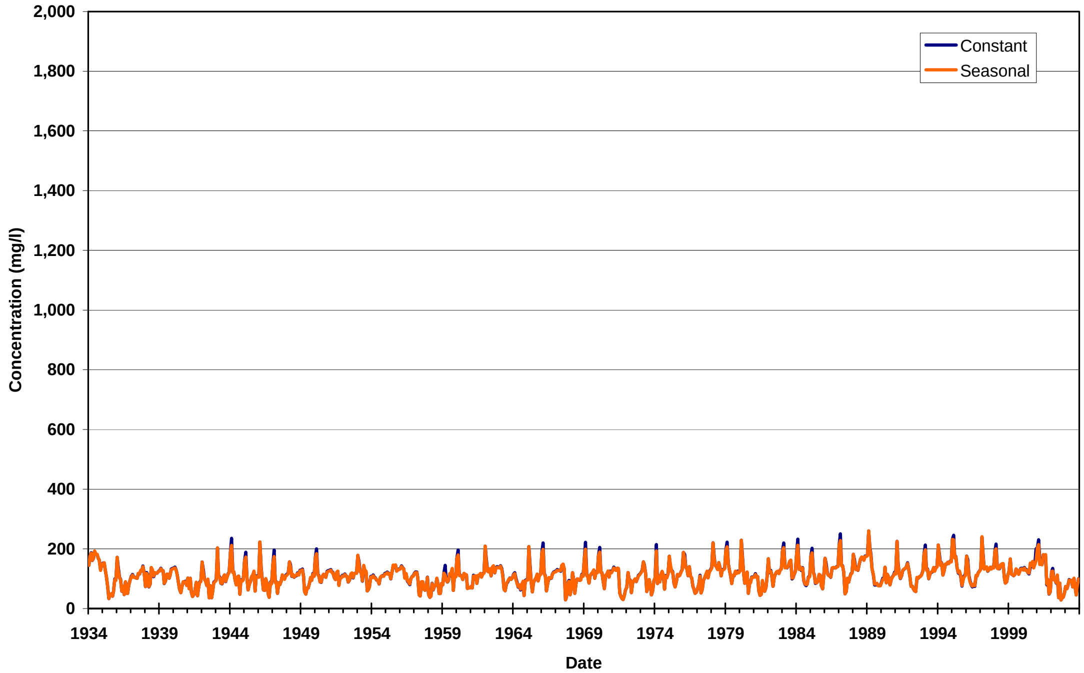
Choke Canyon Reservoir
TDS Time Series for Constant and Seasonal Delivery



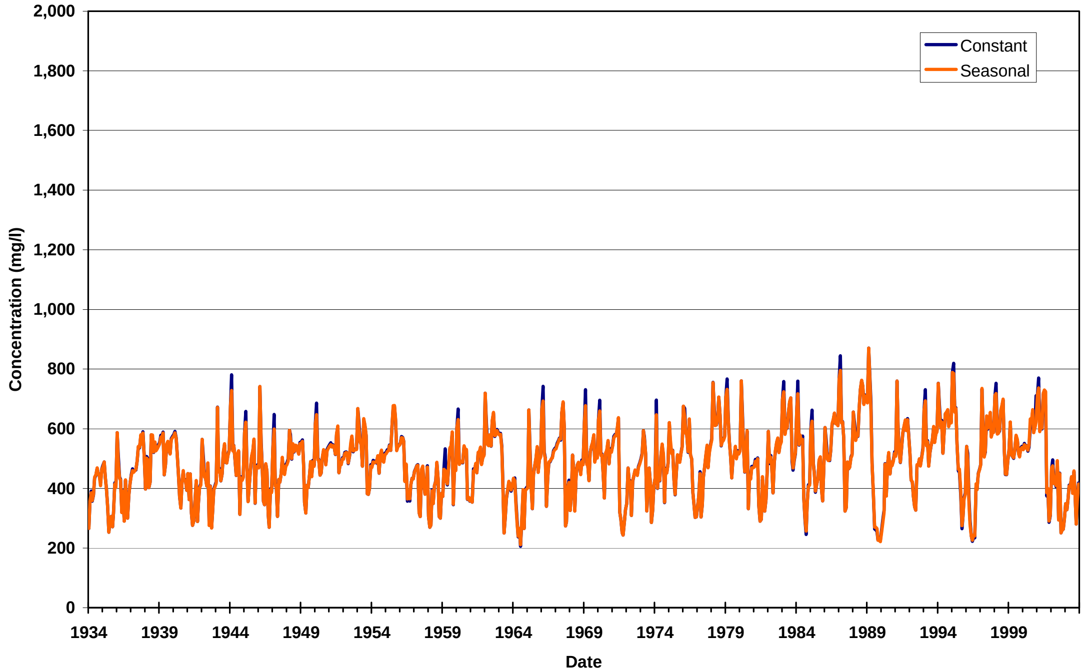

Lake Corpus Christi
Chloride Time Series for Constant and Seasonal Delivery
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date
Constant
Seasonal

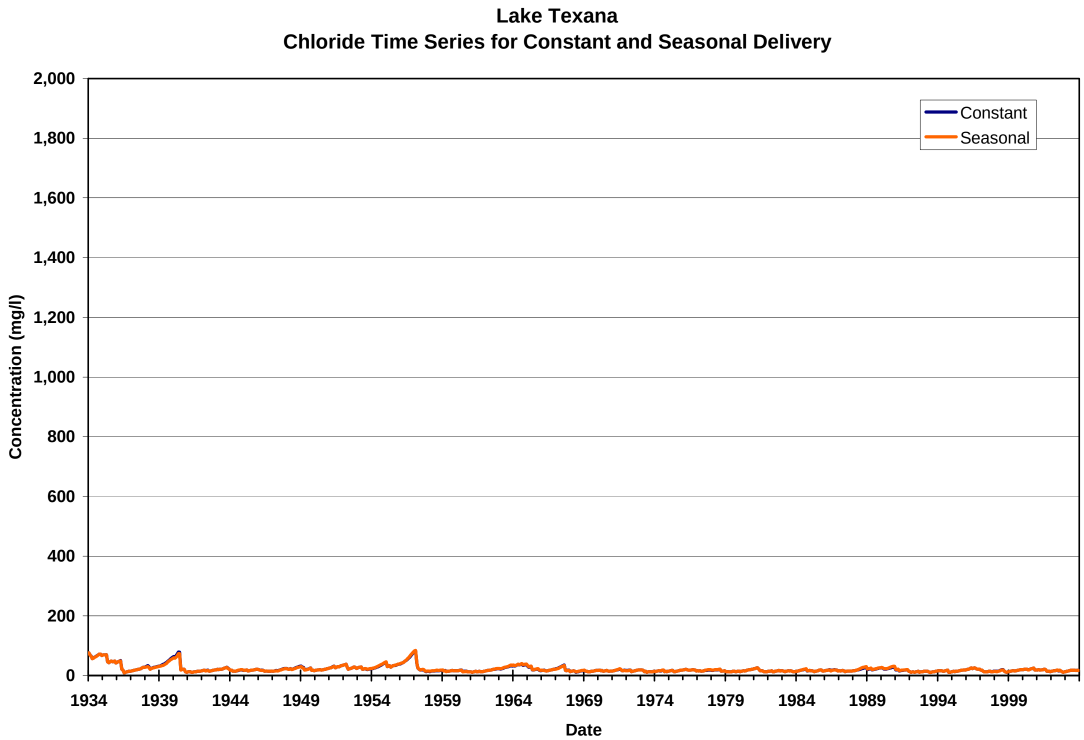

Lake Corpus Chrisit
TDS Time Series for Constant and Seasonal Delivery
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date
Constant
Seasonal

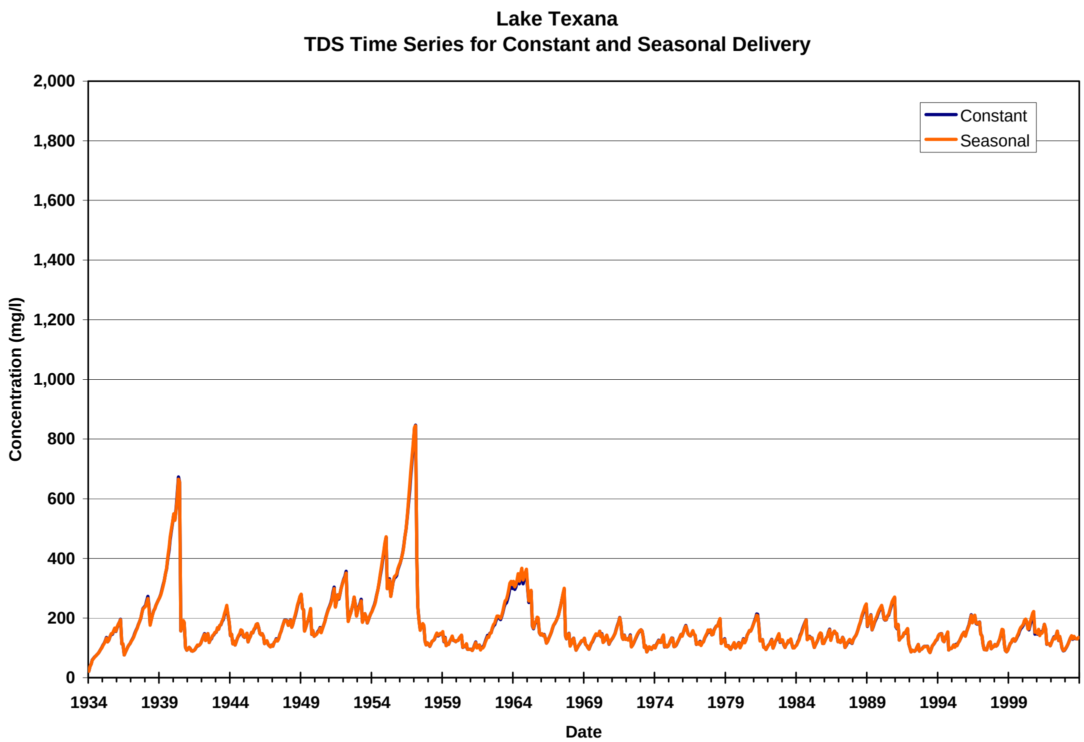
Calallen Pool
Chloride Time Series for Constant and Seasonal Delivery



Calallen Pool
TDS Time Series for Constant and Seasonal Delivery

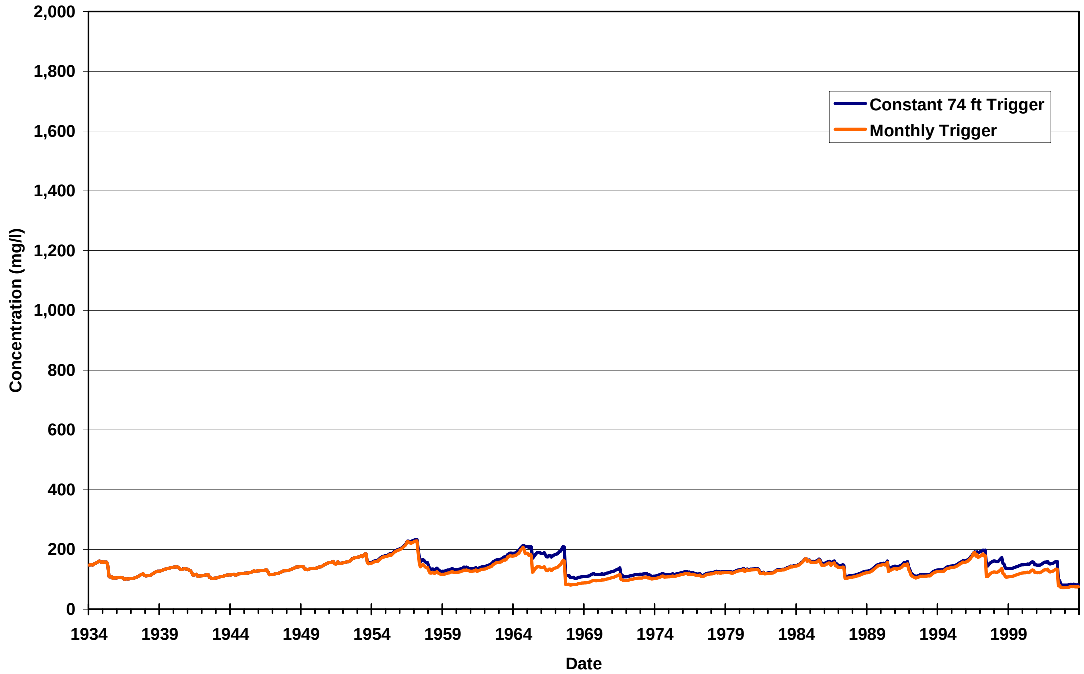



Lake Texana
Chloride Time Series for Constant and Seasonal Delivery
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Concentration (mg/l)
Constant
Seasonal
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date

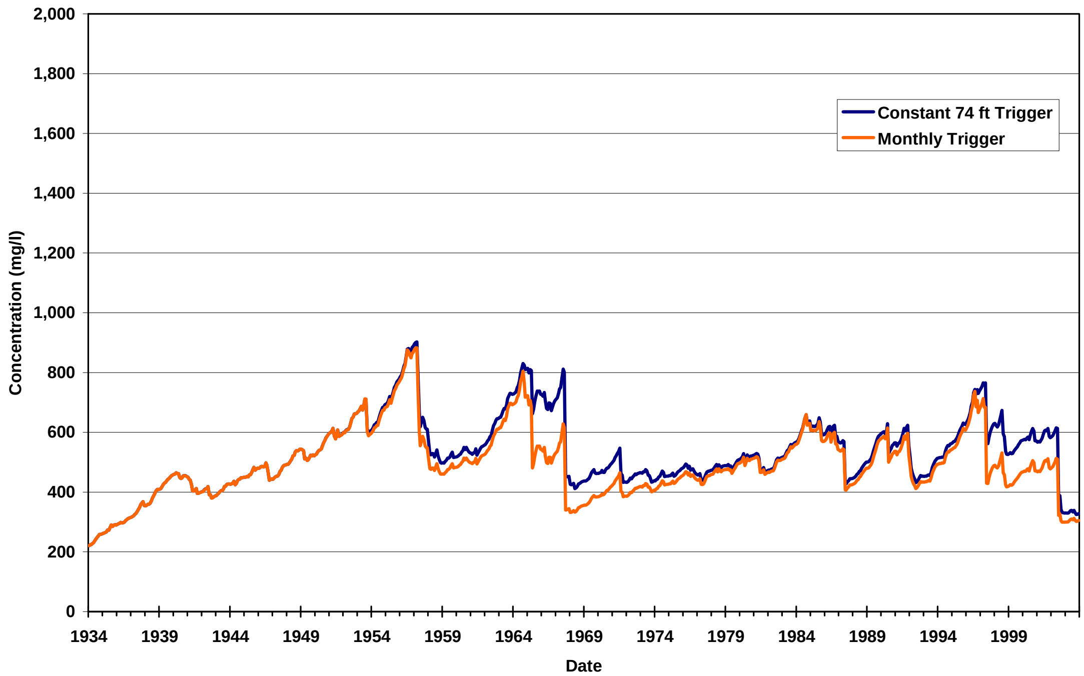

Lake Texana
TDS Time Series for Constant and Seasonal Delivery
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Concentration (mg/l)
Constant
Seasonal
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date

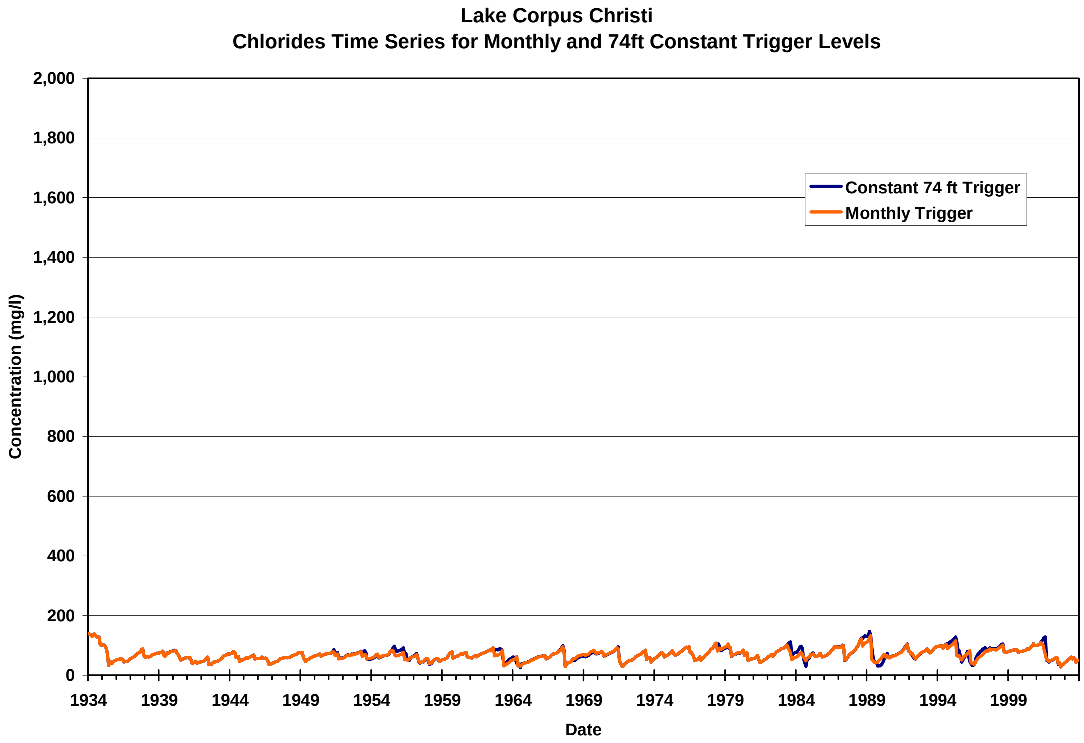
Attachment D-4:
Monthly variable LCC trigger level for water level delivery from CCR to LCC (Scenario 4)

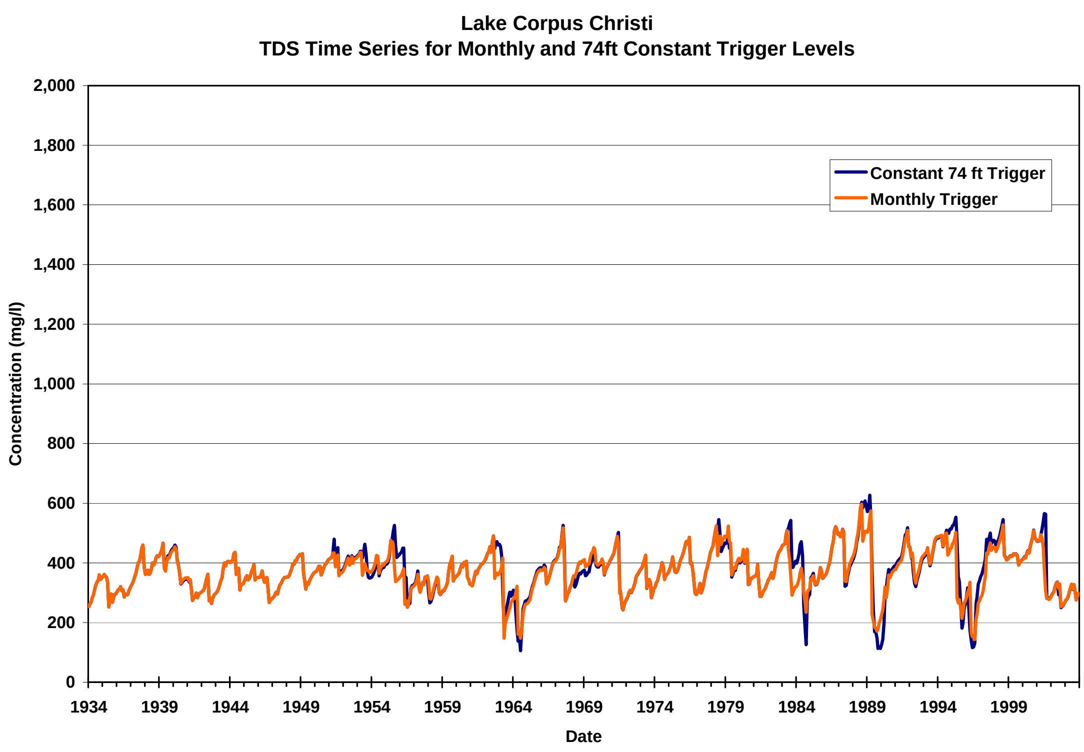
Choke Canyon Reservoir
Chlorides Time Series for Monthly and 74ft Constant Trigger Levels



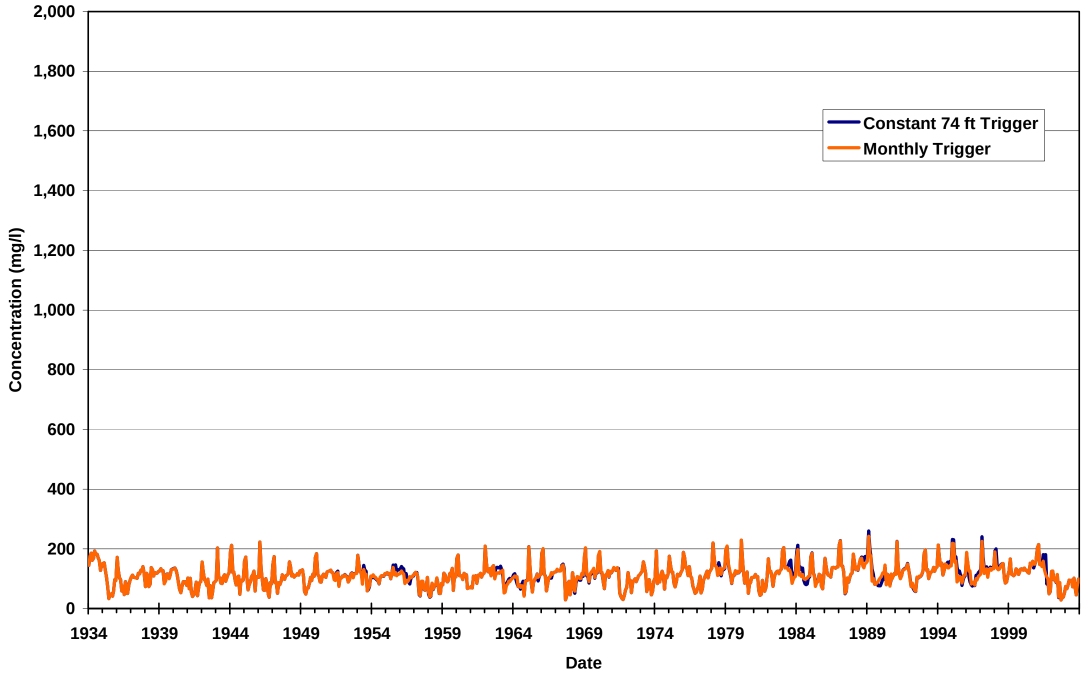
Choke Canyon Reservoir
TDS Time Series for Monthly and 74ft Constant Trigger Levels



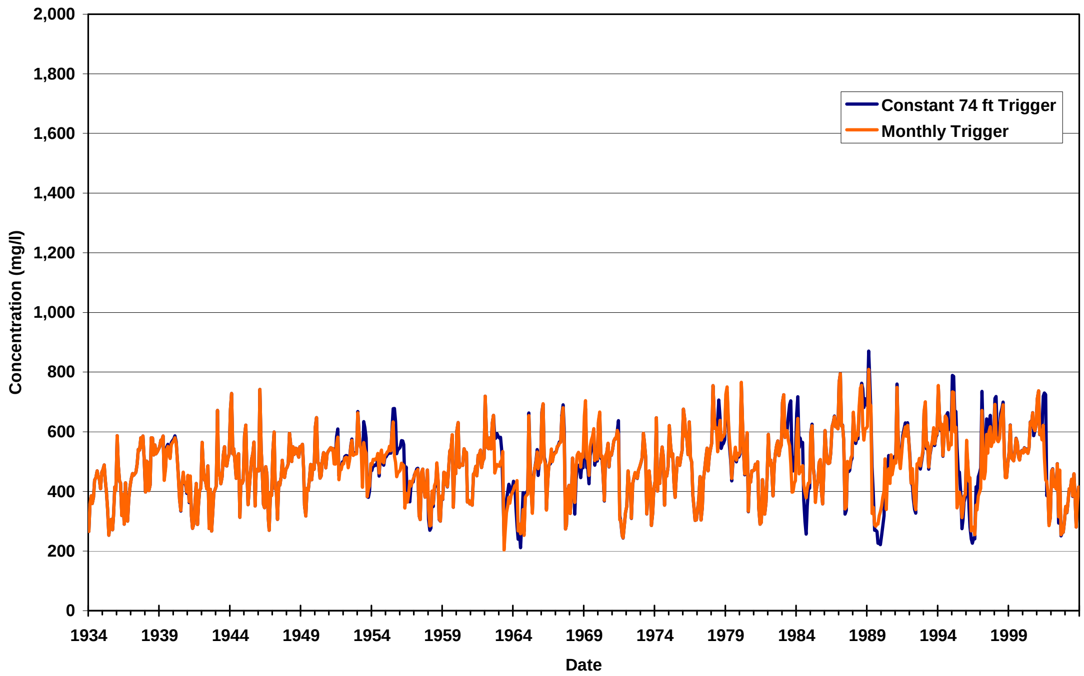

Lake Corpus Christi
Chlorides Time Series for Monthly and 74ft Constant Trigger Levels
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date
Constant 74 ft Trigger
Monthly Trigger


Lake Corpus Christi
TDS Time Series for Monthly and 74ft Constant Trigger Levels
Concentration (mg/l)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1934
1939
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Date
Constant 74 ft Trigger
Monthly Trigger

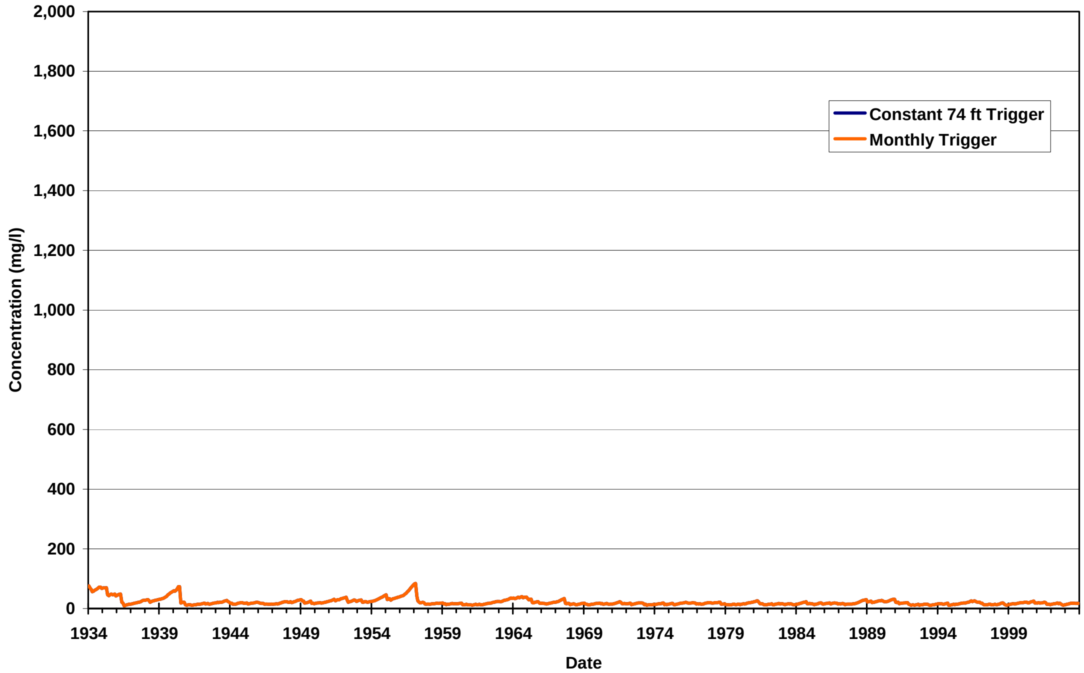
Calallen Pool
Chlorides Time Series for Monthly and 74ft Constant Trigger Levels



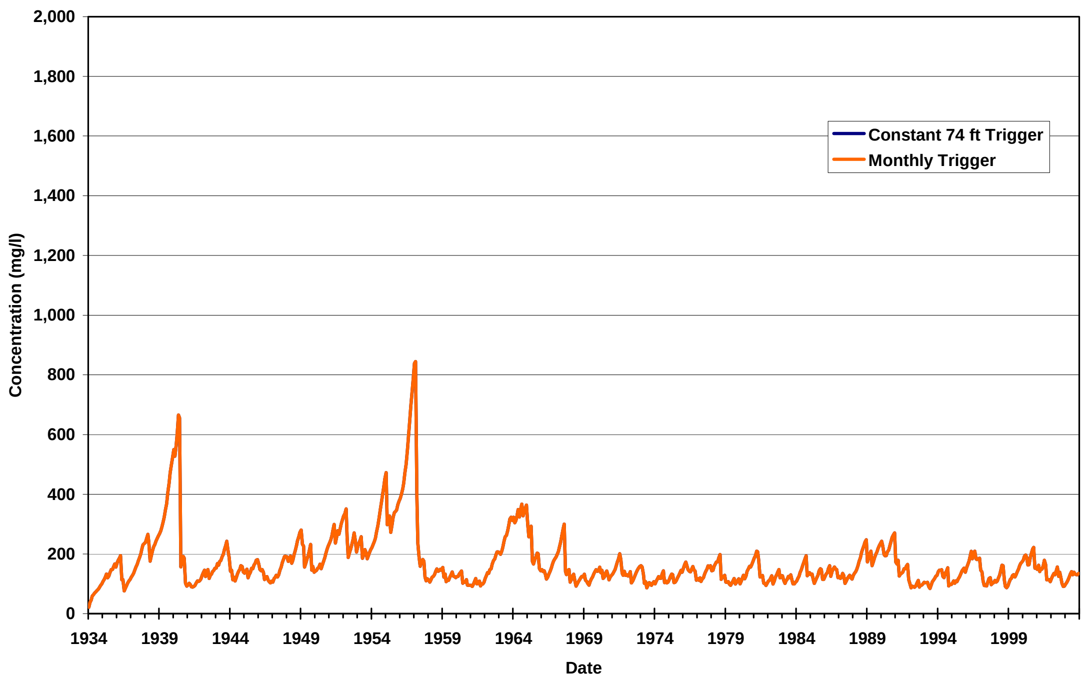
Calallen Pool
TDS Time Series for Monthly and 74ft Constant Trigger Levels



Lake Texana
Chlorides Time Series for Monthly and 74ft Constant Trigger Levels



Lake Texana
TDS Time Series for Monthly and 74ft Constant Trigger Levels



Appendix E
TWDB Comments and
Summary of the Coastal Bend RWPG Responses

TWDB Contract No. 0704830699

Region N, Region-Specific Study 4:

<u>TWDB Comments on Draft Final Region-Specific Study Reports:</u>

4) Water Quality Modeling of Regional Water Supply System to Enhance Water Quality and Improve Industrial Water Conservation

Region-Specific Study 4: Water Quality Modeling of Regional Water Supply System to Enhance Water Quality and Improve Industrial Water Conservation

1. Page ES-1: Executive summary does not summarize the findings from the four operating scenarios that were evaluated under Task B. Please summarize results of evaluation of operating scenarios and any associated recommendations in the report.

   Response: This information is presented in the main body of the report in Section 6.0. The executive summary was revised to include a summary of this information, as requested.

2. The contract Scope of Work, Task C states that the report will include sections including: "purpose of study including how the study supports regional water planning, methodology, results, and recommendations." Section 6.0, "Evaluation Summary", does not collectively summarize the results of the four operating scenarios evaluated or facilitate comparisons between scenarios to support overall conclusions. Evaluation section does not make recommendations. Please include 'results' and 'recommendations' sections in the final report.

   Response: The Scope of Work Task C as included in Exhibit C of the contract states that a draft and final report would be prepared to include "the following sections: executive summary, purpose of study including how the study supports regional water planning, methodology, results, and recommendations, *if applicable* (emphasis added). Report has been prepared to include description of model updates, methodology, and model operating scenario results with summary tables and graphs."

   The report was developed in accordance with the Scope of Work proposed report sections in Task C and includes: executive summary (Section ES), purpose of the study (Section 1.0- Need for Study and Project Objectives), methodology (Section 3.0- Methodology and Approach), results (Section 5.0 Study Results), description of model updates (Section 4.0- Model Calibration), and model operating scenario results with summary tables and graphs (Sections 5.2 – 5.5). The Evaluation Summary (Section 6.0) summarizes the results of the four operating scenarios that were evaluated in the study. Appendix B, C, and D include frequency plots and median monthly water quality graphs to allow comparison of water quality results (tds or chlorides; for each reservoir or Calallen Pool) amongst scenarios.

Since the results of various reservoir operation simulations did not indicate a substantial change in overall water quality using the model's monthly time step (especially at Calallen Pool where most intakes are located), a separate recommendations section was not included. The following text was added to Section 6.0: "Based on the results of the four operating scenarios which show minimal impacts to water quality for LCC and Calallen Pool where regional water supply intakes are located, no changes to reservoir operations are recommended at this time for water quality."

3. Pg. 3, Figure 3-1, suggest labeling Calallen Pool for reference.

   Response: Added label per comment.

4. Executive summary and Section 6.0: Suggest including concise summary of how model results could "enhance water quality and improve industrial water conservation" as stated in title of report.

   Response: The following text was added to the Executive Summary and Section 6.0: "The CCWSM enhanced with the water quality database is capable of simulating chlorides and TDS for the existing CCR/LCC/Lake Texana system for various potential reservoir operating conditions. There are five municipal and industrial water supply intakes in the Calallen Pool area, where chlorides and TDS fluctuations have been reported. By using the CCWSM to evaluate reservoir operations, overall water quality of the Calallen Pool can be stabilized and the reliability of regional water supplies can be increased which will reduce water consumption and treatment costs. Poor raw water quality causes more water to be used in industrial cooling towers; therefore improvements to water quality will directly support industrial water conservation."

5. Pg. 23, first paragraph states that the model "was enhanced to allow for water quality evaluation of chlorides and TDS concentrations in existing ...water supplies ... and potential future water supplies from the Lower Colorado River" without any background information. Please provide brief summary of the potential Lower Colorado supplies in the final report.

   Response: The following text was added to Section 6.0: "The City of Corpus Christi has an existing, interbasin transfer permit for supplies from the Lower Colorado River (Garwood Project) and is considering delivery of potential supplies via a canal or pipeline into West Mustang Creek and ultimately Lake Texana. These raw water supplies could then be withdrawn from Lake Texana and transported through the Mary Rhodes Pipeline. If delivered in this manner, the Garwood Project supplies being diverted through Lake Texana would likely have raw water quality that is the same as the existing Lake Texana water quality, which is currently simulated in the CCWSM. If a different delivery option of the Garwood Project or different supply is being integrated into the CCR/LCC/Lake Texana System, then the CCWSM water quality database would need to be updated to simulate the water quality of the future supply based on historical data for the source water (as available) using the method and approach described in Section 3.0."