TECHNICAL MEMORANDUM

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TO:	Michael V. Reedy, P.E.
FROM	Philip I. Taucer, P.E.
SUBJECT:	Proposed Lowering of Lake Conroe Conservation Pool: Potential Impacts on San Jacinto Basin Water Supplies
PROJECT:	SPH18133
DATE:	April 9, 2018

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1. BACKGROUND AND PURPOSE

Freese and Nichols, Inc. (FNI) has performed a modeling analysis of the potential impacts of lowering the Lake Conroe conservation pool elevation on lake storage and elevation, available diversions from the lake (average and firm), and downstream junior water rights. This memorandum summarizes the study objectives, water rights examined, modeling approach, and results of the analyses. The objectives of the study included the following:

- Use of the Texas Commission on Environmental Quality (TCEQ)-approved Water Availability Model (WAM) for the San Jacinto River Basin, modified to reflect estimated year 2010 sedimentation conditions for Lakes Conroe and Houston, to evaluate impacts to Lake Conroe and downstream junior water rights.
- Development of a spreadsheet model of Lake Conroe simulating 1940 through 2016 hydrology on a monthly timestep based on data from the TCEQ WAM for the San Jacinto River Basin, records for the post-1996 period, and estimates of year 2010 sediment and storage conditions.
- Application of the spreadsheet model to evaluate impacts on reservoir storage of reducing the Lake Conroe conservation pool to 200, 199, and 198 feet above mean sea level (ft-msl) with maximum permitted diversions for the lake. Reductions of conservation storage for the entire year and seasonal reductions limited to August and September were considered.
- Application of the spreadsheet model to evaluate impacts on firm yield due to reducing the Lake Conroe conservation pool to 200, 199, and 198 ft-msl.

Key assumptions applied in the study include the following:

- Sedimentation was assumed to be at estimated year 2010 conditions for Lakes Conroe and Houston.
- Both spreadsheet and WAM analyses were performed at a monthly timestep.
- For WAM analysis of firm yield, each right was evaluated independently through iterative adjustment of its annual diversion target.

2. WATER RIGHTS

Lake Conroe is located in Montgomery County, Texas, on the West Fork of the San Jacinto River near the City of Conroe. TCEQ Certificate of Adjudication (CoA) 10-4963 authorizes the impoundment of up to 430,260 acre-feet (ac-ft) of water in Lake Conroe, with a priority date of January 12, 1959 for the impoundment of 380,430 ac-ft of water. The diversion and use of 100,000 ac-ft of water per year (66,000 ac-ft/yr for municipal use, 28,500 ac-ft/yr for industrial use, and 5,500 ac-ft/yr for mining use) is also authorized at a January 12, 1959 priority date. The impoundment of the remaining 49,830 ac-ft of water is at a June 28, 1965 priority. The water right is held by the City of Houston (COH) and the San Jacinto River Authority (SJRA). The conservation storage pool of the lake is 201 ft-msl (National Geodetic Vertical Datum 1929).

There are two non-saline perpetual water rights junior to CoA 10-4963 and located downstream of Lake Conroe. CoA 10-5807, held by the COH and SJRA, is located at Lake Houston and authorizes the use of 28,200 ac-ft/yr of the unappropriated firm yield of Lake Houston for municipal and industrial uses at a priority date of June 19, 2003. The right is subject to special conditions, including conditions related to instream use. CoA 10-5808, held by the COH and SJRA, authorizes the diversion and use of up to 80,000 ac-ft/yr of run-of-river water from Lake Houston for municipal and industrial uses at a priority date of June 19, 2003. The right is subject to special conditions, including conditions related to instream use.

3. WAM MODEL DEVELOPMENT

3.1 WAM OVERVIEW

WAM modeling scenarios examined in this study were based on the TCEQ WAM Run 3 for the San Jacinto River Basin. The WAM simulates water rights in a prior appropriation framework for a period of historical hydrology for 1940 through 1996, with perpetual water rights and reservoirs active for the full simulation period. For the Run 3 WAM, rights are assumed to attempt their full permitted diversion each year, with use assumed to be fully consumptive unless mandated otherwise by permit or other special conditions. In the WAM, it is assumed that all water rights follow strict priority order, with junior water rights able to use water rights only if it is available after the operation of senior water rights. Reservoir storage in the Run 3 WAM typically reflects original (non-sediment) storage. It should be noted that the WAM is intended as a statistical tool for analyzing reservoir response under a range of historical hydrology rather than as a predictive model.

3.2 BASELINE 2010 WAM

In order to represent year 2010 conditions, a modified version of the Run 3 WAM was developed to reflect estimated reservoir elevation-area-capacity conditions for Lakes Conroe and Houston. The year 2010 area, capacity, and elevation data for Lake Conroe was obtained from the report *Volumetric and Sedimentation Survey of Lake Conroe: June – August 2010 Survey* published by Texas Water Development Board (TWDB) in July 2012. Elevation-area-capacity data for Lake Houston was obtained from the report *Volumetric and Sedimentation Survey of Lake Houston: December 2011 Survey* published by TWDB in July 2013. For purposes of this study, the 2011 survey of Lake Houston was assumed to be representative of the year 2010 elevation-area-capacity conditions. WAM input was adjusted to reflect 2010 elevation-area-capacity conditions. The resultant Baseline Model was used as the basis for WAM analyses for the study.

4. SPREADSHEET MODEL DEVELOPMENT

4.1 OVERVIEW OF MODEL OPERATION

Spreadsheet modeling of Lake Conroe was performed using a Microsoft Excel-based monthly timestep water balance model developed by FNI. The model uses various parameters including reservoir storage configuration, inflow, releases, target diversions, and evaporation to simulate reservoir response. While structured as a single reservoir water balance model rather than a complex multi-right program, the spreadsheet model follows a similar conceptual approach to the WAM. Like the WAM, the spreadsheet model is intended as a statistical tool for analyzing reservoir response under a range of historical hydrology rather than as a predictive model. Execution of the model requires the following input data:

- Reservoir area, capacity, and elevation table
- Starting and maximum conservation pool volume
- Net evaporation rate
- Monthly releases
- Monthly inflow
- Demand distribution pattern
- An annual diversion target

For each monthly timestep, a mass balance analysis is used to determine available diversions, spills, lake storage, and lake elevation.

4.2 INPUT DEVELOPMENT

Model input data was developed utilizing a number of information sources, as described in the following subsections. Inputs for the portion of the simulation period from 1940 through 1996 were derived primarily from the Baseline WAM discussed in *Section 3.2*. Inflow and outflow parameters for 1997 through 2016 were estimated using data from the SJRA and multiple state and federal agencies.

A. Reservoir Elevation-Area-Capacity Data

The year 2010 elevation-area-capacity data for Lakes Conroe and Houston was obtained as described in *Section 3.2*. Estimation of inflows for the 1997 to 2016 period also utilized information in TWDB's 2010 survey of Lake Conroe related to TWDB's earlier 1996 survey.

B. Reservoir Evaporation

Monthly net reservoir evaporation rates for 1940 through 1996 were extracted from the Baseline WAM. Monthly net reservoir evaporation for 1997 through 2016 was determined from historical data using the formula:

$$E_{net} = E_{gross} – (P_{gross} - R_{eff})$$

Where:

E_{net}	Net reservoir evaporation
E_{gross}	Historical monthly evaporation

P_{gross} Historical monthly precipitation

R_{eff} Effective unit runoff

Historical reservoir evaporation rates and precipitation rates were obtained from TWDB data for Quadrangle 712, in which Lake Conroe is located. Effective unit runoff is runoff from a representative measuring point divided by the drainage area of that measurement point. Because of the presence of multiple water rights and wastewater discharges in much of the San Jacinto River Basin, for this study the effective runoff was calculated using the difference in monthly flow between two USGS gauges (USGS 08070000 near Cleveland and USGS 08070200 near New Caney) on the East Fork of the San Jacinto River, divided by the incremental drainage area between the two measurement points. These points were selected because the water rights in the intervening stream were not shown by TCEQ records to divert flow during the available records and the only wastewater discharge identified was permitted for an amount small relative to the typical flows in the stream.

C. Releases for Senior Rights

Monthly releases for downstream senior rights for 1940 through 1996 were derived from the Baseline WAM discussed in *Section 3.2*, with the following additional modifications applied:

- Addition of an off-stream synthetic control point and water right used to store information on Lake Conroe outflow immediately prior to application of diversions from the lake in the WAM calculation loop.
- Deactivation of the default dual simulation option to allow available flow parameters to be written to the WAM output file appropriately for each diversion from the lake.

Monthly releases for downstream senior rights were then calculated as the outflow from the Lake Conroe control point before application of lake diversions less flow available to the most senior diversion at the lake. Because Lake Conroe was not required to pass inflows to downstream senior rights under a priority call in the 1997-2016 period, potential releases for senior rights were estimated as the lesser of (a) unfilled end of month storage below the conservation elevation in Lake Houston and (b) and calculated inflow to Lake Conroe. This volume was calculated using USGS records of Lake Houston elevation and TWDB's 2011 survey of Lake Houston. It should be noted that because 1997-2016 inflows were estimated from historical data when the senior Lake Houston water right was not exercised to the full permitted amount, required releases under full WAM Run 3 conditions would potentially be higher than those estimated.

D. Total Releases

Total historical reservoir releases were used in the estimation of inflow for the 1997 through 2016 period as well as for model validation. Total releases were obtained from SJRA records of Lake Conroe service outlet and spillway releases.

E. Lakeside Water Use

Lakeside water use was used in the estimation of inflow for the 1997 through 2016 period as well as for model validation. Lakeside water use for 1997 through 2014 was obtained from TCEQ records of SJRA use of CoA 10-4963 through 2014 and SJRA records of monthly diversions for 2015 and 2016.

F. Reservoir Inflow

Reservoir inflow for 1940 through 1996 was determined from Baseline WAM output by adding the regulated flow (outflow) at the Lake Conroe control point to the streamflow depletions at that point for each month. Reservoir inflow to Lake Conroe for 1997 through 2016 was estimated using a water balance approach. USGS data for the gage at Lake Conroe (USGS 08067600) was used to determine a beginning and ending water surface elevation for each month, with the reservoir storage datasets discussed in *Section 3.2* used to calculate beginning and ending volumes and areas. The difference in beginning and ending volume was used to calculate a volume change, to which historical total releases, lakeside diversions, and net reservoir evaporation (net reservoir evaporation X average area) were added to generate a preliminary inflow estimate. In the occasional cases where this resulted in a negative inflow estimate for a month, the inflow for that month was adjusted to zero and the negative amount was distributed to the preceding and following months.

G. Demand Pattern

A monthly water demand pattern was used in the study to distribute the annual diversion target into monthly values to correspond with the monthly timestep of the spreadsheet model. The TCEQ Run 3 WAM applies two monthly water demand patterns to Lake Conroe, with one for municipal diversions and the other for industrial diversions. A composite pattern was developed by multiplying each pattern by the full target for the corresponding use type and dividing the monthly sum of both patterns by the total permitted diversion to generate a monthly percentage of the annual diversion target.

4.3 MODEL VALIDATION

Prior to the evaluation of scenarios, the spreadsheet model was validated to confirm proper operation. Because the model data was derived from separate sources for 1940 through 1996 (WAM data assuming full permitted diversions) and for 1997 through 2016 (recent historical data with historical rather than permitted diversions), the two subsets of hydrology were first validated separately, with a comparison of the full spreadsheet model to the WAM used as a final validation step.

A. 1940 to 1996 Data

Spreadsheet modeling of 1940 through 1996 hydrology was validated in comparison to the Baseline WAM. The spreadsheet model was populated with the WAM-derived input data including year 2010 area, capacity, and elevation parameters. Initial and maximum storage were set to 411,022 ac-ft, corresponding to a conservation pool of 201 ft-msl from TWDB's 2010 Lake Conroe survey. The annual diversion target for the lake was set to 100,000 ac-ft to match the full permitted amount of CoA 10-4963. Resultant end of month stored volumes were compared to end of month storage from the Baseline WAM, as shown in *Figure 1*. The comparison results in an R^2 value of 0.999999, indicating that that the spreadsheet model generates results similar to those from the WAM. As an additional validation step, both the spreadsheet model and the Baseline WAM were also iteratively adjusted to calculate a firm diversion target for CoA 10-4963 to the nearest hundred ac-ft/yr. Both models returned a firm diversion result of 80,200 ac-ft/yr.

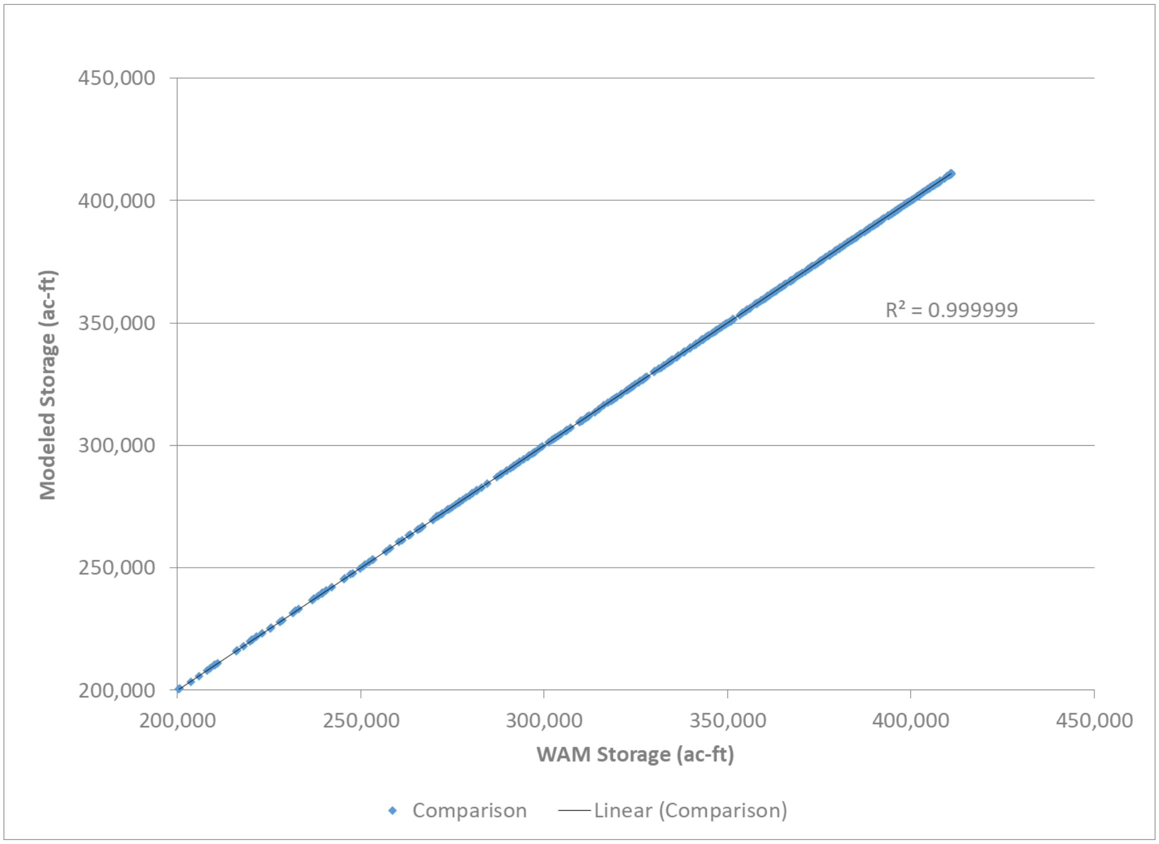

Figure 1: Comparison of Spreadsheet Model and WAM Storage for 1940 Through 1996

B. 1997 to 2016 Data

Because input hydrology for 1997 through 2016 was not developed from WAM data under full permitted diversion conditions but rather estimated from recent records of hydrology and diversion, comparing this portion of the input against WAM-analogous assumptions would not provide an applicable validation. For that reason, spreadsheet modeling of 1997 through 2016 modeling was validated against historical reservoir storage. The spreadsheet model was populated from historically derived data including the following:

- Year 2010 elevation-area-capacity parameters
- Estimated reservoir inflow
- Net reservoir evaporation rate
- Total releases
- Lakeside diversions
- Historical initial storage

Resultant end of month stored volumes were compared to end of month storage estimated from historical water surface elevations, as shown in *Figure 2*. The comparison results in an R^2 value of 0.9907, indicating that the spreadsheet model generates values closely matching historical results.

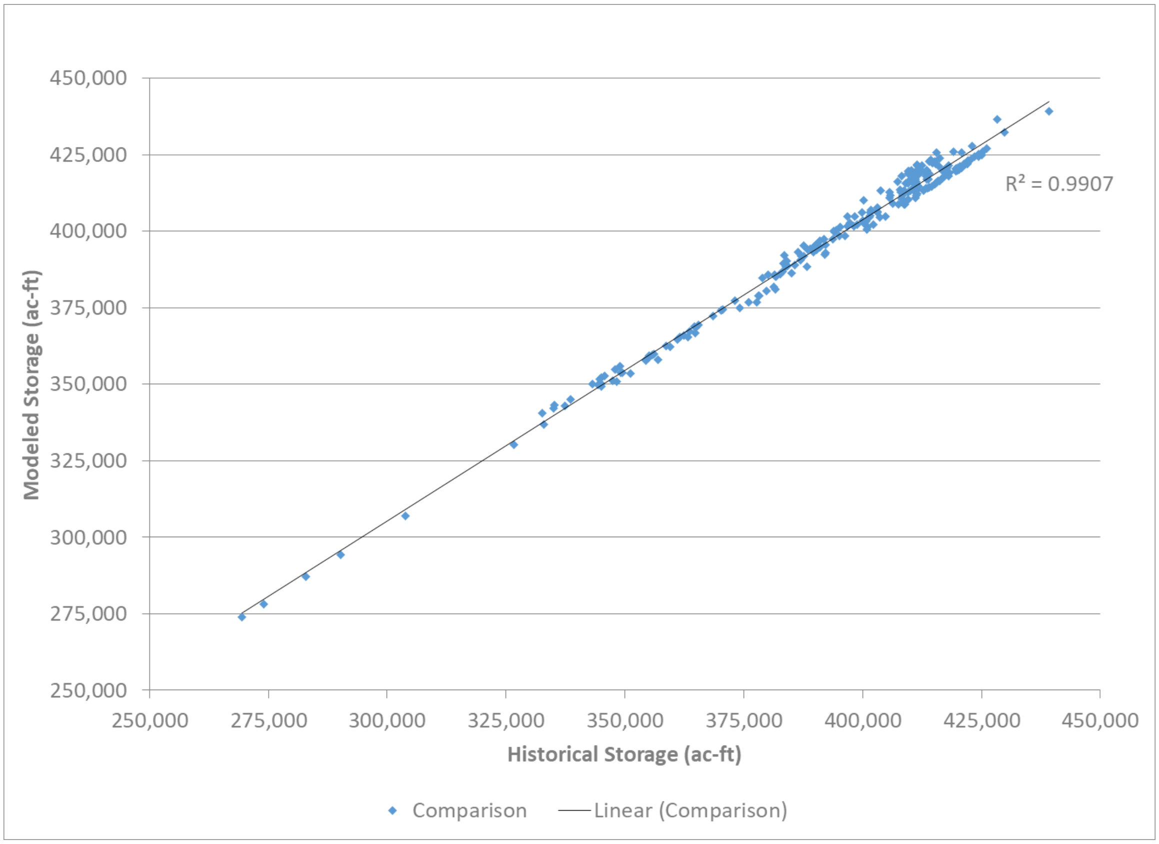

Figure 2: Comparison of Spreadsheet Model and Historical Storage for 1997 Through 2016

C. Full Simulation Period

An additional check of the spreadsheet model was performed for the full 1940 through 2016 period. The input data from both date ranges were combined, with the following changes applied for 1997 through 2016 data to allow WAM-analogous operation:

- Replacement of historical total release volume with releases for downstream senior water rights
- Replacement of historical lakeside diversions with a monthly distribution of the annual diversion target

The annual diversion target in the spreadsheet model was iteratively adjusted to calculate a firm diversion target for CoA 10-4963 to the nearest hundred ac-ft/yr to test model function. The resultant firm yield value of 80,200 ac-ft/yr matches the result obtained from the Baseline WAM.

5. ANALYSES AND RESULTS

5.1 WAM ANALYSIS

The Baseline WAM as described in *Section 3.2* was used as the basis for WAM evaluation of Lake Conroe conservation pool scenarios. Four scenarios were examined: a baseline scenario and three alternative scenarios with permanent modification of the conservation pool to 200, 199, and 198 ft-msl (*Table 1*), respectively. The baseline scenario represents the current normal conservation pool, in which the conservation pool target elevation is 201 ft-msl year-round.

Table 1. WAM Model Scenarios

Scenario	Conservation Pool (ft-msl)	Max. Conservation Pool Capacity (ac-ft)
Baseline	201	411,022
200’	200	392,078
199’	199	373,635
198’	198	355,653

Each scenario was first executed with full permitted diversion targets to assess reservoir storage and diversion response under permitted diversions as well as to identify the minimum annual diversion of run-of-river right CoA 10-5808. Additionally, for each scenario the diversion targets for CoA 10-4963 at Lake Conroe and CoA 10-5807 at Lake Houston were iteratively adjusted to determine the corresponding modeled firm diversion. This iterative process was performed separately for the two water rights.

A. Lake Conroe

Modeled impacts on Lake Conroe are summarized in *Table 2* and *Figure 3*.

Table 2. Lake Conroe Impacts for WAM Scenarios

Scen.	Cons. Pool (ft-msl)	Firm Diversion (ac-ft)	Full Permitted Diversion Target					
			Total Shortage (ac-ft)	Min Vol (ac-ft)	Avg Volume (ac-ft)	Avg Elev. (ft-msl)	Top of Conservation Storage (ac-ft)	Months Below 197 ft-msl
Baseline	201	80,200	99,472	0	319,329	194.4	411,022	282
200’	200	78,000	111,881	0	302,984	193.4	392,078	329
199’	199	75,800	123,756	0	287,021	192.3	373,635	390
198’	198	73,700	134,721	0	271,497	191.2	355,653	455

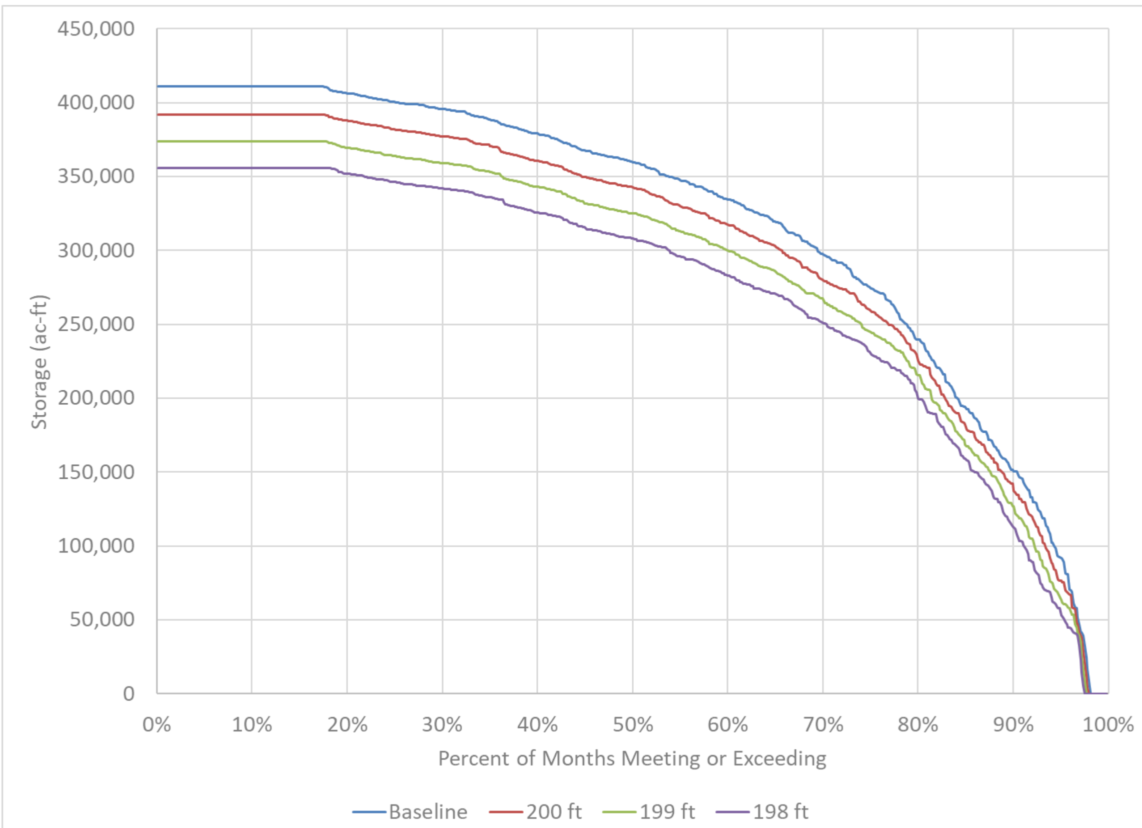

Figure 3: Lake Conroe Storage-Duration Response for Full Target in WAM

As shown in *Table 2* and *Figure 3*, potential reduction of the conservation pool elevation impacted multiple parameters, with the largest impacts observed for a reduction in maximum storage to 198 ft-msl (355,653 ac-ft). This scenario showed the lake below elevation 197 ft-msl, the trigger for mandatory drought response measures, for 173 more months (over 1.6 times more often) than the baseline scenario. Modeled impacts to storage and total shortages in permitted diversions were observed for all conservation pool reduction scenarios. Total shortages are shortages modeled for the full 1940 through 1996 period. The greatest magnitude of impact was observed for the 198 ft-msl conservation pool scenario, which demonstrated a 3.2-ft reduction in average pool elevation and an additional 35,249 ac-ft of total diversion shortage relative to the baseline scenario. Additionally, the 198 and 199 ft-msl scenarios under full permitted diversion target conditions had an average elevation of 191.2 and 192.3 ft msl, respectively, over the full modeled period from 1940 through 1996. These average pool elevations are below the minimum observed conservation pool volume of 192.7 ft-msl recorded during drought conditions in 2011. Reductions in firm diversion ranged from 2,200 ac-ft/yr for a 1-ft reduction in the conservation pool to a 6,500 ac-ft/yr reduction for a 3-ft reduction in conservation pool elevation. This maximum impact is approximately 8.1 percent of the firm diversion under the baseline scenario.

B. CoA 10-5807

Modeled impacts on water right CoA 10-5807 at Lake Houston are summarized in *Table 3*. As shown in the table, lowering the Lake Conroe conservation pool in the model did not result in impacts to CoA 10-5807 diversion reliability.

Table 3. CoA 10-5807 Impacts for WAM Scenarios

Scenario	Firm Diversion (ac-ft)	Annual Diversion for Full Permitted Diversion Target		
		Min Diversion (ac-ft)	Avg Diversion (ac-ft)	Max Diversion (ac-ft)
Baseline	11,300	23,519	28,036	28,200
200’	11,300	23,519	28,036	28,200
199’	11,300	23,519	28,036	28,200
198’	11,300	23,519	28,036	28,200

A. CoA 10-5808

Modeled impacts to water right CoA 10-5808 are summarized in *Table 4*. It should be noted that this water right is a run-of-river right which does not access reservoir storage. For this reason, the table reflects the minimum annual diversion under the full permitted diversion target rather than a firm diversion. As shown in the table, lowering the Lake Conroe conservation pool in the model did not result in impacts to CoA 10-5808 diversion reliability.

Table 4. CoA 10-5808 Impacts for WAM Scenarios

Scenario	Annual Diversion for Full Permitted Diversion Target		
	Min Diversion (ac-ft)	Avg Diversion (ac-ft)	Max Diversion (ac-ft)
Baseline	0	64,578	80,000
200’	0	64,578	80,000
199’	0	64,578	80,000
198’	0	64,578	80,000

5.2 SPREADSHEET MODEL

Seven scenarios were assessed using the spreadsheet model, including the baseline model described in *Section 4.3C*, permanent modification of the Lake Conroe conservation pool at three different elevations, and temporary modification of the conservation pool at three different elevations (*Table 5*). The baseline scenario represents current reservoir operations, in which the conservation pool is set at a target elevation of 201 ft msl year-round. All spreadsheet model runs were first executed using the maximum permitted diversions for Lake Conroe (100,000 ac-ft/yr) to determine impacts on diversions and storage response. The firm yield for diversions from Lake Conroe was then determined for each scenario.

Table 5. Spreadsheet Model Scenarios

Scenario	Conservation Pool (ft msl)	Pool Reduction Type	Maximum Conservation Pool Capacity (ac-ft)
Baseline	201	N/A	411,022
200’ (temp)	200*	Temporary	411,022
200’	200	Permanent	392,078
199’ (temp)	199*	Temporary	411,022
199’	199	Permanent	373,635
198’ (temp)	198*	Temporary	411,022
198’	198	Permanent	355,653
** Temporary maximum conservation storage for August and September.*			

5.3 STORAGE RESPONSE

At the full permitted diversion target, modifications to the conservation pool impacted both the maximum storage capacity and the temporal pattern of available diversions and storage throughout the model period. The effect of modified operations on the average volume stored in Lake Conroe are shown for the entire model period in *Table 6*; results for years 1997 through 2016 are summarized in *Table 7*. Storage-duration and elevation-duration results for both the full model simulation period and the subset of results for years 1997 through 2016 shown in *Figure 4* through *Figure 7*. Storage-duration and elevation-duration curves illustrate the frequency during the modeled period of record that storage in the lake meets or exceeds a certain volume or elevation. Storage time series data for the full simulation period and subsets of model results for the 1950s drought and recent 1997-2016 hydrology are included in *Attachment 1* to this memorandum.

Table 6. 1940-2016 Storage Properties (Full Target)

Scenario	Average Storage (ac-ft)	Average Elevation (ft-msl)	Average % of Baseline Capacity	Months Below 197 ft-msl
Baseline	313,947	194.1	76.4%	391
200’ (temp)	311,393	193.9	75.8%	400
200’	297,674	192.9	72.4%	451
199’ (temp)	305,006	193.4	74.2%	416
199’	281,840	191.8	68.6%	536
198’ (temp)	295,237	192.6	71.8%	479
198’	266,480	190.6	64.8%	622

Table 7. 1997-2016 Storage Properties (Full Target)

Scenario	Average Storage (ac-ft)	Average Elevation (ft-msl)	Average % of Baseline Capacity	Months Below 197 ft-msl
Baseline	298,616	192.9	72.7%	110
200’ (temp)	296,764	192.7	72.2%	111
200’	282,585	191.7	68.8%	122
199’ (temp)	288,748	191.9	70.3%	116
199’	267,118	190.3	65.0%	146
198’ (temp)	279,828	190.9	68.1%	130
198’	252,224	189.1	61.4%	167

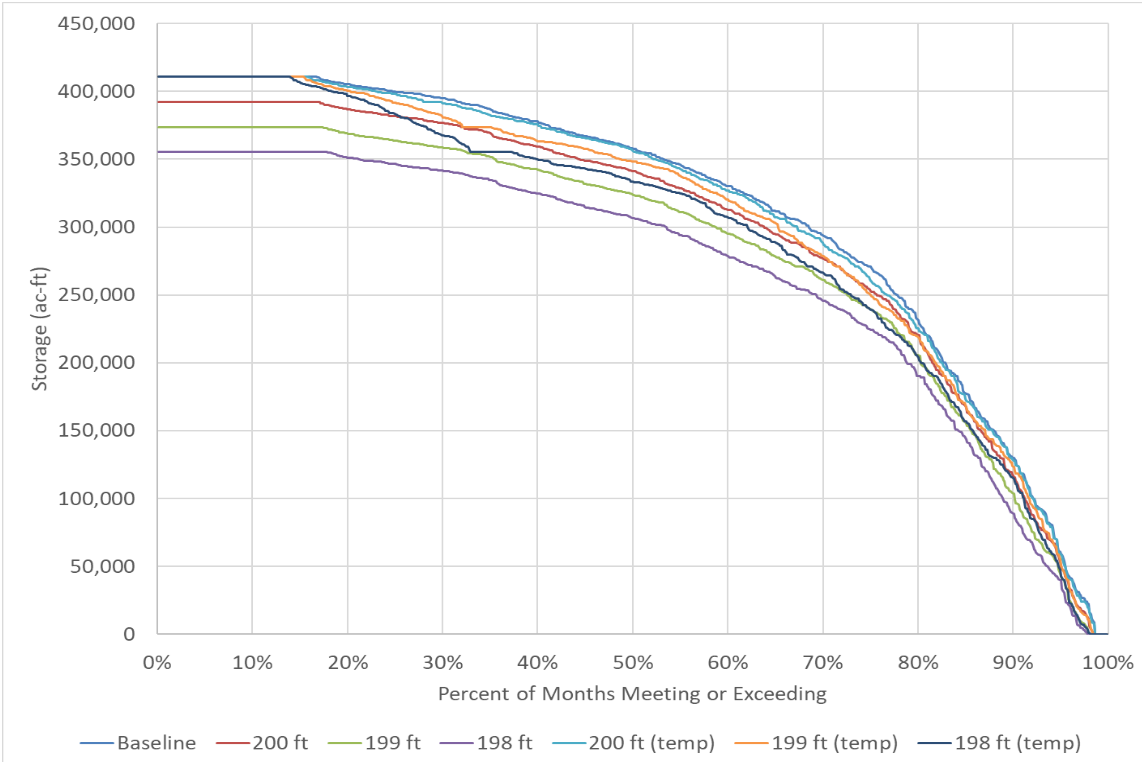

Figure 4: Spreadsheet Model Storage-Duration Curve (1940-2016 Hydrology)

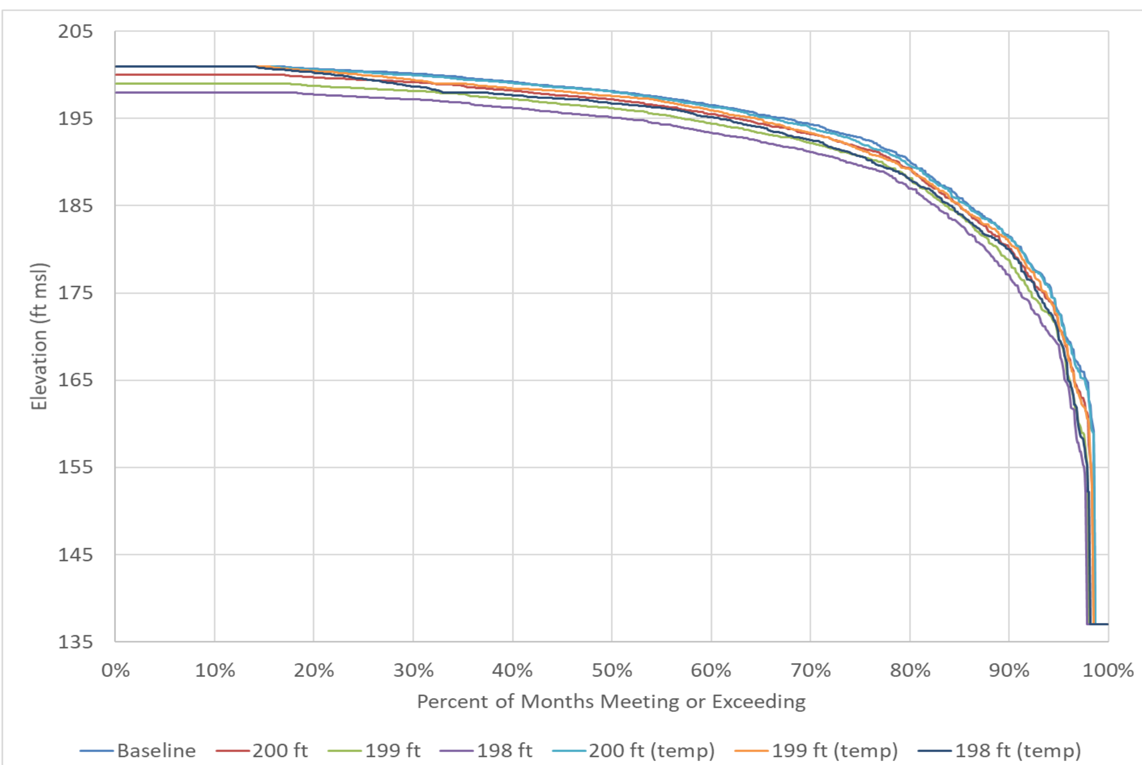

Figure 5: Spreadsheet Model Elevation-Duration Curve (1940-2016 Hydrology)

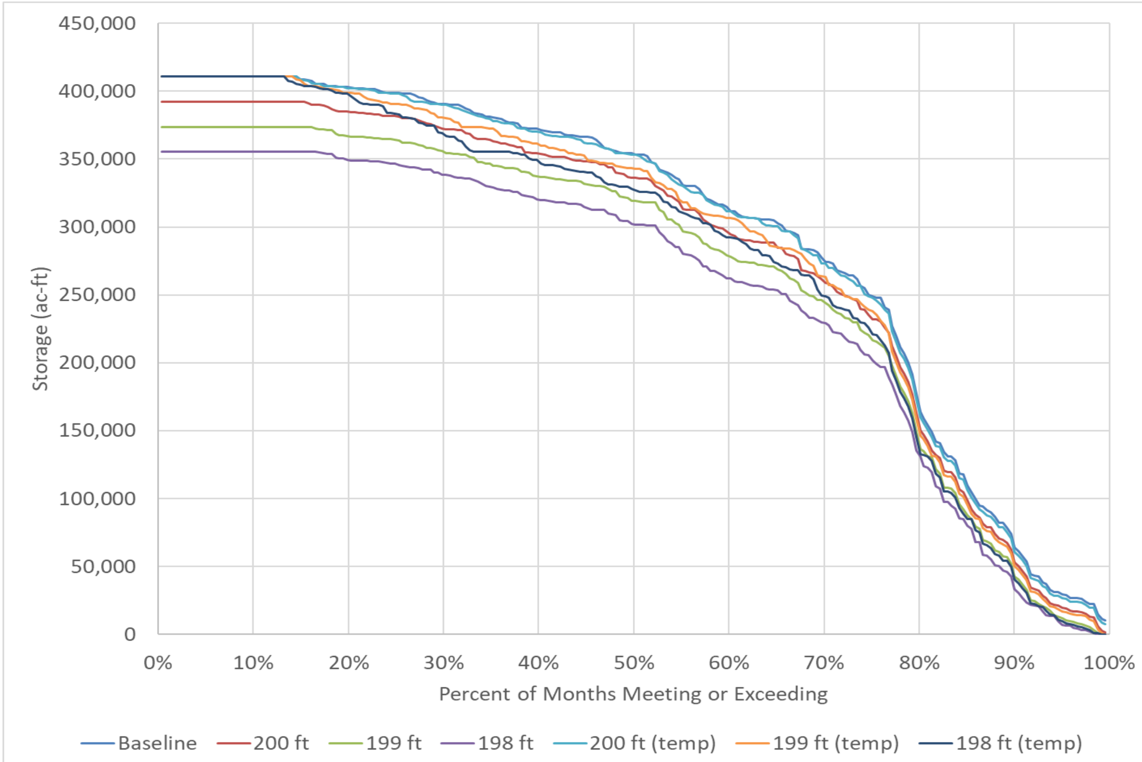

Figure 6: Spreadsheet Model Storage-Duration Curve (1997-2016 Hydrology)

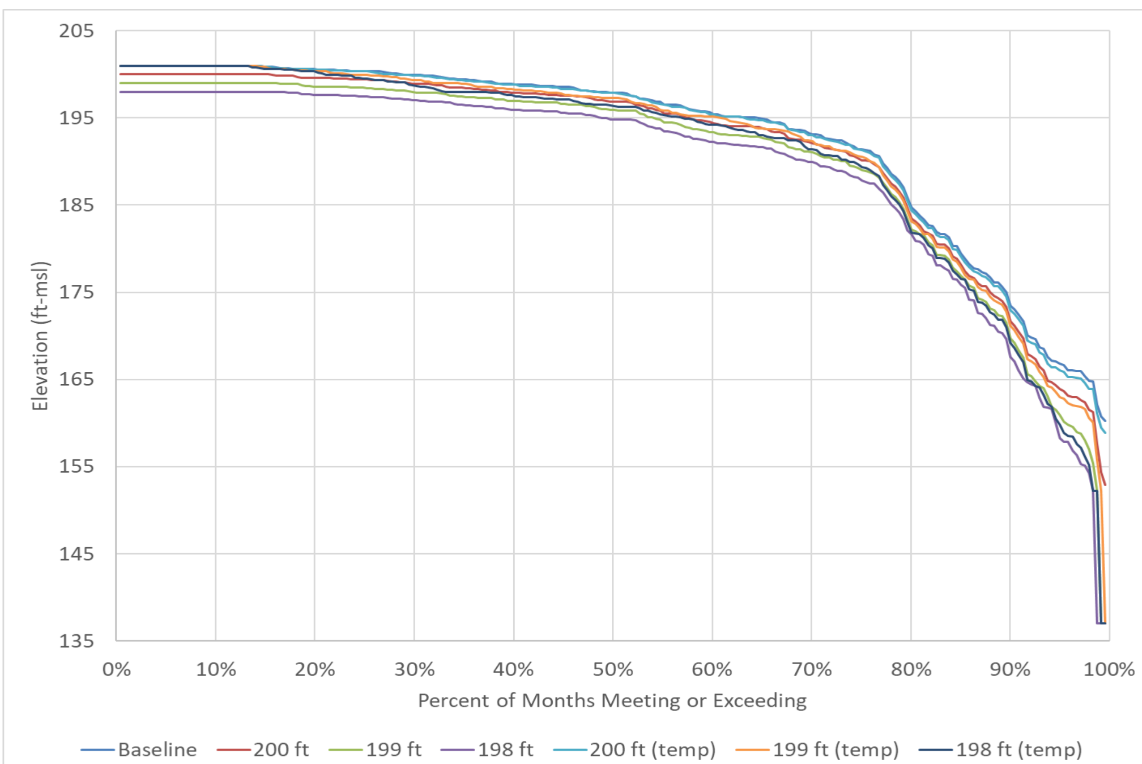

Figure 7: Spreadsheet Model Elevation-Duration Curve (1997-2016 Hydrology)

The following observations were made regarding storage response under full permitted diversion target conditions:

- Comparing Lake Conroe storage results from the spreadsheet model for baseline and permanent conservation pool reduction scenarios to analogous scenarios for the WAM analysis (*Table 2*) demonstrates lower modeled average storage for the spreadsheet model (*Table 6*). Due to the spreadsheet model's close validation with the WAM data (*Figure 1*), this appears to be due to the inclusion of hydrology for years 1997 through 2016 in the spreadsheet model. An examination of the information in this section, as well as the storage time series data in *Attachment 1,* indicates that 1997 through 2016 included prolonged occurrence of limited inflow and extended reduction in modeled stored volume.

- As indicated in *Section 4.2*, model hydrology for years 1997 through 2016 is based on a historical period with the senior water right at Lake Houston not exercised at the full permitted diversion amount. Under full WAM Run 3 conditions with all rights attempting full permitted diversions, Lake Conroe would potentially be subject to greater calls for release of inflows with associated impacts to storage during years 1997-2016 than those shown in this analysis.

- The data presented in *Table 6* and *Table 7* and *Figure 4* through *Figure* 7 show impacts to modeled reservoir storage response for all reductions in conservation pool elevation, with larger reductions in storage for larger reductions in conservation elevation. For the period 1940 through 2016, all three scenarios for permanent reduction in conservation elevation resulted in average modeled elevation below the historically-observed minimum of 192.7 ft-msl for Lake Conroe.

- Permanent reductions in conservation elevation resulted in greater reductions to modeled average Lake Conroe storage than for temporary reductions to the same elevation. It should be noted that while a temporary reduction to 200 ft-msl was the closest to the baseline scenario in storage response, it still resulted in some reduction in average storage volume. This change would also make available less than 20,000 ac-ft of extra emptied capacity for a portion of each year. However, reductions in storage were still observed for all three temporary pool reduction scenarios, with greater impacts for greater temporary conservation elevation reductions. Temporary reduction to 198 ft-msl reduced modeled average storage more than permanent reduction to 200 ft-msl.

- Overall patterns of modeled reservoir storage were similar for the scenarios examined, as shown in the storage timeseries data in *Attachment 1*. However, the magnitude of decline relative to the baseline scenario was generally more severe for greater reductions in conservation elevation. As with the summary statistics shown in this section, permanent reductions in conservation elevation generally resulted in greater reductions in stored volume than for scenarios with temporary conservation reductions to the same elevation.

- For portions of the time series with prolonged low inflow, reductions in conservation elevation, except for temporary reduction to 200 ft-msl, typically resulted in more frequent and earlier emptying of reservoir storage. For example, a permanent reduction in conservation elevation to 198 ft-msl resulted in modeled storage emptying five months earlier than the baseline scenario during the drought of the 1950s.

- Recovery from emptying or major prolonged storage declines was generally similar for the baseline and pool reduction scenarios up to the applicable maximum elevation. However, it should also be noted that for both the drought of the 1950s and the more recent prolonged dry period, temporary conservation pool scenarios caused a reduction in storage shortly after recovery. It is possible that given slightly different timing for high flow events at the end of a dry period, temporary pool reduction could slow recovery to full conservation storage.

- The spreadsheet model discussed in this section is intended to act as an analogue to the Run 3 WAM and therefore does not modify operations to reflect drought contingency triggers and responses from SJRA's Drought Contingency Plan for Lake Conroe. However, the results of this section indicate that reduction in the conservation pool elevation would increase the frequency of triggering both voluntary and non-voluntary drought response measures. For example, reduction in conservation elevation to 198 ft-msl causes storage to fall below the threshold for mandatory drought response measures for 231 more months (1.59 times more often) than the baseline scenario, as shown in *Table 6*. It is likely that reduction of conservation pool elevation would necessitate reevaluation of drought triggers.

5.4 FIRM DIVERSION

Target diversions in the spreadsheet model were reduced iteratively to find the firm diversion of Lake Conroe for all seven scenarios to the nearest 100 ac-ft. Results of this analysis are shown in *Table 8* and *Figure 8*.

Table 8. Spreadsheet Model Lake Conroe Firm Diversions

Scenario	Firm Diversion (ac-ft/yr)	Change from Baseline (ac-ft/yr)
Baseline	80,200	0
200’ (temp)	80,200	0
200’	77,900	-2,300
199’ (temp)	78,800	-1,400
199’	75,800	-4,400
198’ (temp)	76,600	-3,600
198’	73,600	-6,600

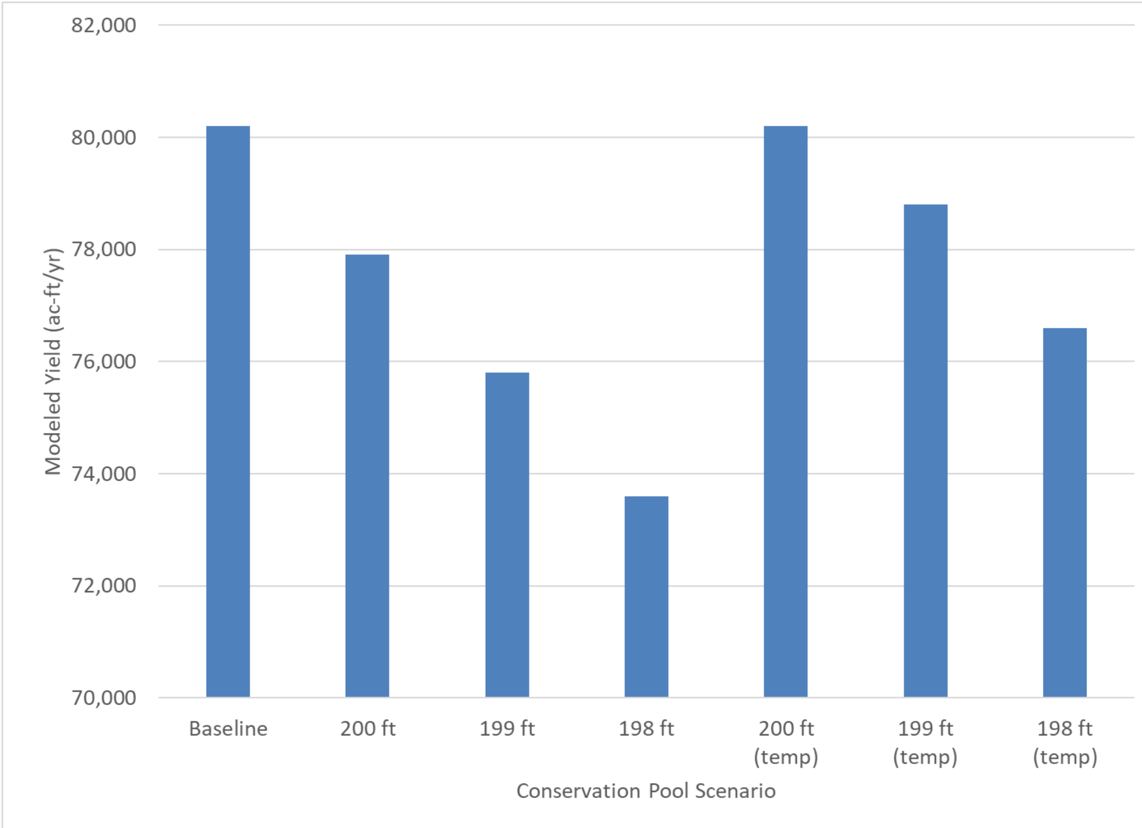

Figure 8: Spreadsheet Model Lake Conroe Firm Diversions

Under baseline conditions, Lake Conroe has a firm diversion of 80,200 ac-ft/yr. Reductions in firm yield vary from 0 ac-ft/yr for temporary reduction of the conservation pool to 200 ft-msl to a maximum of 6,600 ac-ft (8.2 percent of baseline firm diversion) for permanent reduction to 198 ft-msl. Based on these results, modeled firm diversion was not impacted by a temporary conservation pool elevation reduction of 1 ft, but firm diversion was reduced for all other scenarios whether temporary or permanent.

Figure 9 compares yield results from the WAM and spreadsheet models for the baseline scenario and three permanent conservation elevation reduction scenarios. The resultant values are within 100 ac-ft/yr for analogous scenarios.

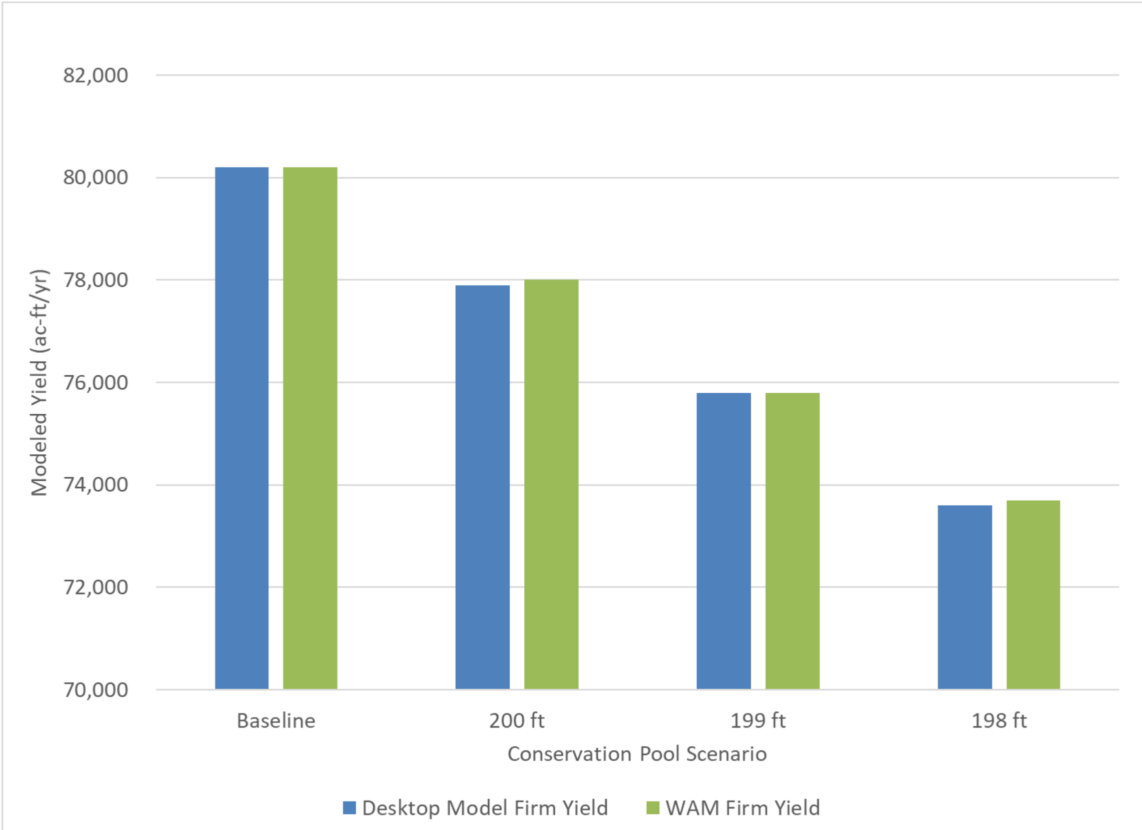

Figure 9: Spreadsheet Model and WAM Lake Conroe Firm Diversions

6. COST

As indicated in the previous sections, reduction of the conservation pool elevation of Lake Conroe reduces the modeled firm diversion available from the reservoir. A preliminary conceptual-level unit cost analysis was performed to estimate the cost of replacing this raw water availability. Costs were based on potential future water management strategies associated with SJRA recommended in the *2016 Regional Water Plan* (RWP) for the Region H Water Planning Area. Analyses considered two strategies to provide additional supply to SJRA service areas: development of brackish groundwater in the Catahoula Aquifer and transfers from Lake Livingston. The SJRA Groundwater Reduction Plan water management strategy was excluded from this analysis, as the strategy as included in the RWP represents expanded utilization of already existing supplies. Other strategies for which applicable cost information was not available were also excluded. Estimated capital costs, which reflect planning, permitting, design, construction, and interest during construction are shown in *Table 9*. Estimated unit costs, which include annualized debt service during a 20-year debt term, annual operational and maintenance costs, and estimated energy costs for pumping are shown in *Table 10*. The purchase cost of water is not included. Information from the 2016 RWP was adjusted to current (year 2018) values using indices as reported in the Engineering News Record Construction Cost Index (CCI) and the U.S. Bureau of Labor Statistics Producer Price Index (PPI). Total costs are based on yields at full completion of both projects.

Table 9. Estimated Capital Cost

Water Management Strategy	Yield (ac-ft/yr)	Capital Cost ($)	Unit Capital Cost ($/ac-ft)
Lake Livingston to SJRA Transfer	50,000	$175,621,804	$3,512.44
SJRA Catahoula Aquifer Supplies	7,840	$12,363,233	$1,576.94
Yield-Weighted Total	57,840	$187,985,037	$3,250.09

Table 10. Estimated Annualized Cost

Water Management Strategy	Yield (ac-ft/yr)	Annual Cost ($/yr)	Unit Annual Cost ($/ac-ft/yr)
Lake Livingston to SJRA Transfer	50,000	$16,375,915	$327.52
SJRA Catahoula Aquifer Supplies	7,840	$1,818,647	$231.97
Yield-Weighted Total	57,840	$18,194,562	$314.57

Spreadsheet model firm diversion reduction results from *Table 8* were multiplied by the above composite unit costs to develop estimated firm yield replacement costs as shown in *Table 11*. It should be noted that the costs shown in the table are conceptual-level estimates; actual project implementation cost would be dependent on project-specific infrastructure, source, yield, and timing.

Table 11. Estimated Yield Replacement Cost

Scenario	Reduction in Firm Div. (ac-ft/yr)	Capital Cost ($)	Annual Cost ($/yr)
Baseline	0	$0	$0
200’ (temp)	0	$0	$0
200’	2,300	$7,475,207	$723,504
199’ (temp)	1,400	$4,550,126	$440,394
199’	4,400	$14,300,396	$1,384,095
198’ (temp)	3,600	$11,700,324	$1,132,442
198’	6,600	$21,450,594	$2,076,143

7. SUMMARY AND CONCLUSIONS

Based on the results of the modeling analyses summarized in *Section 5*, the following key observations were made:

- Lowering of the Lake Conroe conservation elevation did not impact the modeled reliability of non-saline downstream junior water rights CoA 10-5807 and 10-5808.
- The 1997 through 2016 period included an extended period of low inflow which would result in prolonged reduced storage. The spreadsheet model hydrology for years 1997 through 2016 is based on a historical period with the senior water right at Lake Houston not exercised at the full permitted diversion amount. Under full WAM Run 3 conditions with all rights attempting full permitted diversions, Lake Conroe would potentially be subject to greater impacts to storage during years 1997-2016 than those shown in this study due to calls for release of inflows.
- All modeled reductions in the conservation elevation for Lake Conroe reduced average storage and elevation below the value shown in the baseline scenario, and all but temporary reduction to 200 ft-msl resulted in 1,400 to 6,600 ac-ft/yr reduction in firm diversion relative to the baseline. It should be noted that for year 2010 elevation-area-capacity conditions, a temporary pool reduction to 200 ft-msl would make available less than 20,000 ac-ft of extra emptied capacity for two months of the year.
- Permanent reductions in conservation elevation resulted in greater modeled impacts to Lake Conroe than did temporary reductions to the same elevation. For the modeled period from 1940 through 2016, all three scenarios for permanent reduction in conservation elevation resulted in average modeled elevation below the historically-observed minimum of 192.7 ft-msl for Lake Conroe under full permitted diversion conditions.
- It should be noted that any permanent reduction in conservation pool elevation could necessitate reevaluation of drought response triggers related to the reservoir.
- Based on model storage timeseries results, reduction in conservation elevation could result in larger and more prolonged reductions in storage during dry conditions. Further, temporary conservation pool reductions could potentially delay recovery to 201 ft-msl depending on the timing of high flow events following prolonged periods of low inflow.
- It should also be noted that the results shown in this study reflect year 2010 sedimentation conditions, and additional sedimentation with time could increase impacts as storage

reductions would represent a greater percentage of the remaining reservoir volume over time.

- Replacement of firm diversion reduced by a lowering of conservation pool capacity could require the development of major project infrastructure with associated costs dependent on project-specific infrastructure, source, yield, and timing.

Attachment 1

Modeled Lake Conroe Reservoir Storage and Elevation Time Series

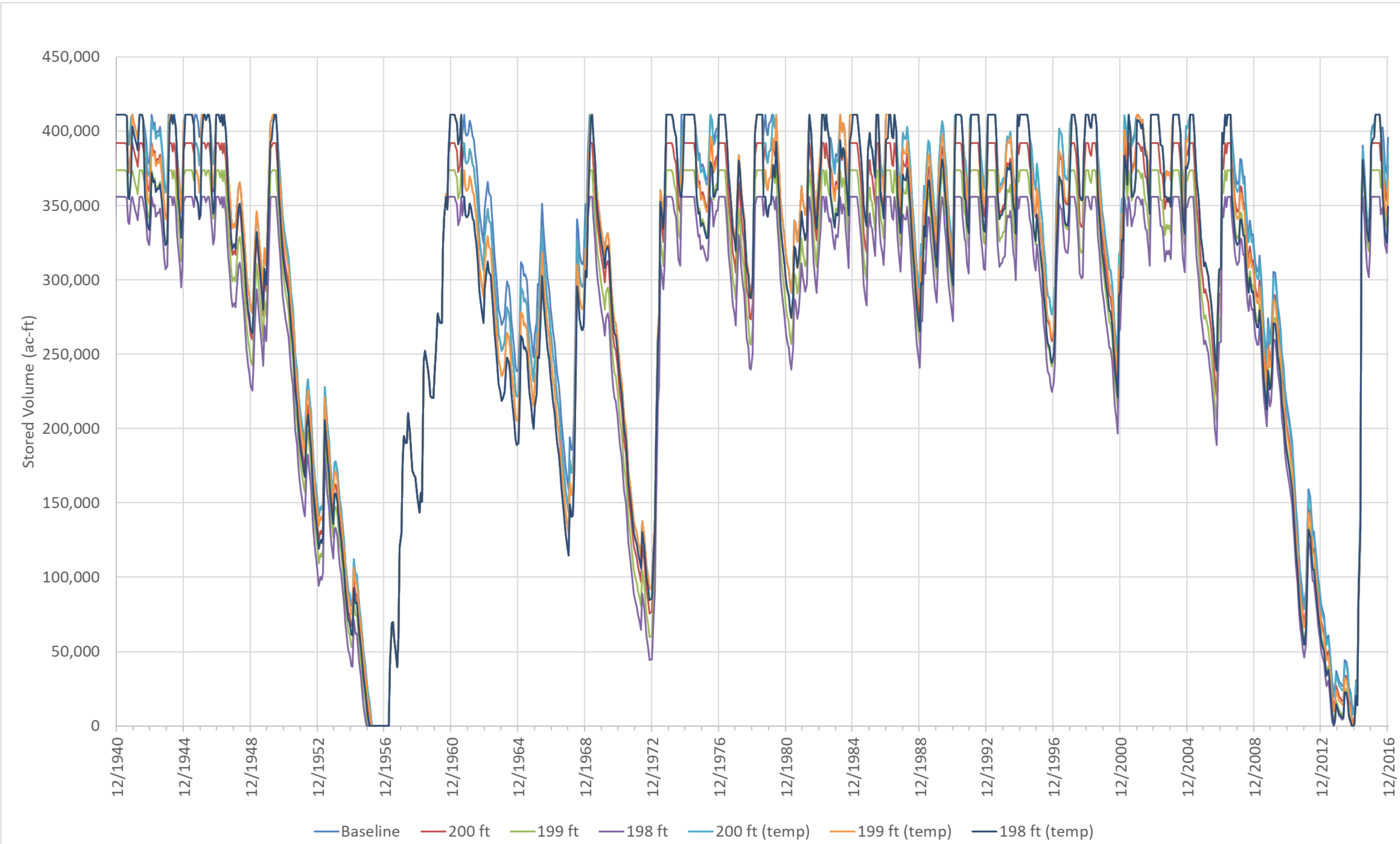

Figure A-1: Modeled 1940 to 2016 Lake Conroe Storage for Hypothetical Conservation Pool Scenarios

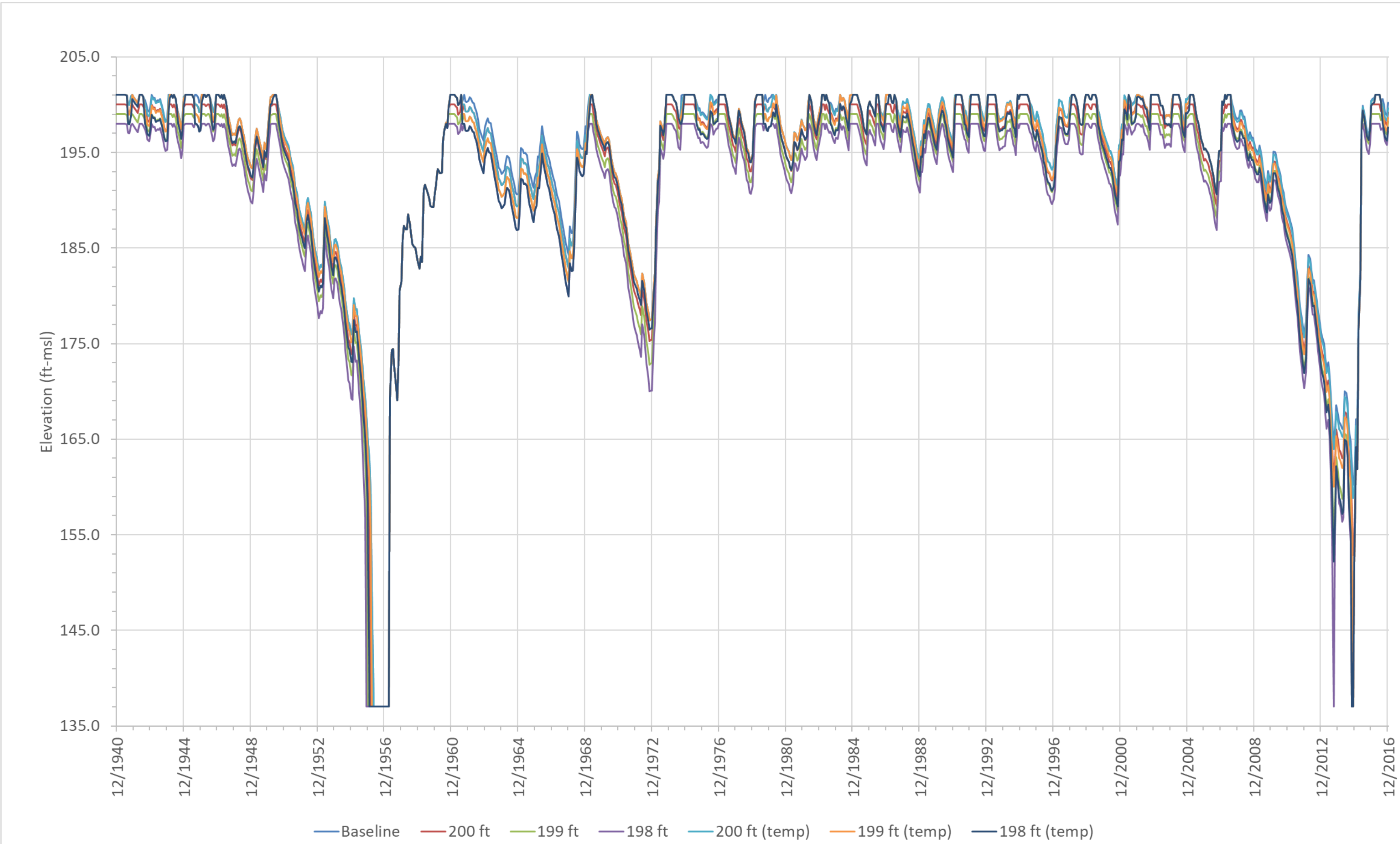

Figure A-2: Modeled 1940 to 2016 Lake Conroe Elevation for Hypothetical Conservation Pool Scenarios

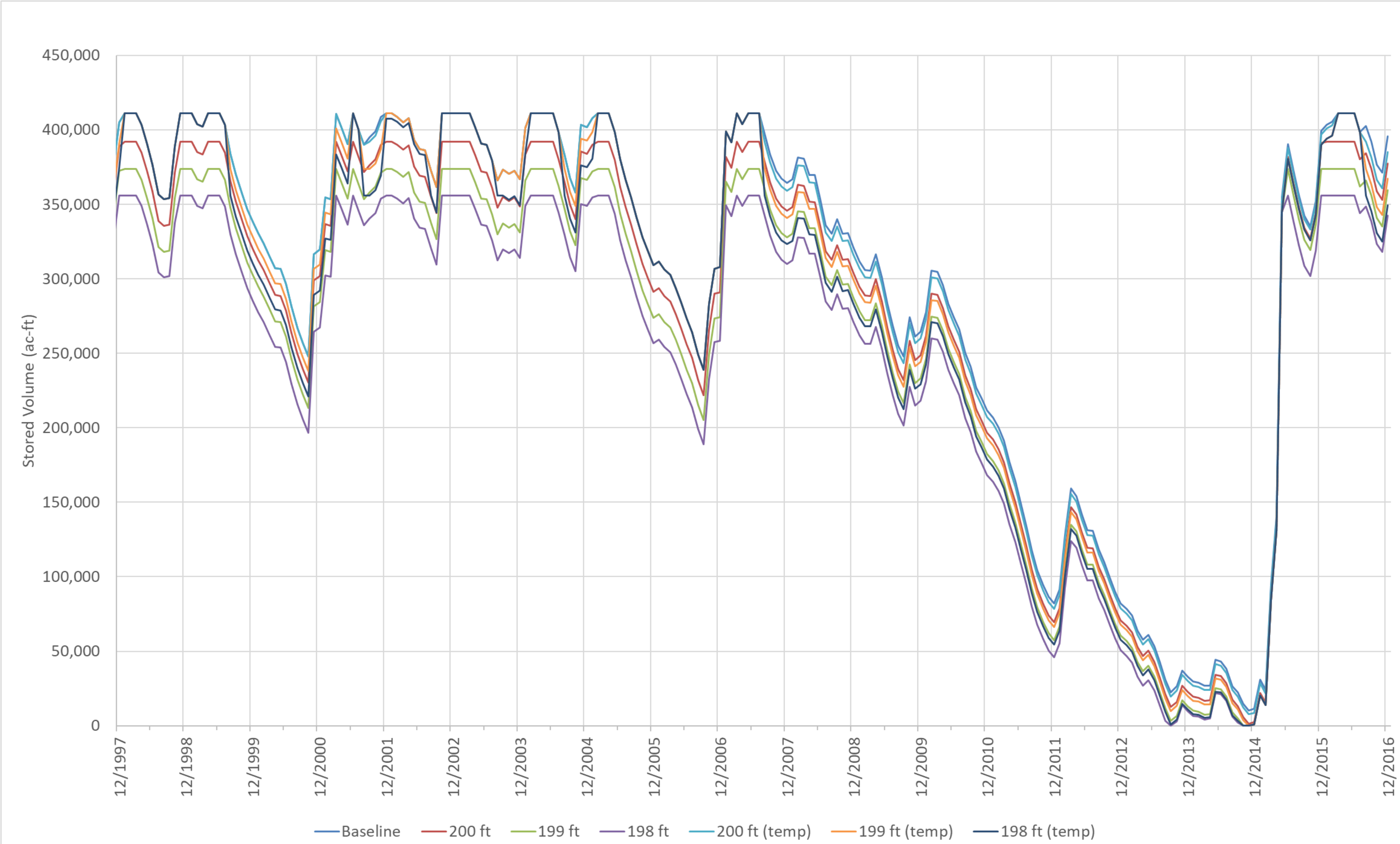

Figure A-3: Modeled 1997 to 2016 Lake Conroe Storage for Hypothetical Conservation Pool Scenarios

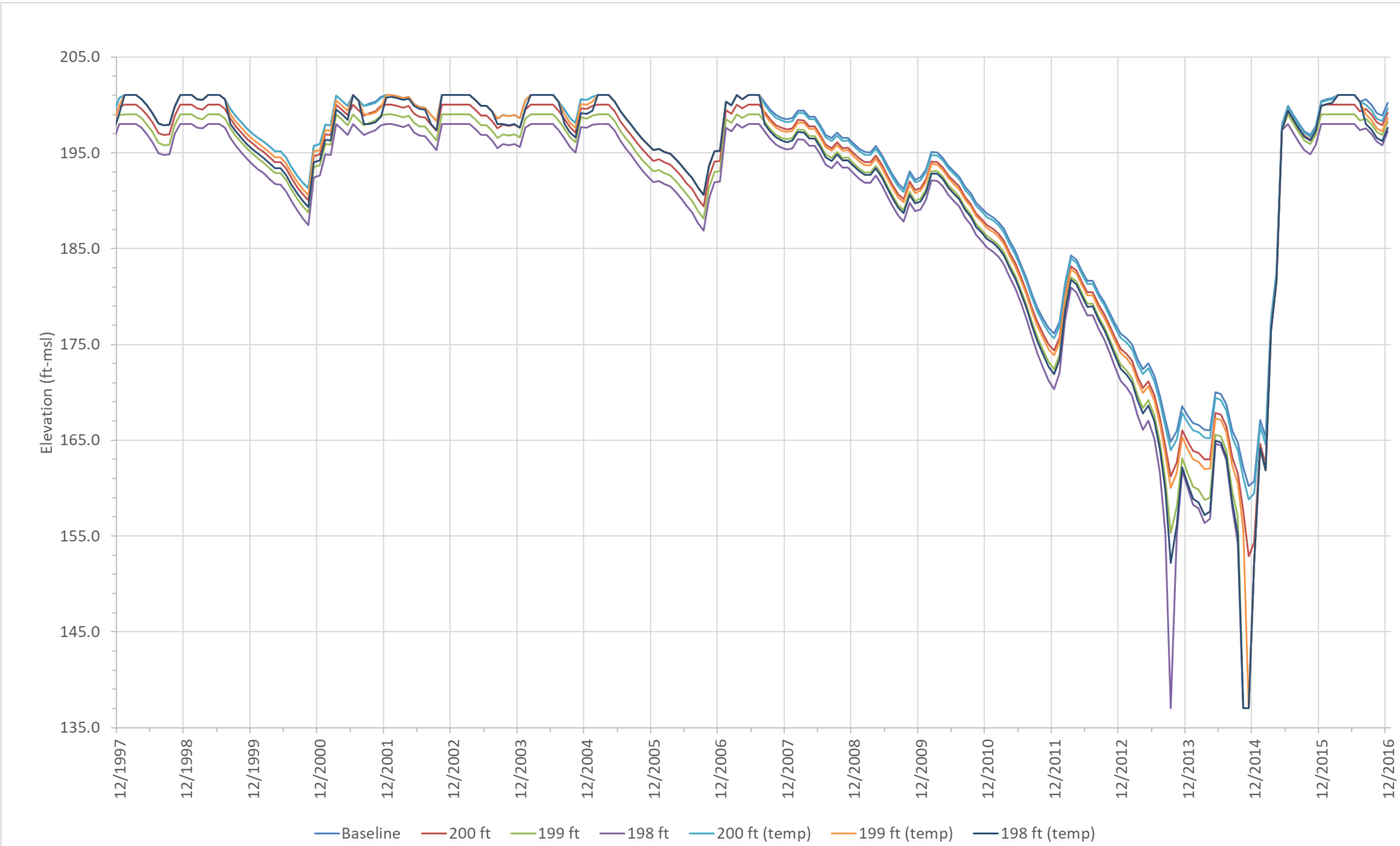

Figure A-4: Modeled 1997 to 2016 Lake Conroe Elevation for Hypothetical Conservation Pool Scenarios

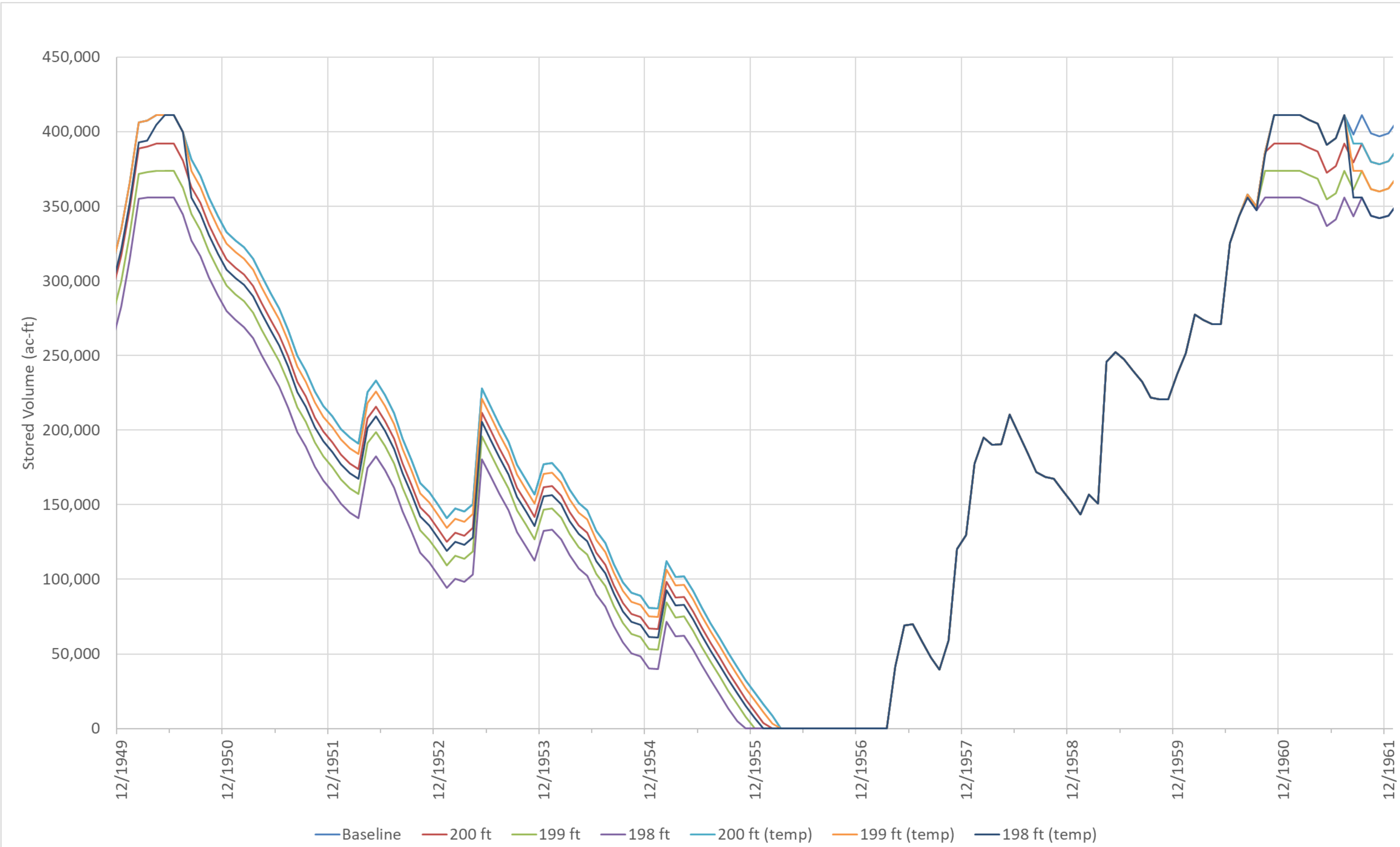

Figure A-5: Modeled Lake Conroe Storage for Hypothetical Conservation Pool Scenarios During 1950s Drought

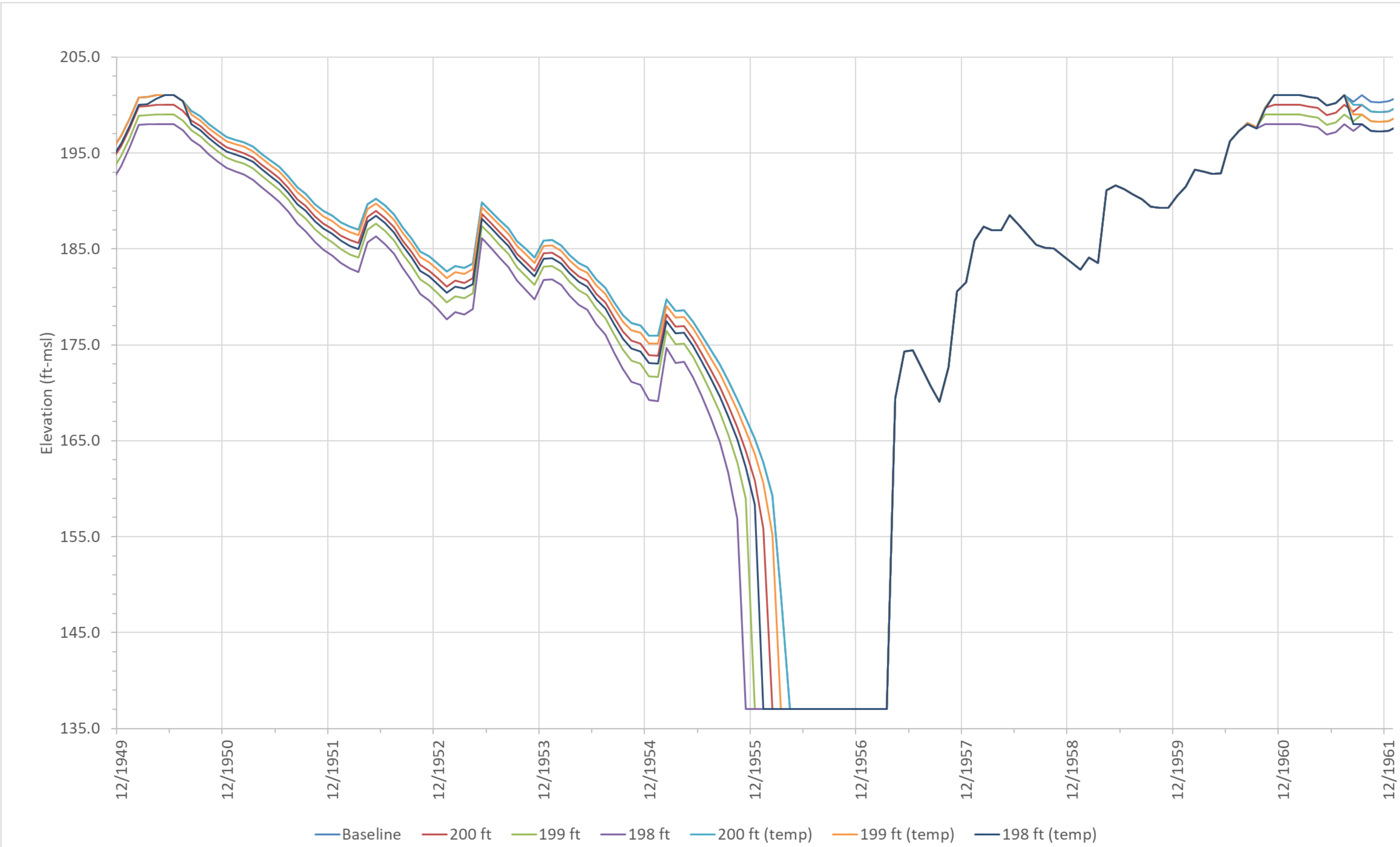

Figure A-6: Modeled Lake Conroe Elevation for Hypothetical Conservation Pool Scenarios During 1950s Drought