Appendix D-1

Williamson County Regional Raw Water System Transmission and Operation Models by CDM

Brazos River Authority

Williamson County Regional Raw Water System Transmission and Operations Models

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Section 1
Project Objectives

The Brazos River Authority (BRA) undertook a computer model development project in order to modernize tools used for short-term and long-term planning and operations of the Williamson County Regional Raw Water (WCRRW) System. Specifically, the modeling tools focus on the expansion and future operations of the pump station at Lake Stillhouse Hollow, which currently includes two pumps, but is expandable to include a total of six pumps for the WCRRW System (four pump spaces are provided for Central Texas WSC). Planning and design for the pump station expansion are in progress, and these tools provided support for the sizing and phasing of new pump installations, as well as a platform for developing and refining operating protocols into the future.

The two primary goals of the model development project were to:

- Support the design and phasing of new pumps at the pumping station on Lake Stillhouse Hollow to divert increasing amounts of water to Lake Georgetown, and

- Provide an accessible platform for the BRA to develop operational guidance (30-day "real-time" plans, or for any planning period from 3 to 60 months), based on cost-effective operations of the existing and expanded pump stations.

The modeling tools include simulation of Lake Georgetown, Lake Stillhouse Hollow, Lake Granger and Lake Belton, and are aimed at clarifying planning and operational decision making by accounting for variable energy cost structures, increasing demand, and uncertain hydrologic patterns. It is important to understand that there is no single cost-effective optimal solution amidst these multiple uncertainties, but rather, opportunities to make informed decisions that account for risk and uncertainty in a quantitative and defensible way. These tools offer user-friendly interfaces and capitalize on advanced computing techniques to provide this quantitative guidance in understandable formats. Ultimately, the models can be used to hone the phasing and operations of the enhanced pumping station to improve its cost-effectiveness and reliability.

More specifically, the following list of questions was formulated by CDM and the BRA as an outline for the functionality of the models, with the understanding that the models would be capable of specifically addressing these questions, at a minimum:

- How can / should the new pumps be phased, and at what capacities?

- What are the "triggers" for the transfer of water to Lake Georgetown that minimize energy costs and spills but maintain an adequate supply of water in Lake

Georgetown to meet customer demands?What are "bracketing" pumping scenarios (best case and worst case, for example) looking forward for a period of time up to five years, accounting for uncertain hydrology and increasing demand?

- How can the BRA operate cost-effectively within a given contract structure for energy pricing (flat rate and MCPE, with user-defined rates that can vary)?

- How can pumping schedules for the current month be optimized for cost-effectiveness?

It was determined that a single model would be inadequate for addressing all of these questions, as some warrant a simulation approach ("what if we tried this…?") while others require more prescriptive guidance ("what is the best way to…?"). Therefore, two separate tools were developed:

- A Planning Simulation Model evaluates "what-if" scenarios and addresses reservoir operations, pump operating (electrical) cost, uncertain hydrology, and future increases in demand.

- An Operations Optimization Model that formulates least-cost operating plans based on specific hydrologic forecasts for 30-day planning periods.

The purpose of this report is to explain the formulation and functionality of these two models in PART 1, and to provide instructions for their use in PART 2. PART 1 also includes preliminary results that provided some insight on the dynamics of the system and were used to assess aspects of the proposed Phase 2 pumps.

Section 2
The WCRRW System

The modeled components that make up the WCRRW System include reservoirs, raw water transfers, and customer water demands. The reservoirs include Lake Georgetown, Lake Stillhouse Hollow, Lake Belton, and Lake Granger. Raw water can be transferred from Lake Stillhouse Hollow to Lake Georgetown by way of the Stillhouse Hollow Pump Station (Stillhouse PS) and the WCRRW Pipeline. The model also includes the potential for transfers from Lake Belton to Lake Stillhouse Hollow in the future. Information on existing and future customer water demands was compiled for all customers that have supply contracts in the four reservoirs. The following information on these three components was used in the development of the models.

2.1 Reservoirs

A schematic of how the four modeled reservoirs are connected is shown in **Figure 2-1**. This includes existing and potential transfers to and from reservoirs and inflow and outflow connections. All the lakes are part of the Little River System with Lake Belton, Lake Stillhouse Hollow, and Lake Granger discharging ultimately to the Little River. Releases from Lake Georgetown flow to Lake Granger.

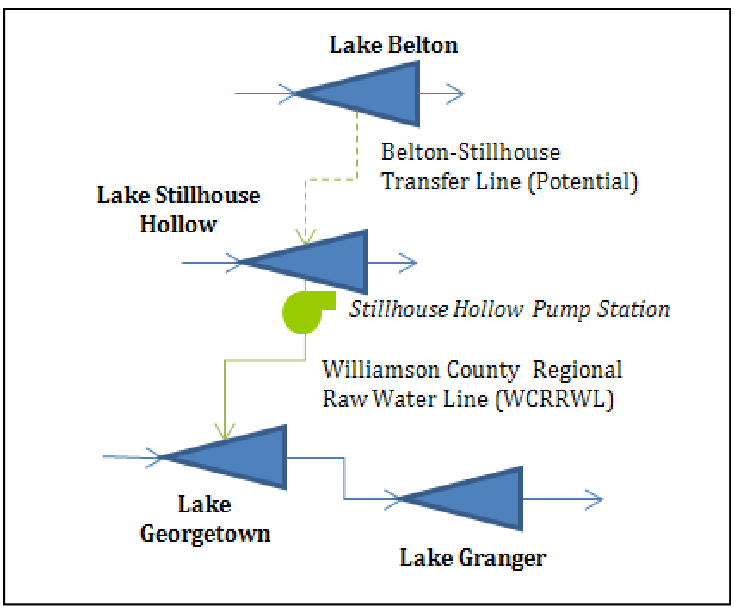

Figure 2-1. Schematic of Reservoir System

The capacity of each reservoir is dependent upon on their bathymetry, represented in the models with Elevation-Area-Capacity (EAC) tables and the defined water surface elevations that represent the top and bottom of the available water in the conservation pools. The EAC tables were developed from the most recent hydrographic surveys for each reservoir and are accessible in the Planning Simulation Model through the

RESERVOIRS worksheet. Elevations for each reservoir range from the bottom of the lake to the highest surveyed point available; therefore, it is necessary to establish significant elevations that represent what the BRA considers to be the available capacity of each reservoir, also known as the conservation pool. Graphs showing all the significant elevations and where they cross the capacity curves are shown in **Figures 2-2** through **2-5**. Additional characteristics including drainage area, surface area at the top of conservation, and capacity at the top of conservation are shown in **Table 2-1**.

Table 2-1. Reservoir Characteristics

Reservoir	Drainage area (sq mi)	Surface area at top of conservation (acres)	Capacity at top of conservation (acft)
Lake Georgetown	247	1,287	36,904
Lake Stillhouse Hollow	1,313	6,484	227,825
Lake Belton	3,570	12,135	435,225
Lake Granger	730	4,064	52,525

2.2 Stillhouse Pump Station and WCRRW Pipeline

The Stillhouse PS pumps raw water by way of the WCRRW Pipeline from Lake Stillhouse Hollow to Lake Georgetown. The Stillhouse PS and WCRRW Pipeline were initially put into service in early 2006. Currently, the Stillhouse PS has a total pumping capacity of 30,106 ac-ft/yr, which is achieved using two vertical turbine pumps. The pump station has four additional positions available for the BRA to install future raw water pumps. The WCRRW Pipeline is 149,000 feet (28.2 miles) in length and 48 inches in diameter. As part of the design work for expanding the pump station, the pipeline was studied to determine the overall friction factor of the line. The C value is the friction factor used in the Hazen-Williams formula to determine headloss in the pipeline at a given flow. Based on studies completed during the development of the models, the design C value is 140. Please refer to **Appendix A** for details on this study. The C value could change over time; therefore, the models were designed to allow for user-defined C values. Based on a C value of 140 the maximum capacity of the WCRRW Pipeline is 64,240 ac-ft/yr or about 40,000 gallons per minute (gpm).

The maximum volume planned for transfer from Lake Stillhouse Hollow to Lake Georgetown via the WCRRW Pipeline each year is 61,121 acft. This limit represents existing contracts of the customers that own the Pipeline. The owners of the Stillhouse PS and WCRRW Pipeline are the water customers that currently have water contracts in Lake Stillhouse Hollow and other reservoirs and rely on the system to pump that contracted water to Lake Georgetown for diversion. These customers include City of Georgetown, City of Round Rock, Chisholm Trail Special Utility District (SUD), and Brushy Creek Municipal Utility District (MUD). While Jonah SUD currently owns a small amount of supply in this system, they may choose not to use this supply because they have obtained supplies from the East Williamson County Water System.

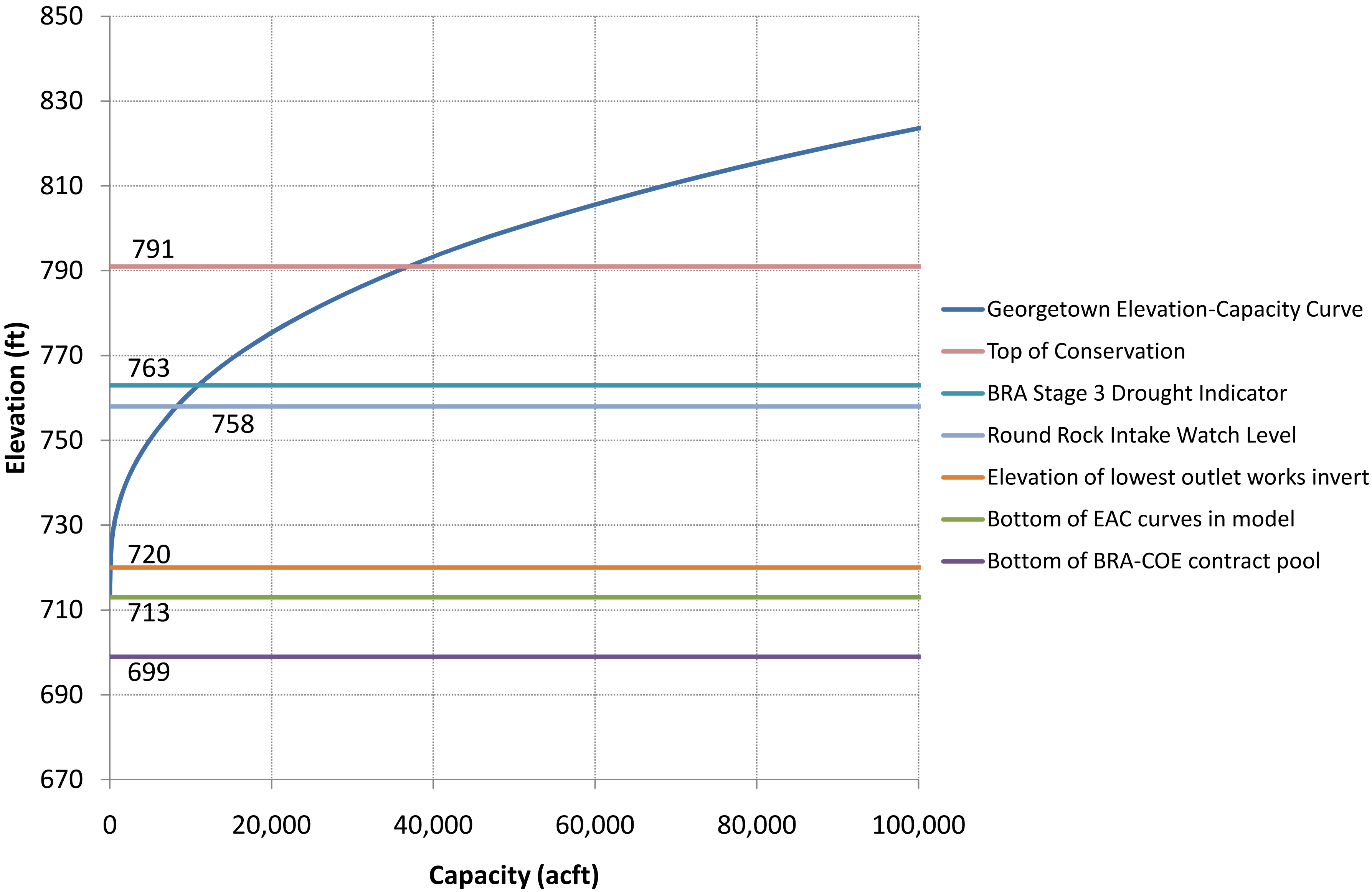

Figure 2-2 Lake Gerogetown Elevation-Capacity Curve and Significant Reservoir Elevations

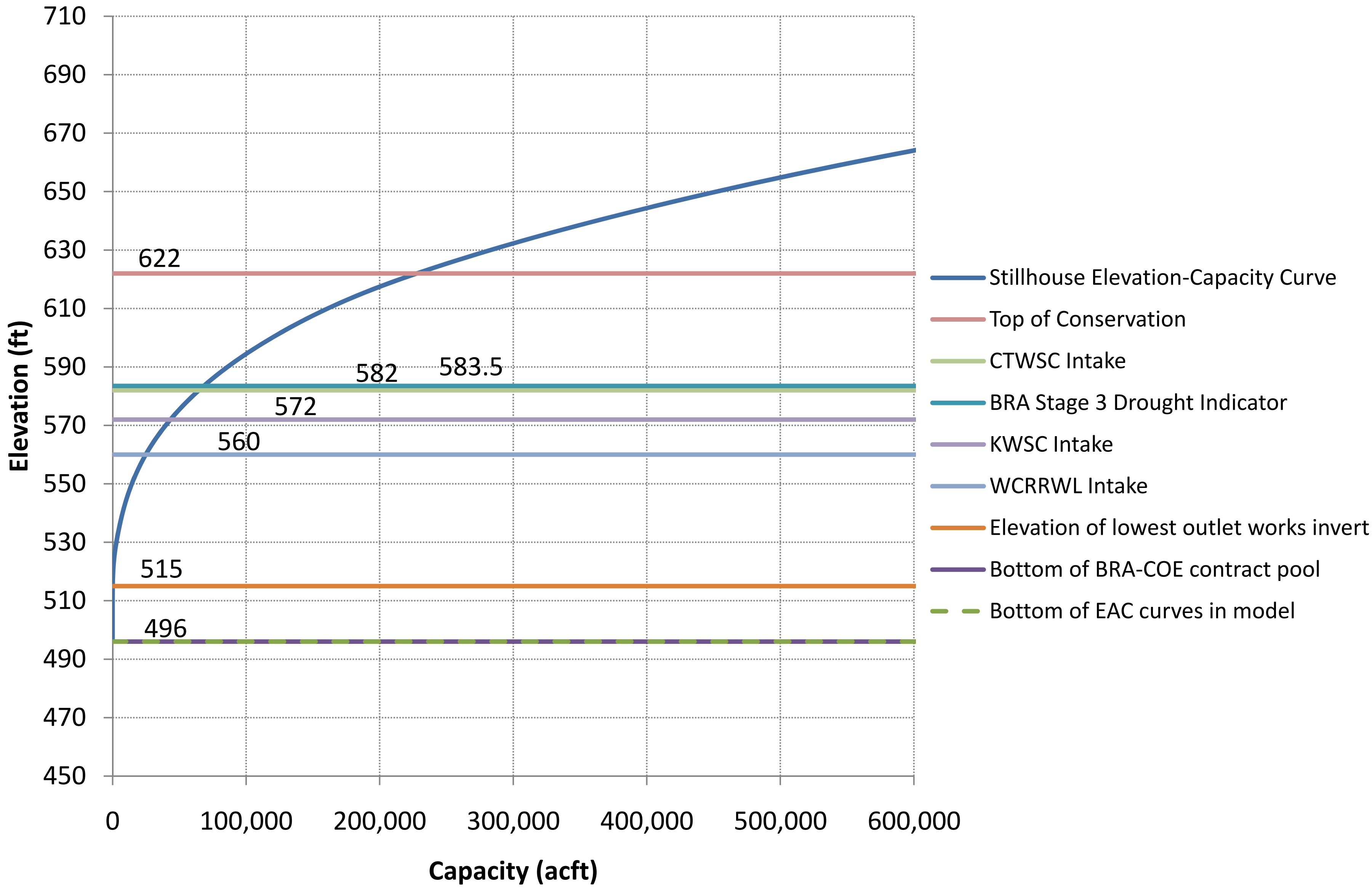

Figure 2-3 Lake Stillhouse Hollow Elevation-Capacity Curve and Significant Reservoir Elevations

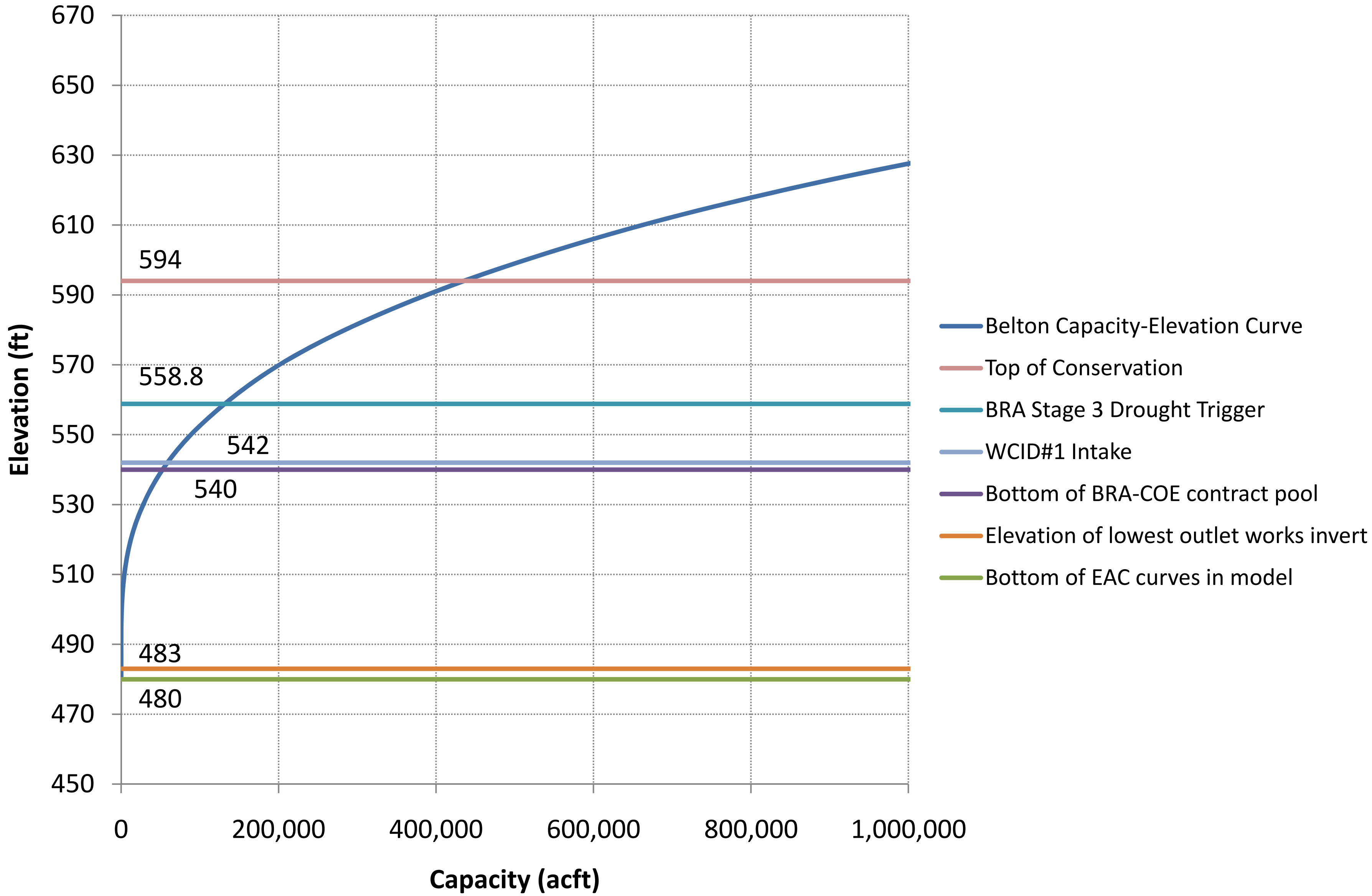

Figure 2-4 Lake Belton Elevation-Capacity Curve and Significant Reservoir Elevations

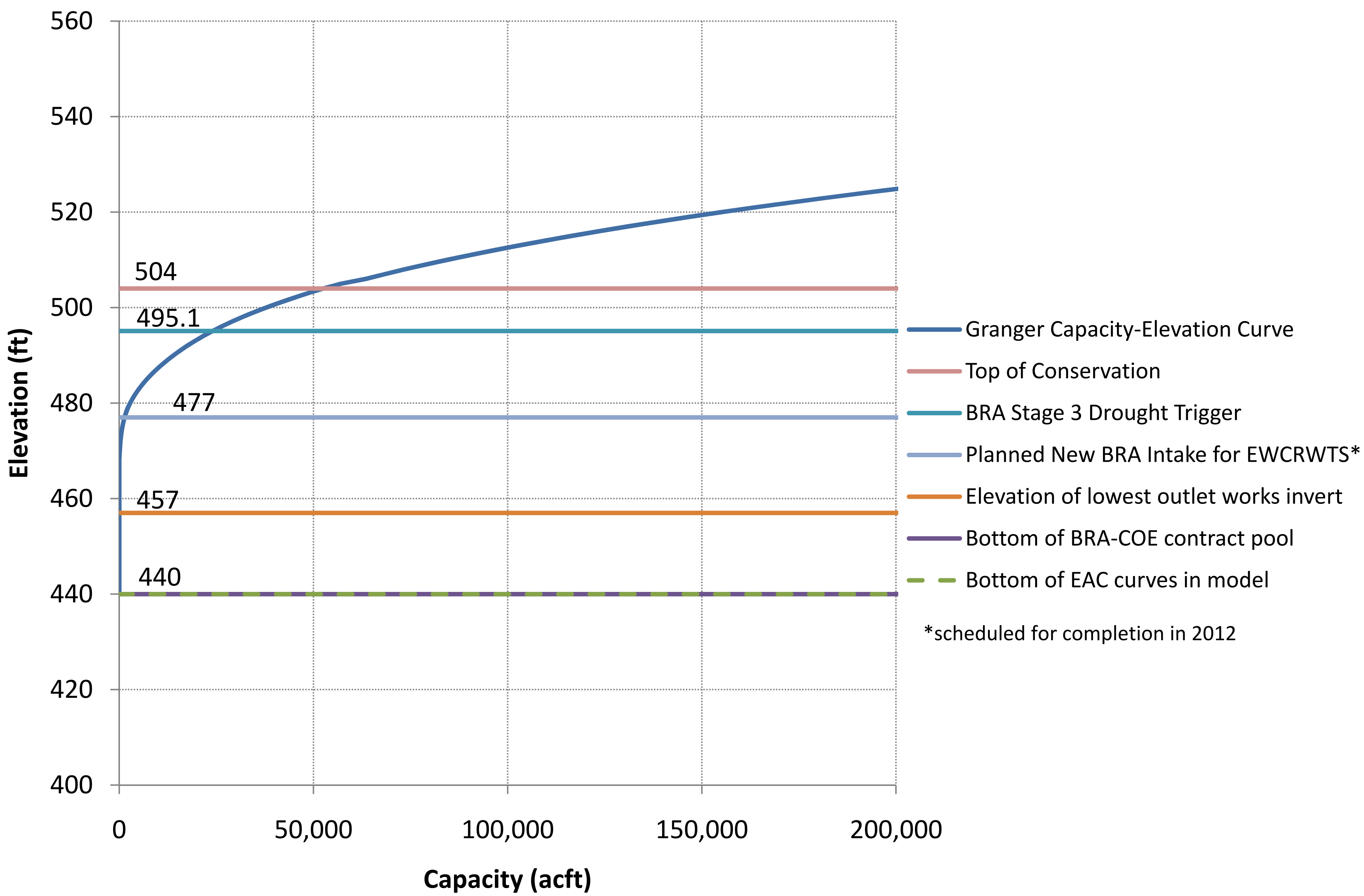

Figure 2-5 Lake Granger Elevation-Capacity Curve and Significant Reservoir Elevations

2.3 Customer Water Demands

Current and projected water demands for customers on all four reservoirs were taken into consideration when developing the models. Sources of average day demand information include the Texas Water Development Board (TWDB) Region G Reports and water master plans developed for some of the municipalities. The customers that rely on the Stillhouse PS and WCRRW Pipeline were consulted directly to ensure that water demand projections were as realistic as possible for modeling demand on the pump station and pipeline. Monthly demand factors are used to take into account seasonal fluctuations in water use.

Average daily water demands projected for each customer are provided in the Planning Simulation Model in 10-year increments, and the model will interpolate linearly for any demand year selected. **Table 2-2** summarizes the average day demands developed for each customer from 2000 to 2060. Most of the supply contracts for these customers apply to the reservoir from which each customer diverts water directly. The customers that divert water from Lake Georgetown (WCRRW Pipeline customers) have supply contracts in Lake Georgetown and/or Lake Stillhouse Hollow. They may also have a supply referred to as System Water. System Water refers to existing contracts in which the water is committed against the entire BRA water supply system but has a Lake Stillhouse Hollow diversion point. The Lake Stillhouse Hollow and System Water contract supplies must be transferred via the WCRRW Pipeline to Lake Georgetown. The supply contract amounts for the WCRRW Pipeline customers are shown in **Table 2-3**.

Monthly demand factors adjust the average daily demands to account for fluctuations in water use by month. The monthly demand factors initially supplied in the Planning Simulation Model for each customer are based on recent records provided by the BRA on water use for the Lake Georgetown customers. It was assumed that the other customers in the system would have similar demand factors. These factors can be changed in the model as additional information is collected.

Table 2-2. Water Demands by Customer

Water Customer	Source (Diversion Location)	Demand by year (ac-ft/yr)						
		2000	2010	2020	2030	2040	2050	2060
Brushy Creek MUD[1]	George-town	1,902	3,000	4,000	4,000	4,000	4,000	4,000
City of Georgetown[1]	George-town	1,087	7,556	12,459	16,668	19,418	24,237	28,805
City of Round Rock[1]	George-town	8,724	20,202	24,854	24,854	24,854	24,854	24,854
Chisholm Trail SUD[1]	George-town	0	935	6,820	11,100	11,100	11,100	11,100
Central Texas WSC[2]	Stillhouse	8,200	10,321	11,021	11,771	12,121	12,471	12,921
City of Harker Heights	Stillhouse	300	300	300	300	300	300	300
City of Lampasas	Stillhouse	1,224	1,594	1,640	1,662	1,673	1,683	1,669
Country Harvest	Stillhouse	8	8	8	8	8	8	8

Table 2-2. Water Demands by Customer (Continued)

High Gabriel WSC	Stillhouse	310	310	310	310	310	310	310
Jarrell-Schwertner WSC	Stillhouse	470	754	1,061	1,414	1,781	2,171	2,583
Jerry Glaze	Stillhouse	100	100	100	100	100	100	100
Bell County WCID#1 South	Stillhouse	0	0	3,560	7,120	10,000	10,000	10,000
Bell County WCID#1	Belton	27,036	36,203	38,736	43,090	46,065	52,050	57,383
Bluebonnet WSC	Belton	8,301	8,301	8,301	8,301	8,301	8,301	8,301
City of Gatesville	Belton	2,777	3,497	4,330	5,141	5,715	6,217	6,621
City of McGregor	Belton	913	919	926	932	937	941	947
City of Temple	Belton	19,357	21,312	23,577	25,985	27,953	27,953	27,953
Coryell City WSD	Belton	300	300	300	300	300	300	300
Fort Gates WSC	Belton	291	332	379	425	457	485	508
The Grove WSC	Belton	400	400	400	400	400	400	400
Wildflower Country Club, Inc.	Belton	200	200	200	200	200	200	200
City of Taylor	Granger	2,281	2,609	2,999	3,462	3,966	4,514	5,102
Jonah SUD	Granger	238	814	1,433	2,082	2,788	3,527	4,345

1. WCRWWL Customers
2. Includes Kempner WSC, Dog Ridge WSC, and Salado WSC

Table 2-3. Water Supply Contracts for the WCRRW System Customers

Customers that Divert Water from Lake Georgetown	**Supply Contracts by Source (ac-ft/yr)**			**Total Supply to be Transferred using the WCRRW Pipeline**
	Lake Georgetown	**Lake Stillhouse Hollow**	**System Water**	
Brushy Creek MUD	0	4,000	0	4,000
City of Georgetown	6,720	15,448	10,000	25,448
City of Round Rock	6,720	18,134	0	18,134
Chisholm Trail SUD	0	3,760	7,340	11,100
Jonah[1]	0	2,439	0	2,439
			SUM =	61,121

[1] *Jonah was not included in the modeling because they may not use their supply.*

Section 3
Model Overview and Potential Uses

As stated in Section 1, it was determined that a single model would be inadequate for addressing all of the questions framing the need for modernized tools. Some of the questions warrant a simulation approach ("what if we tried this…?") while others require more prescriptive guidance ("what is the best way to…?"). Therefore, two separate tools were developed, a Planning Simulation Model and an Operations Optimization Model.

3.1 Planning Simulation Model

The Planning Simulation Model tests the effectiveness of various operating practices such as pump triggers and reservoir levels, and also evaluates the impacts of various energy cost structures on total operating costs. This tool can be used to evaluate planning periods which can vary from 3 to 60 months, or evaluate long-term system performance over the entire period of hydrologic record (1941-2007). Primary output includes supply reliability, pump utilization, operating costs, and timeseries plots of reservoir storage and water levels. Analysis can address uncertainty in hydrologic conditions, as well as increasing demand over time within any given scenario.

3.1.1 Brief Description of Planning Simulation Model

The Planning Simulation Model is a Microsoft Excel spreadsheet with a user interface developed in Visual Basic for Applications (VBA). The model was developed in order to be compatible with both Excel 2003 and Excel 2007. Due to inconsistencies in the two versions of Excel, some formatting may not display correctly in Excel 2007, but functionally the model is compatible. The interface allows users to define scenarios through definition of the following:

- Type of planning period:
  - Continuous simulation for any period between 1941-2007
  - Any planning period lasting between 3 and 60 months
  - Type of output (discrete or probabilistic)
  - Projected demands, and how much demands will (or will not) increase (or decrease) during the scenario
- System configuration:
  - Available pump configurations
  - Pump and pipeline hydraulic and operational characteristics

- Water level triggers for pumping
- Dam leakage

- Energy cost structure and rates:
  - Structure: Fixed rate, MCPE rates, or Day/Night variable rates
  - Rates: Default (recent historical rates from 2006 – 2008) or user-defined rates.
- Reservoir Bathymetry
- Hydrology (historical traces or cumulative percentiles)
- User-defined pump operations (optional): Instead of letting the model compute the least-cost pump configurations for each month in a scenario, the user may specify a specific schedule of pump configurations by month and test the impacts on costs, supply reliability, and water levels.

The model simulates the specified scenario and reports water levels, pumping costs, pump utilization, etc. Users can view discrete results for a specific hydrologic scenario or probabilistic results that are based on all historical sequences.

3.1.2 Potential Uses of Planning Simulation Model

The Planning Simulation Model was developed specifically to address a subset of the fundamental questions formulated by the BRA (See Section 1). The following examples illustrate ways in which the model can be used to address each of the relevant questions.

- *How can / should the new pumps be phased, and at what capacities?*

  The model has been used to help determine a phasing strategy. Alternative pump curves were analyzed over the period of record using the Long-Term mode and made available in different years (at demand levels corresponding with projections ramping up annually through 2030). Model results yielded reliability and cost estimates through this planning period and allowed CDM and the BRA to develop a cost-effective phasing plan for the pump station expansion plans.

- *What are the "triggers" for the transfer of water to Lake Georgetown that minimize energy costs and spills but maintain an adequate supply of water in Lake Georgetown to meet customer demands?*

  There are numerous ways to evaluate the effectiveness of ON/OFF triggers for the pump station. The Long-Term mode is equipped specifically with a **Trigger Analysis** function. The model will run the long-term analysis for each physically plausible combination of ON/OFF triggers at Lake Georgetown, in increments of 10% of available storage. For example, the model will first evaluate trigger settings of ON below 10% of conservation storage / OFF above 10% of conservation storage, then ON below 10% / OFF above 20%...up to ON below 90% / OFF above 90%. Output for each combination of ON/OFF triggers includes average annual operating cost, average annual deficits, and average annual spills. With this information, the BRA can identify the combination of triggers that is most likely to fully satisfy demand at the lowest cost. Other modes may also be used to experiment with specific trigger settings, and the Batch mode can be particularly useful for examining the probability of low water levels in the coming years based on current conditions and specified triggers. **Section 7.1** presents a preliminary analysis of trigger levels for pump operations.

- *What are "bracketing" pumping scenarios from a point in time looking forward for a period of time up to five years (accounting for uncertain hydrology and increasing demand)?*

  The Mid-Term and Batch modes are ideal for this analysis. Alternative trigger settings can be applied in either mode to help reduce the risks of low drawdown and understand the associated operating costs. In the Mid-Term mode, hydrologic percentiles can be selected as planning benchmarks, both high and low percentiles can help bracket the range of hydrologic input and corresponding operating plans and costs. In the Batch mode, trigger levels that result in unacceptable drawdown risks can be ruled out.

- *How can the BRA operate cost-effectively within a given contract structure for energy pricing (flat rate and MCPE, with user-defined rates that can vary)?*

  Section 7.2 provides an example of how the Batch mode can be used to address this question. It identifies upper limits on fixed energy cost rates and day/night rates for these rate structures to be preferable to an MCPE pricing structure. The model was also used to identify the impacts of different pump scheduling techniques to help reduce energy costs; continuous operations at specific settings until desired monthly volumes were achieved, and intermittent operations that distribute total monthly pumping hours into the least-cost hours of the days.

3.2 Operations Optimization Model

The Operations Optimization Model determines least-cost pump schedules for a 30-day planning period for specific hydrologic inflow forecasts to Lake Stillhouse Hollow and Lake Georgetown. It is aimed at helping identify which pump configurations should be planned for operations during the upcoming month, and for how long they should be used.

3.2.1 Brief Description of Operations Optimization Model

The Operations Optimization Model was developed in Microsoft Excel with an add-on program for optimization called the Premium Solver Platform, developed by Frontline Systems, Inc. The model contains water balance accounting for the reservoirs and pump station, 30-day hydrologic forecasts for reservoir inflows, hydraulic calculations for pump and pipeline capacities, cost accounting, and an optimization algorithm to identify least-cost operating plans for 30-day periods.

For any 30-day planning period, users enter the following information:

- Choice of objective:
  - Minimize Costs (energy costs, utility costs, or both)
  - Minimize water delivery shortfalls
- Constraints on water deficits (deliveries will normally be constrained to 100% of demand, but for scenarios in which reliability is not feasible, minimum reliability can be identified through optimization, and the resulting reliability can be required while minimizing cost)
- 30-day hydrologic forecasts from the Advanced Hydrologic Prediction Service (AHPS: simulated statistical estimates of daily river flows into Lake Stillhouse Hollow and Lake Georgetown, provided by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS))
- Current energy costs averaged into 6-hour time-blocks
- Pump information:
  - Number of available pumps
  - Required downtime
  - Updates to hydraulic characteristics of pumps or pipeline
- Expected demands for upcoming 30 days
- Initial conditions for reservoir water levels
- Minimum allowable water levels in Lake Stillhouse Hollow and Lake Georgetown
- Target for ending water levels in Lake Stillhouse Hollow and Lake Georgetown

The model then finds the optimal schedule for pumping that either minimizes cost or delivery shortfalls while satisfying constraints on pump station operability, reservoir water levels, etc. The constraints are built into the model, but can reflect user input for any given scenario (such as limits on drawdown). Results are presented in the form of a schedule in 6-hour increments through the 30-days in which the optimal pump configuration (if any) for each time block is specified. Results are also presented for alternative operating schedules, which match the total monthly volume of water that is transferred but with the pumps operating continuously until the volume is achieved rather than at the lowest-cost times of day, for example.

Costs, reservoir traces, and deliveries are all presented as output. Though the nature of the output is inherently prescriptive, the results are intended to be used as guidance only. Because of inherent uncertainty in even short-term hydrologic forecasts, the results of this module should not be construed as daily imperatives, but rather, as guidance for planning cost-effective pumping schedules for the upcoming 30 days.

3.2.2 Potential Uses of Operations Optimization Model

The model is intended for use on 30-day periodic basis by the BRA, whenever it is likely that pumping may be required or beneficial during the coming month. Again, because of inherent uncertainty in the hydrologic forecasts, the results of this module should be used as a guidance tool for planning cost-effective pumping schedules.

The interpretation of results is dependent on two things:

- The percentiles of the statistical streamflow forecasts (the BRA can apply conservative low percentiles, medians, or other percentiles in accordance with preferences or planning protocols). The BRA may also choose to "bracket" the hydrologic forecasts by using both low and high percentiles from the AHPS forecast envelope. In this way, expected 30-day costs could be effectively bounded, and their sensitivity to hydrologic expectations can be clearly documented.

- The degree to which daily operational adjustments might reduce costs. Optimal cost results may specify frequent adjusting of pump station settings on a 6-hour basis, which may or may not be practical or desirable. The program also presents the expected costs associated with an alternative operating schedule, which utilizes the same pump configurations to transfer the same volume of water, but assumes continuous running of each for the total required duration within the month, without regard to time of day and associated variability in energy costs. The model also displays costs for using each available pump configuration alone, operated for the number of continuous days required to provide the necessary water volume to Lake Georgetown. These comparative costs provide guidance on how sensitive the expected costs are likely to be to alternative operating strategies for the pump station.

Section 4
Modeling Approach

This section describes the modeling methodology for the Planning Simulation Model (3 – 60 month scenarios) in **Section 4.1**, and for the Operations Optimization Model (30-day scenarios) in **Section 4.2**.

4.1 Planning Simulation Model

This section describes the modeling approach for the WCRRW System Planning Simulation Model. This model was used to support pump station design and can also be used for future operations planning for periods of 3 months to 60 months.

4.1.1 Model Approach

The Planning Simulation Model was developed in Microsoft Excel with modules written in Visual Basic for Applications (VBA), as needed. An intuitive graphical user interface (GUI) was designed to facilitate model use by planners and engineers alike. The model retains the functionality of the existing Williamson County Water Supply Pipeline Model, but includes a number of extensions and enhancements, including:

- Variable simulation period and duration;
- Different modes for simulating various hydrologic conditions (dry, wet, normal, and probabilistic hydrology) based on the available period of record (1941 – 2007);
- Variable customer demand (both annually and monthly variable, including annual ramping rates);
- Alternative pump capacities and configurations at the pump station on Lake Stillhouse Hollow;
- Alternative electric price structures, including a fixed price structure and a system based on market clearing price for energy (MCPE);
- Potential downstream minimum flow requirements for each reservoir;
- Conceptual transfer of water from Lake Belton to Lake Stillhouse Hollow, which does not include simulation of Lake Belton pumping or associated pumping costs;
- Demands on Lake Granger; and
- Reporting of probabilistic outcomes, including demand shortages, reservoir spills, and lake levels.

4.1.2 Model Modes

The Planning Simulation Model was developed to analyze system performance over multiple planning period durations and with opportunities for both discrete and probabilistic output. Three modes are available for various types of analysis. All three modes evaluate system operations on a monthly timestep.

- **Long-Term Simulation** (1941 – 2007 continuous simulation)
  The long-term simulation mode evaluates system performance over the period of record using user-defined fixed demand levels (historical or projected) and system configurations. Results are presented as both time series and frequency distributions of annual system performance metrics such as reservoir drawdown, pumped volumes, costs, etc. The purpose of this mode is to evaluate the adequacy of pump station configurations, operational plans, and lake level triggers for pumping over the full range of potential hydrologic conditions.

- **Mid-Term Simulation** (3 – 60 months, user defined)
  This mode is intended for near-term and mid-term operations and contract planning under specific expected hydrologic conditions. When a future forecast can be made with some confidence (for example, current trends suggest that the next year may be expected to be relatively dry or relatively wet) the user can run a single, short-term simulation of 1 – 5 years based on pre-defined representative dry, normal, and wet conditions based on historical record (or any percentile of cumulative historical hydrologic flows). This can be particularly useful for examining system performance over the most severe historical droughts defined for different durations (e.g. the worst 6-month drought, the worst 12-month drought, the worst 18-month drought, etc.).

- **Batch Runs** (1 – 5 years)
  When future hydrology is uncertain, the analysis can be run in batch mode (also known as position analysis). The difference between batch mode and long-term simulation is that batch mode preserves the impact of initial conditions on near-term operations, but still accounts for the full historical hydrologic record in a probabilistic framework. The model will run each historical period of the user-defined duration, always re-initializing to specified initial conditions. For example, if the user defines a simulation period of 2 years, then every 2-year period of the historical hydrologic record would be run separately (1941-1942, 1942-1943, etc), starting each scenario with the specified initial conditions. Results such as lake levels, pump usage, costs, etc. are then tabulated statistically, and can be interpreted (for example) as "*Given current lake levels and pump station capacities, we are likely to spend X dollars over the next year to meet demand, and there is a Y% probability that lake levels would drop below desired levels.*" In other words, this mode helps in evaluating the stability or level of risk of the current conditions, and puts bounds on best case and worst case scenarios.

4.1.3 Scenario Input and Output

For each scenario, the user must specify the following simulation options through the model interface.

Initial Conditions

- Lake levels

Hydrologic Conditions

- Depends on the selected mode (see above). The model contains monthly hydrologic records from 1941 through 2007, and analysis can focus on selected years, percentiles of flow, or the entire record depending on the selected mode.

Customer Demand

- Annual customer demands with monthly factors for Lake Stillhouse Hollow, Lake Georgetown, Lake Belton, Lake Granger, and any other demands downstream of these reservoirs. The annual demand levels can increase or decrease each calendar year for multi-year scenarios based on user-defined rates.

Lake Stillhouse Hollow Pump Station

- Two existing, 1,200 horsepower, vertical turbine pumps at Lake Stillhouse Hollow Pump Station

- Addition of up to four pumps with individual user-defined hydraulic characteristics such as pump curves, efficiencies, etc.

Operational Plans

- Lake level pumping triggers (variable by month, if desirable). These are used to govern the simulated operations of the pumps, and include water level thresholds both for initiating pumping and terminating pumping. Because operations with up to six pumps and multiple pump combinations are more complex than operating the existing two pumps only, the model does not consider separate triggers for each individual pump (as currently used for just the existing two pumps). Rather, the model uses the triggers to define the need for pumping (a "yes" or "no" question each month) and then finds the lowest-cost configuration for that month given the needed amount of water. Alternatively, the user can prescribe a specific sequence of pump operations that do not respond to specific lake level triggers as a way to experiment with alternative schedules.

- Customer intake elevations (minimum reservoir elevations below which additional withdrawals are not possible).

Energy Charge Structures

- Fixed rate is a constant energy charge for the simulation period, defined by the user.
- Day/Night is a variable energy charge including a rate for daytime use and a rate for nighttime use. Although the model calculates operational flows on a monthly timestep, energy needs and operating costs are post-processed to account for hourly variability in costs.
- Market Clearing Price for Energy (MCPE) is a variable energy charge based on historical hourly values or user-defined hourly costs.

Transfer from Lake Belton

- The user can specify a fixed-rate conceptual transfer from Lake Belton to Lake Stillhouse Hollow. Hydraulics and pumping costs are not computed for this transfer of water.

Once a scenario is defined, the Planning Simulation Model performs a simple mass balance of water in each reservoir on a monthly timestep based on the following inputs and outputs:

- Precipitation
- Evaporation
- River Inflows
- Reservoir Releases and Spills
- Customer Demand Withdrawals
- Water Transfers via the WCRRW Pipeline or the potential Lake Belton-Lake Stillhouse Hollow pipeline

Model output is presented using summary statistics, timeseries graphs, and frequency distributions (where applicable). In the long-term mode and batch mode, distributions of lake levels, WCRRW Pipeline transfer flows and costs, demand shortages, and reservoir spills are included in the form of frequency-exceedence curves to help ascertain operational risk levels and probable costs. Timeseries plots of these variables are also generated for each simulation.

4.1.4 Operating Logic

The WCRRW Pipeline transfer from Stillhouse Hollow Lake to Georgetown Lake is governed by lake level triggers and energy cost considerations. The amount of flow is calculated using hydraulic pumping equations as a function of head difference between the lakes, head loss through the transfer pipe, number of pumps operational to meet the need, and pump curves.

Lake level pumping triggers are used to govern the simulated operations of the pumps, and include water level thresholds both for initiating pumping and terminating pumping. Because operations with up to six pumps and multiple pump combinations are more complex than operating the existing two pumps only, the model does not consider separate triggers for each individual pump (as currently used for just the existing two pumps). Rather, the model uses the triggers to define the need for pumping (a "yes" or "no" question each month) and then finds the lowest-cost configuration for that month given the needed amount of water. Alternatively, the user can prescribe a specific sequence of pump operations that do not respond to specific lake level triggers as a way to experiment with alternative schedules.

4.2 Operations Optimization Model

This section describes the modeling approach for the WCRRW System Operations Optimization Model. This model can be used to plan for 30-day pump scheduling based on predicted streamflows, user demands, and current reservoir conditions. This model generates output in the form of pump schedules aimed at meeting demand and reservoir targets at minimum energy cost and with minimal spillage.

4.2.1 Model Approach

The Operations Optimization Model was developed in Microsoft Excel with navigation and pre-processing modules written in Visual Basic for Applications (VBA), as needed. The worksheets simulate a daily water balance in each reservoir, accounting for initial storage, hydrologic inflows, net evaporation, pumping, withdrawals, and spills.

The spreadsheet model was coupled with the Premium Solver Platform (SOLVER) developed by Frontline Systems, Inc. The SOLVER includes algorithms for optimizing specified objectives by adjusting decision variables within defined constraints. For any 30-day planning scenario, the system is optimized around a set of 30-day streamflow forecasts associated with the two principal reservoirs (Lake Georgetown and Lake Stillhouse Hollow).

The model is formulated to solve a problem that can most easily be described through its constituent parts:

- A mathematical **objective**, which is to be minimized. In this case, the user chooses the objective, which can be either the minimization of water deficits at all delivery points for the 30-day forecast period, or the minimization of energy and/or utility charges for the forecast period. Either of these objectives can also be coupled with the minimization of spills.

- A set of **decision variables** which represent actual operational and planning decisions and are allowed to vary during the solution process. In this case, there are three types of decision variables:

- Number of hours that each pump configuration is used during each 6-hour time-block over the 30-day forecast period
- Water deliveries at each of four lumped demand locations (Lake Stillhouse Hollow, Lake Georgetown, and downstream of both of these reservoirs).
- Spills from Lake Stillhouse Hollow and Lake Georgetown.

■ A set of **constraints** that limit the values of the decision variables (referred to as "bounds") and mathematical functions of decision variables (referred to as "constraints", e.g. resultant storage) and create a multi-dimensional "decision space." In this case, constraints include:

- Maximum number of hours that each individual configuration can be used in a 6-hour time block (6 if configuration is active, 0 if not).
- Maximum number of hours that any combination of pump configurations can be used in a 6-hour time block
- Total number of hours in the month that pumping can take place (percentage of the 30 days that pumps are available, as a function of user input)
- Minimum and maximum allowable storage in Lake Stillhouse Hollow and Lake Georgetown at any time during the month
- Minimum end-of-period storage in Lake Stillhouse Hollow and Lake Georgetown
- Maximum delivery at each demand node cannot exceed the demand (avoids model oversupplying one node where water is available to compensate for deficit elsewhere where water is not available, and balancing out to an artificial net effect of no deficit).
- Minimum demand levels to satisfy, if specified by the user (normally expected to be 100%, but flexible if desired).

Because of inherent uncertainty in even short-term climate and hydrologic forecasts, the results of this module should not be construed as imperatives, but rather, as guidance for planning cost-effective pumping schedules for the upcoming 30 days.

4.2.2 Scenario Input and Output

The Operations Optimization Model was formulated on the premise that it would be used by the BRA once per month to help guide pumping plans for current and expected conditions. The model runs a 30-day period, beginning with current conditions. Each day is divided into four 6-hour periods to reflect diurnal variations in energy prices. Scenarios are formulated around user-defined inputs, including a 30-day hydrologic forecast, current demand expectations for the coming month, initial reservoir conditions, and current energy prices. Output is designed to suggest cost-effective pumping schedules aimed at meeting demand reliably, satisfying storage targets, and minimizing pumping costs.

4.2.2.1 Inputs

Users input the following information to formulate a 30-day scenario:

- ***Hydrology forecast:*** Two 30-day forecasts of reservoir inflows from the Advanced Hydrologic Prediction Service (NOAA/NWS). One forecast is for the Lampasas River at Lake Stillhouse Hollow and the other is for the San Gabriel River at Lake Georgetown. Forecasts are developed based on historical precipitation statistics, current antecedent conditions, and simulation modeling. Net evaporation forecasts are based on historical daily average values corresponding with the 30 days in the planning scenario.

- ***Demand:*** Monthly demand expectations for each user are entered. It is assumed that any daily or hourly variability is attenuated by the storage in the system, and not necessarily managed by the pump station.

- ***Number of pumps that are available for use:*** This allows the model to reflect whatever current physical infrastructure is available, and also allows users to simulate pumps being taken offline for maintenance. Input is converted into pump configurations that are practical when the pump and system curves are overlapped (a pre-processing exercise in the model based on default or adjusted pump curves, user-specified friction factor, etc.) This input is coupled with a factor that specifies a minimum amount of time during the 30-day period that the pump station is inoperable (for maintenance, start-up, shut-down, etc.)

- ***Current energy prices –*** For the purposes of short-term optimization, energy prices are discretized into four 6-hour periods per day, and applied to total flow through the pump station at a constant unit rate for each of the 6-hour periods. This allows the BRA to simulate flat rate scenarios, in which all four 6-hour rates are identical, and MCPE scenarios, in which the 6-hour unit rates differ. This is a simplification of MCPE pricing, but in its intended utility as a forecasting tool in which the 15-minute variability of energy costs cannot be confidently predicted, the "6-hour average" approach should represent an appropriate balance between too much uncertain data and not enough data to distinguish between alternative times of day for pumping.

- ***Initial conditions –*** Reservoir elevations for Lake Stillhouse Hollow and Lake Georgetown at the start of the 30-day period are entered.

- ***Reservoir ending targets –*** Without specifying ending targets (or acceptable thresholds) for the two reservoirs, the model could theoretically draw them down as far as possible before triggering pump operations (and incurring cost). Therefore, users are allowed to enter a target ending elevation for each of the two reservoirs, and the model will formulate operations such that the targets are achieved if physically possible. This also provides a helpful platform for testing alternative targets and examining their impact on potential pumping costs. Additionally, minimum allowable lake levels throughout the entire 30-day period can be entered as constraints.

- ***Weights for objective function*** – The objective function is divided into component parts, and frequently includes subsets of the following constituents:
  - Energy Charge
  - Utility Charge
  - Spills
  - Deficits

Users can emphasize or de-emphasize constituents of the objective function. ***However, because some of the subsets involve values with different units, care must be exercised to ensure that results are not misinterpreted. It is recommended that when experimenting with weights, trials are made with weight values that vary over many orders of magnitude.***

4.2.2.2 Outputs

The Operations Optimization Model provides three principal types of output:

- Pump Schedule: First, the model provides an optimal schedule of pump usage in 6-hour increments for the 30-day period. Again, this output is not to be construed as a mandated schedule, since it is based on a hydrologic forecast with uncertain timing and magnitude of events. Rather, it can be interpreted as follows (for example): "It makes economic sense to plan to utilize 1 pump full time, and two pumps for 6 hours per day between 12:00 AM and 6:00 AM."

- Cost and Flow Statistics: Accompanying this type of pump schedule forecast are the expected energy and utility charges that make up the total energy cost, a summary of the total water conveyed in the scenario, and a summary of deliveries vs. demands. Cost results are presented several different ways, recognizing that frequent 6-hour adjustments at the pump station may not be practical. Costs are presented for the optimal schedule, and for schedules adjusted to pump the same amount of water using the same pump configurations but with fewer changeovers (pumps running continuously for specified durations).

- Reservoir Dynamics: The output also includes the projected 30-day traces of reservoir water levels, along with any specified end-of-period targets.

4.2.3 Model Formulation

The Operations Optimization Model also consists of two principle analytical modules: the physical representation of the system and water movement and the optimization SOLVER. The physical representation of the system is a tabulated set of calculations in the spreadsheet that tracks flows and storage in each element in response to changes in hydrology and operational decision variables (pump station settings, spills, and deliveries, as described below). The SOLVER is an algorithm that varies the flow management decisions (within defined constraints) until a given objective is mathematically minimized (see above listing of objectives, decision variables, and constraints in **Section 4.2.1**).

The spreadsheet passes information on each of the three principal components of the optimization program to and from the SOLVER, which adjusts the decision variables until the objective is minimized.

<u>Optimization Objectives</u>

The model has been formulated to provide the user with a choice of primary objectives: either cost minimization or deficit minimization. It is suggested that deficit minimization be used only to determine whether or not demand can be fully satisfied prior to minimizing costs (if it can, deliveries can be constrained to 100% of demand during the cost optimization, and if not, they can be constrained to the maximum possible deliveries based on minimization of deficits).

Minimization of total energy cost includes terms for energy charge and utility charge (via penalties for higher peak power settings). They can be minimized individually or conjunctively. However, because the power settings are represented as step functions based on discrete pump combinations, the truest mathematical representation of utility charge is nonlinear, and this creates computational complexity and uncertainty that can easily be avoided (see discussion below on Assumptions of Linearity in **Section 4.2.4**). Utility charge minimization is therefore handled with penalty functions, as described below, and hence the units of the two constituents are not consistent (dollars and penalties). It is therefore advisable to solve any given problem all three ways in order to identify the purest optimum:

- Minimize energy charge only
- Minimize utility charge only
- Minimize both charges concurrently

The minimization of spills from Lake Georgetown and Lake Stillhouse Hollow can be added as a secondary objective to either of the primary objectives.

The objective function, therefore, consists of four constituents, but the program automatically excludes the cost terms if the deficit is selected as the primary objective, and vice versa. The user can include or exclude the cost factors or spills as desired. Mathematically, the objective function can be expressed as follows (**Decision variables in bold** – all other values are constants for a given timestep):

Deficits: $$W_1 \sum_{x=1}^{4} \sum_{d=1}^{30} \frac{1}{30} (\text{Demand}_{x,d} - \mathbf{Delivery}_{x,d})$$ *{Average daily deficits}*

Energy Chrg: $$W_2 \sum_{t=1}^{120} \sum_{i=1}^{9} \boldsymbol{n}_{i,t} P_i (C_t + Adder)$$ *{kWh for each configuration multiplied by cost rates}*

Utility Chrg: $$W_3 \sum_{t=1}^{120} \sum_{i=1}^{9} \boldsymbol{n}_{i,t} Pen_i$$ *{hours of operation for each setting multiplied by penalties}*

Spills: $$W_4 \sum_{d=1}^{30} [\, \boldsymbol{Spill(GT)_d} + \boldsymbol{Spill(SH)_d} \,]$$

Where the following are used as indices:

d=daily index (1 – 30)
i= Pump station configuration index (up to 9 available configurations)
t =6-hour index (1 – 120)
x = Demand node index (4: from both reservoirs, and downstream demands)

And the following are variables:

Adder = fixed rate additional cost per kWh ("retail adder")
C = cost per kWh for a given 6-hour time block
n = number of hours station operates at a given configuration
P = Power required to operate a particular pump configuration
Pen = Penalty applied to increasing peak power usage (for each pump configuration that incurs a higher power draw, the penalty increases by a factor of 10^3.
Spill(y) =Downstream spill from Lake Georgetown or Lake Stillhouse Hollow
W = weights to emphasize or de-emphasize the constituents

Caution is advised with the application of priority weights, since the fundamental terms in the objective function are represented in different units (cost, penalties, and flow). Experimentation with the model and various combinations of weights is necessary to understand the influence of the weights on solutions.

Decision Variables

This model includes 1,260 decision variables for each 30-day period, as delineated below:

- (***n***): Number of hours that each pump configuration is used during each 6-hour time-block over the 30-day forecast period. Based on 9 available configurations and 120 6-hour periods, there are 1,080 decision variables in this category. However, the number of decision variables is diminished for scenarios that do not include all 6 pumps in the pump station. The total pumped volumes for all 4 periods within a day are aggregated into a daily value for the water balance calculations.

- (***Delivery***): Water deliveries at each of the four lumped demand locations (Lake Stillhouse Hollow, Lake Georgetown, and downstream of both of these reservoirs). These are daily variables that change only once per day instead of once every 6 hours. There are 120 of these decision variables, accounting for 4 demand nodes over 30 days.

- (***Spills***): Spills from Lake Stillhouse Hollow and Lake Georgetown. If spills are minimized, they will only occur if there is excess water above the conservation pool at the end of a timestep. These are daily variables that change only once per day instead of once every 6 hours. There are 60 of these decision variables, accounting for 2 sets of spill values over 30 days.

System Constraints

Table 4-1 lists the constraints applied by the model on decision variables and associated functions. Note that storage values are used in lieu of water surface levels, since storage is a linear function of decision variables, but water levels are not. Water levels are used for input and output purposes, since this does not impact the SOLVER algorithm, but are converted to storage for computations. See discussion below on Assumptions of Linearity in **Section 4.2.4**.

Table 4-1. Operations Optimization Model Constraints

Constraint	Notation
Maximum number of hours that each individual configuration can be used in a 6-hour time block	$\boldsymbol{n_{i,t}} \leq 6$ {if configuration 'i' is active} $\boldsymbol{n_{i,t}} = 0$ {if configuration 'i' is inactive}
Maximum number of hours that any of the pump configurations can be used in a 6-hour time block	$\sum n_i \leq 6$
Total number of hours in the month that pumping can take place *(percentage of the 30 days that pumps are available, as a function of user input)*	$\sum \boldsymbol{n_{i,t}} \leq$ [(720 hrs) × (% TimeAvail)]
Minimum and maximum allowable storage in Lake Stillhouse Hollow and Lake Georgetown at any time during the month *(lower storage limits are specified by the user, upper storage limits coincide with the top of the conservation pools)*	$STORAGE_{Min} \leq VOL_d \leq STORAGE_{Max}$ *{where VOL_t is the volume of a reservoir at the end of a timestep, calculated as a function of inflows and outflows, including decision variables}*
Minimum end-of-period storage in Lake Stillhouse Hollow and Lake Georgetown *(user specifies ending storage targets, if desired)*	$VOL_{d=30\ days} \geq FINAL\ STORAGE$
Maximum delivery at each demand node cannot exceed the demand (avoids model oversupplying one node where water is available to compensate for deficit elsewhere where water is not available, and balancing out to an artificial net effect of no deficit).	$\boldsymbol{Delivery_{x,d,} \leq Demand_{x,d}}$

Constraint	Notation
Minimum demand levels to satisfy, if specified by the user (normally expected to be 100%, but flexible if desired).	$[\sum \mathbf{\mathit{Delivery}}_d]_x = [\sum \mathbf{\mathit{Demand}}_d]_x$

4.2.4 Assumptions of Linearity

All optimization programs involve search algorithms that methodically compare different combinations of decision variables, screen out ineffective combinations, and work toward identifying the combination that optimizes the value of the objective function. The process of searching depends on the formulation of the problem. The problems can range from simple (several decision variables and dozens of constraints) to complex (hundreds or thousands of decision variables with hundreds or thousands of constraints). The Operations Optimization Model is composed of 1,260 decision variables and 1,768 constraints and bounds, and therefore requires an efficient search algorithm.

Optimization models can be formulated in one of two general ways:

- **Linear Programming (LP):** LP is the most common and effective optimization tool for two reasons – mathematically it is the simplest, and it is the only formulation of an optimization problem that guarantees a mathematically optimal solution (most LP programs use the SIMPLEX algorithm, which is a proven and efficient approach). The disadvantage of LP is that all mathematical expressions of objective functions and constraints must be linear functions of decision variables (variables are added, subtracted, or multiplied/divided by constants). While representing complex systems with linear mathematics is often very realistic, it frequently involves simplifications that must be proven credible, and caution is warranted to ensure that the system and its dynamic interdependencies are not oversimplified or misrepresented. The Operations Optimization Model is formulated with linear relationships that required several simplifications of the system representation (discussed below).

- **Non-linear Programming (NLP):** NLP is applied when linear representation of complex systems is either infeasible or requires oversimplification. In such a formulation, either the objective function or the constraints include mathematical expressions that are more complex than linear combinations of variables or multiplication by constants (such as two or three decision variables multiplied by each other, a decision variable that is raised to an exponent, or constraints that include if-then-else Boolean logic, which is nonlinear due to inherent discontinuities). In such a formulation, the solution algorithms may converge toward an optimal combination of decision variables, but a true optimum solution cannot be guaranteed. This is because there may be numerous 'peaks' and 'valleys' in the decision space, and metaphorically, the search algorithms can become trapped on a peak that may not be the highest. These lower peaks are referred to as 'local optimal solutions,' since they represent solutions that are optimal within a small neighborhood of values of decision variables. The highest peak is referred to as the 'global optimum solution,' since it is truly the best combination of decision variables over the entire decision space. If a search algorithm leads to local optima, it will see that changes in any direction detract from the objective function, and the search will terminate. Genetic Algorithms, or "Evolutionary Algorithms," are used frequently to help avoid this problem, and can solve non-linear optimization problems with a higher probability of identifying values of decision variables that are very close to the true optimal combination. They rely on logic that, by trial and error, identifies productive combinations of variables and continuously reformulates combinations using these productive combinations to 'evolve' toward an optimal solution. Regardless of the algorithm employed, nonlinear problems take much longer to solve (for a model of the BRA's magnitude, solution times could be several hours or longer) and no algorithm exists that can guarantee a true mathematical optima for a nonlinear problem.

The Operations Optimization Model was formulated as a Linear Program, to facilitate fast and efficient convergence to globally optimal solutions. The objective function is a linear combination of separate linear combinations or functions of decision variables, and all constraints are linear functions of the decision variables. The formulation involved several simplifications or abstractions of the mathematical representation of the system, as described below, but none of these were deemed to substantially impair the fundamental dynamics of the simulated system.

<u>Linearity Simplifications:</u>

Energy Charge: To minimize cost, the model computes the energy needed to run each pump configuration for the prescribed durations and schedule, and assigns variable cost rates depending upon the time of day. The energy charge is a nonlinear function of flows and water surface levels, and the time of day could be formulated most easily as an if-then-else function. Both of these would be nonlinear, so to linearize the cost function, the decision variables are the number of hours within each 6-hour time block at which each configuration of pumps would be operated. These time-based variables are then multiplied by pre-calculated energy needs and cost rates for the associated pump configuration and time of day, respectively. This preserves the mathematical integrity of the nonlinear energy calculations, which are calculated before optimization using the full nonlinear equations, and applied in the model as constants which are multiplied by the time of operation and associated cost rate. Effectively, the formulation multiplies the decision variables (number of hours) by two constants (pre-calculated energy need and cost rate), which is a linear representation that preserves the nonlinear integrity of the complex hydraulics.

- **Utility Charge:** Utility charge is computed as a function of the maximum instantaneous power used during a scenario. While Excel can easily compute a maximum or minimum value from a series, this function is inherently nonlinear because it is discontinuous. There are ways of minimizing the maximum value in a series using linear equations, but these involve the addition of new variables and constraints that can be relatively cryptic in comparison to those which actually represent a physical aspect of the system. To keep the formulation as simple as possible, and linear, the total hours at each pump configuration (linear sum of decision variables) is multiplied by "penalties," which are constants that increase with higher power requirements. This technique is only applied when the minimization of power costs is included in the objective function (a user decision). Tests suggest that this is an effective method of minimizing the power costs while retaining the linearity of the model.

- **Cost Averaging:** While energy charge rates can be expected to vary every fifteen minutes, we do not have sufficient foresight to predict when and how the rates will change with that much resolution. Therefore, values are averaged into 6-hour increments, which still provide clear distinctions between times of day that exhibit markedly different unit energy costs, and also provide simple linear multipliers for the hours of operation within each 6-hour time block.

Volume-Elevation Relationships: The relationships between storage volume and water surface elevation in Lake Stillhouse Hollow and Lake Georgetown are inherently nonlinear, as they are in most water reservoirs. While many of the model inputs and outputs are presented in terms of water surface elevation, the model handles all water balance computations as functions of storage volume. Storage volume is a linear function of inflows and outflows, but water surface elevation is a nonlinear function of these terms. Hence, input data in the form of water surface elevation is converted to storage volume prior to optimization, and resulting storage volumes after optimization are again translated into corresponding water surface elevations. This allows linear calculations with no reduction of accuracy or resolution while allowing input and output terms to be displayed in more familiar units.

Section 5
Mathematical Formulations

The Planning Simulation Model and the Operations Optimization Model include similar calculations for several components of each model. These components are described in this section and include the following:

- Mass balance of hydrologic fluxes
- Extended historical hydrology
- Stillhouse Pump Station hydraulic calculations
- Energy cost structure for the Stillhouse Pump Station
- Stillhouse Pump Station operations

The specific applications of these components in each model are described in more detail in Part 2.

5.1 Mass Balance

The reservoirs modeled were simulated as individual storage elements subject to the hydrologic fluxes shown in **Figure 5-1**.

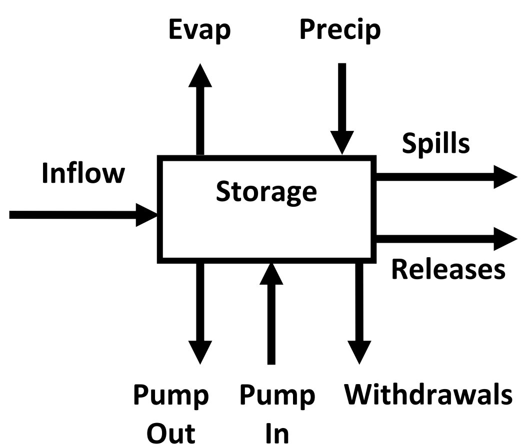

Figure 5-1. Reservoir Mass Balance

The change in storage in each reservoir was simulated as the difference between the inflows and outflows shown in Figure 5-1, which is represented by the equation:

$$S(t+1) = S(t) + \sum Inflows(t) - \sum Outflows(t)$$
$$S(t+1) = S(t) + Inflow(t) + Precip(t) + Pump\ In(t) - Evap(t) - Spills(t) - Releases(t) - Pump\ Out(t) - Withdrawals(t)$$

where $S(t)$ is the reservoir storage at time t.

In the model, evaporation and precipitation are combined into a single flux called net evaporation:

$$Net\ Evaporation(t) = Evaporation(t) - Precipitation(t)$$

If net evaporation > 0 then evaporation exceeds precipitation and there is a net flux of water *out of* the reservoir, and if net evaporation < 0 then precipitation exceeds evaporation and there is a net flux of water *into* the reservoir. The historical time series of net evaporation were calculated in units of depth per time (ft/month). The total volumetric flux over each time step is calculated by multiplying the net evaporation rate by the surface area of the reservoir for that timestep. The source of the hydrologic timeseries is described below in **Section 5.2**.

The withdrawal flux is the minimum of the demand and the available volume for each timestep:

$$Withdrawal(t) = Min\big(Demand(t), Volume_{Avail}(t)\big)$$

where $Demand(t)$ is the total demand on the reservoir at time *t*, and $Volume_{Avail}(t)$ is the volume available for withdrawal after accounting for inflows, net evaporation, pumping inflows/outflows, and releases for time *t*:

$$Volume_{Avail}(t) = S(t) - S_{min} + Inflow(t) + Pump\ In(t) - Net\ Evaporation(t) - Pump\ Out(t) - Releases(t)$$

where S_{min} is the minimum storage volume available for withdrawal.

Spills were calculated by the equation:

$$Spill(t) = \begin{cases} 0 & \mathrm{S}(t_{end}) \leq S_{max} \\ S(t_{end}) - S_{max} & \mathrm{S}(t_{end}) > S_{max} \end{cases}$$

where $\mathrm{S}(t_{end})$ is the storage at end of time *t* after accounting for all other inflows and outflows for time t, and S_{max} is the maximum storage equal to total reservoir volume when the water surface is at the top of the conservation pool. In other words, if there is excess water in the reservoir above the conservation storage at the end of the month, after all other flows are accounted for, it is assumed to spill downstream. These spills are accounted for in the month they occur, which is time *t*.

Releases are specified by the user, and can vary by month.

The amount of water pumped into or out of each reservoir is determined by the operational logic described below in **Section 5.5**. The volume transferred through the WCRRW Pipeline is equal to the volumes pumped out of Lake Stillhouse Hollow and into Lake Georgetown. The transfer over the conceptual Belton-Stillhouse Line equals the volumes pumped out of Lake Belton and into Lake Stillhouse Hollow. There is no pumping flux into or out of Lake Granger.

5.2 Hydrology

The rates of inflow and net evaporation (evaporation-precipitation) for each reservoir were calculated by Freese and Nichols (FNI) for the period 1941-1997 and by Franklin Engineering Associates for the period 1998-2007. Franklin used the same methodology as FNI in order to maintain a consistent time series. **Part 3, the Hydrologic Report,** describes the methodology used to calculate historical inflows and net evaporation and provides a comparison between the FNI and Franklin datasets.

Reservoir characteristics including drainage area, surface area at top of conservation and capacity at top of conservation are shown in **Table 5-1** to convey the relative size of each reservoir. The distributions of annual inflow and net evaporation for the four reservoirs are shown in **Figures 5-2** and **5-3**. The median monthly inflow and net evaporation for the four reservoirs are shown in **Figures 5-4** and **5-5**.

Table 5-1. Reservoir Characteristics

Reservoir	Drainage Area (sq mi)	Surface Area at Top of Conservation (acres)	Capacity at Top of Conservation (acft)
Lake Belton	3,570	12,135	435,225
Lake Stillhouse Hollow	1,313	6,484	227,825
Lake Georgetown	247	1,287	36,904
Lake Granger	730	4,064	52,525

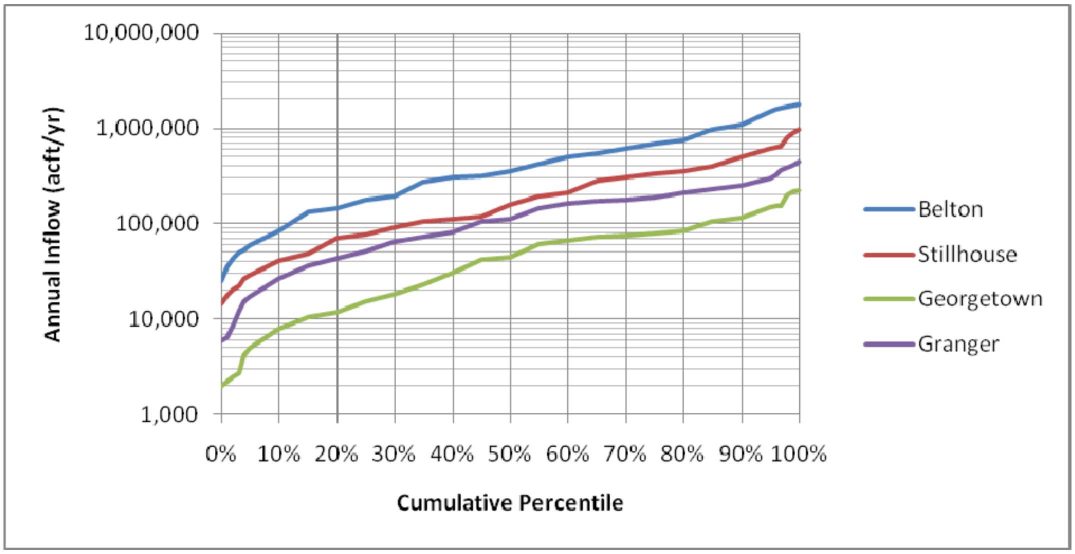

Figure 5-2. Cumulative Distribution of Annual Inflows

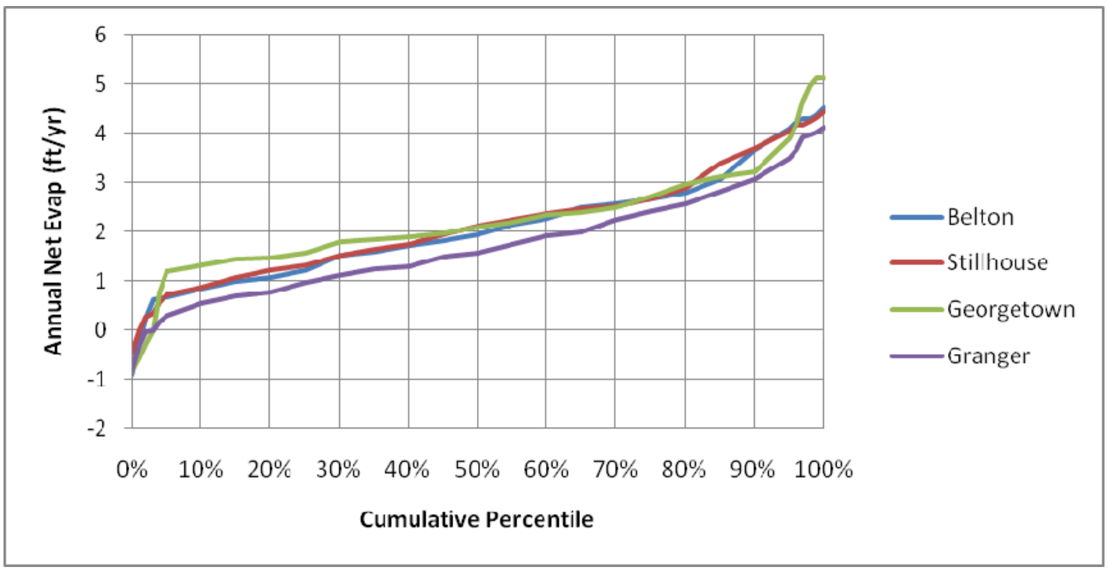

Figure 5-3. Cumulative Distribution of Annual Net Evaporation

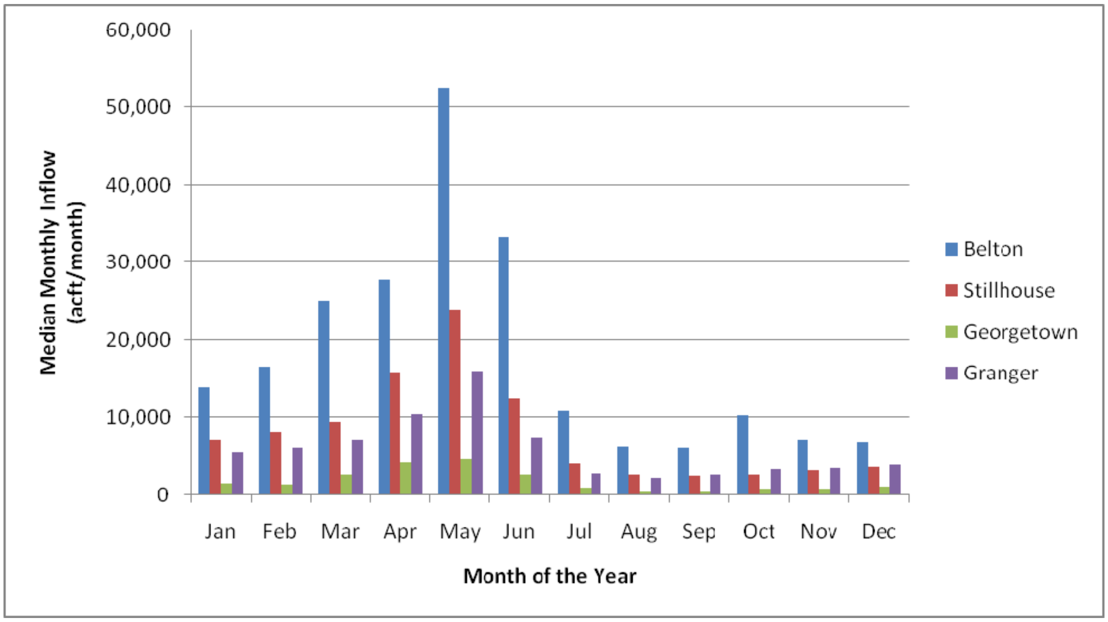

Figure 5-4. Median Monthly Inflows

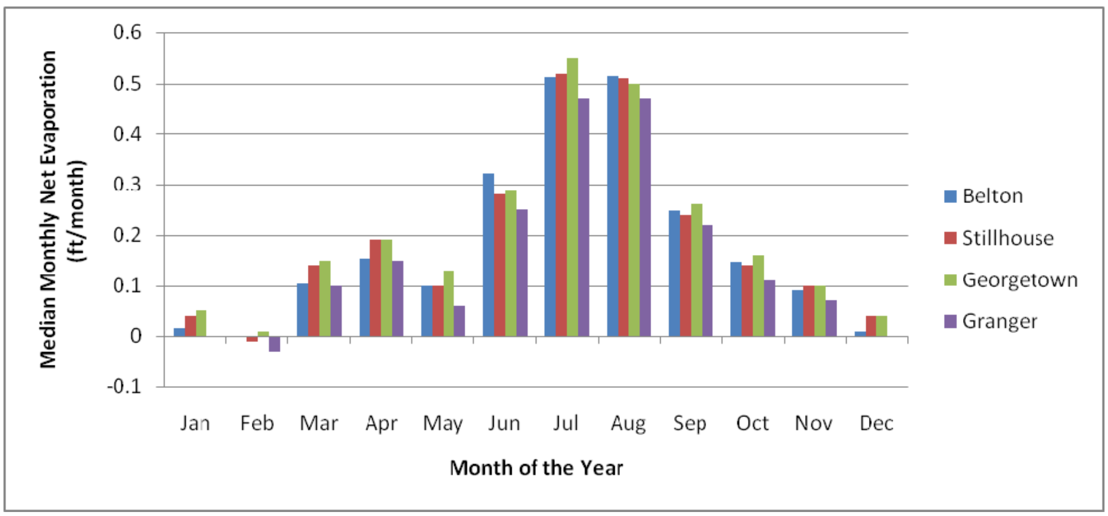

Figure 5-5. Median Monthly Net Evaporation

5.3 Pump Station Calculations

Included in the models are calculations that determine the available pumping capacities of the Stillhouse PS and the energy required to operate the pump station. Hydraulic equations are used to develop system curves at different lake levels, and pump curves are developed that represent different pump combinations. The intersections of the system and pump curves represent possible capacities for the Stillhouse PS. The models evaluate these intersections and use the results to generate optimum pumping scenarios. Based on the calculated capacity and head, power and energy are also calculated to determine operational costs.

5.3.1 Physical Components

The physical components that affect the capacity and energy calculations include the pumps, pipeline, and lake surface elevations. The BRA's portion of the Stillhouse PS has the infrastructure available for six pumps. There are two pumps in place at this time, and they are referred to as the "small" pumps. It was assumed that in future phases, two "medium" and two "large" pumps would be installed, though these terms are used very generally in this report and in the models to distinguish between the existing pumps, the Phase 2 pumps ("medium" pumps) and the eventual 5th and 6th pumps ("large" pumps). The capabilities of the pumps are described by their pump curves, which associate flow and head. Curves for efficiency are also given in terms of flow. The pump curves for flow and efficiency for the existing small pumps are included in the model inputs. Proposed medium pump curves have also been included, but they should be adjusted depending on the pumps that are finally installed. A pump curve provided by Fairbanks Morse, which represents the desired pump curve for design, is shown in **Appendix B**[1]. Temporary curves for the large pumps are also included and can be changed. From the pump curves for single pumps, curves for different combinations of pumps are developed, and these combinations are referred to as pump configurations in the models. Only those combinations of pumps that are physically feasible are considered in model solutions.

The physical aspects of the WCRRW Pipeline that affect the capacity and energy calculations include the diameter, length, profile, and roughness. All except for roughness are easily definable. Because the roughness of a 28-mile pipeline can significantly affect the capacity calculations, CDM tested the pipeline extensively to gather enough data to accurately describe the current roughness of the pipeline. The documentation for this study can be found in Appendix A. Based on this study, the roughness or C factor currently recommended for analysis is 140. Roughness can also change over time; therefore, the roughness coefficient is a user-defined parameter so that the effect of roughening due to age and usage on the capacity of the pipeline can be evaluated.

Finally, the water surface elevation at Lake Stillhouse Hollow and the pipeline profile define the static head or height that the Stillhouse PS has to lift the water in the transfer to Lake Georgetown. This affects the available capacity of the pumps and the required energy.

5.3.2 Formulas

Total head, power, and energy calculations were required for assessing pump station capacities and energy costs. Total head is the sum of the static head and the friction head. The static head is the difference in elevation from the water surface elevation at Lake Stillhouse Hollow to the elevation in the WCRRW Pipeline where the flow changes from pressure to gravity. In other words, it is the height that water needs to

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[1] The Fairbanks Morse curves represent the curves used for planning purposes in developing the model. Also shown in Appendix B are curves that represent the shop drawing curves provided by Sulzer, the company selected to provide the pumps for this project.

be lifted. The friction head developed in the pipeline was calculated using the empirical Hazen-Williams formula, which is stated as follows:

$$h_f = 0.002083L\left(\frac{100}{C}\right)^{1.85}\frac{Q^{1.85}}{d^{4.8655}}$$

where h_f is friction head in feet, L is the length of the pipeline under pressure conditions in feet, C is the roughness coefficient (dimensionless), Q is flow in gallons per minute (gpm), and d is the diameter of the pipeline in inches.

Based on the characteristics of the pipeline (length, diameter, roughness) and the elevation in Lake Stillhouse Hollow, total head is calculated for several flows to develop a system curve. The characteristics of the pipeline and the elevation in Lake Stillhouse Hollow are static parameters in the Operations Optimization Model; therefore, the system curve is set for a given model run. This is because the model only runs for one month and it is assumed that the elevation in Lake Stillhouse Hollow will not change significantly during the month. For the Planning Simulation Model, the elevation of Lake Stillhouse Hollow is a dynamic parameter that changes with each timestep. This results in a different system curve for each month in the model run.

The pump curves for each configuration are calculated at the beginning of a model run based on the pump curve information provided for the small, medium, and large pumps and minor loss calculations. The minor losses are calculated using the following formula:

$$h_m = k\frac{V^2}{2g}$$

where h_m is the total minor losses in feet, k is the loss coefficient (dimensionless), V is velocity in feet per second, and g is the acceleration due to gravity in feet per second squared. The intersection of each pump curve along the system curve describes the capacity of a particular pump configuration. Since the system curve changes with each timestep in the Planning Simulation Model, the capacity of each configuration also changes.

Energy usage is calculated by determining the power required to run a particular pump configuration given capacity, head, and efficiency. Energy usage in kilowatt hours (kWh) is power multiplied by time. The power required for pumping is calculated using the following equation:

$$P = 0.746\frac{QH}{3960\mu}$$

where P is power in kilowatts (kW), Q is flow in gpm, H is TDH in feet, μ is efficiency, and the constants are conversion factors. Efficiency for each pump configuration is calculated from the efficiency curves that are provided for each pump, which relate efficiency to flow. The flow that each pump is contributing for a pump configuration is determined, and the efficiency for each pump is derived from the curve. The pump configuration efficiency is the average of the derived efficiencies weighted by the flow from each pump.

5.3.3 Summary of Conditions and Restrictions

The following is a summary of the conditions in the model that affect the capacity and energy calculations:

- Pipeline diameter and profile: These parameters affect the calculation of TDH and they are static in the models. They cannot be changed by the user.

- Pipeline roughness: A roughness coefficient (C value) of 140 was calculated from collected data. This is a static parameter, but it can be changed by the user.

- Lake Stillhouse Hollow water surface elevation: This is a dynamic parameter in the Planning Simulation Model that is dependent upon the timestep calculation of reservoir fluxes. The elevation of top of conservation for Lake Stillhouse Hollow is 622 feet. The model can calculate system curves for an elevation range of 496 to 640 feet. The Lake Stillhouse Hollow elevation is also a dynamic parameter in the Operations Optimization Model that is calculated every 24 hours, but the variation in elevation for a 30-day period is not significant enough to re-calculate the system curve each day. Therefore, the system curve is a static parameter that is calculated once based on the initial water surface elevation in Lake Stillhouse Hollow.

- Pump curves describing the pump configurations: These are calculated from the three pump curves inputted for the small, medium, and large pumps. They are static inputs, but the medium and large pumps curves can be changed by the user

Restrictions considered in the modeling include the following:

- Allowable pump configurations

- Pump station operating strategies

- Pressure rating on the pipeline

These restrictions are discussed in the following sections.

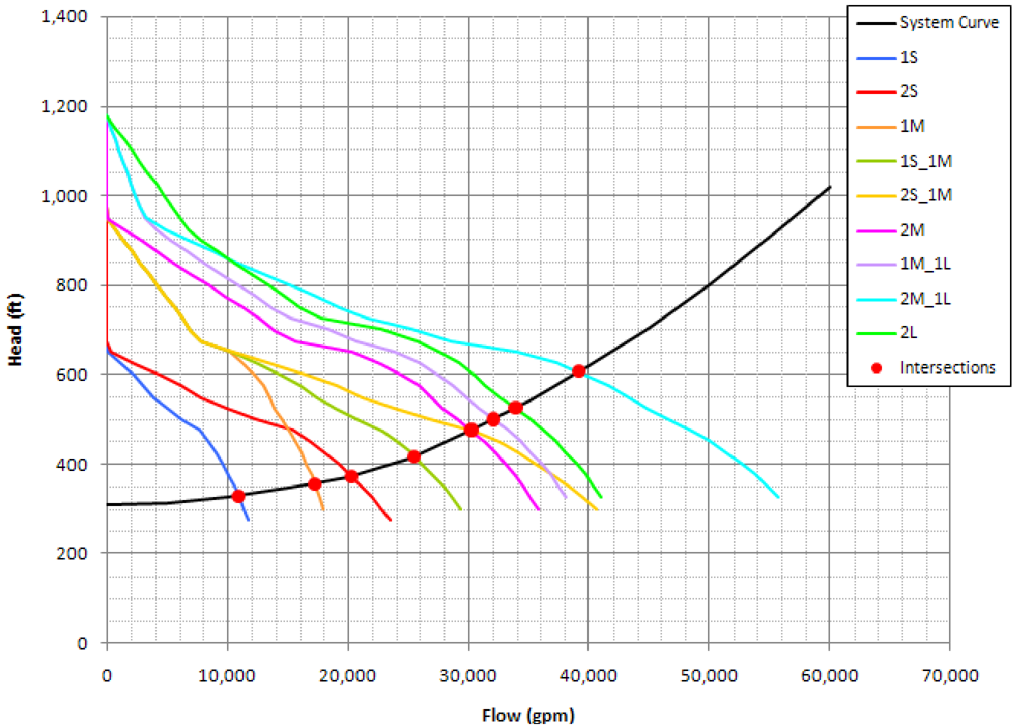
5.3.3.1 Allowable Pump Configurations

Only certain combinations of pumps can successfully run together; therefore, pre-determined combinations of the small, medium, and large pumps were established and are set in the models. **Figure 5-6** shows the pump curves for all allowable pump configurations and the system curve given a Lake Stillhouse Hollow elevation of 622 feet and a C value of 140. The designations are “S” for small, “M” for medium, and

"L" for large. The numbers indicate how many of each pump is included for each configuration. For example, the 2M_1L configuration includes two medium pumps and one large pump. Below the graph in Figure 5-6 is a table of the flow, head, and efficiency calculated from the intersections of the pump curves and the system curve.

Since the small pumps represent the pumps currently installed and the medium pumps are in design, allowable combinations of those pumps are well known. The only combination of those pumps that is not feasible is two small pumps with two medium pumps. In most situations, the head would be too high for the small pumps to function properly when running them at the same time as the two medium pumps. In other words, the small pumps would have to operate in an undesirable part of their curve if turned on with the two medium pumps. For the same reason, it was assumed that two medium pumps would not be able to run with two large pumps, but the actual pump curve for the large pumps is unknown at this time because they have not been selected. It is also reasonable to assume that the large pumps will not be able to run with any of the small pumps, because the large pumps are likely to run at much higher head values compared to the range of head values that the small pumps can operate at.

The pump configurations that include only one small or one medium pump were included, but one large pump was not included. One medium pump has less capacity compared to two small pumps but it may use slightly less energy in some cases. One medium pump was included because there may be a few scenarios where it would be more beneficial to run one medium pump instead of two small pumps. The practicality of using one medium pump is unknown until the final designed pumps are installed. One large pump was not included because it is likely that the energy required to run one large pump will exceed the amount of energy needed to run another pump configuration that has a greater capacity.



Q and H for Each Pump Configuration

Configuration	*# Pumps*	*Q (gpm)*	*H (ft)*	*Efficiency*
1S	1	10,911	330.3	0.826
2S	2	20,260	373.9	0.857
1M	1	17,191	357.1	0.762
1S_1M	2	25,455	418.2	0.813
2S_1M	3	30,283	476.7	0.830
2M	2	30,223	475.9	0.831
1M_1L	2	32,074	500.6	0.834
2M_1L	3	39,111	605.6	0.869
2L	2	33,888	525.9	0.840

Figure 5-6. Graph of Pump Curves and System Curve (Stillhouse Elevation of 622 feet, C Value of 140) and Table of Corresponding Flow, Head and Efficiency for Each Pump Configuration

5.3.3.2 Pump Station Operating Strategies

There are two operating strategies that were included in the Planning Simulation Model and three strategies in the Operations Optimization Model. The operating strategies describe when the pump configurations are turned on and off.

The two strategies in the Planning Simulation Model are:

- Operations 1: Pump configurations run continuously for the number of days per month necessary to transfer the required volume of water.

- Operations 2: Pump configurations run intermittently for the number of hours necessary each day to transfer the required volume of water for the month. The total hours required in the month are distributed evenly to each day in the month.

The purpose of Operations 2 is to take advantage of running the pumps during the hours when the cost of energy is lowest. For Operations 1, the pumps are run continuously for the number of days needed regardless of the cost of energy.

The three strategies in the Operations Optimization Model are:

- 6-Hour Optimized Schedule: Every six hours a different pump configuration can be activated as determined by the optimization solver.

- 6-Hour Total Continuous Pumping: Multiple configurations run continuously for as long as necessary as determined by the optimization schedule. The hours allocated to each pump configuration in the optimized schedule are added, without regard to time of day.

- Continuous Pumping by Configuration: Single configurations run continuously for as long as necessary to achieve the target elevation.

Energy and utility charges are calculated for the last two strategies to compare to the charges for the optimized schedule. These comparative costs provide guidance on how sensitive the expected costs are likely to be to alternative operating strategies for the pump station.

5.3.3.3 Pipeline Pressure Rating

The pressure rating varies along the length of the WCRRW Pipeline. Pressures were calculated along the pipeline for different flows and friction factors (C values) to determine at what flow rate the pressure ratings would be exceeded given a friction factor. A graph displaying this information for a C value of 140 is shown in **Figure 5-7**. As shown in Figure 5-7, the calculated pressure exceeds the rated capacity along the 100 psi class pipe near a flow of 40,000 gpm.

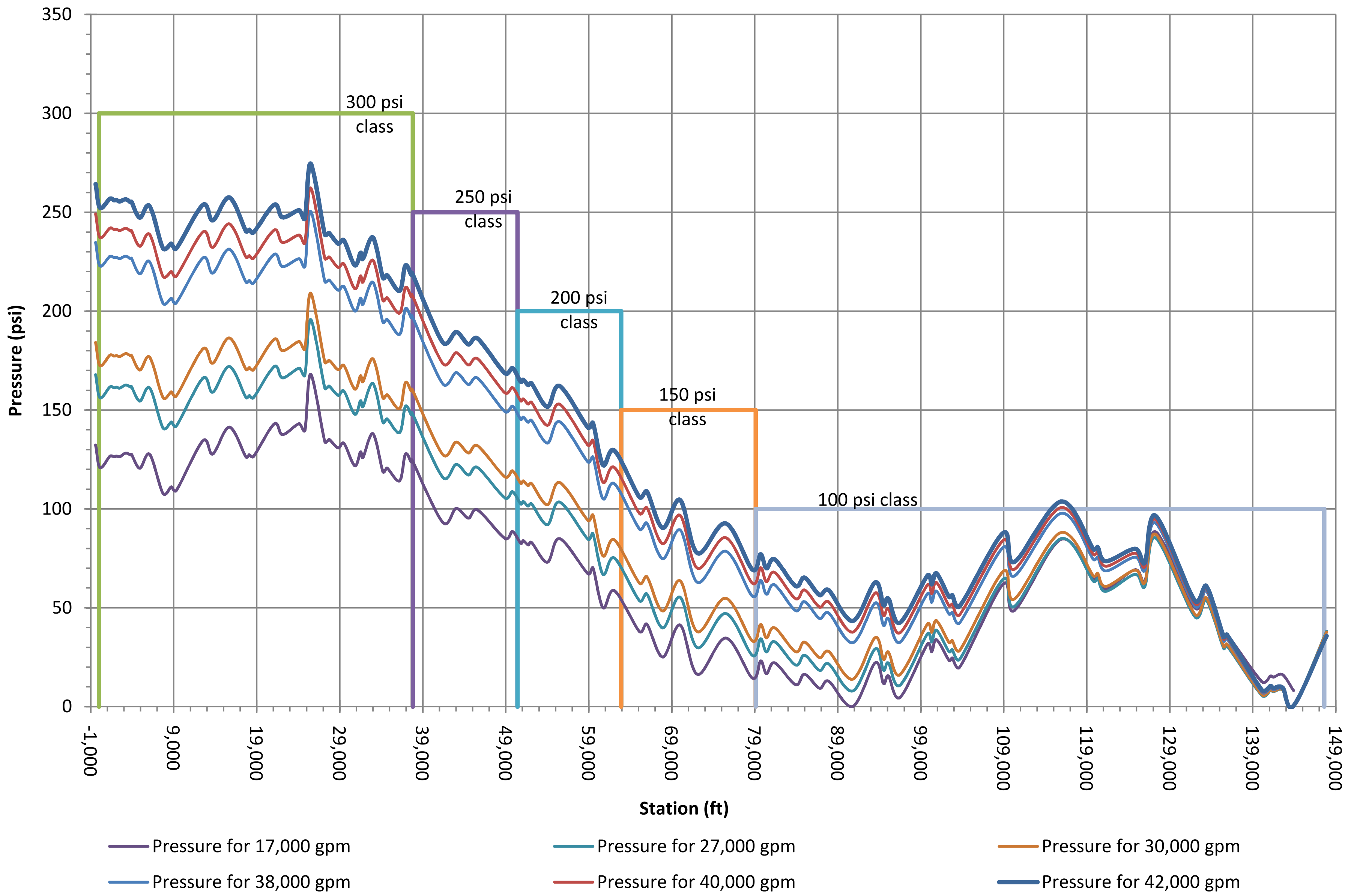


Figure 5-7 Pressures and Pressure Classes along the WCRRW System Pipeline (C Value of 140)

In the models, the maximum capacity of the line based on pressure ratings is calculated from the C value. The maximum capacity limits which pump configurations are available when running the models. If the capacity of a pump configuration exceeds the maximum capacity of the pipeline, the models exclude the configuration from the analysis. The user can override this restriction by entering a user defined maximum capacity or eliminating the maximum capacity all together.

There are situations in which the user would want to override the maximum capacity restriction. For example, analyses of future demands may require water transfers that exceed the current pressure-based capacity of the pipeline. To fully study these scenarios the models should not be restricted by this capacity. Adjusting or removing the restriction allows the user to analyze scenarios in which the pipeline is upgraded to handle greater pressure.

5.4 Energy Cost Structure

Both models calculate energy costs based on several parameters. The total energy cost that is billed to the BRA is made up of two components: energy charges and utility charges. Energy charges are based on total energy used and the price of energy. Utility charges make up the cost of power transmission. Overall, it is important to note that the energy charge structure can be varied in the model, but the utility charge structure cannot be varied (although the prices can be modified). This section discusses all the aspects of the energy costs including the current method of calculating energy charges which is based on the Market Clearing Price for Energy (MCPE).

5.4.1 Energy Charges

The energy charges are determined from the total amount of energy used in kWh. The unit cost for energy can be a fixed or variable rate. Currently, the energy charges for the Stillhouse PS are based on the MCPE which is a rate that varies every 15 minutes. The models are setup to include this energy charge structure in addition to two other structures. A fixed rate and a day/night rate are also available so that the user can compare the difference in total energy cost based on different energy charge structures. Depending on the contract, a fixed rate add-on may also be included in the energy charges. The BRA's current contract with Constellation NewEnergy, Inc. includes an add-on at the rate of $0.01146/kWh.

In summary there are two energy charges included in the models:

- Basic energy charge: based on a cost rate that can be the MCPE, a fixed rate, or a day/night rate

- Energy charge add-on: based on a fixed rate

The cost rates for the basic energy charge are discussed in the following sections and each is available as an energy charge rate structure to be used in the models. The energy charge add-on is included regardless of the modeled structure, but the rate can be changed as needed based on the most current contract rate or proposed rates.

5.4.1.1 The Market Clearing Price for Energy (MCPE)

The basic energy charge for the Stillhouse PS is currently based on the MCPE. The MCPE, according to the Electric Reliability Council of Texas (ERCOT), is the "highest price (for energy) associated with a Congestion Zone for a Settlement Interval for Balancing Energy deployed during the Settlement Interval." Simply, it is a unit cost for energy that varies every 15 minutes (the Settlement Interval) and is dependent upon the Congestion Zone. The economic theory and formulas for determining the MCPE are complicated, but it is not necessary to completely understand how it is calculated. The variation of the MCPE is based on the energy market and how energy is being distributed throughout the system. How energy is distributed is based on several variables such as energy demand, the capacity of energy generation from a location, and facility constraints. The variation in energy demand typically follows a diurnal pattern as well as an annual pattern. If other variables stay relatively constant, these patterns can be observed in the MCPE as well.

Historical MCPE data were analyzed statistically to determine how the Stillhouse PS energy charges can be modeled. Three years (2006-2008) of historical MCPE data were analyzed to determine average values and patterns that can be used to calculate the cost of energy in the Stillhouse PS models over a simulated time period. The MCPE data consists of the unit cost for energy ($/MWh) in a Congestion Zone for each 15 minute interval for each day of the year. The Congestion Zones are defined as either a Load or a Resource for the four zones that cover Texas (Houston, North, South, or West Zone). For the Stillhouse PS, the energy cost is for a Load in the North Zone.

In order to analyze the diurnal patterns, the MCPE values were normalized based on the average value for each day in the record. Diurnal patterns with one-hour intervals were developed for each month in each year to determine if there was significant variation in the diurnal pattern from month to month. The data was simplified to one-hour intervals because no aspect of the modeling would be detailed enough to require energy prices in 15-minute intervals. Additionally, 15-minute variability of energy costs cannot be confidently predicted. In comparing the monthly patterns for each year, it was obvious that each month had a definable pattern; therefore, it was determined that a different diurnal pattern for each month should be used to calculate energy costs in the model. The normalized diurnal patterns developed for each month are based on an average of the three years of record and are shown in **Figure 5-8**. It is shown that the patterns for the colder months dip down around hour 16 while the warmer months peak at that hour.

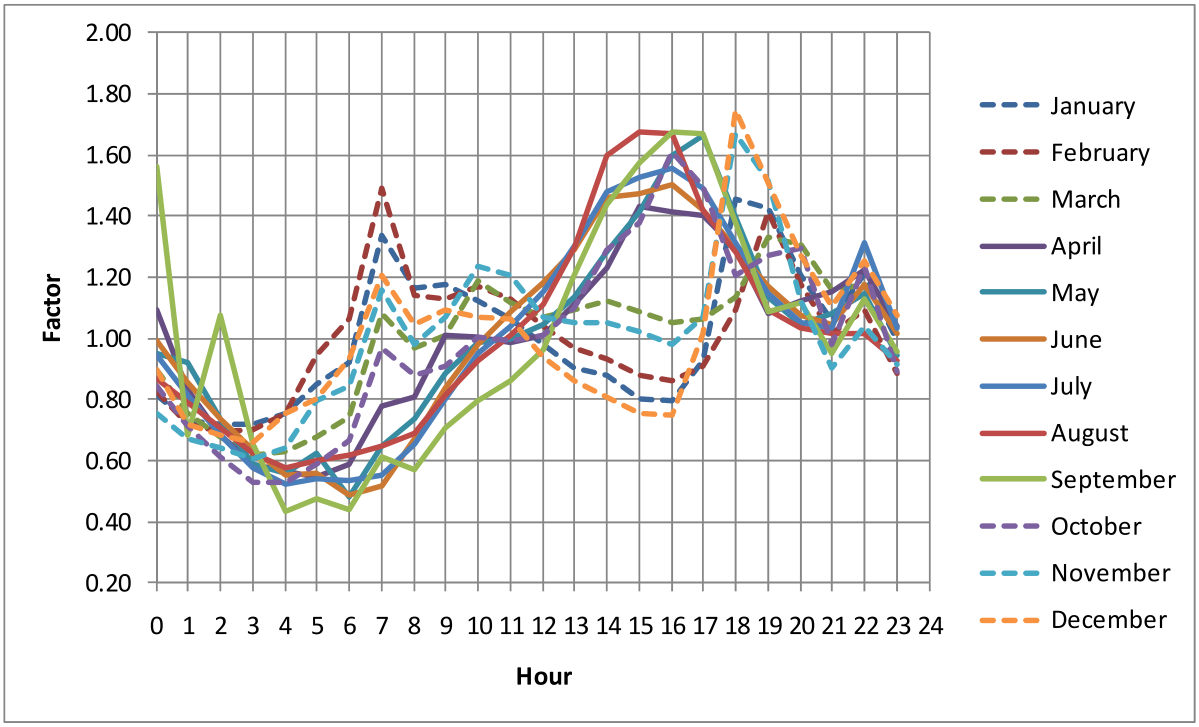


Figure 5-8. Normalized MCPE Diurnal Pattern by Month

Average MCPE values were also calculated for each month. The average values are multiplied by the normalized diurnal patterns to model the MCPE for every hour of every month. **Figure 5-9** shows the average MCPE of each month for each year in the record and **Table 5-2** shows the average MCPE for each month over all three years.

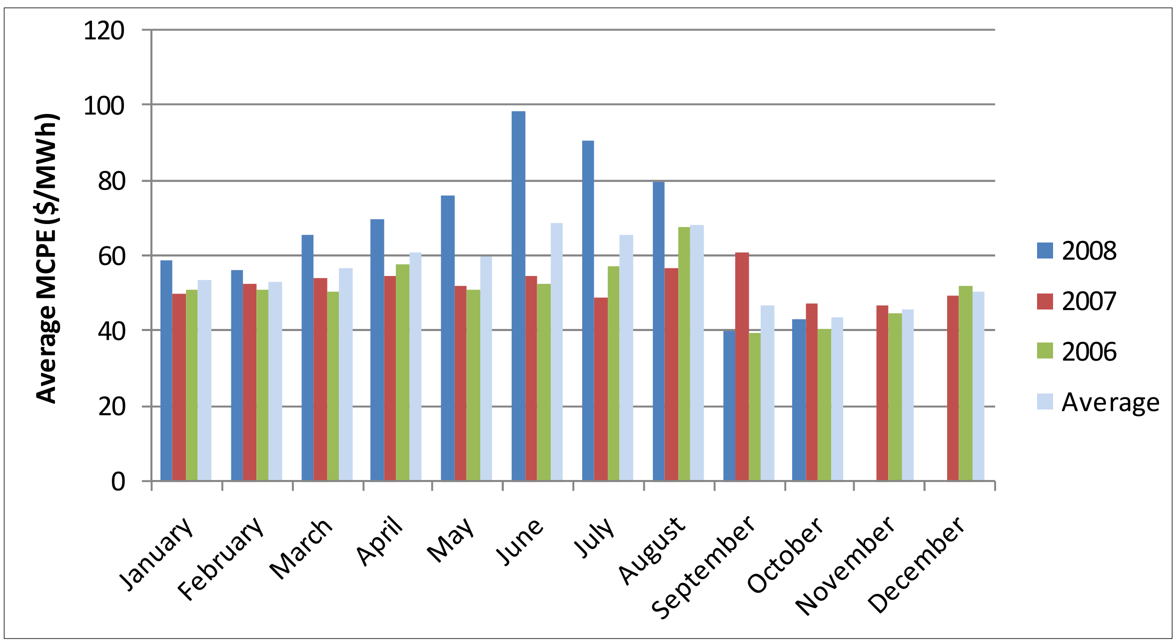


Figure 5-9. Average MCPE by Month for Each Year

Table 5-2. Average MCPE by Month

Month	Average MCPE ($/MWh)	Month	Average MCPE ($/MWh)
January	53.50	July	65.61
February	53.34	August	68.16
March	56.87	September	46.84
April	60.85	October	43.61
May	59.87	November	45.91
June	68.70	December	50.82

The diurnal curves in Figure 5-8 and the average monthly MCPE values in Table 5-2 are used in the models to develop the basic energy charge given the MCPE energy charge structure. For the Planning Simulation Model, a series of calculations are performed to generate a look-up table of MCPE prices for each month and over durations from 0 – 24 hours (not including 0 hours). During a simulation, once the model has determined the number of hours per day pumping is required for a given month, it uses this table to find the average MCPE price for that month and duration, which is multiplied by the energy used to determine the monthly energy charge. This calculation is performed only for intermittent pumping (Operation 2 in the Planning Simulation Model). For continuous pumping (Operation 1), the monthly average MCPE price is used to calculate the energy charge, because this operating strategy assumes the pumps are running for entire days and requiring no diurnal variation in cost.

For the Operation Optimization Model, the hourly MCPE prices developed from the diurnal curves and the average monthly MCPE prices are averaged over six-hour intervals for each month. The model looks up the six-hour prices based on the month(s) over which the model is being run. Again, this is a simplification of MCPE pricing, but in its intended utility as a forecasting tool in which the 15-minute variability of energy costs cannot be confidently predicted, the “6-hour average” approach should represent an appropriate balance between too much uncertain data and not enough data to distinguish between alternative times of day for pumping.

Although there are default values in the models for the MCPE based on the data analyzed from 2006 to 2008, the user may enter new MCPE prices based on an updated analysis of available MCPE data. The BRA should consider updating this information every two to three years.

5.4.1.2 Fixed Energy Charge

A fixed energy charge structure is available to use in the model instead of the MCPE. This is a constant rate compared to the MCPE, which is variable. The energy charge add-on still applies to this energy charge structure, but it can be changed as needed.

5.4.1.3 Day/Night Energy Charge

The day/night energy charge was developed as a custom cost structure option. The MCPE and fixed rate are the typical rates used in energy cost contracts, but the BRA should be able to negotiate other types of rates due to the deregulation of energy in Texas. For the day/night energy charge structure, two rates can be set to represent costs during low system demand (typically during the night) and high demand system demand (typically during the day). The duration for each rate can be adjusted in the model, but the night rate must always be set as the lower cost rate.

5.4.2 Utility Charges

Utility charges make up the cost to the customer for energy transmission, which is separate from the cost of energy itself. The rate of energy usage (power) and when peaks in power occur drive the utility charges. The utility charge structure is based on state regulations; therefore, the structure is modeled, but it cannot be changed in the model. The following is a list of the utility charges based on the "Tariff for Retail Delivery Service", effective starting July 15, 2008, and the type of service and meter equipment for the Stillhouse PS (2008 unit costs are in parentheses):

- Basic Customer Charge and Metering Charge (fixed at $41.55)
- System Benefit Fund ($0.000655/kWh)
- Distribution Charge ($3.55/kW)
- Transmission Charge ($1.47/kW)
- Transmission Cost Recovery Factor ($0.59/kW)
- Transition Charge ($0.167/kW)
- Nuclear Decommissioning ($0.044/kW)
- Transition Charge 2 ($0.264/kW)

Note that the utility charges shown have the 2008 unit costs shown in parentheses. These unit costs will change over time and they should be updated in the model as they change. Billing records can be used to keep track of these unit costs.

The Basic Customer Charge and Meter Charge are fixed charges that are added to the total cost. The System Benefit Fund, although it is a utility charge, is based on total energy use and not peak power. The remaining charges depend on a peak power demand (a rate) that will be referred to as the demand. Although demand is referred to as a rate in kW, it is calculated by integrating power over a 15-minute interval.

There are two demands that are calculated by the power transmission company: the Billing kW and the 4 CP kW. Each of the utility charges above uses one of these demands. The Billing kW and the 4 CP kW are discussed below and the corresponding utility charges for each are listed. Additionally, each demand is affected by the power factor. If the power factor goes below 0.95, the demand is increased based on an equation to be discussed in **Section 5.4.2.3**.

5.4.2.1 Power Demand: Billing kW

The Billing kW demand as described by the Tariff for Retail Delivery Service "shall be the higher of the Non-Coincident Peak power (NCP kW) for the current billing month or 80% of the highest monthly NCP kW established in the 11 months preceding the current billing month". This is referred to as the "80% ratchet". For example, if the NCP kW observed in December 2007 is the largest observed compared to 80% of the NCP kW observed for the rest of 2007, the NCP kW for December becomes the demand. The demand has now been set for December 2007 and will remain the same for the next 11 months unless an NCP kW that is higher than 80% of the December NCP kW is observed within that time frame. This demand applies to the **Distribution Charge**, **Transition Charge**, **Nuclear Decommissioning**, and **Transition Charge 2**.

5.4.2.2 Power Demand: 4 CP kW

The BRA has an IDR meter, which means the 4 CP kW demand is used for the remaining utility charges. This is different from the Billing kW demand because the 4 CP kW demand examines the demand from the previous calendar year to set the demand for the current calendar year. The 4 CP kW according to the Tariff for Retail Delivery Service is "the average of (BRA's) integrated 15 minute demands at the time of the monthly ERCOT system 15 minute peak demand for the months of June, July, August, and September of the previous calendar year." This means that the BRA's demand that occurred during the time of peak of the entire system would be recorded for each of the listed months and the average of those four values would be the 4 CP kW. Since it is not possible to model the time of the system peak demand, assumptions are required. The most conservative approach is to take the BRA's peak demand for each summer month and use the average of those values as the 4 CP kW. The 4 CP kW is updated each calendar year and applies to the **Transmission Charge** and the **Transmission Cost Recovery Factor**.

5.4.2.3 Power Factor

The power factor is the ratio of the real power to the apparent power and ranges in value from zero to one. Real power is the capacity of the circuit performing work in a given timestep, and apparent power is the product of the current and voltage of the circuit. If the power factor goes below 0.95, the power demand is increased based on the following equation:

Adjusted demand = (demand * 0.95)/power factor

The power factor cannot be modeled due to the number of variables that can affect it, but it can be monitored; therefore, the power factor is included as a user-defined value in the model. The user can put in a typical value based on recent billing records. Action can be taken to install equipment that will increase the power factor if it is found to be unreasonably low on a regular basis.

5.5 Pump Operations

Pump operations in the Planning Simulation Model are controlled by a set of triggers that are used to achieve a target elevation in Lake Georgetown at the end of each month. These operational triggers differ from the operations logic used in the previous FNI model, in which a trigger was assigned to each individual pump (when just 2 pumps were available). With the installation of up to four new pumps, the increase in number of potential pump combinations makes the individual pump trigger method impractical. In the Planning Simulation Model, the model selects the optimal pump configuration needed to minimize both the deficit in Lake Georgetown and the associated pumping cost for each month, and triggers the use of the most effective pump configuration based on lake levels or volumes.

There are four triggers that determine the transfer through the WCRRW Pipeline:

- On Triggers (both of the following triggers must be satisfied for the pumps to be activated):
  - Lake Georgetown Trigger – the elevation in Lake Georgetown must be below this trigger for the pumps to activate.
  - Lake Stillhouse Hollow Trigger – the elevation in Lake Stillhouse Hollow must be above this trigger for the pumps to activate. If the elevation in Lake Stillhouse Hollow is below this trigger, then the pumping is not permitted regardless of the level in Lake Georgetown in order to prevent excessive drawdown of Lake Stillhouse Hollow.
- Off Triggers (either of the following triggers will deactivate the pumps):
  - Lake Georgetown Trigger – when the elevation in Lake Georgetown rises above this trigger, then the pumps are deactivated.
  - Lake Stillhouse Hollow Trigger – if the elevation in Lake Stillhouse Hollow falls below this trigger, then the pumps are deactivated regardless of whether Lake Georgetown has reached its off trigger.

These triggers can vary by month and can be specified either as a water surface elevation or percent of available capacity, which is the capacity between the top of the conservation pool and the **minimum allowable elevation for withdrawals**. There is an identical set of triggers for the conceptual transfer between Lake Belton and Lake Stillhouse Hollow.

With the triggers defining when the pumps are turned on and shut off, the volume of water transferred each month then depends on the following factors:

- Elevation in Lake Georgetown – when the elevation in Lake Georgetown is below the On Trigger and the pumps are activated, the requested transfer volume is set to the storage volume deficit which is defined as the volume below the target level (Off Trigger) in Lake Georgetown at the beginning of the month. In the Planning Simulation Model, the user has an option to include the current month's demand in this deficit in order to achieve the target elevation at the end of the month, see third bullet below.

- Elevation in Lake Stillhouse Hollow – the transfer is limited by the available volume in Lake Stillhouse Hollow which is the difference between the level at the beginning of the month and the Off Trigger. If the pumps were on in the previous month and the level is below the Off Trigger at the start of the current month then no transfer is permitted. If the pumps were not on in the previous month and Lake Georgetown, at the start of the current month, is below its On Trigger but Lake Stillhouse Hollow is also below its On Trigger, then no transfer is permitted. Both On Triggers must be satisfied for the pumps to be activated. Note that the status of the pumps is only checked and updated at the beginning of each month and will not change mid-month.

- Expected demand in Lake Georgetown – the expected demand in the current month can be added to the storage volume deficit in Lake Georgetown in order to reach the target elevation by the end of the month (the user has the option to disable including the expected demand, see below).

- Maximum Pump Capacity – the transfer volume is limited to the maximum volume of water that can be transferred by the pumps.

- Hydraulic Pipe Capacity – individual pump configurations are deactivated if their flow rate exceeds the hydraulic capacity of the WCRRW Pipeline, which depends on the C value and pressure rating of the pipeline. This is calculated automatically by the model for each timestep since it depends on the elevation in Lake Stillhouse Hollow. Instead of being calculated, this restriction can also be re-defined by the user or removed altogether. There are situations in which the user would want to override the maximum capacity restriction. For example, adjusting or removing the restriction allows the user to analyze scenarios in which the pipeline is upgraded to handle greater pressure.

- Annual Contract Volume – because the maximum annual BRA transfers will be no greater than the sum of its contracts (currently 61,121 acft/yr), the model tracks the cumulative transfer volume for each year and limits transfers to prevent exceeding this annual volume.

In most cases, the transfer volume is limited by either the storage volume deficit in Lake Georgetown or the maximum pump capacity. For a given transfer request, the energy model is used to calculate the cost resulting from each valid pump configuration (see **Section 5.4**). The configuration with the lowest cost that meets the requested transfer volume is used in the model for that month. The pump configurations are re-examined each month to find the lowest-cost configuration for the desired transfer volume and current conditions.

For the conceptual transfer from Lake Belton to Lake Stillhouse Hollow, the pipeline and pump hydraulics are not calculated since the pipeline and pump station have not been designed. Therefore, transfers are determined simply by the storage volume deficit in Lake Stillhouse Hollow and a maximum transfer volume defined by the user.

Section 6
Model Validation

The actual calculations for the different components of each model discussed in **Section 5** were checked for accuracy, but the validity of the overall setup of each model was checked by comparing the model results to other available sources of similar information. This included comparisons of firm yield, predicted lake levels, and total energy costs. For firm yield, the results from the Planning Simulation Model were compared to published values of firm yield for each reservoir. The lake levels predicted for Lake Georgetown for a particular set of conditions were compared to the results of the BRA's previous planning model, the FNI model. Finally, energy costs calculated in both models were compared to actual billing data.

6.1 Firm Yield Analysis

In order to verify that the simulated hydrology and reservoir dynamics in the new tools were reasonable and credible, the firm yield of each reservoir in the WCRRW System was calculated using the Planning Simulation Model. Reservoir firm yield is the amount of water that the reservoir can supply on a continuous annual average basis without shortfall based on the hydrologic record (including the drought of record). As a verification check of the Planning Simulation Model, the firm yield calculated in the model was compared to firm yields obtained from other sources. Exact replication of firm yield is not expected because of potential differences in assumptions and technique. The purpose of this analysis is to verify the reservoir dynamics and hydrologic features of the Planning Simulation Model by showing that it can reproduce other modeled values of yield with reasonable accuracy.

The results of the firm yield analysis are shown in **Figure 6-1**. The results from the Planning Simulation Model are based on the total capacity of each reservoir down to the bottom of their elevation-area-capacity curve. Also shown are firm yields calculated by others. They include the BRA's firm yield estimates based on the Texas Commission on Environmental Quality (TCEQ) Brazos Water Availability Model (BWAM) and the Texas Water Development Board (TWDB) 2006 Region G Water Planning Report, which also used the BWAM. The two estimates that use the BWAM model vary because the results of the model are dependent upon inputs including sediment conditions, elevation-area-capacity data, the hydrologic period, return flows, etc.

The firm yield analysis results for the Planning Simulation Model tend to fall between the BRA and TWDB estimates. The TWDB estimate for Belton and Granger are significantly lower compared to the BRA and Planning Simulation Model estimates in terms of percent difference. This may be due to a conservative estimate of sediment conditions that would reduce the available capacity in these reservoirs. Some of the differences in input data for the Planning Simulation Model compared to the BRA and

TWDB inputs include updated elevation-area-capacity data and updated inflow and evaporation data.

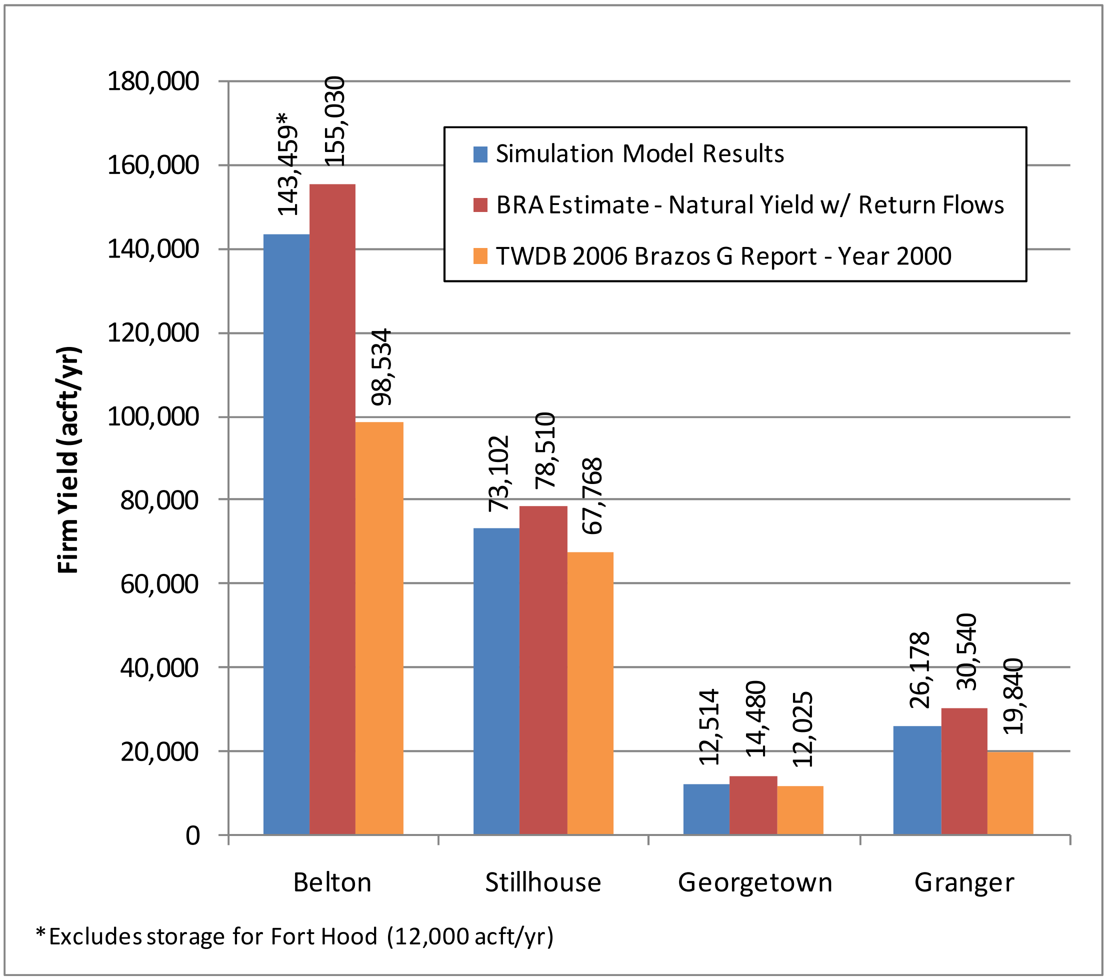


Figure 6-1. Firm Yield Results from Simulation Model Compared to Other Sources

6.2 Comparison to FNI Model

The Planning Simulation Model was compared to the existing FNI model to ensure that the two models produced comparable results. Although the two models differ in a number of ways, particularly the pump operation logic, it was important to confirm that they reproduce similar reservoir dynamics under current conditions (two existing pumps).

In order to compare the two models, both were used to simulate a specific scenario requested by the BRA. In March 2009, the level in Lake Georgetown was approaching the elevation of the intake for one of its customers. The BRA used the model to determine the lowest expected elevation in Lake Georgetown over the following summer given the initial conditions in March 2009. Both models were thus used to simulate the worst-case scenario using the lowest recorded inflow and the highest recorded net evaporation beginning in the month of March (which corresponded to the years 1954 for inflow and 1956 for net evaporation).

The FNI model was configured with the following settings:

- Initial Lake Georgetown elevation – March 2009 conditions (~773 ft)
- Inflow for March 1954 – February 1955
- Net evaporation for March 1956 – February 1957
- Total demand of 35,000 acft/yr on Lake Georgetown
- 5% pump down time
- Pumping triggers were 60% total volume for one pump, and 50% for two pumps

The results of the FNI model were provided by the BRA and are shown in **Figure 6-2**. This figure includes the results for other periods of inflow and net evaporation to show the distribution of expected reservoir levels between the worst case and best case scenarios. Under the worst case scenario, the volume of Lake Georgetown reaches a minimum of 8,300 acft, which corresponds to an elevation of 758 ft.

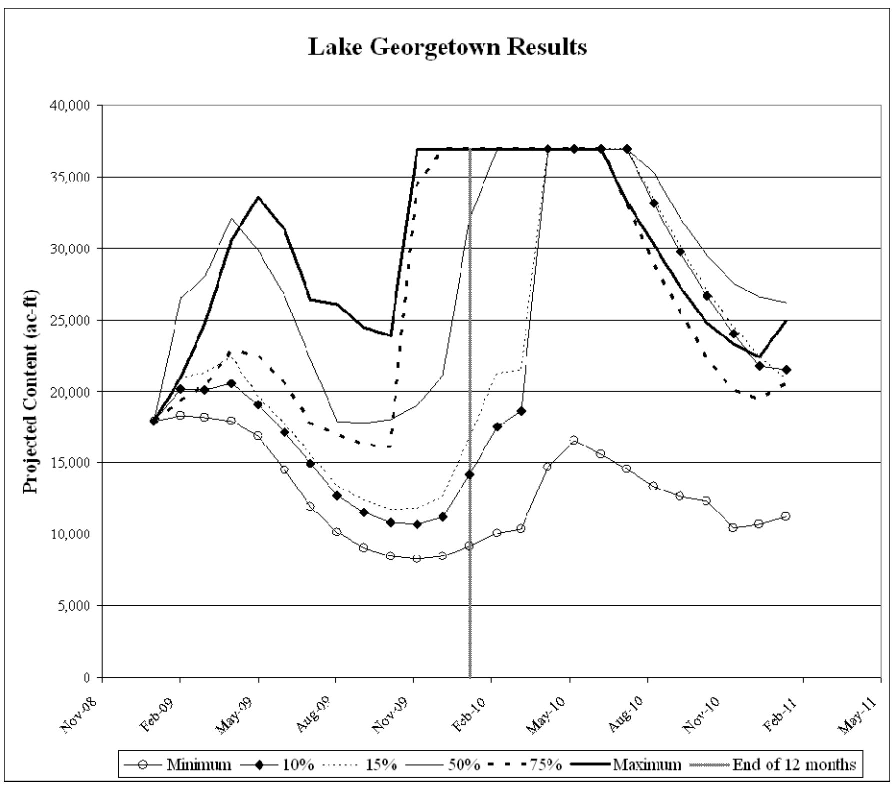


Figure 6-2. Lake Georgetown Elevation of the March 2009 Scenario using the FNI Model (provided by the BRA)

The same scenario was set up in the CDM Simulation Model using the following settings:

- Initial Lake Georgetown elevation – March 2009 conditions (~773 ft)
- Mid-Term mode over 24 months
- Total demand on Lake Georgetown of 35,000 acft/yr
- Inflow period beginning March 1954
- Net evaporation beginning March 1956
- Pump station includes the two existing small pumps only
- On and off triggers for Lake Georgetown set to 42% Available Volume, which corresponds to 55% Total Volume and is midway between the two triggers used in the FNI model simulation

Figure 6-3 shows the results of the CDM Planning Simulation Model, which predicts a minimum volume of 8,700 acft corresponding to an elevation of 758.8 ft. The results of the CDM model are therefore very similar to that predicted by the FNI model.

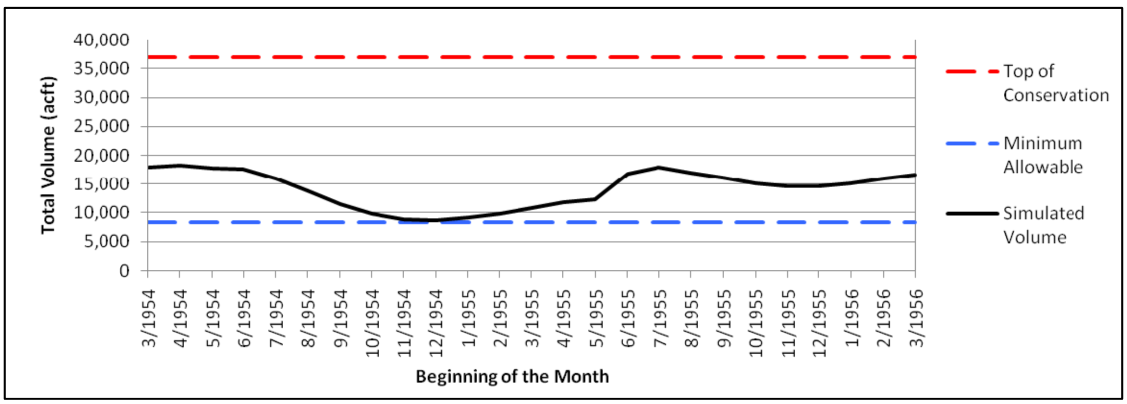


Figure 6-3: Lake Georgetown Elevation for the March 2009 Scenario using the CDM Simulation Model

6.3 Comparison of Calculated Costs to Billing Records

Billing records were provided by the BRA from December of 2005 to May of 2008 to assist in the development of the energy cost modeling for both models. Once the models were completed, the cost data from the bills for October of 2006 to June of 2007 were used to verify the calculation of energy costs. This timeframe represents a good variation of pumping to be compared to the models.

The billing data cannot be compared directly to the model output because which pumps were running and when is unknown for the timeframe of comparison. Additionally, the models only provide guidance on pumping schedules based on the inputs available and cannot predict how the pumps were actually used. Total energy used each month is known from the billing records and the model output; therefore, the total costs were normalized by the total energy, and then they were compared for verification purposes.

Table 6-1 compares the billing records data and the results from the Planning Simulation Model and **Table 6-2** compares the data to the Operations Optimization Model results. The last column in each table shows the percent difference in normalized cost between what was billed and what was modeled. The difference in normalized cost is due to the difference in MCPE unit costs and the inability to model utility charges exactly. The MCPE values used in the models and this analysis are based on three-year averages. Utility charges are based on several factors and not all can be effectively modeled. The differences shown are not perceived as influencing the interpretation of results, since there is some monthly variability. Comparing overall energy use and total cost for the entire timeframe that was examined, the differences are less than two percent.

Table 6-1. Cost Verification for Planning Simulation Model

Billing Month Ending	Billed			Modeled (Simulation)			% Diff. in Norm. Cost
	kWh	Total Cost	Norm. Cost	kWh	Total Cost	Norm. Cost	
Oct-06	601,775	$33,199	$0.0552	1,117,984	$69,202	$0.0619	12.2%
Nov-06	602,433	$41,650	$0.0691	1,082,035	$69,694	$0.0644	-6.8%
Dec-06	589,755	$40,972	$0.0695	1,118,279	$77,322	$0.0691	-0.5%
Jan-07	1,212,671	$80,024	$0.0660	1,118,335	$81,797	$0.0731	10.8%
Feb-07	943,940	$71,838	$0.0761	1,004,599	$74,034	$0.0737	-3.2%
Mar-07	548,825	$42,474	$0.0774	268,431	$23,243	$0.0866	11.9%
Apr-07	6,129	$7,867	$1.2836	6,128[A]	$7,106	$1.1594	-9.7%
May-07	5,751	$7,851	$1.3652	5,751[A]	$7,098	$1.2342	-9.6%
Jun-07	5,147	$7,778	$1.5113	5,146[A]	$7,098	$1.3791	-8.7%
Overall	4,516,424	$333,654	$0.0739	5,726,690	$416,594	$0.0727	-1.5%

[A] Values assumed. Pump station uses a small amount of energy even when the pumps are not running and this amount is not modeled

Table 6-2. Cost Verification for Operations Optimization Model

Billing Month Ending	Billed			Modeled (Optimization)			% Diff. in Norm. Cost
	kWh	Total Cost	Norm. Cost	kWh	Total Cost	Norm. Cost	
Oct-06	601,775	$33,199	$0.0552	873,121	$55,572	$0.0636	15.4%
Nov-06	602,433	$41,650	$0.0691	576,261	$40,795	$0.0708	2.4%
Dec-06	589,755	$40,972	$0.0695	362,646	$24,561	$0.0677	-2.5%
Jan-07	1,212,671	$80,024	$0.0660	1,138,301	$81,204	$0.0713	8.1%
Feb-07	943,940	$71,838	$0.0761	1,138,492	$82,767	$0.0727	-4.5%
Mar-07	548,825	$42,474	$0.0774	887,011	$65,680	$0.0740	-4.3%
Apr-07	6,129	$7,867	$1.2836	6,128[A]	$7,441	$1.2141	-5.4%
May-07	5,751	$7,851	$1.3652	5,751[A]	$7,453	$1.2959	-5.1%
Jun-07	5,147	$7,778	$1.5113	5,146[A]	$7,441	$1.4458	-4.3%
Overall	4,516,424	$ 333,654	$0.0739	4,992,859	$372,914	$0.0747	1.1%

[A]*Values assumed. Pump station uses a small amount of energy even when the pumps are not running and this amount is not modeled*

Section 7
Analysis and Results

Once the models were developed, they were used to conduct analyses that were useful in gaining a better understanding of the WCRRW System and its capabilities. The two analyses presented in this section examined trigger levels and total energy costs. Trigger levels were examined for different demand targets for the existing pumps only and then with the proposed pumps. Total energy costs were compared for each operating strategy given each available cost structure. Note that these results are based on the versions of the models developed at the time these analyses were conducted. The most current versions of the models should be used to obtain the most reliable results.

7.1 Minimum Trigger Levels

Trigger levels are the water surface elevations in Lake Georgetown and Lake Stillhouse Hollow that determine when the pumps in the Stillhouse PS should be turned on and off. Minimum trigger levels were evaluated given a demand year and available pump configurations using the long-term mode in the Planning Simulation Model. Currently, the Stillhouse PS has two pumps available and they are referred to as the "small" pumps in the models. The Phase 2 pumps, which are referred to as the "medium" pumps in the model, are to be installed in the next one to two years. Trigger levels were first analyzed based on year 2009, 2010, and 2011 demands to determine the minimum trigger levels required to meet all demands at the lowest average cost given the currently installed pumps. This information provides guidance to the BRA on trigger levels given the current capacity of the Stillhouse PS. Next, the medium pumps were included in the analysis and demands were increased until the capacity of the pump station was reached.

This analysis considers all installed pumps, existing and proposed, to be operable. This means that firm capacity, the capacity with the largest pump out of service, was not considered in determining minimum trigger levels. With only the two small pumps currently in service, the BRA should take into consideration what would result if only one pump was available. Minimum trigger levels would be significantly higher. Note that the model is capable of such an analysis by reducing the pumps available to one small pump. The BRA may also experiment with different percent downtimes for the pumps. This analysis assumed 5 percent downtime.

On the other hand, with the Phase 2 pumps installed, firm capacity is provided, because the maximum capacity of the pump station is approximately the same with or without the largest pump out of service. This is because all four pumps (two small and two medium) cannot efficiently run together, and the capacity of two small with one medium pump is very similar to the capacity of two medium pumps.

7.1.1 Results

The results of this analysis are to be used for guidance purposes only for a number of reasons. First, the analysis of trigger levels is based on percent of available volume, which is defined by the user. The lowest levels allowable for each reservoir in this analysis were based on the customer intakes. Second, the recommended trigger levels were determined by lowest average annual costs that results in no shortages, but the BRA may prefer to choose trigger levels that are more conservative. Finally, the results sometimes show that turning the pumps on and off at the same level comes out to be the most cost effective option, but it is not practical to operate the pump station this way. The difference in cost to have the "off" level ten percent higher than the "on" level (to allow refill to occur) is usually insignificant.

The recommended trigger levels that result in no demand shortages at the lowest average annual cost for the existing pumps are shown in **Figure 7-1**. The results for year 2009 default model demands show that the pumps do not need to be triggered until a water surface elevation of 772 feet is reached, which is low considering the drought conditions experienced thus far in 2009. This is because the default model demands on Lake Georgetown for 2009 are lower than the actual demands experienced up to the end of August 2009. This increase in demand for surface water in 2009 was partially due to unexpectedly low groundwater levels. It is not recommended that the default demands be changed to represent higher demands in 2009 because the demands in the model are based on research from master plans and data from the Texas Water Development Board (TWDB) Region G report that looked at historical trends and population projections. The demand projections should not be influenced by one year of high demands during a drought year. Actual demand data for January through August of 2009 was found to be between the 2010 and 2011 default demands projected in the model; therefore, it is suggested that the results for 2010 and 2011 be consulted when assessing current trigger levels. The BRA may also use the user-defined demand fields and adjust the monthly demand factors to better represent current conditions and then re-run the trigger analysis. Overall, the BRA must choose how inputs, such as demands, should be adjusted to represent current conditions and meet certain factors of safety.

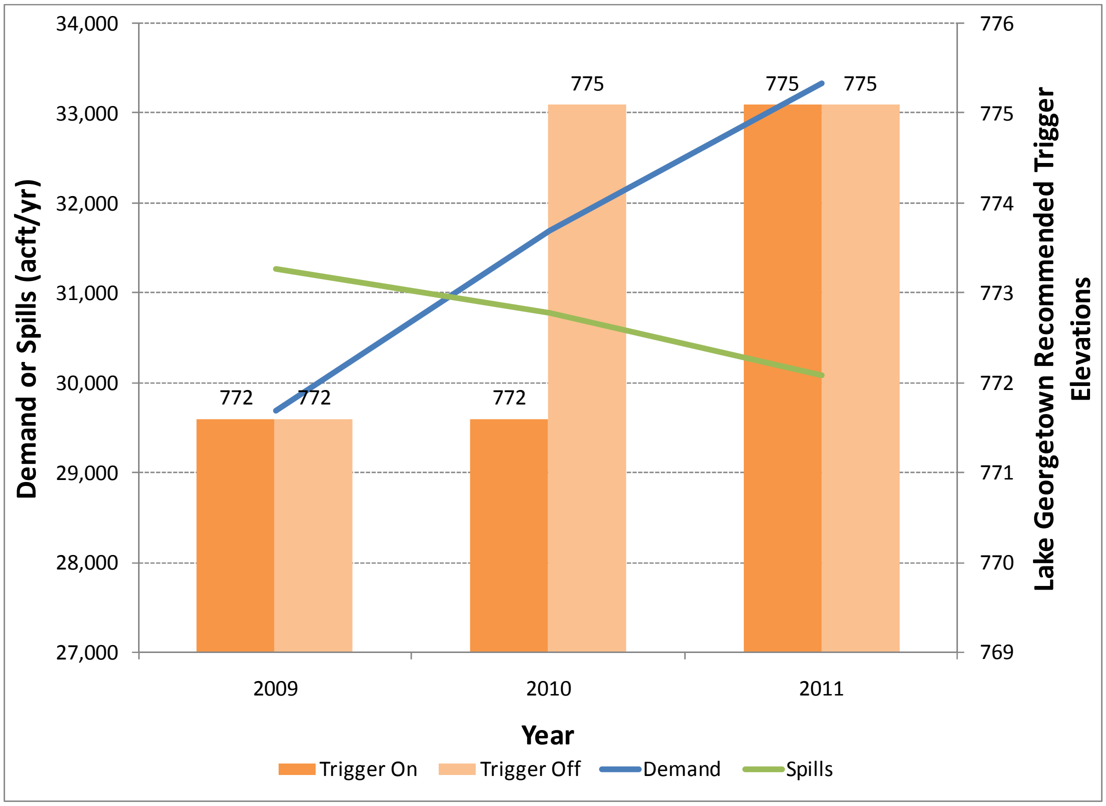


Figure 7-1. Recommended On/Off Trigger Levels and Corresponding Spills in Lake Georgetown given the Existing Pumps (2 Small Pumps)

The recommended trigger levels that result in no demand shortages at the lowest average annual cost for the existing plus proposed pumps are shown in **Figure 7-2**. As demand increases, the trigger levels must increase, because more water needs to be kept in reserve to meet projected demands. It is recommended when planning for future operations to look ahead to future demands for determining appropriate pump trigger levels. The results in Figure 7-2 are based on a long-term simulation that starts the reservoirs at 100 percent full. If the reservoirs are already low when demands start to increase, shortages could occur.

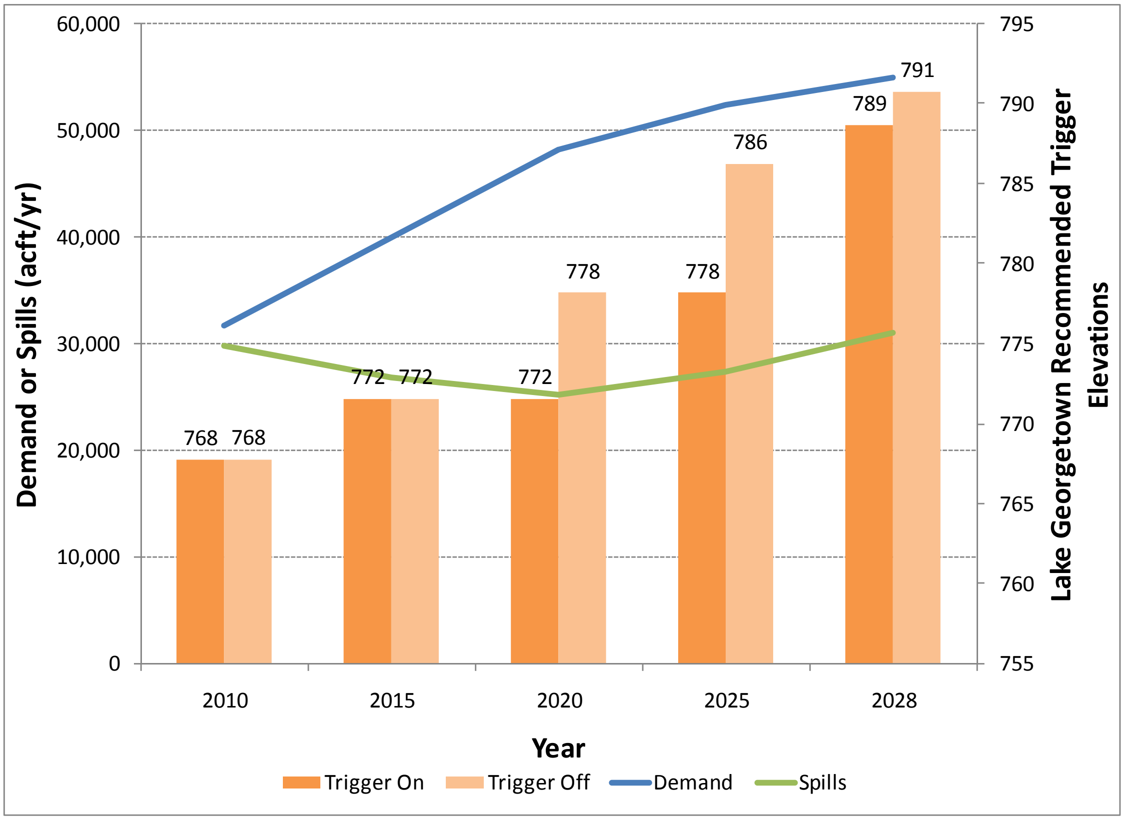


Figure 7-2. Recommended On/Off Trigger Levels and Corresponding Spills in Lake Georgetown given the Existing Pumps (2 Small Pumps) plus the Proposed Pumps (2 Medium Pumps)

7.1.2 Conclusions

The overall recommendation from the trigger level analysis is that pump operation levels should be set based on looking ahead at future demands and what is operationally feasible. As demand increases, the water surface elevations in the reservoirs must be kept at a higher level, and the BRA must plan ahead so that the volume available does not fall behind demand. The results also show that once the medium pumps are installed, it should be possible to keep the Lake Georgetown reservoir at a lower level since the bigger pumps are able to pump the volume needed faster, keeping up with demand. This should also reduce losses due to evaporation.

These models provide guidance on what levels are optimal given demand and available pump configurations using the trigger analysis tool in the Planning Simulation Model. Note that this analysis tool only looks at trigger levels in increments of 10 percent of available volume. A more detailed analysis can be performed by the BRA to determine optimal levels more accurately for their particular situation. Again, these results are offered more in the interest of illustrating potential uses of the model than of providing firm guidelines for current operations. They are conditioned on one set of assumptions, and the BRA may wish to examine broader ranges of future conditions and constraints.

7.2 Total Energy Costs

Total energy costs were compared for the two operating strategies and for the three cost structures available in the model. The purpose of this analysis is to determine if and when it may be economically advantageous to run certain pump configurations at certain times given different cost structures. The operating strategies as described in **Section 5.3.3.2** are as follows:

- Operation Strategy 1: Pump configurations run continuously for the number of days per month necessary to transfer the required volume of water.
- Operation Strategy 2: Pump configurations run intermittently for the number of hours necessary each day to transfer the required volume of water for the month. The total hours required in the month are distributed evenly to each day in the month.

Operation Strategy 2 attempts to take advantage of running the pumps during the hours of the day when the energy charges are at a minimum given a variable rate energy cost structure. The three cost structures evaluated are described as follows:

- Fixed: This is a constant rate cost structure.
- Market Clearing Price for Energy (MCPE): This is a variable rate cost structure based on market prices. Since these values cannot be predicted, they are modeled based on an analysis of MCPE rates over the last three years.
- Day/Night: This is a variable rate cost structure that includes two rates: one for day time (high cost) usage and one for night time (low cost) usage.

Note that these cost structures only affect the energy charges and not the utility charges. The total energy cost is the sum of energy charges and utility charges. The energy cost structures are described in more detail in **Section 5.4**. Also, these results are only based on using the batch mode in the Planning Simulation Model.

7.2.1 Results

Without having actual rates based on quotes from power companies for the Fixed and Day/Night cost structures, a direct comparison of costs from model results does not have much meaning. Instead the models were used to determine what Fixed rate or Day/Night rate would result in a lower cost compared to the MCPE, which is the cost structure that the BRA currently uses. Also, the operation strategies within each cost structure were compared to determine if Operation Strategy 2 had a significant effect on cost within each structure.

For the Fixed and Day/Night structures to be comparable to the MCPE structure, the rates would need to be approximately equal to or less than

- $0.054 /kWh for the Fixed cost structure and

- $0.076/kWh for the day rate and $0.031/kWh for the night rate for the Day/Night cost structure.

It is important to note that these are approximate values since every scenario run in the models can have slightly different results depending on the inputs set by the user. Also, the MCPE is based on the three years of historical rates and not actual market values. These values can be used for guidance purposes if the BRA is considering changing their cost structure, but it is recommended that the BRA experiment with different cost rates for the Fixed and Day/Night structures under different model conditions to determine an appropriate range of rates that are comparable to the MCPE.

Operation Strategy 2 was found to decrease costs when demands are low and the available pumping capacity is high for the variable rate cost structures. The annual cost savings for Operation Strategy 2 is at most 5 percent using the MCPE cost structure. As demands increase and pumping is required continuously during an entire timestep, the difference in cost between Operation Strategy 1 and 2 becomes negligible or zero. **Figure 7-3** shows the cost savings between using Strategy 2 versus Strategy 1 for each demand year analyzed. These results are based on the trigger levels determined in the previous analysis and using the batch mode for 5-year increments with the lake levels starting at 100 percent full.

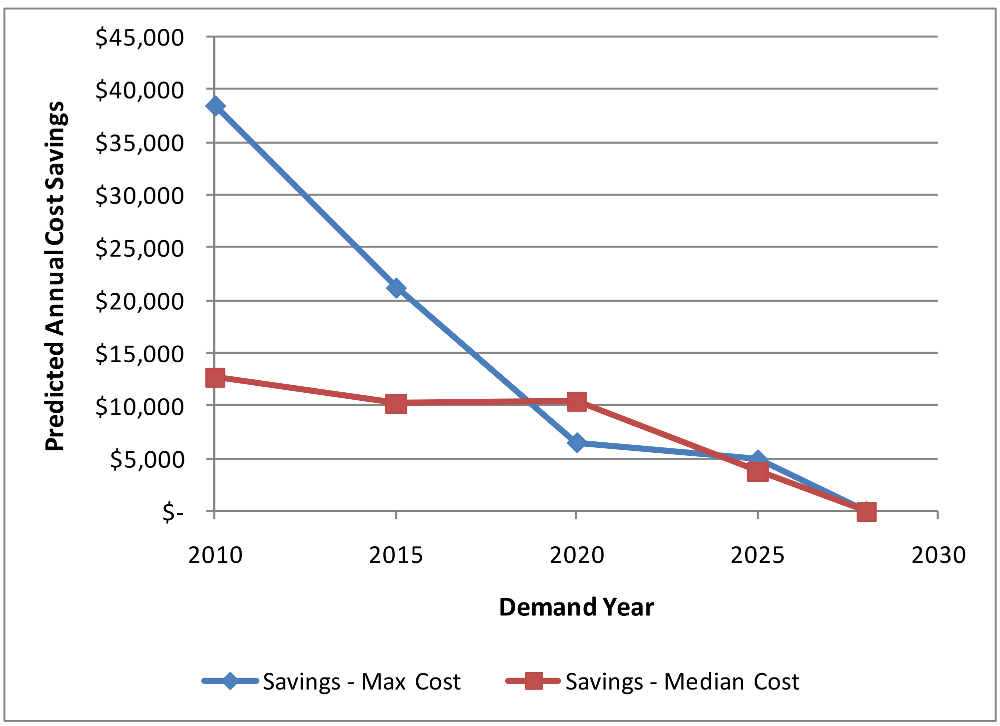


Figure 7-3. Predicted Annual Costs Savings of Operation Strategy 2 Over Operation Strategy 1 for the MCPE Cost Structure

An additional analysis was conducted to determine if using the medium pumps (Phase 2 pumps) when initially installed would be more cost effective compared to using the small pumps, since it would take less time to transfer the water needed using the medium pumps. For the modeled pump configurations, more energy will always be required to transfer the same volume of water using a configuration that uses more power, and the medium pumps require more power. A configuration that uses more power can move the water faster; therefore, it could be advantageous to use a higher power configuration during times when energy costs less. On the other hand, using more power increases the utility charges, and that increase will remain in the total cost for 12 months regardless of whether or not the BRA uses less power during that time.

Given the historical MCPE values used in these models, the results of this analysis show that it is unlikely that it will be economically feasible to use a higher power configuration to transfer the amount of water that could be transferred using a lower power configuration. Using the Day/Night cost structure, it was possible to determine what rates may result in lower costs for using a higher power configuration. It was found that the night rate has to be extremely low compared to current market rates to achieve any savings. Additionally, there are only a few scenarios for which savings are achieved even with a low nightly rate. This analysis assumed Operation Strategy 2 is being utilized and only year 2010 demands. Operation Strategy 1 and larger demands would only decrease any savings.

7.2.2 Conclusions

One conclusion of this analysis is that some savings can be achieved using Operation Strategy 2, but they may be small. Specific scenarios should be analyzed separately and as needed to determine if the predicted cost savings are worth pursuing. The Operations Optimization Model would be more effective in the short-term for specific analyses since it requires more specific information on current demands and forecasted hydrology. Another conclusion is that the BRA is not likely to achieve savings by running a higher power pump configuration for a shorter time compared to running a lower power configuration for a longer time. The lower power pumps are generally preferred if they can achieve the required transfer volume.

Note that the above analyses are provided principally as examples of the model utility, but they may also provide some guidance based on the stated assumptions and current conditions. Since some conditions are always changing, it is important to always keep the models updated based on the latest conditions. Both models provide many options for adjusting conditions in order to keep the models current. The BRA may also want to re-considered or vary the assumptions to understand the sensitivity of the model results to certain parameters.

APPENDIX A

Pipe Friction Factor,
Pump Analysis for Williamson County,
Regional Raw Water Line

Memorandum

This document is released for the purpose of interim review under the authority of Allen Woelke, P.E. No. 54386, on September 4, 2009.

To: *Engineering Services Manager, Brazos River Authority*

From: *CDM*

Date: *May 21, 2009*

Subject: *Pipe Friction Factor,*
Pump Analysis for Williamson County
Regional Raw Water Line

The Brazos River Authority (BRA) operates a 28-mile, 48-inch diameter raw water pipeline from Lake Stillhouse Hollow in southern Bell County, TX, to Lake Georgetown in central Williamson County, TX, and a raw water pump station at Lake Stillhouse Hollow that delivers contracted raw water for the City of Georgetown, City of Round Rock, Brushy Creek MUD, Chisholm Trail SUD and Jonah SUD from Lake Stillhouse Hollow to Lake Georgetown. This system of pump station and pipeline, collectively known as the Williamson County Regional Raw Water System (WCRRWS), was initially put into service in early 2006. The existing total pumping capacity of 30,106 ac-ft/yr is achieved using two existing vertical turbine pumps. There are six pump positions in the raw water pump station for BRA on the north side of the pump station. There are four positions available for Central Texas Water Supply Corporation (CTWSC) on the south side of the pump station.

It is apparent based on current lake levels in Lake Georgetown and mathematical modeling of the demands and the Lake Georgetown and WCRRWS System that existing usage requires expansion of the pump station to deliver enough water from Lake Stillhouse Hollow to Lake Georgetown to meet the current and future water demands placed on Lake Georgetown.

An evaluation of projected demands was conducted and was summarized in a separate technical memorandum. This technical memorandum describes the work conducted and the methodology used to determine a friction factor for the pipeline and the size of the next pumping increment for the raw water pump station. The original design concept for the WCRRWS was for it to deliver 43,481 ac-ft/yr. Through additional agreements, the amount of water that must now be transferred by 2075 is 61,121 ac-ft/yr.

Using the field determined friction coefficient a system curve for the pipe system is calculated. Following determination of the system curve for the pipeline system, pump selections are discussed. As discussed with BRA, the addition of pumping equipment for a 20-year life is reasonable, and based on the projected demands, this future pumping rate would be between 42,000 and 45,000 ac-ft/yr. Finally, the pressure in the pipeline due to future pumping is determined and compared to the rated capacity of the pipeline.

Friction Factor Determination

Determining the friction factor of the existing pipe is important because with a 28-mile pipeline using an estimate that does not accurately reflect the actual condition could result in pump selections that are incorrect. Also, the increase in design flow from 43,481 ac-ft/yr to 61,121 acre-ft/yr may not be feasible if pipe friction is too large. To accurately determine the pipe friction factor, a plan was prepared where flow measurements would be taken from an existing flow meter at the WCRRWS pump station and pressures would be taken at various points along the 28-mile pipeline. A description of the testing program and how the data was used to calculate a friction factor is described below.

Pressure Readings

From October 14, 2008, through May 15, 2009, CDM took pressure readings along the 48-in raw water pipeline and analyzed them with measured flows for the purposes of determining the friction headloss characteristics of the pipeline.

It was important that pressure readings were taken at points that would be free from interference from accumulated air, experience full pipe flow, and sampled a significant portion of the pipe. A ground profile is shown in **Figure 1**. Pressure measuring recorders were installed at the air relief valve manholes at STA 37+00 and STA 489+00. These locations were selected because we believe these locations will always experience full pipe flow because of the control elevation of 932 ft at STA 903+20 and the ability to retrofit the 8-in air valve for the pressure gauge.

For what is referred to as Series 1, pressure readings were taken October 14, 2008, through November 17, 2008, by two Telog HPR-31 Data Recorders at Stations 37+00 (elevation 682.29 ft) and 489+00 (elevation 756.72 feet) along the raw water pipeline. Series 1 sampled 45,200 feet of the 147,700 foot long pipeline. The recorders were attached to a 21-inch standpipe connecting to the line, which was secured inside a vault. The recorders were left to record for approximately one month, while the pump station alternated between one and two active pumps. Pressures were recorded every ten seconds and then averaged over a 15-minute period continuously for one month. Data was removed from the recorders by a local connection approximately every week while two pumps were running and every day while one pump was running. (A laptop was taken to the site and connected by a specialized computer cable to download the information directly onto the computer).

The piping in the air relief valve manholes was modified to allow continuous measurement of pressure while allowing the air relief valves to function normally. A photo of the pressure gauge piping arrangement is shown in **Figure 2** and a diagram of the recorder is shown in **Figure 3**.

Data for the flow through the pipe and the pressure at the Stillhouse Hollow Pump Station was provided by the BRA.

Using the flow data provided by BRA and the data gathered from Stations 37+00 to 489+00, preliminary calculations indicated that the friction factor for this section of the pipe was 114. Knowing that the friction factor value should range between 130 and 140, this value was unrealistic. It was determined that there must be issues in the section of pipe tested so additional pressure gauges were needed to isolate the section of the pipeline to which the problem was most prevalent.

For Series 2, Ashcroft Grade 2A pressure gauges were installed at stations 37+00 and 489+00 following the removal of the Telog Data Recorders. Additional Ashcroft pressure gauges were added to Stations 774+39, 1072+01, 1377+35, and later station 92+57.37 as shown in **Figure 4**. These newly installed gauges, along with previously installed BRA gauges at Stations 136+09, 251+00 and 358+50, were monitored and at least four pressure readings were taken over a five-month period.

These readings from the Series 2 gauges confirmed that something was happening within the first 13,600 feet of the pipeline that was creating significantly more headloss in this segment than in other segments. Based on the readings, the portion of the pipeline containing the pressure gauges was divided into three areas of calculated friction coefficients. The overall weighted average C-factor was 143 from STA 37+00 to STA 1377+35.

Friction Coefficient Determination

Using the measured pressures and flow information provided by BRA, the friction factor was calculated with two methodologies used for characterizing pipe friction headloss -- the Darcy-Weisbach equation and the Hazen-Williams equation.

Pressure pipe flow can be classified as laminar, critical zone, transitional or turbulent. The main difference between the classifications is in how friction develops between the flowing water and surrounding pipe wall. The characterization of headloss using a single friction factor, such as the Hazen-Williams C-value, requires fully-developed, turbulent flow, and is based on an empirical formula developed at smaller pipe diameters and velocities. Another method for headloss determinations is using the f-factor from the Darcy-Weisbach methodology. The difference between these two methodologies is primarily how the pipe friction headloss is predicted to vary as a function of the velocity head.

Figure 5 shows the Moody Chart, which characterizes pressure pipe flow into the different possible flow regimes. Figure 5 also shows the flow ranges that occurred during the test conducted by CDM in October through November 2008. Figure 5 indicates that tests for which only one pump was active and tests for which two pumps were active did not develop into fully turbulent flow, although they were along the transitional/wholly turbulent border. Since the tests fell along the border either a Darcy-Weisbach or Hazen-Williams friction coefficient could be calculated from the data collected. It was decided that the Hazen-Williams methodology would be used.

Table 1 summarizes the Hazen-Williams C-factor analysis for Series 1 test results for the portion of the pipeline between STA 37+00 and STA 489+00, **Table 2** shows the calculations for the different sections of pipeline using the Series 2 data.

Based upon a review of the test results and pipeline profile, CDM believes that the segment of pipe from stations 136+09 to 1377+35 produced the most reliable results, as well as it was the longest portion tested. The C-value was between 145 and 153, with the weighted average of the line calculated at 141. A design C value of 140 was used. **Figure 8** shows the locations of the measured C values.

System Curve

After the friction coefficient was determined, a system curve graph was developed using the C value of 140 and the pipe profile. Important in the pipe profile is the controlling high point along the pipeline, 932 ft at STA 903+20 and 886 ft at STA 1439+00. Depending on the flow and hence the energy and hydraulic grade line slope, one of these high points controlled the development of the system curve. A single curve using the highest elevation as the control point for that segment was created. For flows up to 20,000 gpm, the control point of 932 ft at STA 903+20 was used. For larger flows, the control point of 886 ft at STA 1439+00 was used. This combined curve for minimum, normal and maximum water elevation levels plus the pump system curve (adjusted for the headloss in the pump column and control valve) can be found in **Figure 6**.

The pressure in the pipeline caused by the increased pump head was another point of concern, so a pressure chart comparing the pipes pressure rating with the calculated pressure in the pipe was constructed to determine whether the pressure was within the pressure rating of the existing pipeline. The results of this analysis can be found in **Figure 7**.

From these system and pressure curves, determinations were made on the needed pump capacity and head to maintain the required contractual service. Two future flow values, 26,955 gpm (43,481 acre-ft/yr) and 37,890 gpm (61,121 acre-ft/yr), were evaluated and used as the criteria.

Results

Using the portion of the pipeline from stations 136+09 to 1377+35 and a design C value of 140 for the evaluation, it was determined that the two pumps currently in operation at Stillhouse Hollow would not be sufficient to handle the future increased capacity. After reviewing the details, two pumps with a capacity each of at least 14,000 gpm at 525 feet of head would be necessary to continue to run at the proficient operating levels. This would give the pump station a firm capacity of approximately 27,000 gpm at 490 ft adjusted head.

It was determined that all sections of the pipeline would be able handle the pressure caused by the increase in capacity to 26,955 gpm, as well as be able to handle the pressure created by the contractual future flow of 37,890 gpm which will be reached sometime after 2075.

Summary

Using the design C-factor of 140, it is recommended adding two new pumps with a larger capacity at a higher head to be able to deliver the required 43,481 ac-ft/yr. For future assessment, it was predicted that the continued growth of the Williamson County area would require the system to handle a pump flow of 37,890 gpm but not until after the year 2075. With the current and recommended pumps, this goal would not be reached.

The pipeline testing demonstrated that something happened in the first 13,600 feet that needs to be investigated. The unexpected results lead us to believe there could be biological growth occurring along the inner wall as experienced in other raw water pipelines. A physical inspection of the line would need to be completed to see the type and extent of the problem. Installing a pig launching system or a chlorimination system could keep the line free of growth in the future. These control techniques will be discussed further in another technical memorandum.

The electrical design will also be addressed in a separate technical memorandum.

FIGURE 1 GROUND PROFILE OF EXISTING 48-IN RAW WATER LINE

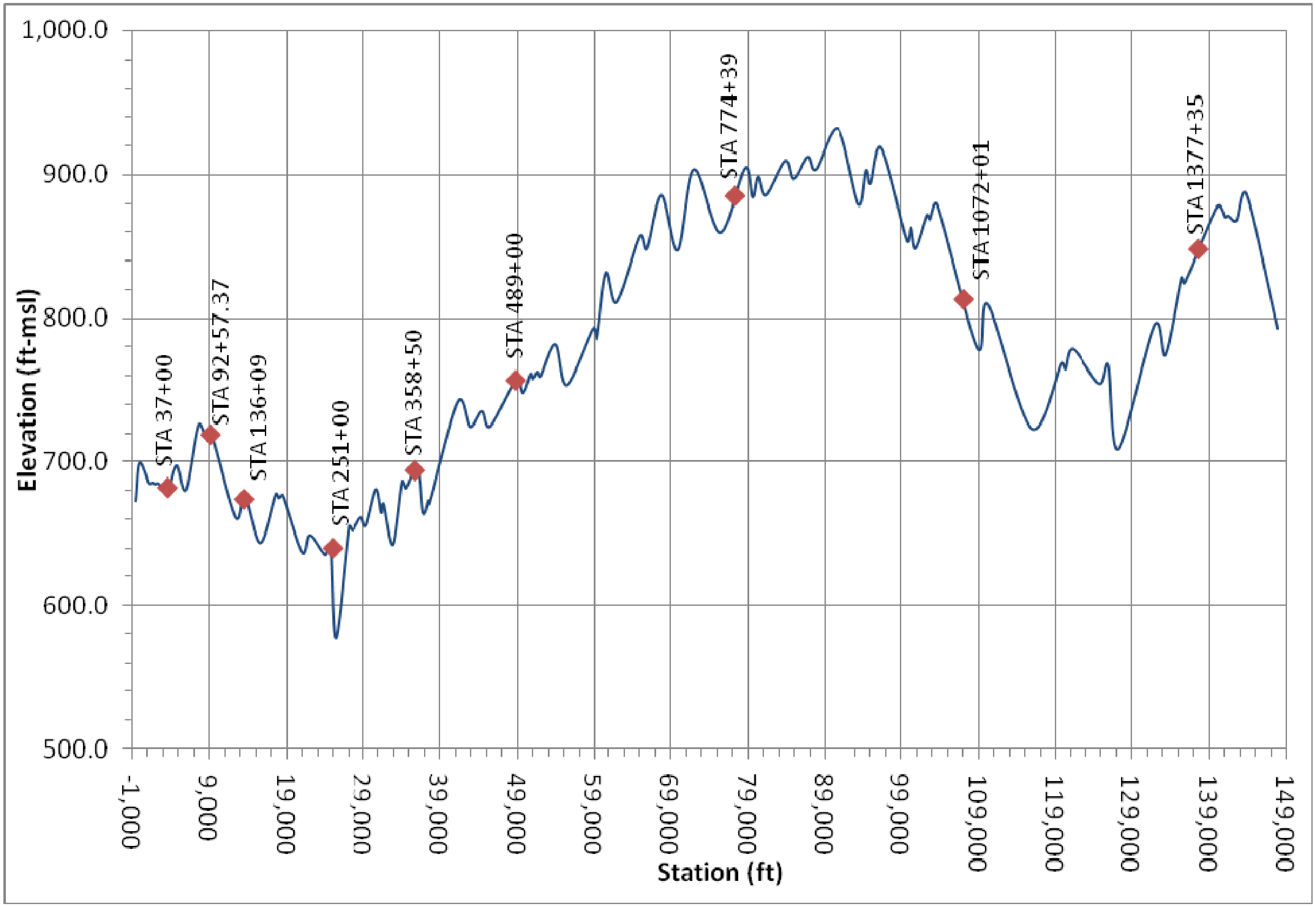


FIGURE 2 PIPING ARRANGEMENT PICTURE

FIGURE 3 TELOG DATA RECORDER DIAGRAM

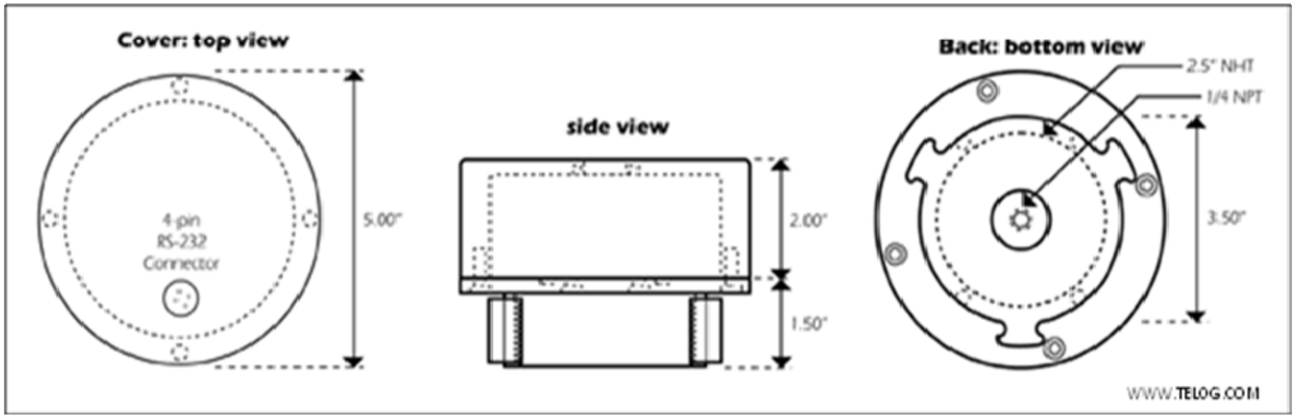


FIGURE 4 ASHCROFT PRESSURE GAUGE

FIGURE 5 MOODY CHART SHOWING REYNOLDS NUMBER, FRICITON FACTOR OF TESTED FLOWS

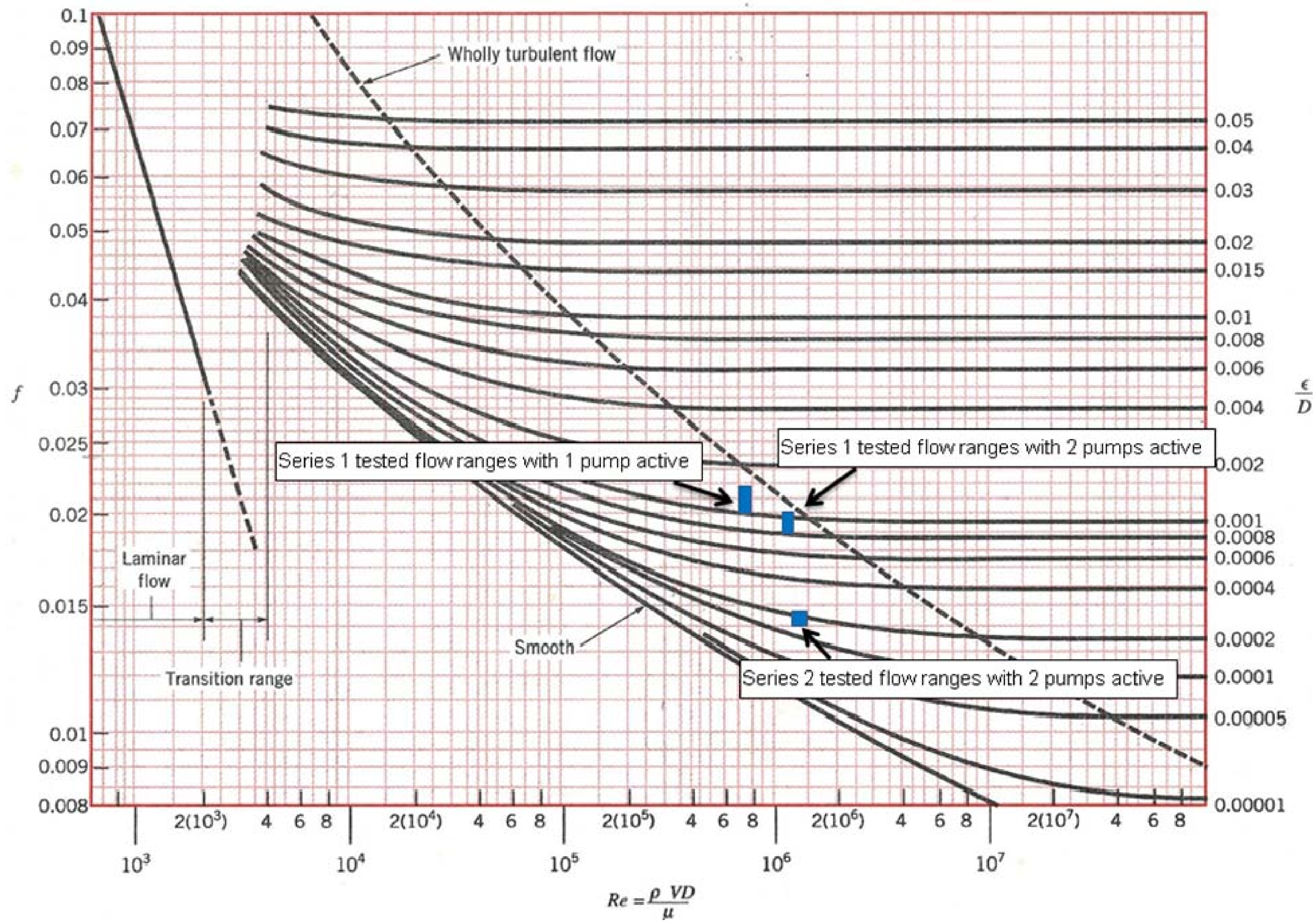


FIGURE 6 PUMP/COMBINED CONTROL POINTS SYSTEM CURVES USING HAZEN-WILLIAMS METHODOLOGY

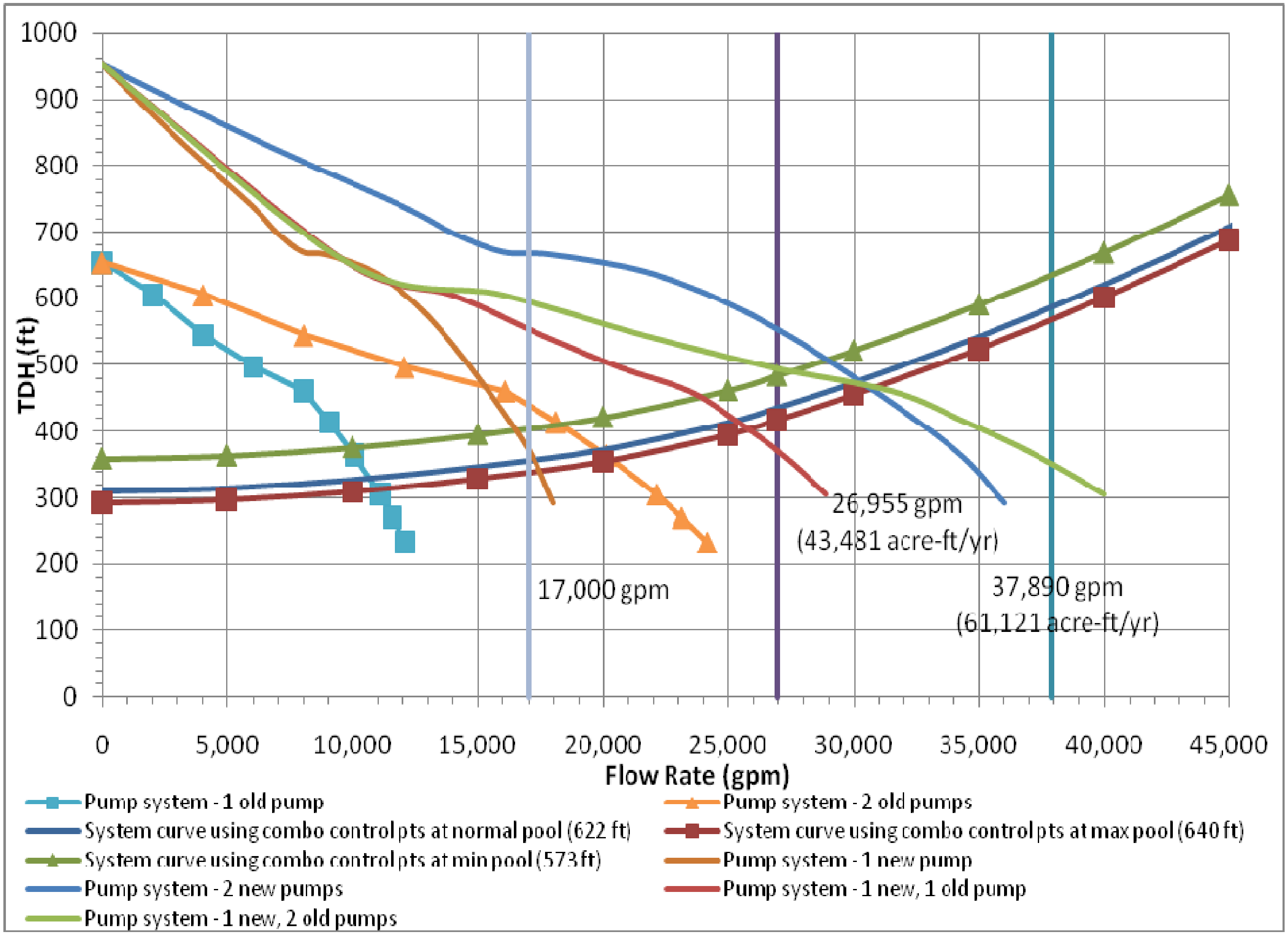


FIGURE 7 PRESSURE RATING/PRESSURE CREATED CURVES USING HAZEN-WILLIAMS METHODOLOGY

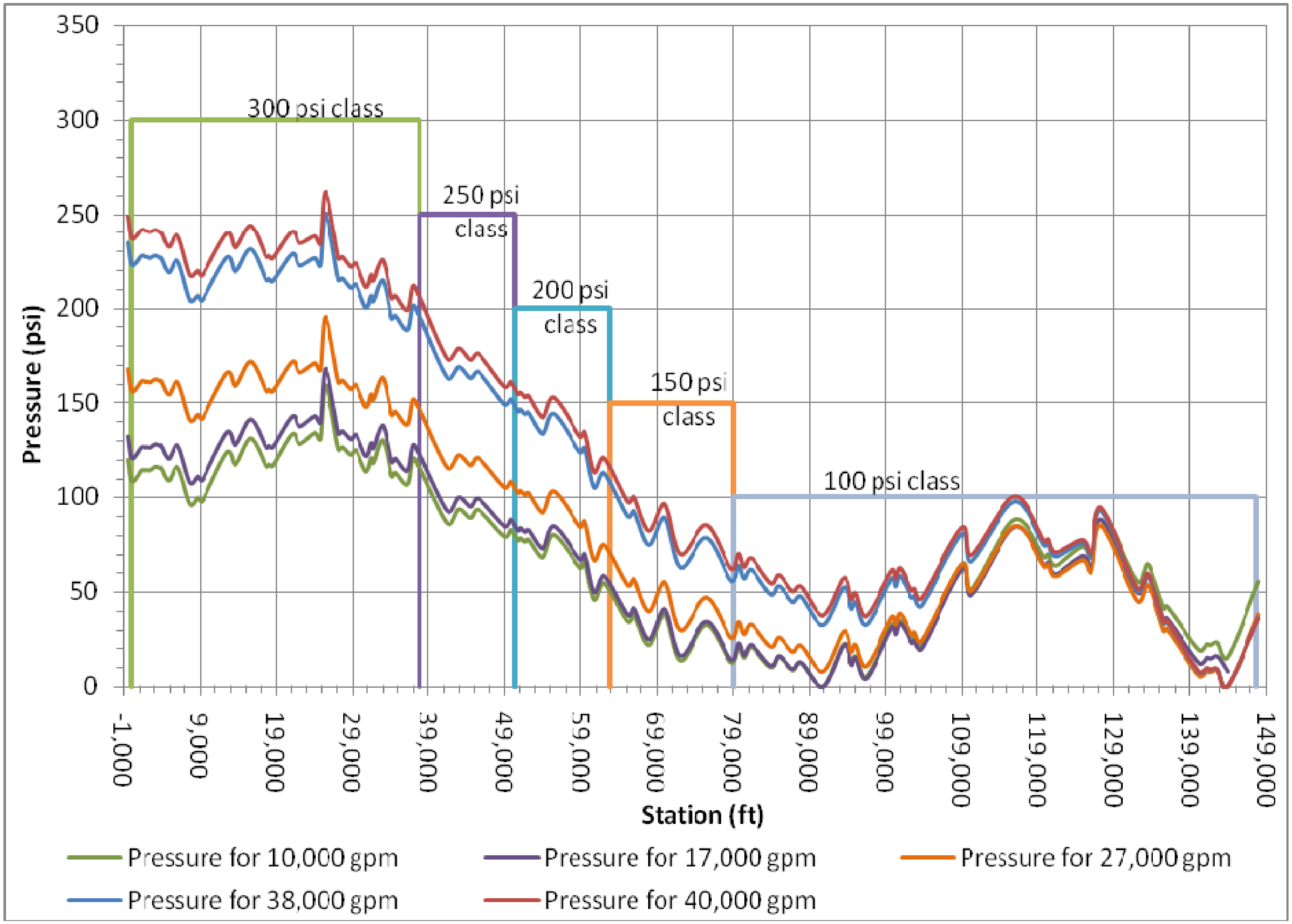


TABLE 1 RESULTS USING THE HAZEN-WILLIAMS METHODOLOGY AND TELOG DATA RECORDERS (SERIES 1)[1]

Date	Pressure, Recorder #2 (psi)	Pressure, Recorder #1 (psi)	Flow in pipe (MGD)	Velocity (fps)	Total Head, Recorder #2 (ft)	Total Head, Recorder #1 (ft)	Slope, Recorder #2 to #1	C
10/14/2008	132.904	83.225	27.241	3.35	988.197	948.43	0.00088	114
10/15/2008	132.941	83.226	27.257	3.36	988.282	948.43	0.00088	114
10/16/2008	132.979	83.221	27.237	3.35	988.368	948.42	0.00088	113
10/17/2008	132.956	83.215	27.210	3.35	988.316	948.41	0.00088	113
10/18/2008	132.960	83.198	27.184	3.35	988.324	948.37	0.00088	113
10/19/2008	132.973	83.173	27.184	3.35	988.355	948.31	0.00088	113
10/20/2008	132.974	83.147	27.168	3.35	988.357	948.25	0.00089	113
10/21/2008	132.998	83.122	27.188	3.35	988.413	948.20	0.00089	113
10/22/2008	132.995	83.090	27.178	3.35	988.406	948.12	0.00089	113
10/23/2008	132.980	83.033	27.107	3.34	988.369	947.99	0.00089	112
10/24/2008	132.967	83.008	27.119	3.34	988.341	947.93	0.00089	112
10/25/2008	132.926	82.981	27.124	3.34	988.244	947.87	0.00089	112
10/26/2008	132.913	82.968	27.124	3.34	988.215	947.84	0.00089	112
10/27/2008	132.996	82.946	27.139	3.34	988.408	947.79	0.00090	112
10/27/2008	111.913	74.160	14.945	1.84	939.48	927.33	0.00027	118
10/28/2008	112.007	74.199	14.593	1.80	939.69	927.41	0.00027	115
10/29/2008	112.057	74.241	14.307	1.76	939.81	927.51	0.00027	113
10/30/2008	111.951	74.251	14.459	1.78	939.56	927.53	0.00027	115
10/30/2008	132.860	83.199	27.150	3.34	988.093	948.37	0.00088	113
10/31/2008	132.305	83.048	27.173	3.35	986.808	948.02	0.00086	115
11/1/2008	132.126	83.017	26.878	3.31	986.390	947.95	0.00085	114
11/2/2008	132.130	83.045	26.731	3.29	986.397	948.01	0.00085	114
11/3/2008	132.189	83.098	26.751	3.29	986.534	948.13	0.00085	114
11/4/2008	132.227	83.147	26.704	3.29	986.621	948.25	0.00085	114
11/5/2008	132.241	83.211	26.678	3.28	986.654	948.39	0.00085	114
11/6/2008	132.273	83.279	26.686	3.29	986.727	948.55	0.00084	114
11/7/2008	132.312	83.378	26.702	3.29	986.817	948.78	0.00084	114
11/8/2008	132.420	83.499	26.671	3.28	987.067	949.06	0.00084	114
11/9/2008	132.517	83.609	26.694	3.29	987.294	949.32	0.00084	114
11/10/2008	132.599	83.713	26.682	3.29	987.482	949.56	0.00084	114
11/11/2008	132.707	83.786	26.668	3.28	987.733	949.72	0.00084	114
11/12/2008	132.803	83.828	26.681	3.29	987.955	949.82	0.00084	114
11/13/2008	132.903	83.859	26.633	3.28	988.185	949.89	0.00085	114
11/14/2008	132.953	83.869	26.662	3.28	988.301	949.92	0.00085	113
11/15/2008	133.009	83.830	26.675	3.28	988.431	949.83	0.00085	113
11/16/2008	133.017	83.809	26.708	3.29	988.451	949.78	0.00085	113
11/17/2008	133.037	83.806	26.731	3.29	988.497	949.77	0.00086	113

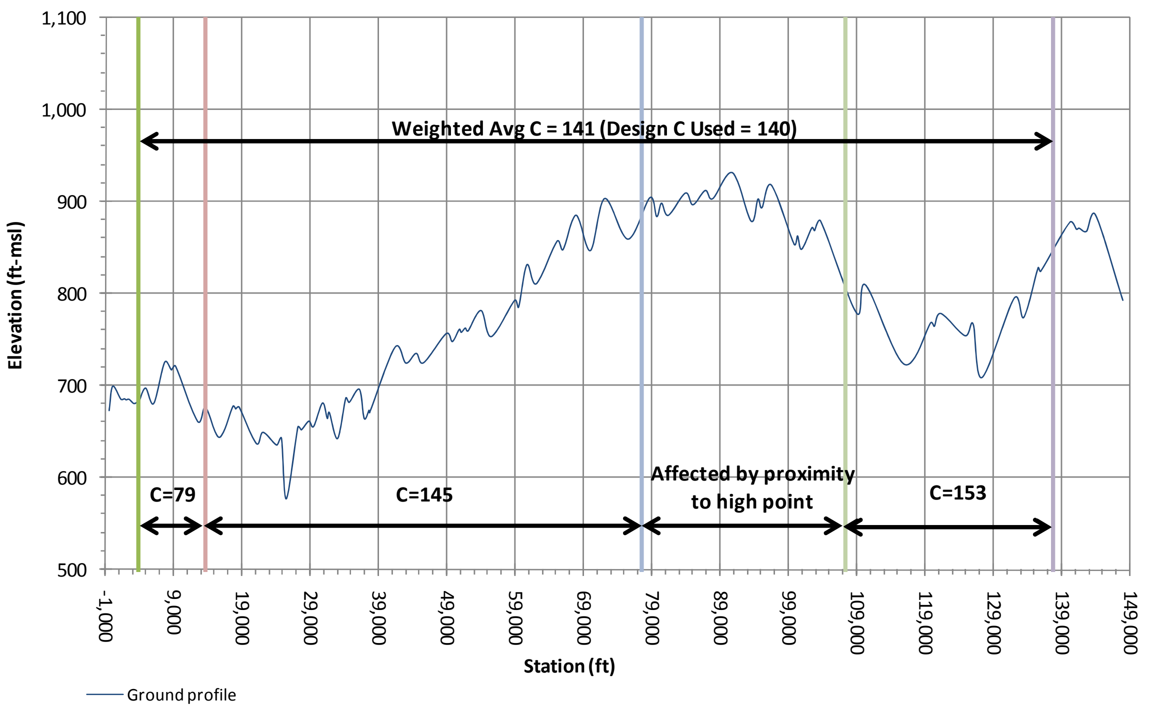
Note: One pump was turned off in the afternoon on October 27 and turned back on the afternoon of October 30. These days are highlighted in the chart. This accounts for the two values on each of these days – one with one pump active and one with two pumps active.

[1] See sample calculations at end of this memorandum.

TABLE 2 RESULTS USING HAZEN-WILLIAMS AND ASHCROFT PRESSURE GAUGES (SERIES 2)

STA	Gauge El (ft)	Gauge Pressure (psi)	Gauge Pressure (ft)	Velocity (fps)	Velocity Head (ft)	Total Head (ft)	Length (ft)	Flow (gpm)	Head (ft)	Hazen's C
37+00	682.29	131.00	302.61	3.40	0.36	985.26				
							9,909	19,165	17.83	79
136+09	676.01	126.08	291.25	3.40	0.36	967.62				
							63,981	19,165	36.71	145
774+39	894.75	15.50	35.81	3.40	0.36	930.91	** Not considered due to proximity to high point at STA 903+20			
1072+01	813.1	37.25	86.05	3.40	0.36	899.51				
							30,534	19,165	15.89	153
1377+35	850.53	14.17	32.73	3.40	0.36	883.61				
								Weighted Average:		141

FIGURE 8 HAZEN C VALUES ALONG PIPELINE



Note: C factors were determined using an average pressure calculated from 3 individual pressure readings.

SAMPLE CALCULATIONS

HAZEN-WILLIAMS METHODOLOGY FOR PIPE SEGMENT BETWEEN 37+00 AND 489+50 (USING TELOG DATA)

Step 1: Determine the total head and slope of the hydraulic grade line from Recorder #2 to Recorder #1.

Total head = Pressure Head + Velocity Head + Elevation Head = P/density + $V^2/2g$ + z

Where:
- P_1 = Pressure at Recorder #2 = 132.904 psi
- Density = Density of water at 76 degrees F = 62.2 lbs/ft^3
- V_1 = Velocity at Recorder #2 (ft/sec)
- z_1 = Elevation at Recorder #2 = 680.33 ft
- P_2 = Pressure at Recorder #1 = 83.225 psi
- V_2 = Velocity at Recorder #1 (ft/sec)
- z_2 = Elevation at Recorder #1 = 755.58 ft
- g = gravity constant = 32.2 ft/sec^2

Q = 27.241 mgd * (1,000,000 gal/1 mg) * (1 ft3 / 7.48 gal) *(1 day/24 hr) * (1 hr/60 min) * (1 min/60 sec) = 42.152 ft^3/sec

$V_1 = V_2$ = Q/A = 42.152 ft^3/sec /(Pi * $(48 \text{ in}/2)^2$ * (1 ft^2/144 in^2)) = 3.35 ft/sec

P_1 = 132.904 lbs/in^2 * 144 in^2/1 ft^2 = 19,138.240 lbs/ft^2
P_2 = 83.225 lbs/in^2 * 144 in^2/ft^2 = 11,984.336 lbs/ft^2

Total $head_1$ = (19,138.240 lbs/ft^2 / 62.2 lbs/ft^3) + $(3.35 \text{ ft/sec})^2$ / (2 * 32.2 ft/sec^2) + 680.33 ft = 988.20 ft

Total $head_2$ = (11,984.336 lbs/ft^2 / 62.2 lbs/ft^3) + $(3.35 \text{ ft/sec})^2$ / (2 * 32.2 ft/sec^2) + 755.58 ft = 948.43 ft

S = Slope of energy grade line = (Total head 1 - Total head 2) / (Distance 2 - Distance 1)

S = (988.20 ft - 948.43 ft) / (48950-3700) = 0.00088

Step 2: Determine the Hazen-Williams Coefficient of Friction for Recorder #2 to Recorder #1.

$V = 1.318 * C * R^{0.63} * S^{0.54}$

Where:
- V = Velocity = 3.35 ft/sec
- C = Hazen-Williams Friction Factor
- R= Hydraulic Radius = d/4 (ft) = (48 in/12) ft / 4 = 1 ft
- S = Slope of energy grade line = (Total head 1 - Total head 2) / (Distance 2 - Distance 1) = 0.00088

C = (3.35 fps) / (1.318 * $(1 \text{ ft})^{0.63}$ * $(0.00088)^{0.54}$) = 114

Step 3: Determine headloss and head for the entire pipeline at given flows.

headloss = 0.002083 * L * $(100/C)^{1.85}$ * $Q^{1.85}/d^{4.8655}$ + (k * $V^2/2g$)

Where:

l = pipe length from STA -4+18 to 1439+00 for 886 ft elevation (ft) = 144,318 ft
C = Hazen-Williams Coefficient of Friction calculated in step 2 = 114
Q = flowrate (gpm) = 10,000 gpm
d = pipe diameter (in) = 48 in
V = velocity at 10,000 gpm (ft/sec) = 1.77 ft/sec
k = constant = 0.23 for 10 fittings in 48" pipeline and 0.12 for 38 smaller fittings in 48" pipeline = 6.9

headloss = 0.002083 * 144,318 ft * $(100/114)^{1.85}$ * $(10,000\ gpm)^{1.85}$ / $(48\ in)^{4.8655}$ + (6.9 * $(1.77\ ft/sec)^2$ / (2 * 32.2 ft/sec^2)) = 39.7 ft

H_{np}= H_s + headloss

Where:

H_{np} = Max head occurring at normal water surface elevation (ft)
H_s = Static Head (ft) = High point (ft) – $WSEL_{np}$ (ft)
High point = Given high point for this segment (ft) = 886 ft
$WSEL_{np}$ = Given minimum water pool elevation (ft) = 622 ft
headloss = Headloss at this flow calculated in step 3 (ft) = 35.4 ft

H_{np} = (866 ft – 622 ft) + 39.7 ft = 303.7 ft

APPENDIX B

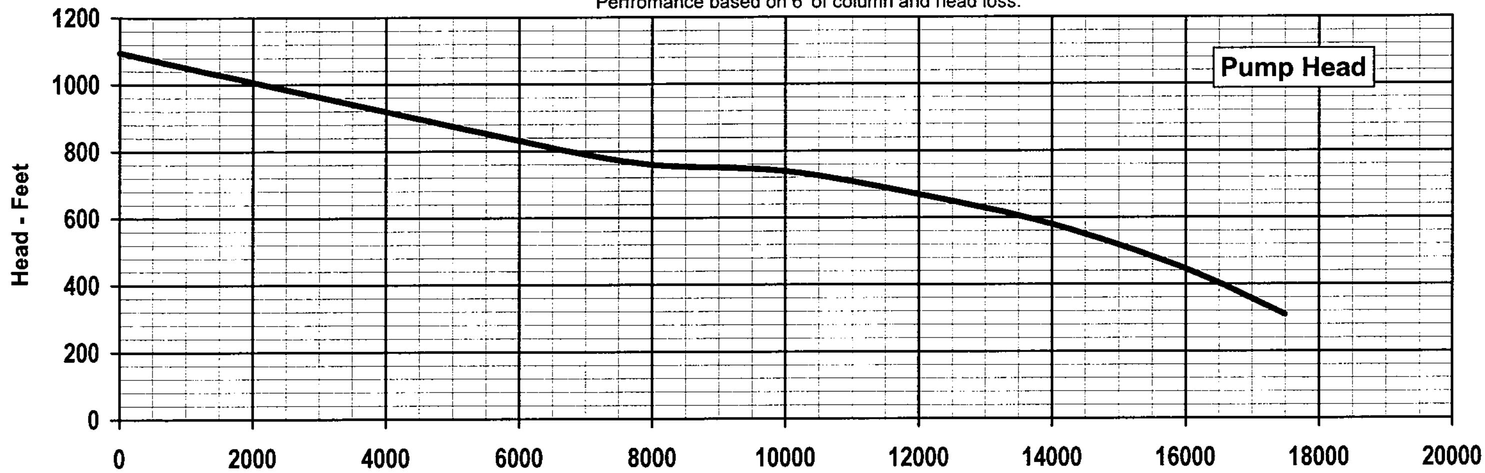
Pump Curves

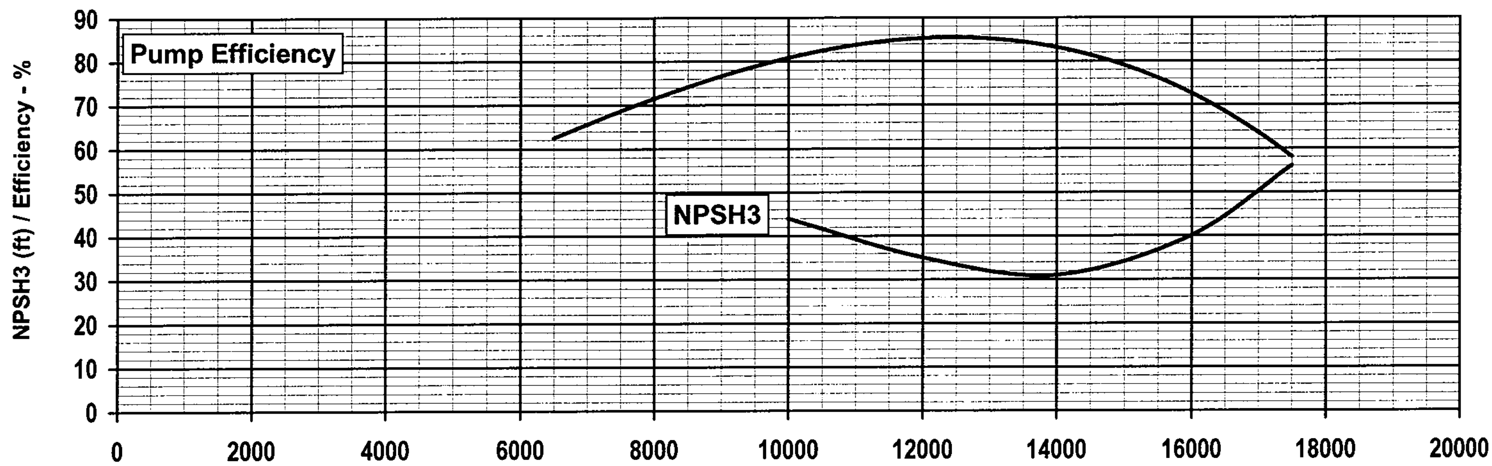
Fairbanks Morse Curves

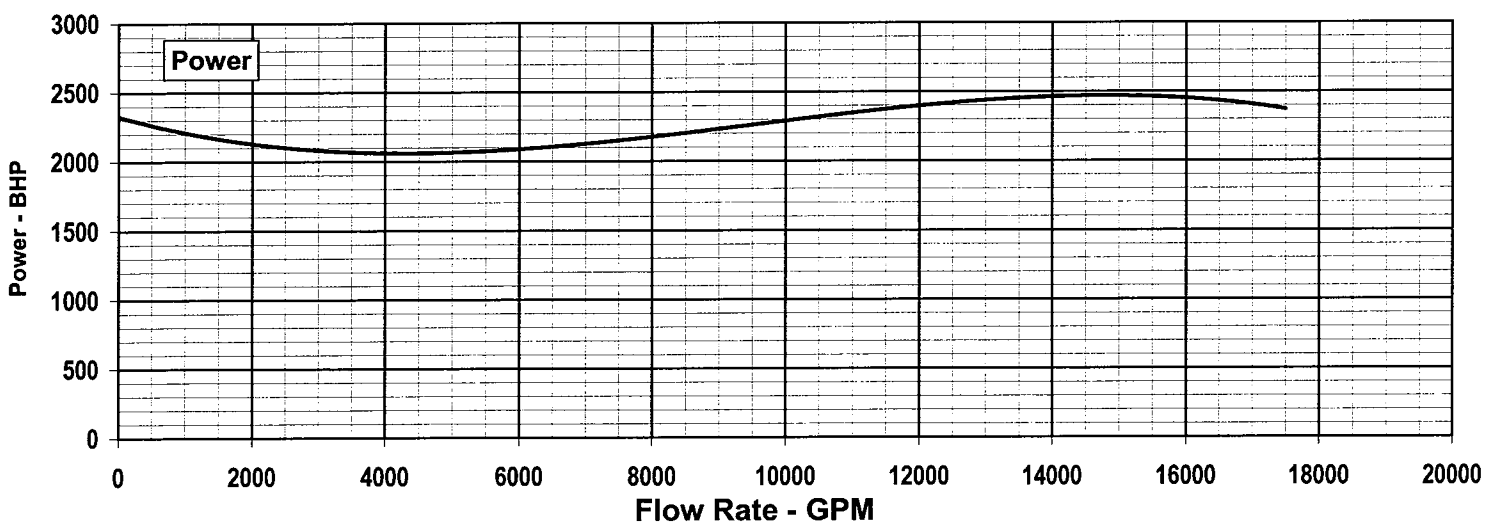
These curves represent the curves used for planning purposes in developing the model.

Fairbanks Morse Pentair Water		31M 7000 SUBMITTAL CURVE						
		SPEED	IMPELLER	DIAMETER	SPHERE	GUARANTEED VALUES		
		1180	STD	18.50	3.25"	FLOW	HEAD	PUMP EFF
		BY	DRIVER	DATE		-----	-----	-----
CURVE NO.:	C-S80708A	SJK	2500 HP	6/3/2009		-----	-----	-----
REV.	5 Stages	THIS CURVE IS BASED ON THE ACTUAL TEST PERFORMANCE OF A SIMILAR PUMP. ONLY THE INDICATED POINT(S) IS GUARANTEED.				-----	-----	-----
PROJECT NO.:	KP-S80708					-----	-----	-----

Perfromance based on 6' of column and head loss.





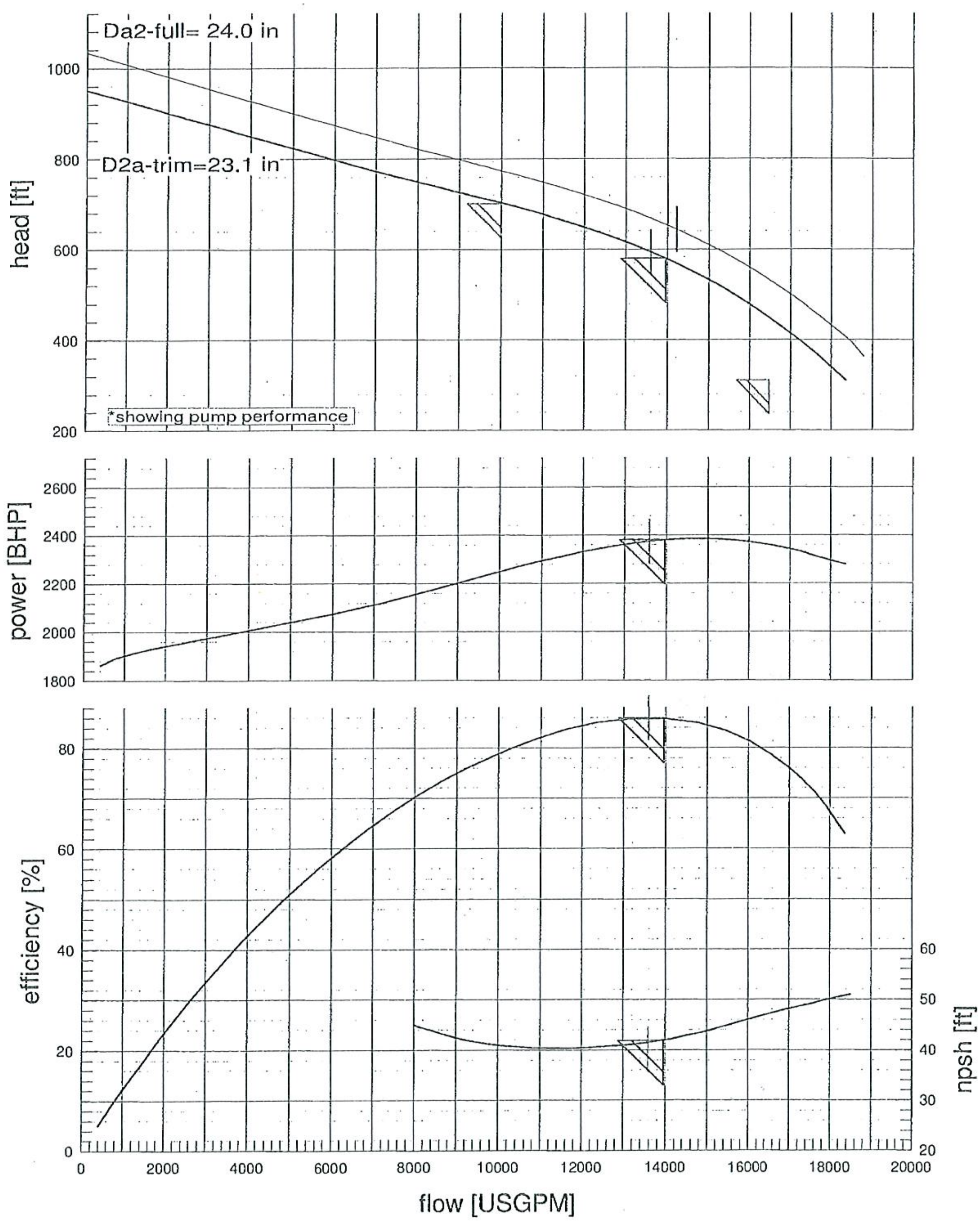


Sulzer Curves

These curves represent the represent the shop drawing curves provided by Sulzer, the company selected to provide the pumps for this project.

Pump type and plant: SJT 30CC-4s Williamson Co. Regional	SULZER

Pump Medium: Water Density: 0.998 S.G. Temperature: 68.00 °F kinem. Viscosity: 1.000 cSt	Shaft speed: 1180 rpm Stage Number: 4 NS: 3111 Basis: SJT TC-10309, TC-8301, TC-14453 (NPSH)	Design Point Flow [USGPM]: 13950 Head [ft]: 580 Efficiency [%]: 86 (pump) Npsh 3% [ft]: 41 Power [BHP]: 2381



Revision:	1	2	3	Drwg No: EPD-4566
Name/Date:	S.Park/14-Aug-09	S.Park/19-Aug-09	S.Park/20-Aug-09	

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Part 2 Instruction Guide

Section 1 Introduction

This instruction guide serves as a user's manual for the Planning Simulation Model and the Operations Optimization Model, which were designed to evaluate various capital improvement alternatives and operating plans of the Williamson County Regional Raw Water (WCRRW) System. This guide is divided into three sections. **Section 1** provides an introduction to the document. **Section 2** supplies guidance for the Planning Simulation Model, which includes three separate simulation modes that are discussed separately. **Section 3** covers the Operations Optimization Model and includes a description and instructions for the Premium Solver Platform add-on to Microsoft Excel.

Each section instructs the user on how to navigate the model, change the model inputs, run the model, and interpret the results. Also included for each model is a list of some key concepts to keep in mind when using the models. It is useful to occasionally look over the key concepts sections to remember some concepts that may not be intuitive or are important for correctly interpreting results. Finally, some example problems are presented at the end of each section with examples of how each model could be used to solve the problems.

It is important to note that this instruction guide provides guidance and examples for executing the models, but it is not a substitute for the training that was provided by CDM to Brazos River Authority (BRA). Rather, it is to be used as a supplement to the training.

Section 2
Planning Simulation Model

The Planning Simulation Model is the principal tool for pump station design and operations planning of the WCRRW System. The model was designed to give the user the ability to evaluate various planning-related activities, such as:

- Selection and phasing of new pumps (accounting for uncertain hydrology and increasing demand)
- Alternative operating rules and/or reservoir targets
- Alternative energy pricing structures
- Alternative water use contracts or projected water use rates

The model consists of three simulation modes that can be used to evaluate the WCRRW System under different conditions and time durations. This section begins with model navigation followed by the global settings that apply to all three simulation modes. Each of the three simulation modes is discussed in later sections.

2.1 Navigation

The model was developed in Microsoft Excel and is contained within a standard spreadsheet workbook. The primary input and output worksheets in the model are described in the OVERVIEW worksheet in the table shown in **Figure 2-1**. From this worksheet, the user can navigate to each sheet by clicking on the name of the simulation mode or model configuration. To return to the OVERVIEW worksheet, the user can click the "Back to Model Overview" link that appears in the upper right corner of each worksheet below the BRA logo.

Simulation Modes	
Long-term	Continuous simulation over period of record (1941-2007) for pump phasing, and capital improvement strategies.
Mid-term	Simulation of 3-60 months for near-term operations and contract planning under specific expected hydrologic conditions.
Batch	Simulation over all 1-5 year historical periods based on current conditions for evaluting system performance under uncertain future hydrologic conditions.

Model Configuration	
Demands	Input projected annual demands and monthly demand factors by customer
System	Set pump configurations, reservoir triggers, pipeline capacity and friction factor, dam leakage
Energy Cost	Set energy cost structures
Reservoirs	Input elevation-area-capacity curves for each reservoir
Hydrology	Input hydrologic time series for each reservoir (inflows and net evaporation)
User Pump Ops	Specify user-defined pump operations for MidTerm or Batch modes (optional)

Figure 2-1. Planning Simulation Model Navigation Table

Alternatively, the advanced user may prefer to navigate by selecting the worksheet tabs at the bottom of the Excel Window once they are familiar with the contents of each worksheet. Table 2-1 provides a description of each worksheet in the model. The input and simulation model worksheets are described in more detail in the following sections.

Table 2-1. Planning Simulation Model Worksheet Descriptions

Worksheet Name	Description	Type
Overview	Overview of model and main navigation table	Navigation, Information
Demand	Annual customer demands and monthly demand factors	User Input
System	System configuration including transfer constraints, pump configurations, operational triggers, reservoir releases	User Input
Energy Cost	Energy cost structure and pricing parameters	User Input
Reservoirs	Elevation-area-capacity curves and conservation pool limits	User Input
Hydrology	Historical and user-defined hydrologic timeseries of inflow and net evaporation	User Input
User Pump Ops	User-defined pump schedule	User Input
LongTerm	Long-term simulation mode ***(CONTINUED)***	Simulation Mode
MidTerm	Mid-term simulation mode	Simulation Mode
Batch	Batch simulation mode	Simulation Mode
Triggers	Operational trigger analysis	Analysis
Param List	Contains all model parameters on one sheet for archiving simulation runs	Reference
Calc_Param	Parameters for calculation (no user input)	Calculations
Calc_Hydro	Hydrologic mass balance and flow calculations	Calculations
Calc_Costs	Energy cost calculation and pump selection	Calculations
Calc_Costs_User	Energy cost calculation for user-defined pump schedule	Calculations
Mid_Period	Mid-term period selection based on hydrologic percentiles	Calculations
Hydraulics	Hydraulic calculations	Calculations
Total_Sum	Total hydrologic fluxes and pump configuration usage	Results
Results_TS	Timeseries of simulation results	Results
Results_Annual	Sum of fluxes by year	Results
Batch_Stats	Frequency distributions of hydrologic fluxes from Batch mode	Results
Batch_Results_Sum	Total fluxes by batch iteration	Results
Batch_ElevRange	Reference elevations for plotting Batch mode results	Results
Batch_Belton	Timeseries of Lake Belton elevation for each Batch iteration	Results
Batch_Stillhouse	Timeseries of Lake Stillhouse Hollow elevation for each Batch iteration	Results
Batch_Georgetown	Timeseries of Lake Georgetown elevation for each Batch iteration	Results
Batch_Granger	Timeseries of Lake Granger elevation for each Batch iteration	Results
Cost_Annual	Total cost by year	Results
Cost_Op1	Frequency distribution of monthly and annual cost for Operations 1*	Results
Cost_Op2	Frequency distribution of monthly and annual cost for Operations 2**	Results
Cost_BoxPlot	Quartiles of monthly costs for box plots	Results
Lists	Reference lists for drop down menus and other calculations	Reference

** Operations 1: Run pumps continuously for n days/month*
*** Operations 2: Run pumps intermittently over the entire month for m hours/day when energy prices are lowest*

2.2 Model Inputs

The Planning Simulation Model has three simulation modes. A series of global settings apply to all three modes, as described below in this section. In addition to the global settings, each of the three modes has its own set of model inputs, which are described in **Section 2.4**.

There are six global settings worksheets for setting up a simulation scenario:

- DEMANDS – Total annual customer demands and monthly demand factors.
- SYSTEM – System configuration parameters for the WCRRW System including pump station configuration of the Lake Stillhouse Hollow pump station (Stillhouse PS), pump curves, the WCRRW Pipeline C-factor, transfer capacities, percent down time of the Stillhouse PS, and operational trigger levels; conceptual transfer Pipeline from Lake Belton to Lake Stillhouse Hollow including maximum monthly transfer capacity, monthly releases from each reservoir, dam leakage, return flow from the City of Georgetown to Lake Granger. Pump curves are for "small," "medium," and "large" pumps. The small pumps represent the existing pumps, the medium pumps represent the proposed Phase II pumps, and the large pumps represent the eventual 5^{th} and 6^{th} pumps to be installed in the Stillhouse PS. For more details on these pump designations, please see **Part 1, Section 5.3.1** of this report.
- ENERGY – Type of energy cost structure (MCPE, Fixed, Day/Night) and associated cost parameters such as unit energy and utility charges.
- RESERVOIRS – Elevation-Area-Capacity curves, and elevations denoting the top of the conservation pool, the minimum allowable elevation for withdrawals, and a user-defined custom elevation. This worksheet also includes a reference table for converting between elevation, total volume, available volume and percent available volume.
- HYDROLOGY – Historical hydrologic timeseries for each reservoir, which cannot be changed by user, and a user-defined hydrologic timeseries that may be used in the Mid-term simulation mode.
- USER PUMP OPS – User-defined pump operation schedule for simulating specific operational sequences in Mid-term or Batch modes.

2.3 Calculations

The Planning Simulation Model can be run in one of three modes, as will be described further in **Section 2.4**:

- Long-Term
- Mid-Term

- Batch

Each mode performs the same set of calculations but over different time periods. The Long-term mode simulates the period of record, which is from January 1941 through December 2007. The Mid-term mode simulates a period between 3 and 60 months (5 years) using either historical hydrology or user-defined hydrology timeseries. The batch mode simulates a period between 1 to 5 years in sequential groupings, starting with each year in the period of record. For example, a 2-year batch mode simulation would run every 2-year period in the period-of-record (1941-1942, 1942-1943, 1943-1944, and so on).
Model calculations are primarily performed on the following two worksheets:

- CALC_HYDRO – Hydrologic mass balance, fluxes, transfer logic.

- CALC_COSTS – Energy and utility charges, and pump configuration logic that selects the optimal configuration to meet transfers while minimizing cost. There is a similar worksheet, CALC_COSTS_USER, which performs the same cost calculations for the user-defined pump schedule when selected in the Mid-term or Batch modes.

The three simulation modes each utilize these worksheets to perform the model calculations, which employ standard Excel formulas with the exception of linear interpolations that are calculated using a function written in Visual Basic for Applications (VBA).

Hydrologic Calculations
The hydrologic calculations are based on the hydrologic mass balance equations described in **Part 1, Section 5.1**. For each timestep, the hydrologic fluxes are used to compute an overall mass balance for each reservoir and the total demand satisfied by the system.

Energy Cost Calculations
Energy costs are calculated for each of the three cost structures as described in **Part 1, Section 5.4**. The energy cost calculations are also used to select the optimal pump configuration that meets the transfer while minimizing cost.

Pump Station Operating Strategies Calculations
The operating strategies describe when the pump configurations are turned on and off. The calculations for these strategies only affect the energy cost calculations. The two strategies evaluated in the Planning Simulation Model are:

- Operations 1: Pump configurations run continuously for the number of days per month necessary to transfer the required volume of water.

- Operations 2: Pump configurations run intermittently for the number of hours necessary each day to transfer the required volume of water for the month. The total hours required in the month are distributed evenly to each day in the month.

Details on how the energy charges are calculated for these strategies are provided in **Part 1, Section 5.4.1**.

2.4 Simulation Modes

The Planning Simulation Model can be used in three different modes:

- Long-term Mode – for assessing system performance over the complete hydrologic period of record under various pump station configurations, operational triggers, and customer demands.
- Mid-term Mode – for evaluating system performance over durations from 3 to 60 months for a specific time period to develop operating plans.
- Batch Mode – for generating frequency distributions of reservoir levels, spills, pumping costs, and any demand shortages over short-term periods (1 – 5 years) based on the full range of hydrologic patterns from the period-of-record.

2.4.1 Long-term Mode

The Long-term mode was designed to assess system performance over the period-of-record using user-defined fixed demand levels (historical or projected) and system configurations. The results are summarized as time series and frequency distributions of annual system performance metrics such as reservoir levels, demand shortages, transfer volumes, operating costs, etc. The purpose of this mode is to evaluate the adequacy of pump station configurations and operational trigger levels over the full range of potential hydrologic conditions including the drought of record. The Long-term mode is the principal mode used for design guidance of capital improvements.

2.4.1.1 Inputs

The inputs to the Long-term simulation mode are shown in **Figure 2-2** and described below. These inputs are specific to the Long-term mode, and are used in addition to the global settings discussed in **Section 2.2**.

Simulation Settings			
Simulation Period			
		Start	End
Year		1941	2007
Initial Conditions			
	Elevation (ft)	Total Volume (acft)	% Available Volume
Belton	594	435,225	100
Stillhouse	622	227,825	100
Georgetown	791	36,904	100
Granger	504	52,525	100
Firm Yield Analysis			
	Demand Factor	Annual Avg Demand (acft/yr)	Annual Avg Demand Shortage (acft/yr)
Belton	1.00	87,551	0.0
Stillhouse	1.00	24,489	0.0
Georgetown	1.00	57,997	8,356.8
Granger	1.00	6,149	0.0
Pump Selection Parameter			
Large Pump Flow Multiplication Factor			1.00

Figure 2-2. Long-term Mode Settings

- Simulation Period defined by the Start and End Year
- Initial Conditions defined as the initial water surface elevation of each reservoir.
- Firm Yield Analysis inputs are used to determine the firm yield of each reservoir by varying the Demand Factor for each reservoir. The demand factor is multiplied by the annual demands defined on the DEMANDS worksheet. To determine the firm yield, the user can change the demand factor to find the maximum annual average demand that does not result in any shortages. The Excel goal seek function can be used to automatically seek this value. When not performing a firm yield analysis, the demand factors should be set to unity such that the annual demands defined on the DEMANDS sheet are used in the simulation.
- Pump Selection Parameter is used to alter the large pump curve to aid the user in pump selection for the large pumps, the 5th and 6th pumps to be installed in the Stillhouse PS. To begin this evaluation, an actual pump curve obtained from a manufacturer should be used to define the large pump curve on the SYSTEM worksheet. This can be a new curve or the curve for the medium pumps can be copied over to the large pump table. Note that minor head losses in the pump station should not be included in the pump curve, as they are accounted for by the model on HYDRAULICS worksheet. To increase the capacity of the large pump, the Large Pump Flow Multiplication Factor is multiplied by each flow in the large pump curve defined on the SYSTEM worksheet (e.g. a factor of 2.0 would double all flows in the pump curve). The head is adjusted based on the affinity laws, which relate flow to impeller diameter ($Q \alpha D$) and head to the square of the impeller diameter ($h \alpha D^2$). Therefore, each head value in the pump curve is multiplied by the square root of the Large Pump Flow Multiplication Factor. The result is an approximate pump curve that can be used in the model and adjusted until desired conditions are met. When the user does not want to alter the size of the large pumps, this factor should equal unity so that the pump curve defined on the SYSTEM worksheet is utilized by the model.

2.4.1.2 Calculations

The Long-term simulation runs the hydrologic mass balance and energy cost calculations for each month beginning in January of the Start Year through December of the End Year.

The Long-term mode can be used to determine the optimal trigger levels for transferring water from Lake Stillhouse Hollow to Lake Georgetown for a specific set of annual demands and pump station configurations. Ideally, the trigger levels are set to minimize both pumping costs and reservoir spills while ensuring the absence of shortages in either reservoir over the period-of-record, which includes the drought-of-record. Any trigger level that does not result in shortages in the Long-term mode would be expected to suffice for developing operation plans.

A VBA macro was developed to automate the process of searching for the optimal set of trigger levels for a given scenario. This macro can be run by clicking the **Go To Trigger Analysis** button at the top of the Long-term mode worksheet. After clicking the **Run Trigger Analysis** button on the TRIGGERS worksheet, the model will run the Long-term mode simulation iteratively, adjusting the On and Off trigger levels for Lake Georgetown sequentially in 10 percent increments from 0 to 90 percent. The results of each on/off trigger level combination are copied to a table on this worksheet and are plotted to show the average annual shortages, spills, and costs. The x-axes on these plots are labeled as XX_YY where XX is the On trigger and YY is the Off trigger, both in percent available volume. The user can also scan the table below these graphs and identify the trigger level combination with the lowest cost and least spills that does not result in any shortages. The combinations without any shortages are automatically highlighted in yellow.

2.4.1.3 Outputs

Output from the Long-term mode includes:

- Timeseries of Percent Available Volume in each reservoir, monthly volume transferred through the WCRRW Pipeline, and annual average operating costs.
- Annual average fluxes through each reservoir and total changes in storage in each reservoir, which are both used to calculate the overall mass balance, which should always be zero.
- Summary of pumping costs by month, and a plot of pump configuration utilization in terms of percent simulation time that each pump configuration is used.
- Series of timeseries and frequency distributions of total reservoir volumes
- Series of timeseries and frequency distributions of water surface elevations in the four reservoirs
- Timeseries of monthly transfers via the WCRRW Pipeline and the Belton-Stillhouse Line
- Timeseries of annual demand shortages in each reservoir
- Timeseries of pump configuration used for each month

- Timeseries and frequency distribution of annual operating costs
- Timeseries of cost savings for using Operations 2 vs. Operations 1
- Box plots showing the distribution of operating costs by month of the year for Operations 1 and Operations 2

2.4.2 Mid-term Mode

The Mid-term mode is intended for operational guidance, and as a way to re-affirm design and operational plan decisions. This mode is used to assess system performance over planning horizons between 3 months and 5 years. When a future forecast can be made with some confidence (for example, current trends suggest that the next year may be expected to be relatively dry or relatively wet) the user can run a single mid-term simulation for pre-defined representative dry, normal, or wet conditions based on the historical record. The output can be used for mid-term operational planning (especially for droughts) based on the specified initial conditions.

2.4.2.1 Inputs

The following inputs are specific to the Mid-term mode, and the model uses them in addition to the global settings discussed in **Section 2.2**.The inputs to the Mid-term mode are shown in **Figure 2-3** and include:

Simulation Settings			
Simulation Period			
		Duration (3 - 60 months)	60
Initial Conditions			
	Elevation (ft)	Total Volume (acft)	% Available Volume
Belton	594	435,225	100
Stillhouse	614	180,935	74
Georgetown	776	20,546	43
Granger	504	52,525	100
Pump Operations			
		Pump Operation Logic	User Defined
Hydrologic Period			
		Hydrologic Data Source	Historical
		User Defined Start Month	June
Historical Inflow and Evaporation Periods			
		Inflow	Net Evap
	Period Selection Method	Percentile	Percentile
	Percentile	0%	100%
	Choose Percentile Start Month	Selected	Selected
	Start Month	June	June
	Start Year	1946	1946
Annual % Increase in Total Demand			
		Belton	0%
		Stillhouse	0%
		Georgetown	0%
		Granger	0%

Figure 2-3. Mid-term Mode Settings

- Simulation Period as the Duration in number of months (3 – 60 months)
- Initial Conditions as the initial water surface elevation of each reservoir. The corresponding total volume and percent available volume are automatically calculated and shown in this section.
- Pump Operations using either Trigger Levels or a User Defined pump schedule. If Trigger Levels are selected then the model will use the triggers defined on the SYSTEM worksheet to determine the optimal pump configuration and pumping duration for each time step; if User Defined is selected then the model will not use any trigger levels, and instead use the pump schedules defined on the USER PUMP OPS worksheet.
- Hydrologic Period specifies the data source as Historical or User Defined. If User Defined is selected then model uses the user-defined timeseries on the HYDROLOGY worksheet and the User Defined Start Month must be specified. If Historical is selected as the Hydrologic Data Source then the model will use the

parameters set in the Historical Inflow and Evaporation Periods section to determine the appropriate start date.

- Historical Inflow and Evaporation Periods specifies the parameters used to determine the inflow and net evaporation timeseries to use for Mid-term simulation. The user may either specify a specific start month and year for either the inflow or net evaporation timeseries, or set the hydrologic percentiles that are used by the model to find the corresponding period (see below).

- Annual % Increase in Total Demand specifies the percent increase in annual demand for each reservoir. The percent increase is applied at the start of each calendar year in the simulation (January 1st). To use constant annual demands, these percent increases should be set to 0%. A negative percent may also be used to decrease demands each year in the simulation.

2.4.2.2 Calculations

The hydrologic mass balance and energy cost calculations are performed on the CALC_HYDRO and CALC_COSTS worksheets. In addition, if Percentile is selected as the Period Selection Method for either Inflow or Net Evaporation, then the model will perform a set of calculations on the MID_PERIOD worksheet to determine which period corresponds to the specified hydrologic percentiles.

There are two sources for hydrologic timeseries, which is selected as the *Hydrologic Data Source* in cell E17 on the *Mid-term* worksheet:

- **User Defined** – The user-defined hydrologic timeseries are specified in columns L through T of the HYDROLOGY worksheet for a period up to 60 months. This option can be used to simulate forecasted hydrologic conditions or to modify the timeseries from some historical period, such as reducing the inflows during the drought of record by 10 percent (see example below). If **User Defined** is selected as the *Hydrologic Data Source* then the *Historical Inflow and Evaporation Periods* block of the *Simulation Settings* is deactivated.

- **Historical** – The historical hydrology timeseries from 1941 to 2007 is used as the data source for the hydrologic timeseries. If **Historical** is selected as the *Hydrologic Data Source* then the *Historical Inflow and Evaporation Periods* block of the *Simulation Settings* is activated and the user must specify the parameters for selecting the historical period. The Inflow and Net Evaporation timeseries can be specified by either a **Date** or a **Percentile** by *Choose Inflow Period.*

  - **Date** – If *Choose Inflow Period* for Inflow or Evaporation is set to **Date**, then the user must specify the *Start Month* and *Start Year*. The model will select the period starting on this month and year.

  - **Percentile** – If *Period Selection Method* for Inflow is set to **Percentile**, the user must specify the percentile (0% - 100%) where 0% selects the period with the lowest inflow (driest period) and 100% selects the period with the highest inflow (wettest period). The user has the option to force the model to only consider periods starting on a specific month when matching the specified **Percentile** by setting the *Choose Percentile Start Month* to **Selected** and setting the *Start Month*. If *Choose Percentile Start Month* is set to **Any**, then the model will select the period matching the specified Percentile regardless of the starting month. The Net Evaporation timeseries can be specified independently of the Inflow timeseries using the same options of either specifying a **Date** or a **Percentile** as the *Period Selection Method*. For Net Evaporation, a *Percentile* of 0% selects the period with the lowest net evaporation (or wettest period), while the 100% selects the period with the highest net evaporation (or driest period), which is opposite of the percentiles for the Inflow timeseries. The user can also force the model to use the same period for the Net Evaporation timeseries as the Inflow timeseries by setting the *Net Evaporation Period Selection Method* to **Same as Inflow**. Note that if the *Period Selection Method* is set to **Percentile**, then after running the model, the user can find the simulated period on the MID_PERIOD worksheet. Also note that the selected period based on **Percentile** will depend on the simulation duration; the period with the lowest inflows may start in a different month or year if the duration is set to 6 months versus 60 months.

The following is a list of example settings for various hydrologic periods.

- <u>Drought of Record Starting in Any Month</u> – Set the *Hydrologic Data Source* to **Historical**, the *Period Selection Method* to **Percentile** for Inflow and **Same as Inflow** for Net Evaporation, the *Percentile* to **0%** for Inflow, and the *Choose Percentile Start Month* to **Any**.

Hydrologic Period		
Hydrologic Data Source		Historical
Historical Inflow and Evaporation Periods		
	Inflow	Net Evap
Period Selection Method	Percentile	Same as Inflow
Percentile	0%	50%
Choose Percentile Start Month	Any	Selected
Start Month	March	September
Start Year	1954	1967

- <u>Period with Lowest Inflow and Highest Net Evaporation starting in March</u> - Set the *Hydrologic Data Source* to **Historical**, the *Period Selection Method* to **Percentile** for both Inflow and Net Evaporation, the *Percentile* to **0%** for Inflow and **100%** for Net Evaporation, the *Choose Percentile Start Month* to **Selected** for both Inflow and Net Evaporation, and the *Start Month* to **March** for both Inflow and Net Evaporation.

Hydrologic Period		
Hydrologic Data Source		Historical
Historical Inflow and Evaporation Periods		
	Inflow	Net Evap
Period Selection Method	Percentile	Percentile
Percentile	0%	100%
Choose Percentile Start Month	Selected	Selected
Start Month	March	March
Start Year	1954	1967

- All Inflows 10% lower than the Drought of Record and Net Evaporation starting on the same month – Run the Mid-term mode with the settings described above for the Drought of Record Starting in Any Month scenario, and check the MID_PERIOD worksheet to determine when the Drought of Record occurred (May 1947 for a duration of 60 months). Go to the HYDROLOGY worksheet and copy the timeseries for the 60 month period starting on May 1947 to the *User-Defined Hydrologic Time Series* in columns M through T. Then multiply all inflows by 0.9 to reduce them by 10%. Return to the MID-TERM worksheet and set the *Hydrologic Data Source* to **User Defined.**

Hydrologic Period		
Hydrologic Data Source		User Defined
Historical Inflow and Evaporation Periods		
	Inflow	Net Evap
Period Selection Method	Percentile	Percentile
Percentile	0%	100%
Choose Percentile Start Month	Selected	Selected
Start Month	March	March
Start Year	1954	1967

- Median Inflow Period starting in September with Net Evaporation starting on the same month and year - Set the *Hydrologic Data Source* to **Historical**, the *Period Selection Method* to **Percentile** for both Inflow and to **Same as Inflow** for Net Evaporation, the *Percentile* to **50%** for Inflow, the *Choose Percentile Start Month* to **Selected** for Inflow, and the *Start Month* to **September** for Inflow.

Hydrologic Period		
Hydrologic Data Source		Historical
Historical Inflow and Evaporation Periods		
	Inflow	Net Evap
Period Selection Method	Percentile	Same as Inflow
Percentile	50%	100%
Choose Percentile Start Month	Selected	Selected
Start Month	September	March
Start Year	1954	1967

- Inflow period starting on March 1954 and Net Evaporation starting on September 1967 - Set the *Hydrologic Data Source* to **Historical**, the *Period Selection Method* to

Date for both Inflow and Net Evaporation, the *Start Month* to **March** for Inflow and **September** for Net Evaporation, and the *Start Year* to **1954** for Inflow and **1967** for Net Evaporation.

Hydrologic Period		
Hydrologic Data Source	Historical	
Historical Inflow and Evaporation Periods		
	Inflow	Net Evap
Period Selection Method	Date	Date
Percentile	50%	100%
Choose Percentile Start Month	Selected	Selected
Start Month	March	September
Start Year	1954	1967

2.4.2.3 Outputs

Output from the Mid-term mode include:

- Timeseries of percent available volume in each reservoir, monthly volume transferred through the WCRRW Pipeline, and annual average operating costs.
- Total fluxes through each reservoir and total changes in storage in each reservoir, which are both used to calculate the overall mass balance, which should always be zero.
- Total pumping costs over the simulation period, and a plot of pump configuration utilization in terms of percent simulation time that each pump configuration is used.
- Series of timeseries of total reservoir volumes
- Series of timeseries of reservoir elevations
- Timeseries of monthly transfers via the WCRRW Pipeline and the Belton-Stillhouse Line
- Timeseries of monthly demand shortages in each reservoir
- Timeseries of pump configuration used for each month
- Timeseries of monthly operating costs
- Timeseries of monthly cost savings for using Operations 2 vs. Operations 1

2.4.3 Batch Mode

When future hydrology is uncertain, the Planning Simulation Model can be run in Batch mode (also known as position analysis). The model will run each historical period of the user-defined duration, always re-initializing to the specified initial conditions. For example, if the user defines a simulation period of two years, then every two-year period of the historical hydrologic record would be run individually (1941-1942, 1942-1943, etc), with each scenario reinitialized to the specified initial conditions. Frequency distributions of results such as lake levels, pump usage, costs, etc. are tabulated, and can be interpreted (for example) as "Given current lake levels and pump station capacities, we are likely to spend X dollars over the next year to meet demand, and there is only Y percent probability that lake levels would drop below desired levels." In other words, this mode can be used to evaluate the stability or level of risk of the current conditions, and to put bounds on best case and worst case scenarios. The difference between the Batch and Long-term modes is that the Batch mode preserves the impact of initial conditions over near-term operations while accounting for the full range in hydrologic patterns.

2.4.3.1 Inputs

The inputs to the Batch mode are shown in **Figure 2-4** and include:

Simulation Settings			
Simulation Period			
		Duration (1-5 years)	1
		Start Month	June
		Start Year	1941
Initial Conditions			
	Elevation (ft)	Total Volume (acft)	% Available Volume
Belton	594	435,225	100
Stillhouse	614	180,935	74
Georgetown	776	20,546	43
Granger	504	52,525	100
Pump Operations			
		Pump Operation Logic	User Defined
Annual % Increase in Total Demand			
		Belton	0%
		Stillhouse	0%
		Georgetown	0%
		Granger	0%

Figure 2-4. Batch Mode Settings

- Simulation Period specifies the Duration in number of years (1-5 years) with a Start Month and Start Year.
- Initial Conditions defined as the water surface elevation of each reservoir.
- Pump Operations using either Trigger Levels or User-defined pump schedule. If Trigger Levels are selected then the model will use the triggers defined on the SYSTEM worksheet to determine the optimal pump configuration and pumping duration for each time step; if User-defined is selected then the model will not use any trigger levels, and instead will use the pump schedules defined on the USER PUMP OPS worksheet.
- Annual % Increase in Total Demand specifies the percent increase in annual demand for each reservoir. The percent increase is applied at the start of each calendar year in the simulation (January 1st). To use constant annual demands, these percent increases should be set to 0%. A negative percent may also be used to decrease demands each year in the simulation.

2.4.3.2 Calculations

The Batch mode essentially runs the Mid-term mode iteratively beginning with each year in the period-of-record. As in the Mid-term mode, the hydrologic mass balance and energy cost calculations are performed on the CALC_HYDRO and CALC_COSTS worksheets. After each period is simulated, the results are copied to various worksheets with the prefix "BATCH_". The results are then used to generate frequency distributions of the reservoir levels, fluxes, costs, spills, etc.

2.4.3.3 Outputs

Output from the Batch mode include:

- Frequency distributions of the minimum elevation in Lake Georgetown, Average Annual Pumping Costs, and Average Annual Spills from Lake Georgetown.
- Timeseries of the elevation for each reservoir showing all X-year periods
- Frequency distribution of total demand shortages of each reservoir
- Frequency distribution of annual average spills from each reservoir
- Frequency distribution of annual average pumping costs for Operations 1 and Operations 2
- Frequency distribution of annual average cost savings for using Operations 2 over Operations 1

2.5 Setting Up a Scenario

A scenario is set up by following a series of steps:

- Defining annual customer demands and monthly demand factors on the DEMANDS worksheet
- Defining the system configuration on the SYSTEMS worksheet including which transfer pipelines are activated, the transfer capacities, pump station configuration and allowable pump configurations, pump curves, trigger levels, monthly releases, dam leakage and return flow from City of Georgetown to Lake Granger.
- Selecting the energy cost structure and defining the associated cost parameters on the ENERGY COST worksheet.
- Defining the top of the conservation pool, minimum allowable elevation and user-defined elevation on the RESERVOIRS worksheet.
- Defining the User-defined hydrologic timeseries if used for Mid-term mode.
- Defining the User-defined pump schedule on the USER PUMP OPS worksheet if used for the Mid-term or Batch modes.

Once the model is configured using these input worksheets, the user will select the desired simulation mode, define the mode inputs and click the **Calculate** button.

2.6 Results Interpretation

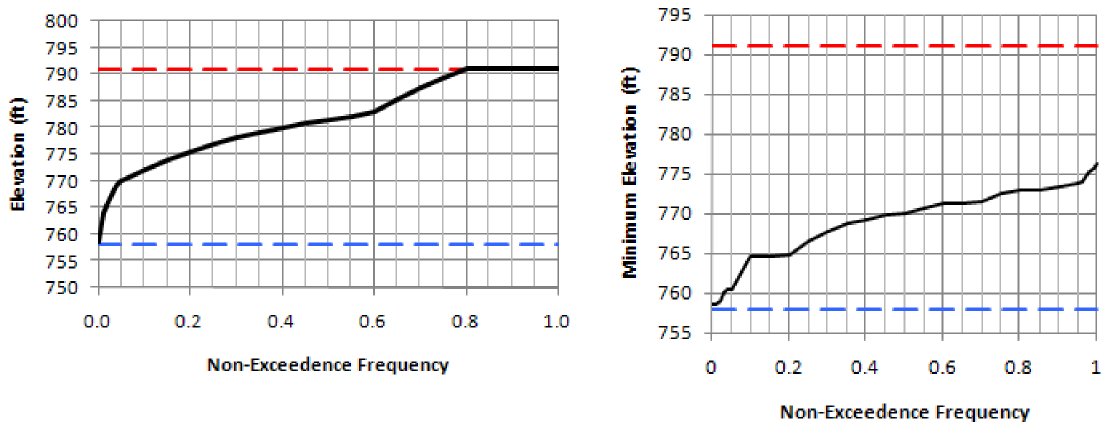
For both the Planning Simulation Model and the Operations Optimization Model, it is important to remember that results should not be viewed as prescriptive. Rather, the results should be used to understand the system and for guidance in decision making and operation planning. Also, no single set of results should be viewed as definitive. Tradeoffs and sensitivities should be studied with multiple scenarios in order to make informed decisions. The following sections discuss some of the results for the Planning Simulation Model and provide some insight on how the results could be interpreted.

2.6.1 Understanding the Frequency Distributions

Model outputs for the Long-term and Batch modes include frequency distribution graphs. It is important to note that all of the frequency distributions are based on the hydrologic record and the sequence in which events took place. Using the Long-term mode, the frequency distributions are based on simulating a particular scenario over a defined period in the hydrologic record (ranging from 1941 to 2007). In the Batch mode, the frequency distributions are based on the model running each historical period of specified duration (1 to 5 years), always re-initializing to the specified initial conditions. Note that initial conditions have more of an impact on the frequency distribution for a shorter period or duration.

Example graphs of cumulative frequency distributions from the Long-term and Batch modes are shown in **Figure 2-5.** These graphs indicate the probability that a value would not be exceeded given the scenario conditions. Graph (a) shows the frequency distribution for the elevation in Lake Georgetown for a particular scenario using the Long-term mode over a specified duration. This graph shows, for example, that there is a 20 percent chance that the elevation in Lake Georgetown will fall below 775 feet given the scenario inputs over a specified period (in this case, the entire hydrologic record). Graph (b) shows the frequency distribution for the ***minimum*** elevation in Lake Georgetown over a user-defined period using the Batch mode. This graph shows that there is a 20 percent chance that the minimum elevation over the user-defined period (in this case, 5 years) could go below 765 feet.

Although the graphs in Figure 2-5 appear to refer to similar output data, they can vary significantly based on the mode and period/duration of simulation even if all other model inputs are the same. Graph (a) represents the distribution of elevations over the entire specified hydrologic period, and graph (b) is only a distribution of ***minimum*** elevations for a specified batch duration.



(a) (b)

Figure 2-.5 Frequency Distribution Graphs for Lake Gerogetown's (a) Elevation using the Long-term Mode and (b) Minimum Elevation using the Batch Mode

2.6.2 Pump Operations and Energy Costs

As described is **Section 2.3**, the Planning Simulation Model simulates the Stillhouse PS operation two different ways: running pumps continuously for n days/month (Operations 1) and running pumps intermittently over the entire month for m hours/day when energy prices are lowest (Operations 2). The significance of modeling these two operations is for calculating energy costs. Both operations will result in the same volume of water transferred over the month. The difference in the simulated cost for each operation represents the possible cost savings in operating the pumps during hours when energy is less expensive. This cost savings should be weighed against the costs and complications of setting up and maintaining the Stillhouse PS such that the pumps can be turned on and off each day.

2.6.3 Sensitivity to Model Inputs

The sensitivity of model inputs for the Planning Simulation Model should be assessed by the user when evaluating different scenarios. The pump triggers, minimum allowable lake levels, WCRRW Pipeline capacity constraint, available pump configurations, and the selected hydrology in the Mid-term mode, for example, are some parameters that can significantly affect results. The results of adjusting such parameters should be assessed by conducting sensitivity analyses. For example, adjusting the pump trigger levels by 10 percent could significantly affect costs, spills, and demand shortages. The Triggers Analysis in the TRIGGERS worksheet can assist with understanding the effect of varying the trigger levels. The sensitivity to the other parameters can be assessed by varying their values and comparing the resulting output.

2.7 Key Concepts

There are a few key things to remember regarding the Planning Simulation Model that every user must be aware of to avoid misinterpreting model results:

- Monthly Demand Factors: These are located on the DEMANDS worksheet and they must average to 1 for each customer. Demand data provided in terms of percent of annual use must be converted to a factor that can be multiplied by the average annual demand.

- Belton to Stillhouse Transfer: For future conditions, it will be necessary to include water transfer from Lake Belton to Lake Stillhouse Hollow. If results are showing that demands cannot be met for future conditions, be sure to check that the Belton to Stillhouse Transfer is set to "on".

- Hydraulic Pipe Capacity: When using the model to assess future conditions, large demands may require a pump configuration that has a capacity that exceeds the current capacity of the WCRRW Pipeline. Pump configurations that exceed this capacity are not included in a model run even if all pumps are selected to be active. The WCRWW Pipeline table located in the SYSTEM worksheet contains the options for the Hydraulic Pipe Capacity. Choose the "User-Defined" or "No Constraint" option to evaluate larger pump configurations for future demand conditions.

- Percent Available Volume: This refers to the percent of *available* storage, which is defined as being between the top of the conservation pool and the minimum elevation allowable for withdrawals. This should not be confused with the total volume of the conservation pool, which is between the top of the conservation pool and the bottom of the elevation-area-capacity curve.

- Simulation Mode Graphs: When navigating between the LONGTERM and MIDTERM worksheets, note that the results shown are based on whichever mode was most recently run. A title at the top of the graphs reminds the user which mode was recently run.

- Trigger Analysis: After running the Trigger Analysis in the TRIGGERS worksheet, the triggers for Georgetown will be set to 90 percent on and 90 percent off in the SYSTEM workbook.

- Historical Hydrology Percentiles: The percentiles for inflow and net evaporation in the MIDTERM worksheet have opposite meanings when it comes to assessing the driest and wettest hydrologic periods. For inflow, 0 percent represents the driest period and 100 percent represents the wettest period. For net evaporation, 0 percent represents the lowest evaporation (wettest period) and 100 percent represents the highest evaporation (driest period).

- User-Defined Hydrology: When using the user-defined hydrology for the Mid-term simulation, note that a start month must be specified. This is the month that all other aspects of the model will be tied to, but the actual user-defined hydrology that is specified on the HYDROLOGY worksheet will start with the values for the first month.

- Mode Selection: There is no single mode that is necessarily the best choice for a particular question. Typically, any mode can address a question from a certain point of view and frequently the user will use more than one mode.

- Non-Exceedence Frequency Results: All probabilities are based solely on the historic or user-defined hydrology. They do not incorporate climate or hydrologic forecasts.

2.8 Example Problem Formulation

Below are two scenarios provided by the BRA as example problems for the Planning Simulation Model.

2.8.1 Scenario 1

Assume it is March 31, 2019. It has been wet, and Lake Georgetown is full. Develop operating plan (trigger levels, etc.) for pipeline/pump operations and O&M budget numbers for FY 2020.

This scenario can be addressed in three steps:

1. Use the Long-term mode to determine the trigger levels given the forecasted demands for 2019

2. Use the Batch mode to determine the expected water level in September of 2019, which is the start of FY2020.

3. Use the Batch mode to determine the expected average and range of energy and utility charges over a 12 month period with Lake Georgetown starting at the expected water level determined in step 2.

Step 1: Trigger Levels

The optimal trigger levels are determined by running the Long-term mode iteratively with different trigger levels using the Triggers Analysis macro. To set up the scenario, the demands are first set to the year 2019. The system is configured such that the Lake Belton to Lake Stillhouse Hollow transfer is turned off and the WCRRW Pipeline is turned on. Assuming the two new medium pumps have been installed, the number of pumps is set with 2 small pumps and 2 medium pumps using the default pump curves. The hydraulic pipe capacity is set to Default, which is calculated based on the C-Factor of 140. Demands are included in the transfer calculations and the max annual transfer is set to 61,121 acft/yr. No monthly releases or dam leakage is specified, and the return flow from City of Georgetown to Lake Granger is set to 60%. On the ENERGY worksheet, the rate structure is set to MCPE and the default values are used for all prices and charges. The default values for the reservoir elevations are used and no user-defined hydrology or pump configuration schedule are defined.

With the scenario set up, the Trigger Analysis is used to determine the optimal trigger values that will meet demand in all years while minimizing spills and energy charges. **Figure 2-5** shows the results of the Trigger Analysis for this scenario, which indicates that an On Trigger of 30% and an Off Trigger of 70% is the trigger combination with the least cost and lowest spills that does not result in any demand shortages. In reality, operators may want to choose a safer set of trigger levels, such as 50% On and 50% Off which resulted in only slightly higher spills and total cost than the 30% On and 70% Off triggers. However, for the scenario, we will use the 30% On and 70% Off triggers.

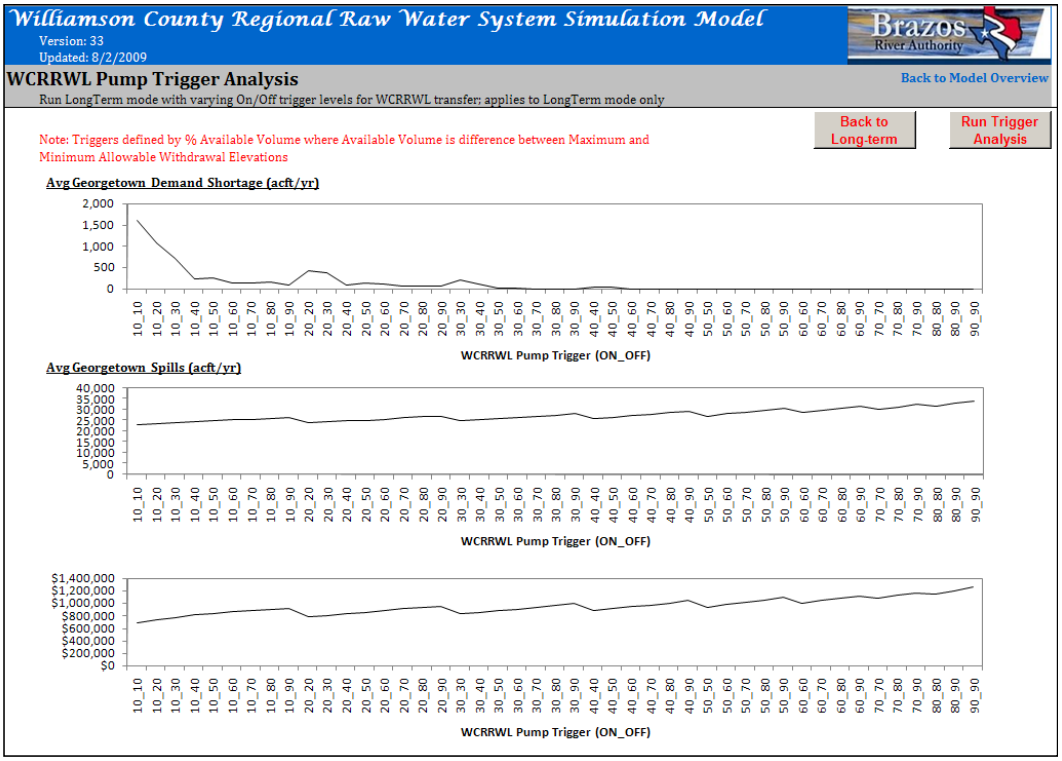


Figure 2-6. Results of the Trigger Analysis for Scenario 1

Step 2: Lake Georgetown Water Level

Because the BRA's fiscal year begins in September, the expected water level at the beginning of FY2020 must be determined using the Batch mode. With the trigger levels selected in Step 1, the Batch mode can be used to run the model for every 12 month period in the period of record beginning in March with Lake Georgetown at full capacity. Before running the Batch mode, the 30% On and 70% Off trigger levels are defined on the SYSTEM worksheet. The On and Off triggers for Lake Stillhouse are both set to 20% to prevent pumping from Lake Stillhouse Hollow to Lake Georgetown when Lake Stillhouse Hollow is below 20% of its available capacity. The other global settings worksheets are left unchanged.

The results of the Batch mode provide the median water level in September 2019. The timeseries of Lake Georgetown water level generated by the Batch mode are found on the BATCH_GEORGETOWN worksheet. The frequency distribution of water levels in September 2019 are shown in **Figure 2-6**. The median water level is 778.6 ft.

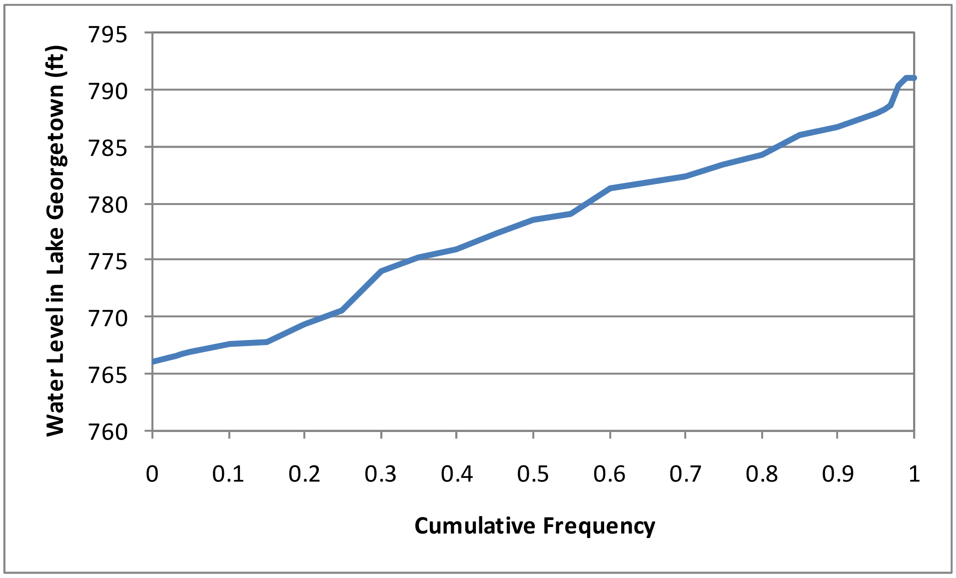


Figure 2-7. Frequency Distribution of Lake Georgetown Water Level in September 2019 for Scenario 1

Step 3: Annual O&M Budget

The Batch mode is again used to determine the expected median pumping cost for FY2020. The initial water level in Lake Georgetown is set to 778.6 ft, and the start month is set to September. **Figure 2-7** shows the frequency distribution of annual energy cost based on the Batch mode simulation for this scenario. The median cost is about $906,000 with a minimum cost of $59,000 and a maximum cost of $1,840,000.

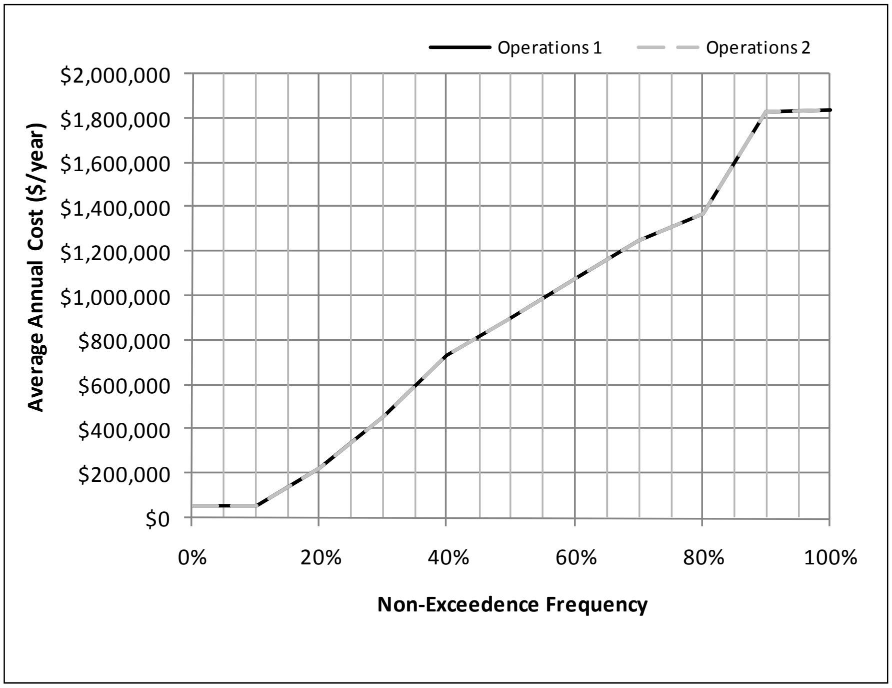


Figure 2-8. Frequency Distribution of Annual Average Cost for Scenario 1

2.8.2 Scenario 2

Assume it is June 1, 2010. The two Phase II medium pumps are installed and operational. The Lake elevation is 776.0. Develop operating plan through the summer for continued dry conditions.

a) *Develop operating plan through the summer for continued dry conditions.*

b) *Evaluate revised operating plan, if any, assuming tropical system refills lake in August.*

c) *Evaluate revised operating plan, if any, assuming lake elevation has dropped to 764 by end of August.*

d) *Evaluate revised operating plan if cumulative inflows from October 2007 through August 2010 are below drought of record for first 35 months.*

As in Scenario 1, the first step is to determine the optimal trigger levels for 2010 demands by using the Trigger Analysis macro. The same configuration is used as Scenario 1 except the demands are set to the year 2010. **Figure 2-8** shows the results of the Trigger Analysis macro which indicate that the trigger levels resulting in the least cost and minimal spills are 20% On and 30% Off.

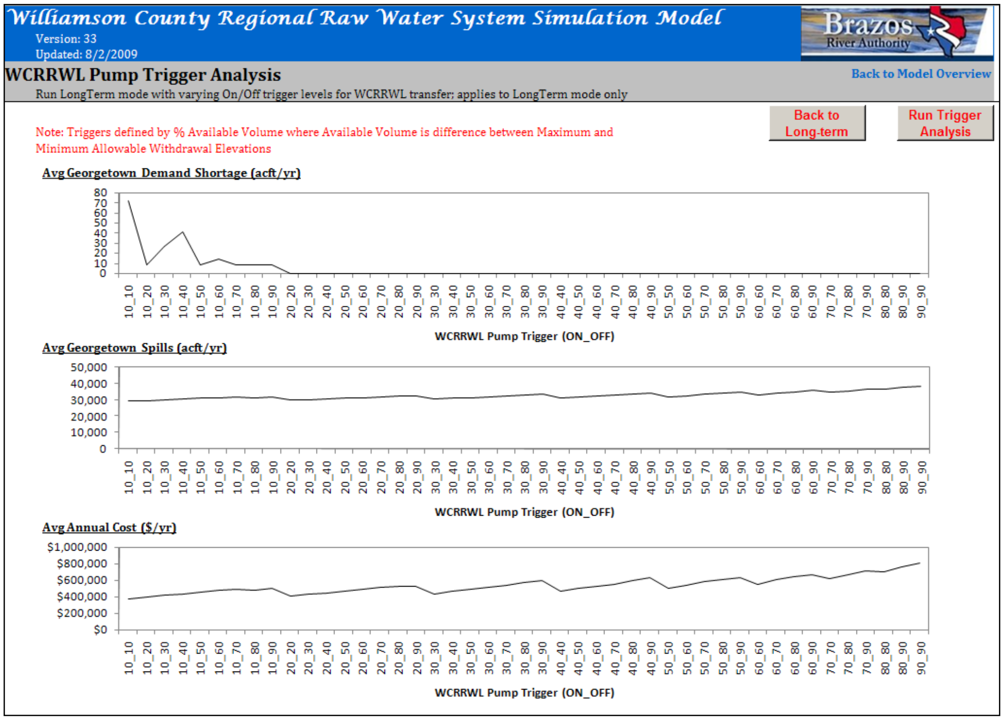


Figure 2-9. Results of the Trigger Analysis for Scenario 2

The operating plan for the summer is therefore to simply operate the transfer according to these trigger levels of 20% On and 30% Off. Whether the lake refills or drops lower by August, the operating plan remains the same since the trigger levels are based solely on the system configuration and customer demands. The pumps are only activated if the water level in Lake Georgetown falls below 20% of its available capacity, which corresponds to a water surface elevation of 767.8 ft. Therefore, for sub-scenario (c), the pumps would be activated if the water level dropped to 764 ft by August.

In order to evaluate the system performance under conditions that are worse than the drought of record, the user-defined hydrologic timeseries can be used. The 12-month drought can be determined using the Mid-term mode by setting the Hydrologic Data Source to Historical, the Period Selection Method to Percentile for both Inflow and Net Evap and setting a Percentile of 0% for the Inflow and 100% for the Net Evap, which will correspond to the lowest inflow and highest net evap. The start month is also set to August. With the hydrologic percentiles set, the Mid-term mode is run and the selected period is determined from the MID_PERIOD worksheet which lists the start month for the inflow and net evap periods, which are August 1995 and August 1955, respectively.

The 12-month timeseries starting in August 1995 for Inflow and August 1955 for Net Evap are then copied to another worksheet, where each Inflow value is reduced by 10% and the Net Evap is left unchanged. The resulting timeseries therefore has less inflow than the drought of record. This timeseries can be used in the model by copying it to the User-Defined Hydrologic Time Series on the HYDROLOGY worksheet.

The Mid-term mode can then be used to run the model using this synthetic timeseries by selecting User Defined as the Hydrologic Data Source and a Start Month of August. The initial elevation in Lake Georgetown is set to 764 ft. The results are shown in **Figure 2-9** and indicate that even with this extreme drought, Lake Georgetown is able to recover to about 50% its available capacity after 12 months. Therefore, these trigger levels may be considered sufficient for meeting demands even under extreme drought conditions.

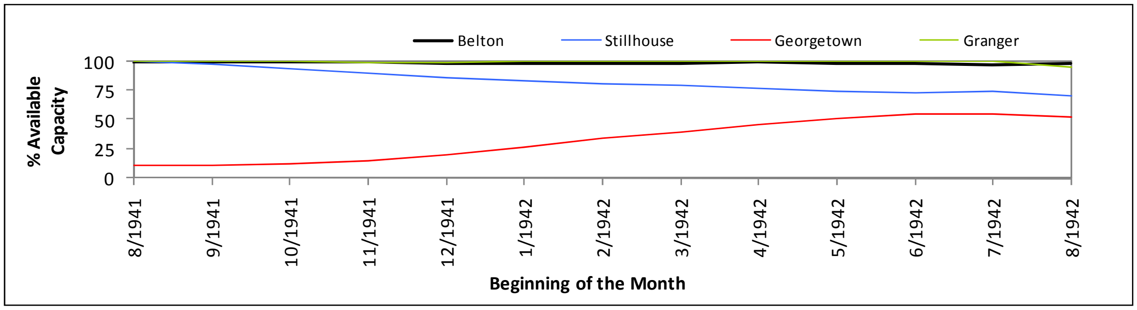


Figure 2-10. Percent Available Capacity in Each Reservoir for 12-month Extreme Drought Simulation.

Section 3
Operations Optimization Model

The Operations Optimization Model provides guidance for developing a 30-day pump operating plan for the Stillhouse PS, which is part of the WCRRW System. The model optimizes pump operations for meeting demand and/or minimizing cost based on user inputs including forecasted hydrology, pump information, cost data, forecasted demand, and initial and targeted lake levels. The model uses the Premium Solver Platform, a tool added to Microsoft Excel, to setup the constraints and solve for the objective function. Key aspects of the model include the following:

- Total model duration is 30 days
- Time step is 6 hours starting at 12:00 AM
- The Premium Solver Platform uses linear programming to optimize the objective function
- Objectives include minimizing demand deficits, energy charges, utility charges, reservoir spills, or some combinations of the above.
- Decision variables include hours of operation per time step, raw water deliveries, and reservoir spills.

Due to the uncertainty in forecasting hydrology and demand, the user must understand that the results are to be used for guidance purposes only. Additionally, resulting pumping scenarios may be impractical given the current state of the system when an optimization run is made. For example, it may be impractical to turn pumps on and off multiple times in a day if the proper equipment is not installed to make frequent adjustments energy efficient.

Table 3-1 lists all of the worksheets in the model with a brief description of each. The text that follows goes into further detail on the components of the model that will be accessed by the user. Also included are discussions on calculations performed, interpreting the model output, understanding the objectives and implications of weighing the objectives, and remembering key concepts. Finally, an example problem formulation is presented.

Table 3-1. Operations Optimization Model Worksheet Descriptions

Worksheet Name	Description	Type
Model Setup	Front worksheet of model where model is described and inputs are entered. All other data input worksheets can be accessed from this worksheet.	Navigation, Information, User Input
River Forecast	Enter 30-day river flow forecasts from Advanced Hydrologic Prediction Service data. Data is entered in cfs.	User Input
Energy Cost Data	Enter cost data or choose default values. Several options are available for entering cost data.	User Input
Pump Data	Enter pump curve data for the small, medium, and large pumps or choose the default pump curves.	User Input
Demand Data	Enter customer demands, downstream demands, and environmental releases.	User Input
Results	All results are displayed here. Graphs and tables are at the top and formatted for printing. Values are at the bottom (below the optimized pump schedule table).	Results
Opt Program	The Premium Solver Platform is accessed from this worksheet. Only necessary user input is the objective function weights.	Calculations, User Input
Res Sim	Reservoir mass balance calculations performed here (reservoir inflows and outflows)	Calculations
Pump Station	Pump station characteristics summarized or calculated here including capacity, head, efficiency, and power.	Calculations
Hydraulics	System and pump station hydraulic calculations performed here. Graphic shows the intersection of the system curve and each pump configuration pump curve	Calculations
Reliability	Tabulates supply deficits for use in either the objective or the constraints, as defined by the user.	Calculations
Cost Calcs	The total energy costs are calculated for the optimized and the continuous pumping operating strategies.	Calculations
Pump Post-Process	Post-processing calculations for energy and energy costs for the continous pumping operating strategy.	Calculations
Default Prices	Contains the default values for calculating energy costs and the MCPE lookup table. The user can choose to change these default values and the values will update on the ENERGY COST DATA worksheet.	Reference
E-A-C	Contains the Reservoir Elevation-Area-Capacity Curves used to calculate the water surface elevations for each daily timestep.	Reference
Controls	Checks the availability of the pump configurations based on the user inputs and pipeline capacity constraints. Also tracks objective inputs.	Calculations
Lists	Lists used in drop-down menus.	Reference

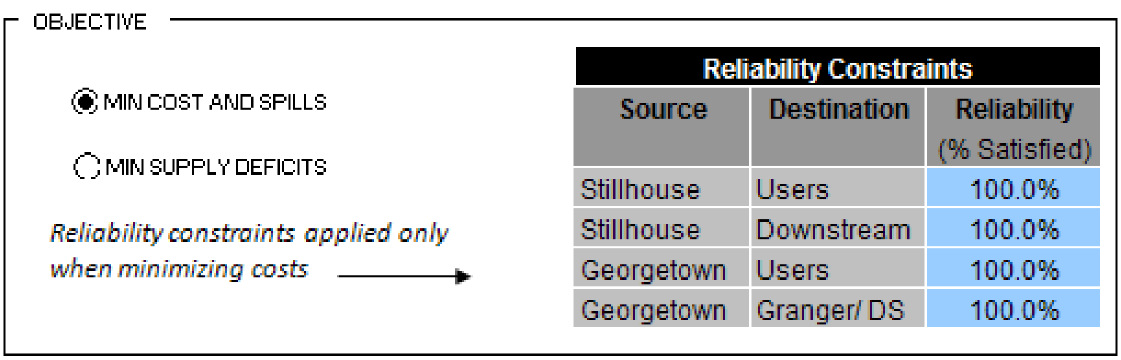
3.1 Navigation and Model Inputs

The MODEL SETUP worksheet of the Operations Optimization Model steps the user through all necessary inputs and initialization of the model before using the Premium

Solver Platform to optimize. This worksheet also includes the description of the color schemes, directions on how to unprotect worksheets, and a purpose disclaimer. The two main components of the MODEL SETUP worksheet are the objective and scenario setup boxes.

3.1.1 Objective

In the Objective box, the user chooses to “minimize costs and spills” or “minimize supply deficits,” (which can also be coupled with minimized spills on the OPT PROGRAM worksheet). If the user chooses to minimize costs or spills, then it may be necessary to adjust the reliability constraints for each demand source. Choosing to minimize costs and spills assumes that all demands can be met to the level of reliability set in the reliability constraints table. If they cannot be met, the model will be unable to converge on a solution. If the user is unsure if all demands can be met given the inputs, the user should choose to minimize supply deficits and run the model to determine the level of reliability that should be used when minimizing costs and spills. The RESULTS worksheet will display the percent of demand met and those values can be used as input in the reliability constraints table. A screenshot of the objective box is shown as **Figure 3-1**.



Reliability Constraints		
Source	Destination	Reliability (% Satisfied)
Stillhouse	Users	100.0%
Stillhouse	Downstream	100.0%
Georgetown	Users	100.0%
Georgetown	Granger/ DS	100.0%

Figure 3-1. Objective Box in MODEL SETUP

3.1.2 Scenario Setup

The Scenario Setup box guides the user through all remaining model inputs. A flow chart with buttons and input tables is used to direct the user to each input. A screenshot of this is shown in **Figure 3-2**. To begin, the user enters the start date for the 30-day optimization. This information is significant for the energy costs as well as keeping track of what date a particular model run was developed for. Next, there are four buttons that will take the user to separate worksheets to enter other inputs. Each of these worksheets is described in detail in the following sections. After entering the data on each worksheet, the user can click on the **Return to Model Setup** button to go back to the MODEL SETUP worksheet. The flow chart next directs the user to several tables that display information and require user input.

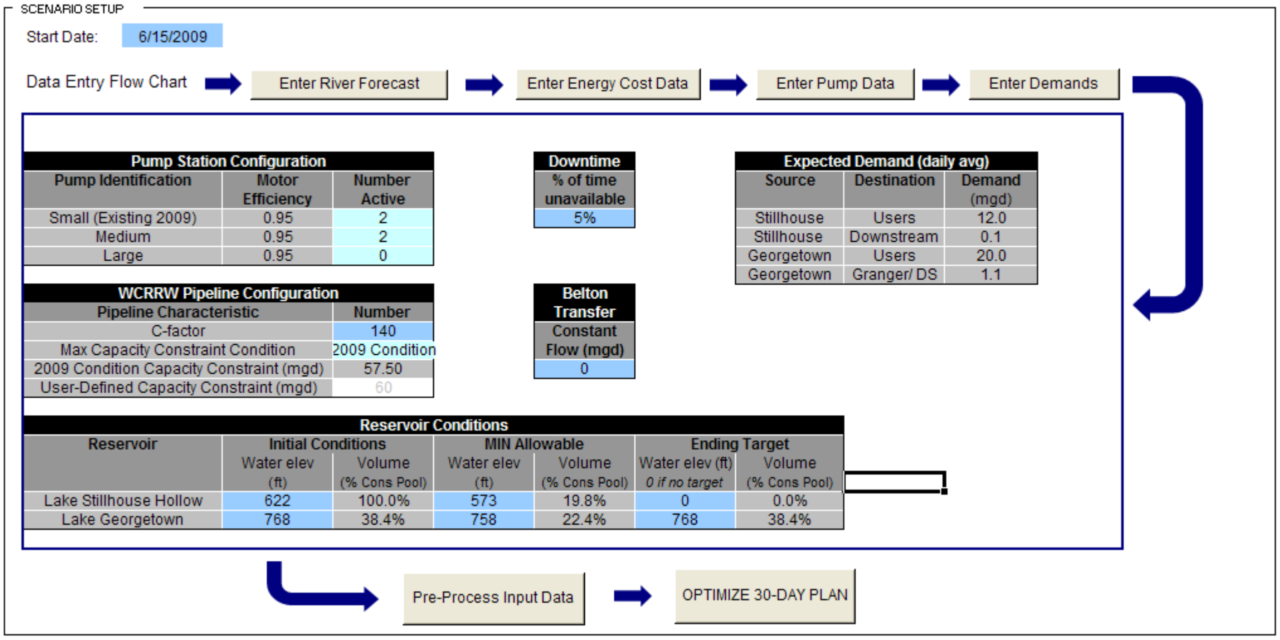


Figure 3-2. Scenario Setup Box in MODEL SETUP

Each table shown in Figure 3-2 is described as follows:

- Pump Station Configuration: The user chooses the number of pumps that are included in the model run for the Stillhouse PS. For each pump size, the user can choose 0, 1, or 2 pumps to be active. Motor efficiency is also displayed, but cannot be edited on this worksheet. Efficiencies can be changed on the PUMP DATA worksheet.

- Downtime: This parameter takes into account issues or maintenance that would cause the Stillhouse PS to be out of service. By modeling a percent downtime, a safety factor is added to the optimization results.

- Expected Demand: This table summarizes the data that is entered in the DEMAND DATA worksheet. No inputs are required.

- WCRRW Pipeline Configuration: Pipeline characteristics include the C-factor and the maximum capacity constraint on the pipeline. The C-factor describes the friction in the pipeline, which may change over time. There are three options for the maximum capacity constraint. The "2009 Condition" is based on the C-factor and the pressure ratings on each section of the pipeline as of 2009. The C-factor can be changed and the capacity constraint will adjust accordingly, but if portions of the pipeline are replaced, this constraint option is no longer valid. The "User-Defined" option allows the user to set the constraint in terms of flow. The "No Constraint" option can be chosen if the user does not want to be limited by the pipeline capacity when optimizing (for theoretical experimentation).

- Reservoir Conditions: The user enters initial, minimum allowable, and target water surface elevations for each reservoir. The *initial conditions* water surface elevation designates the starting point in the 30-day model run, and the model will track the water surface elevation day by day based on the optimized operating plan. The *minimum allowable* is the lowest water surface elevation that the reservoir can reach at any point during the model run. If the water surface elevation cannot stay above the minimum allowable for the duration of the scenario, the model will not find a solution. The *ending target* is the water surface elevation target for the end of the 30-day model run. If additional water must be pumped to reach this target, the optimized plan will include it. If the available pumps do not have enough pumping capacity to meet the ending target, the model will not find a solution regardless of the objective. After entering water surface elevations in feet, the corresponding percent of conservation pool is calculated and displayed. Note that this percentage represents the percentage of the entire conservation pool. ***This is different from the Planning Simulation Model which gives percent volumes based on the minimum allowable water surface elevation.*** Although the determination of ending target elevations are solely at the user's discretion, the Planning Simulation Model can be a very useful companion tool to help establish a reasonable range of target reservoir levels that can minimize the risk of demand shortages long term. Alternatively, historical rule curves could also be used, but perhaps without quite as much insight into risk avoidance as could be obtained with the Planning Simulation Model.

- Belton Transfer: The user can set a constant daily transfer from Lake Belton to Lake Stillhouse Hollow. This affects the volume available in Lake Stillhouse Hollow. The pump station and pipeline for this transfer do not exist at this time; therefore, the flow should be set to zero unless the effects of implementing the system are being studied or the system has been constructed. The energy costs and pumps for this system are not modeled.

After filling in all of the input data, the user is directed to the **Pre-Process Input Data** button. By clicking this button, the model will make any final calculations required before running the optimization, specifically, hydraulic performance values such as flow capacity and energy requirements based on user input. The final step in the flow chart is to click the **Optimized 30-Day Plan** button. This will take the user to the OPT PROGRAM worksheet, which is where the objectives are refined and the Premium Solver Platform is used to run the optimization. The OPT PROGRAM worksheet is discussed in further detail in following sections.

The table at the bottom of the MODEL SETUP worksheet summarizes the pumping configurations available based on the data entered as part of the Scenario Setup. Available configurations will be highlighted in green. The pumping capacity of each configuration is also shown along with the maximum pumping capacity available (clicking the **Pre-Process Input Data** button is necessary to ensure that the performance values in this table are updated to correspond with user input).

The following sections provide more detail about each of the data input worksheets that the user navigates to when following the Data Entry Flow Chart.

3.1.3 River Forecast

Following the flowchart arrows on the SCENARIO SETUP worksheet, the first data entry worksheet is the RIVER FORECAST worksheet. The only input here is the daily, 30-day flow forecast for each reservoir in cfs. The BRA obtains forecasted river flow data directly from the Advance Hydrologic Prediction Service (AHPS) offered through the National Weather Service. The data are provided in the form of statistical probabilities, so that the user can formulate plans based on the desired level of conservativeness. The user can also test the sensitivity of the model by using different forecasts. The most conservative forecast would be the mean distribution at the 90^{th} percentile.

3.1.4 Energy Cost Data

The second data entry worksheet is the ENERGY COST DATA worksheet. For a complete description of how total cost for energy is calculated, please refer to **Part 1, Section 5.4**. The first table on this worksheet that requires user input is the Energy Charges table. This table shows the cost for energy in dollars per kWh for each 6-hour time step for the start and end month. The user has three options for the energy charge data: historical MCPE, user-defined, or real-time. The historical MCPE is based on three years (2006-2008) of data summarized by time step and month. User-defined unit costs can be entered in the blue cells. The values for the real-time data are entered at the bottom of the worksheet. Instructions are provided at the bottom of the worksheet for obtaining real-time data from the ERCOT website. By choosing one of the options for Energy Charges in the drop-down menu, the values that will be used in the model appear in the Modeled Value column.

The remaining tables on the energy cost data worksheet (Energy Charge Add-On, Inputs from Previous Bills, and Utility Charges) all use default or user-defined data. The values in the Modeled Value column are based on which option is chosen in each drop-down menu at the top of each table. The user-defined data is entered in the blue cells. Previous bills can be consulted for all user-defined information in these tables. It is recommended that the user-defined values be used and updated on a monthly basis. The default values only represent typical values based on the data available when the model was developed (2008/2009).

3.1.5 Pump Data

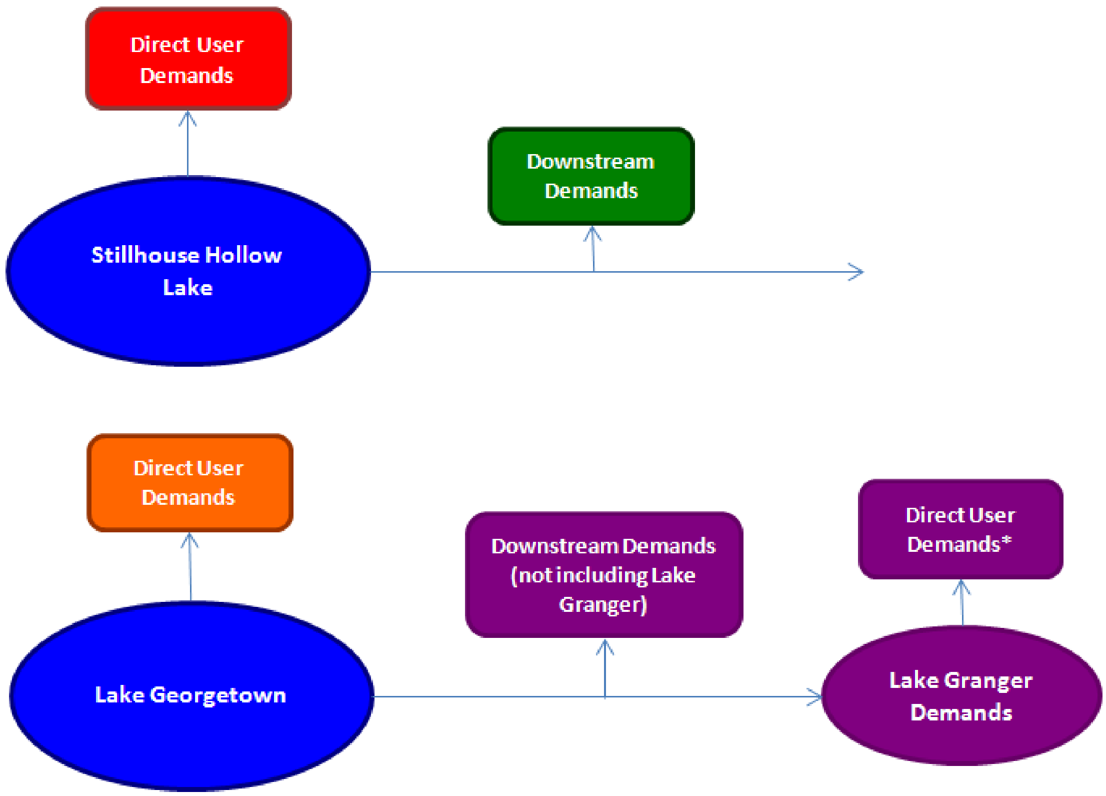
The third worksheet, the PUMP DATA worksheet, allows the user to change the pump curves used for the small (existing 2009), medium, and/or large pumps. The default pump curve values for the small pump represent the pumps currently installed as of 2009. It is recommended that these default values be used unless these pumps are replaced. The medium pump curve default values represent the most recent data on the pumps that are proposed to be installed as part of the Phase II pump design project. A pump curve provided by Fairbanks Morse, which represents the desired pump curve for design and is the pump curve provided in the models for the medium pumps, is shown in **Part 1**, **Appendix B**. These default values should be used until the final pumps are installed and their curves confirmed. The updated curves can be added in as user-defined. At this time, the large pump curve is not representative of any specific pump design. It is currently made up of hypothetical values used for planning purposes. The user can enter different curves in the user-defined column to test different proposed pumps for these slots. The user should ensure that the same curves used in the Operations Optimization Model are used in the Planning Simulation Model, if results from the two models are being used together. For more information on the pumps, please see **Part 1, Section 5.3.1**.

3.1.6 Demand Data

The final data entry worksheet is the DEMAND DATA worksheet. Here, the user enters average daily demand data for direct users, downstream users, and environmental releases, as applicable. Demands on Lake Granger are included here to account for downstream user demands on Lake Georgetown, but no other aspects of Lake Granger are included in the Operations Optimization Model.

Forecasted direct user demands can be entered by customer or by source. The current customers for each reservoir are listed, and three rows are included as custom inputs to account for any new users. The cells for entering demand by customer will be active if “by customer” is chosen from the drop-down menu. Instead of entering demand by customer, the user can choose to enter demands “by source.” The user can then enter the total average day demands on each reservoir. Downstream demands include environmental releases and downstream users (not including Granger). There is no option to enter data by customer or by source for the downstream demands.

All of the demands are then summarized by source and destination in the Combined Demands table. A diagram helps the user to understand all the demands included in the model. As shown in **Figure 3-3**, the diagram and the table are color coded to show which demands are included for each source and destination.



Combined Demands (daily avg)		
Source	Destination	Demand (mgd)
Stillhouse	Users	12.0
Stillhouse	Downstream	0.1
Georgetown	Users	20.0
Georgetown	Granger/ DS	1.1

*Direct User Demands for Granger represent flow that must be released from Lake Georgetown to satisfy Granger demands and NOT the total customer demands on Lake Granger

Figure 3-3. Demands Diagram and Table

3.2 Calculations

Calculations are grouped into pre-processes, optimization, or post-processes. Based on all of the inputs, the model first calculates all of the items necessary to run the optimization. Optimization is run through the Premium Solver Platform. Some post-processing is required to present the model output. This section first describes the Premium Solver Platform along with some instructions on use. Next, the calculations are summarized and described as pre-process, optimization, or post-process calculations. Finally, setting up the objectives to run an optimization scenario is discussed.

3.2.1 Premium Solver Platform

The Premium Solver Platform is the Excel Add-On tool that performs the optimization analysis. The benefit of this tool is that it can be formulated with standard spreadsheet software and Windows dialog boxes, which can aid in troubleshooting and understanding the problem formulation. This section highlights some of the most important and relevant features of the software as they pertain to the Operations Optimization Model, but is not an exhaustive manual on the complete usage and understanding of the software. For a complete description and instructions on the use of the Premium Solver Platform, users are referred to the software documentation that accompanied the software upon delivery.

Any optimization problem consists of three primary elements:

- A mathematical **objective**, which is to be either minimized or maximized. In this case, the user chooses the objective, which can be either the minimization of water deficits at all delivery points for the 30-day forecast period, or the minimization of energy and/or utility costs for the forecast period. Either of these objectives can also be coupled with the minimization of spills.

- A set of **decision variables,** which represent actual operational and planning decisions and are allowed to vary during the solution process. In this case, there are three types of decision variables:

    - Number of hours that each pump configuration is used during each 6-hour time block over the 30-day forecast period (generally, a maximum of one configuration is chosen for any 6-hour time-block, so these variables can usually be interpreted as the pump station settings and whether or not they change every six hours).

    - Water deliveries at each of four lumped demand locations (Lake Stillhouse Hollow, Lake Georgetown, and downstream of both of these reservoirs).

    - Spills from Lake Stillhouse Hollow and Lake Georgetown. Spills are not normally “decisions” but in the model, this formulation is useful. These “decisions” that the model makes result from the constraint to maintain water below the top of the conservation pools. By including the minimization of spills in the objective function (see above), the model automatically limits spills to only occur when absolutely necessary to maintain water levels within the conservation pool.

- A set of **constraints** that limit the values of the decision variables (referred to as “bounds”) and mathematical functions of decision variables (referred to as “constraints”, e.g. resultant storage) and create a multi-dimensional “decision space.” In this case, constraints include:

    - Maximum number of hours that each individual configuration can be used in a 6-hour time block (6 if configuration is active, 0 if not).

- Maximum number of hours that any of the pump configurations can be used in a 6-hour time block

- Total number of hours in the month that pumping can take place (percentage of the 30 days that pumps are available, as a function of user input)

- Minimum and maximum allowable storage in Lake Stillhouse Hollow and Lake Georgetown at any time during the month

- Minimum end-of-period storage in Lake Stillhouse Hollow and Lake Georgetown

- Maximum delivery at each demand node cannot exceed the demand (avoids model oversupplying one node where water is available to compensate for deficit elsewhere where water is not available, and balancing out to an artificial net effect of no deficit).

- Minimum demand levels to satisfy, if specified by the user.

All of these components of the model can be found on the OPT PROGRAM worksheet in the model. Even though the information is, in some cases, gathered from and distributed to other sheets, the SOLVER program interacts only with this single sheet for its input and output. In fact, it can only interact with a single workbook sheet in a spreadsheet program.

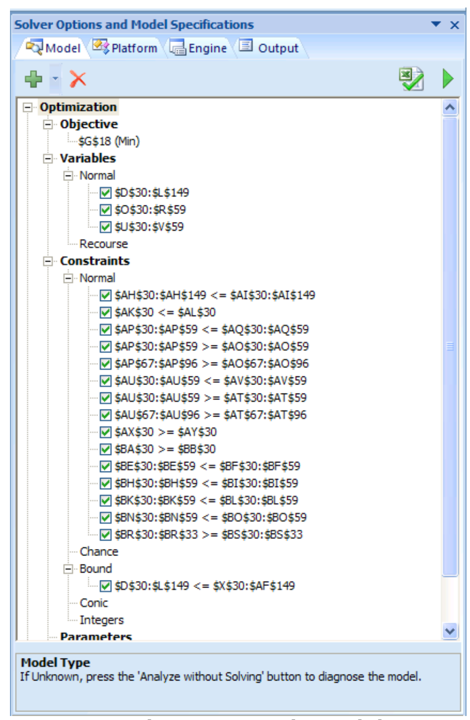


Figure 3-4. Solver Dialog Box

In order for the Premium Solver Platform software to understand the optimization formulation, these elements have been "coded" into the Solver Dialog Box. The Solver specification for this model can only be accessed, modified, or executed from the OPT PROGRAM worksheet. It can be accessed by selecting **Tools – Premium Solver** in Excel 2003, or by selecting **Premium Solver Platform** in the drop down list at the top of the page in Excel 2007, followed by the MODEL button in the ribbon. The typical Solver Dialog Box is shown in **Figure 3-4**. All referenced cells refer to the OPT PROGRAM worksheet.

While it is possible to change or de-activate the elements in the formulation of the optimization program, it is highly recommended that the user not change any entries in the Solver Dialog Box. Upon delivery from CDM, the model will be configured to solve the full program using the linear optimization algorithm. Changes in constraints, variables, objective, or solution engine within the Solver Dialog Box can result in misleading or incorrect results (as can changes in the worksheets, especially if they affect the information passed to or from the SOLVER). ***Note: The model should only be solved with the Standard LP/Quadratic engine (Linear Program). Users can verify the engine by clicking the ENGINE tab at the top of the dialog box or clicking the Options button in the summary dialog box which may appear in the center of the screen.***

Details on certain key components of the Solver Dialog Box are included below. To view more information about an entry in the Solver Dialog Box, including a comment explaining the use of the entry, highlight the entry in the dialog box and click "Change" in the menu on the right. For a complete description and instructions on the use of the Premium Solver Program, users are referred to the software documentation that accompanied the software upon delivery.

Non-negative values: One additional constraint was applied to the model, and it is not listed with the other constraints in the dialogue box. This constraint requires all decision variables to assume non-negative values. Practically, this means that spills and deliveries of water cannot be negative, nor can the time of operation for the pump station. Mathematically, this places bounds on the solution, which would otherwise be characterized by an infinite combination of positive and negative numbers which could negate each other. Different versions of the SOLVER and Excel provide different ways to navigate to this feature, but users should be able to navigate to a dialog box similar to the one on the left of **Figure 3-5** below. From there, click Options and you will see the opportunity to "Assume Non-Negative" values for all decision variables.

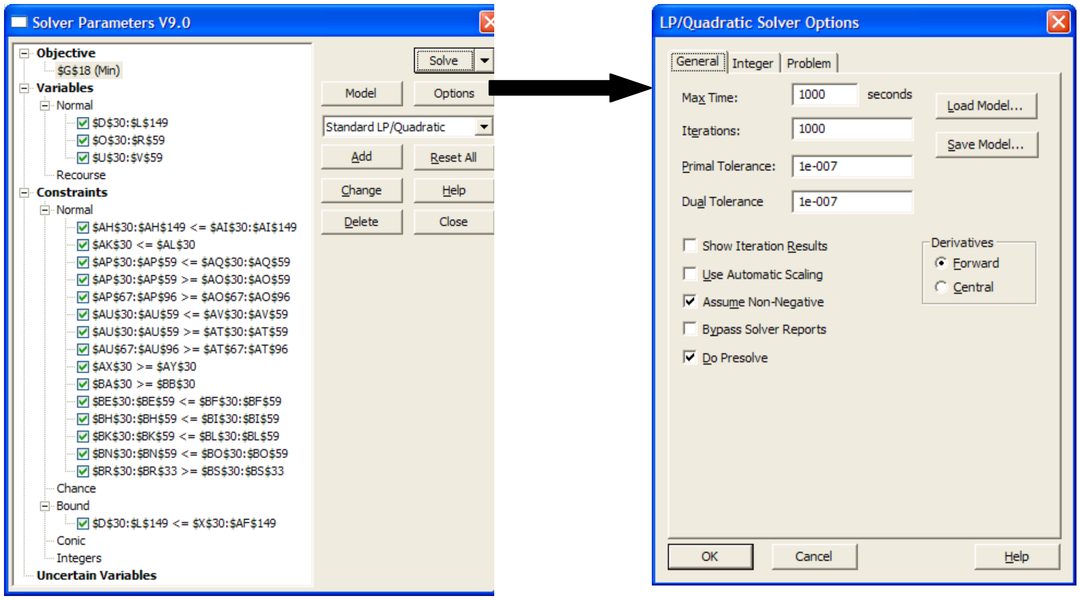


Figure 3-5. Non-Negative Constraints

Precision/Iterations: The model defaults to specifications that limit the solution algorithm to a maximum time and a maximum number of iterations (within the numerical search algorithm). If the model reaches either of these limits during the process of solving, a dialog box will appear asking if you wish to continue or stop the optimization. This is not detrimental, but can become cumbersome when using the model repeatedly for sensitivity analysis, for example. To avoid the recurrance of this interruption, navigate to the dialog boxes shown above in **Figure 3-5** and simply increase the specifications for Max Time and Iterations. There should be no detrimental impact on the speed or accuracy of the solutions.

Formulation Summary: From the sidebar dialog box, the PROBLEM tab will show the size of the optimization problem as currently specified, relative to the limits within the Solver software. The values in the box shown in **Figure 3-6** represent the size of the Operations Optimization Model.

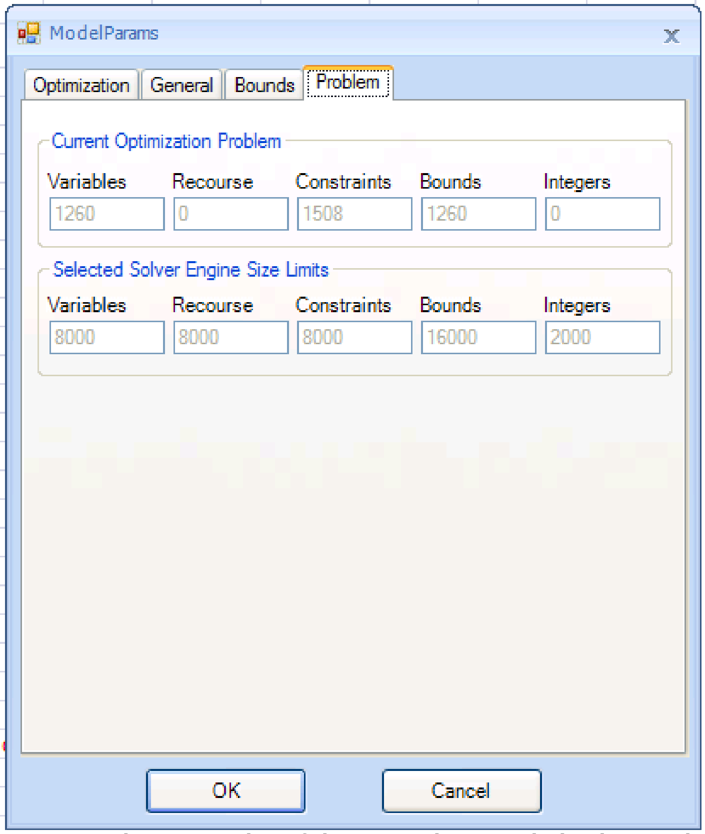


Figure 3-6 Size of the Operations Optimization Model

Output: The optimized solution will be displayed in the spreadsheet worksheets, both on the OPT PROGRAM worksheet and also on the RESULTS worksheet. The SOLVER will determine the solution and write the values of decision variables back into their designated cells on the OPT PROGRAM worksheet. Additional output is available through the SOLVER dialog box. The dialog box will report the status of the solution process while the optimization algorithm is being executed. It will also report whether or not a solution is feasible (this may appear in a separate dialog box or in the sidebar dialog box).

An infeasible solution does not necessarily mean that the problem is incorrectly formulated. It usually means that one or more of the constraints cannot be satisfied. Sometimes, reviewing the information on the SCENARIO SETUP worksheet will help determine which constraint(s) are too restrictive. At other times, it may be useful for the SOLVER to help diagnose the problem (see "Reports" below).

Reports: Sometimes solutions cannot be found, often as a result of constraints that cannot be satisfied (for example, an ending target elevation which cannot be reached regardless of how the water is managed). Several reports are available (from different navigation paths depending on the version of the software and of Excel). The "Feasibility" and "Feasibility-Bounds" reports are generated as new worksheet tabs, and identify which constraints are impossible to satisfy. These reports can also be used to distinguish constraints which are feasible and “binding” (they actually limit the objective function) from those which are non-binding (they could be more restrictive and the objective result would not change). More information on the reports and their interpretation is available in the documentation for the Premium Solver Platform software.

3.2.2 General Calculations

General calculations include the reservoir mass balance, pump station hydraulics, power and energy, and energy costs. The reservoir mass balance is a calculation of all fluxes into and out of each reservoir including runoff, transfers, evaporation, seepage, releases, withdrawals, and spills for each day of the 30-day model run. These calculations include pre-processes and optimization calculations. The OPT PROGRAM, RES SIM, and PUMP STATION worksheets all exchange data during the optimization process to ultimately determine how much water must be transfer each day from Lake Stillhouse Hollow to Lake Georgetown. The water surface elevation is also calculated each day based on the calculated total volume in each reservoir and their Elevation-Area-Capacity curves located on the E-A-C worksheet.

The pump station hydraulics calculations are part of pre-processes only. Based on input from the MODEL SETUP and PUMP DATA worksheets, the capacities for each pump configuration are calculated in the HYDRAULICS worksheet. The capacities are based on the intersection of the pump curve developed for each configuration and the system curve. For more information on these calculations, refer to **Part 1, Section 5.3** of this report.

The power and energy calculations take place in the PUMP STATION worksheet. Power is a pre-process calculation since it is based strictly on the capacity, head, and efficiency of each pump configuration. But the value of power is used in optimization. Since energy is calculated from the amount of time that power is used, it is calculated as part of the optimization step. The equations for power and energy are discussed in more detail in **Part 1, Section 5.3**.

Energy cost calculations are part of optimization and post-processing. Only the energy charges portion of the total energy cost is optimized directly, because the optimization was setup as a linear program as discussed in **Part 1, Section 4.2.4** and the energy charge calculations are linear. The utility charges are optimized indirectly because the functions that define them are non-linear (they are based on finding maximum instantaneous power). To optimize utility charges linearly, the total hours for each pump configuration is multiplied by “penalties”, which are constants that increase with higher power requirements. In post-processing, the optimized total energy cost is calculated based on the optimal pumping schedule. Additionally, energy cost is calculated for alternative operating strategies—strategies not based on optimization. These strategies are discussed in **Section 3.3** as part of the model outputs discussion. Energy cost calculations are discussed in further detail in **Part 1, Section 5.4**.

3.2.3 Adjusting the Objectives

Once the model setup is complete, the **Optimize 30-Day Plan** button takes the user to the OPT PROGRAM worksheet. This is where the objectives are further adjusted and the Premium Solver Platform is accessed to run the optimization. A screenshot of the Objectives table in the OPT PROGRAM worksheet is shown as **Figure 3-7**. The objectives considered when optimizing are listed in the left most column. Each column to the right is described in pop-up comments within the model. The values under Selection are based on input from the MODEL SETUP worksheet. A value of zero means that the objective is not considered during optimization. The Raw Value represents a summary of calculations that pertain to each objective. The Raw Effective Value is the Selection multiplied by the Raw Value. The final Weighted Value is the Raw Effective Value multiplied by the Weight. The user can adjust the values in the Weight column to emphasize or de-emphasize the applicable objectives differently when optimizing.

Objectives					
Objective	Selection	Raw Value	Raw Eff Value	Weight	Weighted Value
Minimize Deficits	0	0.0E+00	0.0E+00	1.00000	0.0E+00
Minimize Energy Charge	1	4.9E+04	4.9E+04	1.00000	4.9E+04
Minimize Utility Charge	1	3.6E+08	3.6E+08	0.00000	0.0E+00
Minimize Spills	1	0.0E+00	0.0E+00	0.10000	0.0E+00
				Total Objective	4.88E+04

Figure 3-7. Objectives Table

When optimizing cost, it is useful to optimize energy charges and utility charges separately before optimizing together. By doing this, the user can gain an understanding of the sensitivity of each objective. When optimizing the two energy charges together, it is suggested that the user experiment with different weights to further gauge sensitivity. This is because energy costs are optimized directly, but utility costs are optimized indirectly, using penalty functions associated with each incremental increase in peak power requirements for the pump configurations. Combining terms with different units may not yield a true optimum without experimentation with relative emphasis.

3.3 Model Outputs

The result of running the Premium Solver Platform is an optimized pumping schedule based on the data inputs and objectives. The schedule shows which pump configurations are run and for how long during each 6-hour time block over the 30-day period based on the optimization. Note that it is not necessarily recommended that this schedule be followed exactly. It is a theoretical optimal solution, but it may not be the most practical because it may require frequent starts, stops, or adjustments of pumps.

The user can view results by clicking on the **Results** button at the top of the OPT PROGRAM worksheet. The RESULTS worksheet summarizes the model outputs and some model inputs using graphs and tables as shown in **Figure 3-8**. The different graphs and tables are described in the following list:

- Basic Summary Data: This information is located in the top left corner of the worksheet. The information includes the total optimized cost, amount pumped, amount spilled, percent of demands satisfied, and which objectives were being considered

- Optimized Pump Station Schedule: This table is located below the graphs. It shows the number of hours of operation at each time step for each pump configuration based on the latest optimization run. It also shows which configurations were available for that run. This table should be used for guidance purposes only – it outlines the theoretical least-cost schedule by assigning pumping operations to the lowest cost hours of the day to the greatest extent possible.

- Comparison of Costs for Alternative Operation Strategies: Results are only presented in this graph if the objective is to minimize cost. The first bar on this graph shows the cost based on the optimized pumping schedule. The color shades represent the energy charges and utility charges which make up the total energy cost. In addition to calculating costs for the optimized pump schedule, costs were calculated for alternative schedules. These alternatives use the results of the explicit 6-hour schedule to develop schedules that may be more practical, while transferring the same monthly volume of water. The graph shows the cost tradeoffs in these alternative pump schedules. The alternatives to the explicit 6-hour schedule are as follows:

    - *6-Hour Total Continuous Pumping*: For this alternative, the hours allocated to each pump configuration in the explicit 6-hour schedule are added, without regard to time of day. The total energy cost is calculated based on the assumption that each pump configuration will run continuously for the total number of hours needed, sequentially. For example, Configuration A might run for 10 days, followed by Configuration B for 5 days. This could differ from the mathematically optimal schedule, which would distribute these pumping times into the least expensive hours of each day to the greatest extent possible. No assumptions are made concerning when, during the 30-day period, any of the configurations will be run. The only assumption is that the configuration will be running continuously for as long as necessary to achieve the required water volume, so there is no consideration for running the pumps during the least expensive hours of the day only. The cost for this alternative is represented in the second bar on the graph. This bar helps illustrate the cost-complexity tradeoff between multiple daily operational adjustments and less frequent adjustments throughout the month.

- *Continuous Pumping by Configuration*: If an available configuration, on its own, can meet the pumping demands within the 30-day period, total energy cost was also calculated based on running that configuration continuously for the total number of days needed. The cost for running each configuration continuously is shown in the remaining bars on the graph. If a pump configuration is not available or would not be able to deliver the flow required to meet the objectives, no cost is shown. These bars help illustrate the cost-complexity tradeoff between operating a single configuration until the desired volume is transferred and operating multiple configurations in various ways to help reduce costs.

- Distribution of Costs: The bottom-right pie graph shows the distribution of the total energy cost based on the optimized pumping schedule. This includes energy and utility charges.

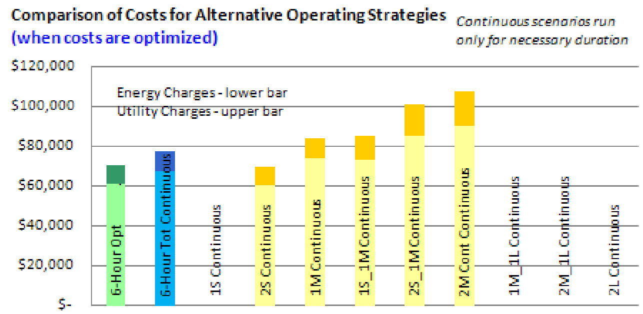
- River Forecast and Reservoir Elevation Graphs: The river forecast graph is directly based on the values entered in the RIVER FORECAST worksheet. The elevation graphs show the water surface elevations for each reservoir based on the results of the mass balance calculations. The dotted lines on these graphs represent the top of the conservation pool and the user-specified minimum level.

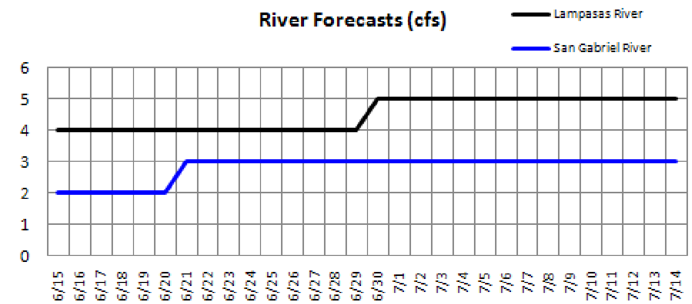
- Total Pump Flow: This is a bar graph that shows the flow pumped for each day in the 30-day period based on the optimized pump schedule.

- Pump Configuration Utilization Graphs: A bar graph and a pie graph summarize the utilization of each pump configuration based on the explicit 6-hour schedule. The bar graph displays utilization in terms of the 6-hour time blocks. The pie graph shows the percent utilization of each pump configuration during the 30-day period.

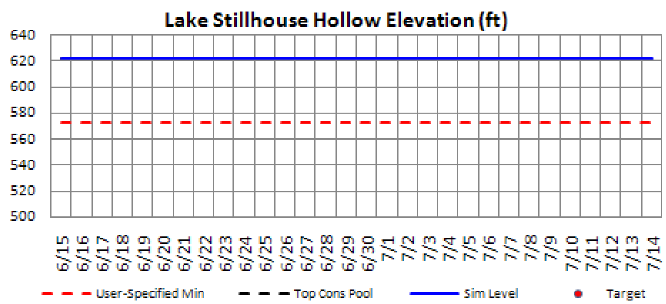
Additional information is shown in the RESULTS worksheet at the very bottom. Mostly this includes the values used in some of the graphs.

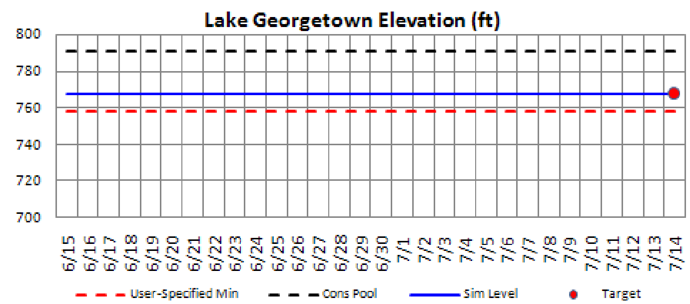
Basic Summary Data	
Start Date	6/15/2009
End Date	7/14/2009
Total Optimized Cost	$70,003
Total Pumped (acft)	1,776.8
Avg. Pumped (mgd)	19.3
Spills (acft)	
Stillhouse Hollow	0.0
Georgetown	0.0



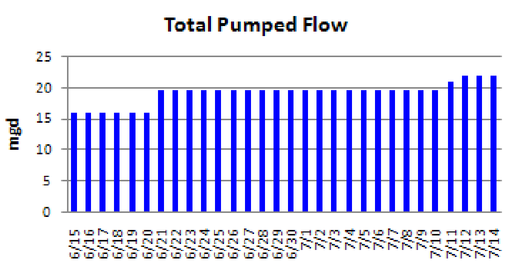


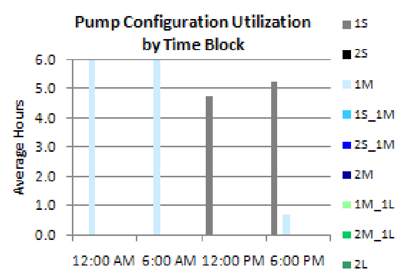
Demand Summary	
Source & Destination	% Satisfied
Stillhouse Users	100.0%
Stillhouse D/S Users	100.0%
Georgetown Users	100.0%
Georgetown D/S & Granger Users	100.0%

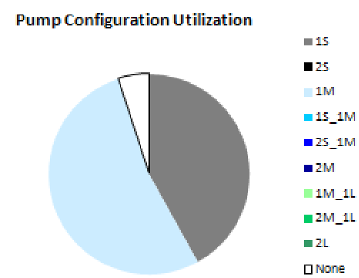




Objective (0=Off, 1=On)	
Minimize Deficits:	0
Minimize Energy Cost:	1
Minimize Utility Cost:	1







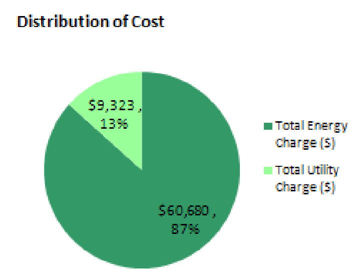


Figure 3-8 Operations Optimization Model Results Page

3.4 Results Interpretation

The results of this model are to be used for guidance purposes only. It is not necessarily feasible or practical to run the optimized pump schedule exactly. Fundamentally, the model determines the necessary volume of water to transfer based on the expected inflow, demands, and water level requirements and then parcels that volume over time periods that are most cost-effective. The model then calculates the cost of alternative operating strategies to compare to the explicit 6-hour schedule so that the user can weigh the benefits. It is important to understand when reading the results that some user inputs are uncertain or variable, and they may or may not have significant impact. The sensitivity of such inputs should be checked to better understand the range of the results and make informed decisions.

Also, the results should not be viewed as final for any 30-day period. The recommended schedules can be easily adapted during the month if conditions change. The model does not need to start at the beginning of a calendar month. Rather, if conditions change mid-month, the user can run a new 30-day scenario with the current conditions as the starting point and a revised forecast from that point forward.

The RESULTS worksheet shows the optimized pump schedule and summarizes other information in graphs and tables as discussed in **Section 3.3**. The following sections further discuss the results and provide some insight on how the results could be interpreted.

3.4.1 Alternative Operating Strategies

The benefit of the explicit 6-hour schedule results are that they can be used to gain an understanding of when it is best to run which pump configuration and which configurations are best suited to the required volume and expected conditions. The Comparison of Costs for Alternative Operating Strategies graph in the RESULTS worksheet is useful for gauging if there is a significant increase in cost if the explicit 6-hour schedule is not used. After developing the optimized 6-hour schedule, the model restructures the pumping schedules in alternative ways to understand the cost-complexity tradeoffs between adjusting the pumps every six hours to capitalize on daily fluctuations in energy costs and adjusting them much less frequently (continuous operations) to minimize the starts and stops.

The cost comparison graph with example results is shown in **Figure 3-9**. The lower bar color is the energy charge while the upper is the utility charge. The first bar (green) is the total energy cost for the optimized pumping schedule, the next bar (blue) is the total energy cost for the 6-hour total continuous pumping strategy, and the remaining bars (yellow) are energy costs for each pump configuration pumping continuously. These alternative operating strategies were discussed in detail in **Section 3.3**. Configurations that do not show a bar with costs either cannot deliver the transfer volume required or they were not available based on the user inputs.

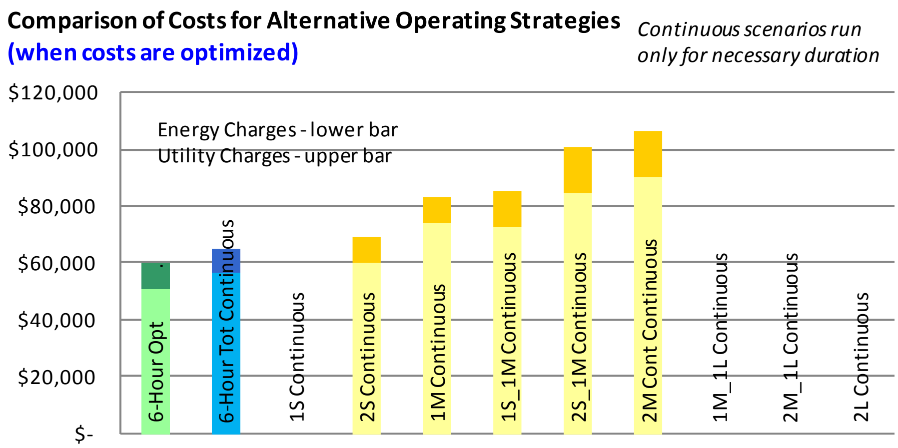


Figure 3-9. Example Results for Cost for Alternative Operating Strategies Graph

A graph that summarizes the explicit 6-hour schedule is shown in **Figure 3-10**. The explicit 6-hour schedule alternates between using the 2S (two small pumps) pump configuration during the less expensive 6-hour time blocks and 1S (one small pump) configuration during the more expensive time blocks. This schedule requires the Stillhouse PS to run almost constantly for the 30-day period. The cost comparison graph shows that the cost of energy increases if each configuration utilized in the explicit 6-hour schedule was run for the total required number of hours without regard to the time of day (blue bar). Cost continues to increase if instead the 2S (two small pumps) configuration is run continuously. For the 2S configuration the pumps only need to run for 21 days out of the 30-day period to satisfy all model constraints, but the cost is greater. The user must determine if the benefit of a simple operating plan outweighs the additional cost. By examining all the results, the user can make a more informed decision when developing an operations plan.

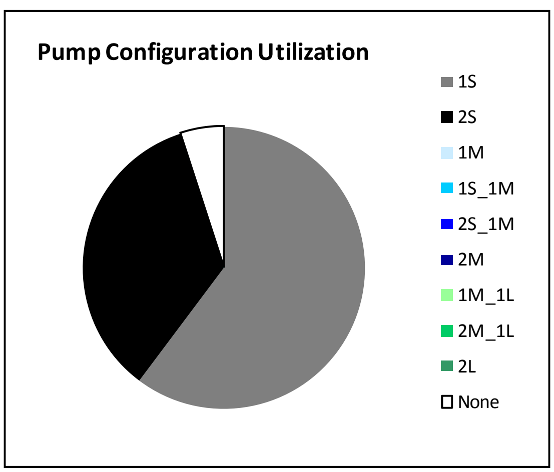


Figure 3-10 Example Results for Pump Configuration Utilization for 6-Hour Optimized Pump Schedule

3.4.2 Significance of Utility Charges

As shown in Figure 3-9, utility charges typically make up about 10 to 20 percent of the total energy cost when the Stillhouse PS is operating. Occasions when it is not necessary to run the pumps for a month, utility charges make up 100 percent of the total energy cost because there are no energy charges, but utility charges still apply. This is because utility charges are based on maximum power usage over the previous 12 months. The consequence of using pump configurations that require more power is that the utility charges increase. Using one pump configuration that requires a large amount of power, even for a short period of time, can increase utility charges for the next 12 months. Although utility charges typically make up a smaller percent of total cost compared to energy charges, the impact of these charges can be significant over time.

3.4.3 Sensitivity to Model Inputs

The sensitivity of model inputs for the Operations Optimization Model should be assessed by the user when evaluating different scenarios. The river forecast and the ending lake targets, for example, are two inputs that are variable and can significantly affect results. The river forecast data obtained from the AHPS are predictions based on recent hydrologic activity in the area, which can be uncertain. Since the data is provided in terms of statistical probabilities the user has some idea about the uncertainty of the data. Overall, it would be wise to run different forecasts (or different percentiles of expected inflow) to gage how sensitive any given month's operating plan is to the forecast, and to make planning decisions with the benefit of understanding the effects of that uncertainty.

It may also be useful to experiment with alternative ending reservoir level targets to understand the incremental cost associated with alternative targets. For example, the 30-day energy cost of the explicit 6-hour schedule developed as part of the discussion in **Section 3.4.1** was around $60,000. That scenario required that the ending target level in Lake Georgetown be the same as the level at the start of the 30-day period. If the target is set one foot lower than the initial level, the predicted total energy cost reduces to about $35,000. If the target is one foot higher than the initial level, the predicted total energy cost increases to about $90,000.

Although the determination of ending targets is solely at the user's discretion, the Planning Simulation Model can be a very useful companion tool to help establish a reasonable range of target reservoir levels that can minimize the risk of demand shortages long term. Alternatively, historical rule curves could also be used, but perhaps without quite as much insight into risk avoidance as could be obtained with the Planning Simulation Model.

3.5 Key Concepts

The following is a list of key concepts to keep in mind when using the Operations Optimization Model. This is a useful list to consult when the optimization calculation does not converge on a solution or if results do not come out as expected.

- Start Date: Be sure to enter a start date. This affects a number of calculations in the program such as the energy costs.

- Max Capacity Constraint: When using the model to assess future conditions, large demands may require a pump configuration that has a capacity that exceeds the current capacity of the WCRRW Pipeline. Pump configurations that exceed this capacity are not included in the optimization process even if all pumps are selected to be active. The table at the bottom of the MODEL SETUP worksheet will gray out configurations that have a capacity that exceeds the pipeline capacity constraint. Choose the "User-Defined" or "No Constraint" option to evaluate larger pump configurations for future demand conditions.

- Reservoir Conditions: The model will not find a solution if the ending targets (or the lower threshold throughout the 30 days) for the reservoirs are physically unachievable based on the hydrologic forecast and expected demands. If the volume that needs to be supplied to the reservoir to meet the target exceeds the capability of the largest capacity pump configuration, it will not be possible to meet all of the constraints. This should be the first constraint to examine if the model returns a message that a feasible solution cannot be found. Note that an ending target need not be specified, but the model will interpret the absence of such a target as "freedom" to draw down to the lowest allowable operating elevation.

- Objective and Reliability Constraints: The two options available for the objective function are to minimize costs or supply deficits, either of which can be combined with minimizing spills. The model will not find a solution if the system cannot meet the demands according to the user-specified demand constraints in the Reliability Constraints table and the objective is set to minimize cost and spills. Verify the reliability of meeting demands by first optimizing the model to minimize supply deficits. The results worksheet displays the percent of demand that can be satisfied for each user (for now, this is expected to be 100% all the time). Those percents can be copied into the Reliability Constraints table in the MODEL SETUP worksheet. It is recommended that the percentages be decreased by 0.1 percent to provide a slight buffer in finding a feasible solution (by avoiding infeasible solutions due to rounding). The objective can then be set again to minimize cost and spills.

- Pre-Process Input Data Button: Be sure to click the **Pre-Process Input Data** button after making any changes to the model inputs. This ensures that all calculations required before optimization are computed. This will also calculate all formulas in case the calculation options are accidentally set to manual.

- Optimize 30-Day Plan Button: This button takes the user to the OPT PROGRAM worksheet, but does not start the Premium Solver Platform. The program must be accessed and then run to complete the optimization. Although the Premium Solver Platform can be accessed from any worksheet in the model, the user must be on the OPT PROGRAM worksheet to run the pump operations 30-day optimization. It will appear blank if accessed from any other page, and will not execute.

- Weights on OPT PROGRAM Worksheet: The objective chosen on the MODEL SETUP worksheet controls the Selection column on the OPT PROGRAM worksheet, which affects which objectives will be included when running the Premium Solver Platform. The Weights can be changed to further adjust the objective function by emphasizing or de-emphasizing certain components. Any positive number can be entered in the Weights column, and it may be useful to experiment with weights that vary over many orders of magnitude, especially because some objective formulations will include terms with different units (dollars and penalties, for example). When optimizing costs, remember that it is useful to optimize energy charges and utility charges separately before optimizing together. Then when optimizing together, experiment with different weights to understand the sensitivity of each charge.

- Optimized Pump Station Schedule: This is located on the RESULTS worksheet and it is to be used for guidance purposes only.

3.6 Example Problem Formulation

Below are two scenarios that were provided by the BRA that can be addressed using the Operations Optimization Model. CDM has provided example problem formulations to each of these scenarios. Note that these are just examples and other methodologies may be viable.

3.6.1 Scenario 1

Based on current conditions (current reservoir levels and expected 30-day reservoir inflow forecasts) and assuming the planned Phase II pumps are operational (small and medium pumps available), what would be an optimal 30-day operating plan for expected demand levels (average) and current energy prices?

Example Problem Formulation:

Set up the model based on the information provided in the scenario description above. This includes everything in the Scenario Setup box in the MODEL SETUP worksheet. Next, set the objective to minimize supply deficits first to ensure that demands can be met. Run the model to confirm that all demands can be 100 percent satisfied given the modeled conditions. Once reliability is confirmed, set the reliability constraints at 100 percent, and change the objective to minimize costs and spills. Adjust the objective function weights on the OPT PROGRAM worksheet before running the Premium Solver.

If a solution cannot be found, check the ending target levels, availability of pump configurations, and demands. It may also be useful to experiment with alternative targets to understand the costs associated with raising the target. The Planning

Simulation Model may also be used to determine appropriate lake level targets that will be beneficial over the long term. A long-term lake level target will help in determining appropriate targets in 30-day increments. Also, experiment with different weights on the objective functions. The explicit 6-hour schedule may vary depending on which cost has more weight.

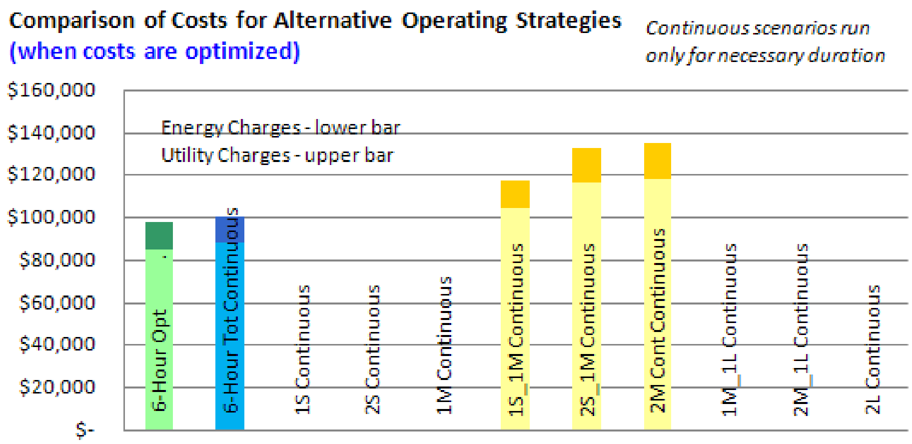
Example results for this scenario are based on the following model inputs:

- Start date is April 14, 2009.
- River forecast data is the median mean value predicted starting April 14, 2009.
- Energy costs are based on the historical MCPE cost values for the months simulated.
- Demands are 11.7 mgd for Stillhouse Users, 26.5 mgd, for Georgetown Users, and 2.98 mgd for Granger.
- Downstream demands are 0.1 mgd for Stillhouse downstream users, 0.1 mgd for Georgetown downstream users, and 0 mgd for all others.
- Percent of time pumps are unavailable is 5 percent
- Initial lake levels are 616.3 feet for Stillhouse and 773.7 feet for Georgetown.
- Ending targets are none for Stillhouse and the same as the initial level for Georgetown.

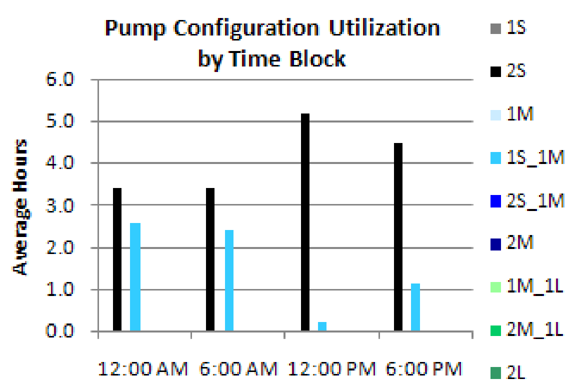
For this scenario, all demands can be met with 100 percent reliability. With the objective to minimize costs and spills, the user-defined weights are 100 for energy charges, 1 for utility charges, and 0.1 for spills. The user can also experiment with other weight values.

Figure 3-11 shows two graphs from the RESULTS page based on the model inputs and weights discussed above. Graph (a) shows the pump configuration utilization by time block. Having more weight on the energy charges results in the solver taking more advantage of using the least power configuration during times when energy charges are more expensive.

Graph (b) shows the costs comparisons for alternative operating strategies. The total 30-day optimized cost based on the explicit 6-hour schedule is $97,890. For the 6-hour total continuous schedule, the cost only increases to $100,648. Therefore, if it is preferable to use a simple pump schedule of running the 2S configuration for most of the 30-day period and then switching to the 1S_1M configuration for the rest of the time, the predicted increase in cost is minimal. If only one pump configuration is chosen to run continuously for the days needed in the 30-day period, the cost increase is more significant. This is because the lowest power configuration that can meet all the requirements is the 1S_1M configuration, which uses more energy and power compared to the 2S configuration.



(a)



(b)

Figure 3-11 Scenario 1 Results including (a) Costs of Alternative Operating Strategies and (b) Pump Configuration Utilization by Time Block

3.6.2 Scenario 2

Obtain an optimal 30-day operating plan for the demand levels and applicable energy prices based on the following assumptions:

- *Assume it is June 1, 2010 and inflows in the past year have been sparse (assumes that forecasted river inflows are minimal or zero).*
- *The Phase II pumps are installed and operational.*
- *Water surface elevation at Lake Stillhouse Hollow is 610.0 feet.*
- *Water surface elevation at Lake Georgetown is 768.0 feet.*

- *Expected demand at Stillhouse, Georgetown, and Granger (daily average) is 12 mgd, 40 mgd, and 4 mgd, respectively.*

Example Problem Formulation:

Similar to Scenario 1, enter all appropriate model inputs and run the model to minimize demand deficits first to ensure that demands can be met. If the results show that demands cannot be 100 percent satisfied, check if there are any inputs that can be adjusted that would improve the reliability. If the demands still cannot be met but the reliability that is achieved is acceptable, insert the resulting reliabilities in the reliabilities constraints table in the MODEL SETUP worksheet and then set the objective to minimize costs and spills.

Example results for this scenario are based on the model inputs listed under the scenario description and the following additional model inputs:

- River Forecast is zero inflows for both lakes.
- Energy costs are based on the historical MCPE cost values for June.
- Downstream demands are 0.1 mgd for Stillhouse downstream users, 0.1 mgd for Georgetown downstream users, and 0 mgd for all others.
- Percent of time pumps are unavailable is 5 percent
- Ending targets are none for Stillhouse and variable as described below for Georgetown.

If no ending target is set for Lake Georgetown, all demands can be met with 100 percent reliability, but the level in Lake Georgetown falls by 6.5 feet. Since Lake Georgetown is at 38.4 percent capacity given the initial conditions for this scenario, the user may prefer to set the ending target level to be the same as the initial condition level for Lake Georgetown. Under those conditions, demands cannot be met with 100 percent reliability as shown in **Figure 3-12**.

Demand Summary	
Source & Destination	**% Satisfied**
Stillhouse Users	100.0%
Stillhouse D/S Users	100.0%
Georgetown Users	94.4%
Georgetown D/S & Granger Users	93.3%

Figure 3-12. Example Demand Results for Scenario 2 and an Ending Target in Lake Georgetown Equal to the Initial Condition

If the percent satisfied is acceptable, the values in Figure 3-12 should be copied to the reliability constraints table in the MODEL SETUP worksheet. It is recommended that the percentages be decreased by 0.1 percent to provide a slight buffer in finding a feasible solution (by avoiding infeasible solutions due to rounding). Then the scenario can be run to minimize costs and spills. The resulting cost for the 6-hour explicit optimized schedule and the alternative operating strategies are shown in **Figure 3-13**. The costs for the different strategies do not vary much because the largest capacity pump configuration must run constantly to meet the demand reliability constraints.

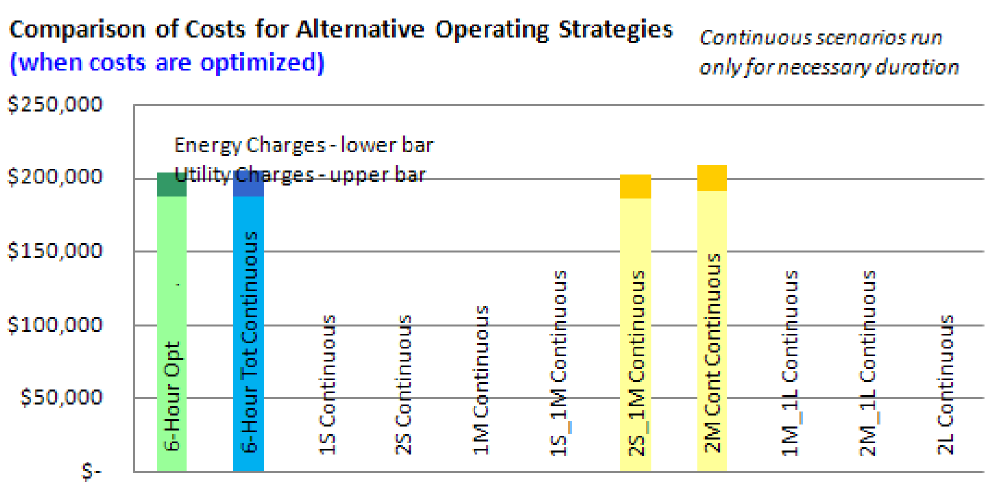


Figure 3-13 Example Energy Cost Results for Scenario 2 and an Ending Target in Lake Georgetown Equal to the Initial Condition

Note that demands can still be met with 100 percent reliability for this scenario if the level in Lake Georgetown is allowed to fall below the initial condition levels. It was found that the lake level would only fall by less than 0.1 feet to meet all demands.

FINAL REPORT

Hydrologic Report on Monthly Inflows for Lake Georgetown, Lake Stillhouse Hollow, Lake Belton, and Lake Granger

Sept. 3, 2009

Prepared by:

Franklin Engineering Associates, L.L.C.

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September 1, 2009

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Executive Summary

Franklin Engineering Associates, L.L.C. developed three datasets of monthly time series stream flows for the current location of the dams impounding Lakes Georgetown, Stillhouse Hollow and Belton. CDM developed a dataset for Lake Granger. The time series represent historical flows at these locations with the effect of the water supply and flood operations of those three reservoirs eliminated, but do not represent fully naturalized flows. Naturalized flows represent the flow if the water resource had not been developed or used at all, if it had not been affected by human-induced land cover and water use changes. The effect of Lake Proctor operations on the inflows into Lake Belton has not been removed from the dataset. The major effects this has on the time series for Lake Belton are a mitigation of flood flows, spreading large releases over several months, and the increased upstream water loss due to evaporation from the surface of Lake Proctor. The time series for Lakes Georgetown, Stillhouse Hollow, and Granger cover the time period from January 1998 through December 2007. The time series for Lake Belton covers the time period January 1940 through December 2007. These time series are reported in acre-feet per month and attached as Appendix A.

The scope of work required the time series for Lakes Georgetown and Stillhouse Hollow to be consistent with the time series developed by Freese and Nichols, Inc. for the period 1941-1997 and presented in a 2001 report entitled "*Williamson County Water Supply Pipeline Model*". The extended time series developed for Lakes Georgetown and Stillhouse Hollow used the same methodology and sources of the Freese and Nichols data. The data for the monthly time series for the period 1988 to 1997 were used as a comparison. While many years show good agreement, for example the data for 1997 were within 1% of the annual flows at Lakes Georgetown and Stillhouse Hollow, there were larger differences in other years and when comparing monthly data. The data were also compared to the Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM) fully naturalized flows for the period 1940-1997 and naturalized flows presented in the Texas Water Resources Institute Technical Report 340 (TR 340) for the period 1998-2007. Comparisons on a monthly basis are provided in the appropriate section.

The time series for Lake Belton was developed using the same methodology as the other lakes. It covers approximately 14 years prior to the deliberate impoundment of water in Lake Belton and the 64 years since impoundment. There was no direction in the scope of work to compare Lake Belton inflows with any other data developed by others, however, examination of historical flow at the Leon River near Belton shows the time series reproduces the pattern of low flows of the drought years and the flood periods well. This time series was also compared to the WAM and TR 340 flows.

Section 1
Introduction

Franklin Engineering Associates, LLC (Franklin) was engaged by CDM to develop a time series of monthly stream flows for the location of the dams impounding Lakes Georgetown, Stillhouse Hollow and Belton. The methodology for Lakes Georgetown and Stillhouse Hollow was to be consistent with the data sets developed by Freese and Nichols, Inc. (FNI) for the period January 1941 through December 1997 and presented in a 2001 report entitled "*Williamson County Water Supply Pipeline Model*". The time series for Lakes Georgetown and Stillhouse Hollow were developed for the period January 1998 through December 2007. The time series for Lake Belton was developed for the period January 1940 through December 2007 using the same general methodology.

The time series represent historical flows at these locations with the effect of the water supply and flood operations of those three reservoirs eliminated, but do not represent fully naturalized flows. Naturalized flows represent the flow if the water resource had not been developed or used at all, if it had not been affected by human-induced land cover and water use changes. The changes in upstream water use have not been removed from this dataset. The effect of Lake Proctor operations on the inflows into Lake Belton has also not been removed from the dataset. The major effect this has on the time series for Lake Belton is a mitigation of flood flows, spreading large releases over several months.

The data thus developed were compared to that developed by FNI for the period January 1988 through December 1997 for Lakes Georgetown and Stillhouse Hollow. Additionally, the data were compared to the Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM) data for the January 1988 through December 1997 period and to the Texas Water Resources Institute Technical Report 340 (TR 340) data for the period January 1998 through December 2007.

Seventy percent (70%) of the comparison years show less than 3% difference in flows between FNI and Franklin at Lake Georgetown, while 40% of the years show less than 3% difference at Lake Stillhouse Hollow. 1991, 1992, 1993 and 1997 show the best correlation, while 1988 and 1996 show the poorest correlation for both lakes.

Section 2
Hydrologic Methods Used

Two methodologies were used to develop historic inflows, the drainage area ratio and the water balance method. In general, a water balance was used to determine inflows. In periods prior to reservoir impoundment, a nearby stream gage was used to estimate flows at the point of interest using a drainage area ratio. In some cases, the drainage area ratio was used to estimate spills from a particular reservoir. These instances will be called out. If FNI had estimated flows previously, Franklin deferred to the method that FNI used, unless there was a particular reason not to, particularly if the FNI data source was not available for a period of time. Those instances where Franklin used a different method or data source will be specifically called out. In each instance, the impact of the alternate source data is evaluated.

2.1 Drainage Area Ratio Methodology

In periods prior to reservoir impoundment, flows at a nearby stream gage were used to estimate flows at the point of interest using a drainage area ratio, for instance to estimate flows at Belton Dam for the period January 1940 - March 1954, when deliberate impoundment began. In other cases, when a stream gage is very close to the dam site, this method was used to estimate spills from the reservoir.

$$Flow_{(dam\ site)} = Flow_{(gage\ site)} * (drainage\ area_{(dam\ site)} / drainage\ area_{(gage\ site)})$$

Stream flows and drainage area data were obtained from the United States Geological Survey (USGS).

2.2 Water Balance Methodology

In general, flows were estimated using a water balance approach.

Flow = change in reservoir storage + lakeside use + spills + net evaporation + or - pipeline deliveries (depending on whether those deliveries were inputs or outputs of the reservoir)

Beginning in 1985, the Brazos River Authority (BRA) kept electronic records which include data obtained from the U.S. Army Corps of Engineers (COE) on the three reservoirs of interest in this report. Because BRA records were more readily available than the COE data, most COE data used in the period 1985-2007 was actually obtained from BRA databases which are sent to BRA by the COE. Much of the data used, and almost all data after 1985, were daily data summed to produce monthly totals.

2.2.1 Change in Reservoir Storage

Data on change in reservoir storage was obtained from the COE and USGS. The USGS data was only available through the end of January 2004. For COE data, the difference in storage at 0800 on the first day of consecutive months was used to determine the change in reservoir storage. For USGS, the difference in storage at midnight of the first day of consecutive months was used to determine the change in reservoir storage.

2.2.2 Lakeside Use

Several of the larger lakeside water users report withdrawals from the lake daily to the COE. Daily lakeside use of all users is reported to BRA monthly. For this report, COE lakeside use is increased by the withdrawals of those lakeside users that report only to BRA.

2.2.3 Reservoir Spills and Releases

In some cases, reservoir spills and releases (spill) data were obtained from the COE. When the FNI methodology used it, the spills were estimated by the drainage area ratio of the nearby downstream gage. COE spill releases are based on theoretical gate equations and tend to be less accurate than USGS gage readings.

2.2.4 Evaporation

Determination of the volume of water evaporated requires data on the depth of water evaporated, the amount of precipitation received and the area of the lake exposed to evaporation.

Gross evaporation and precipitation was obtained from the Texas Water Development Board (TWDB) for the quadrangles near the lakes. Any evaporation, precipitation and lake elevation data collected at the site and reported by COE (pan evaporation data) and USGS (lake levels only) were also considered.

The FNI methodology used the area-elevation results of the 1995 TWDB hydrographic survey to establish the area of the lake exposed to evaporation. Franklin used the most recent hydrographic surveys available for each lake (2003 for Lake Belton and 2005 for Lakes Georgetown and Stillhouse Hollow) to establish the area of the lake exposed to evaporation. The difference between inflows calculated with the two hydrographic surveys was negligible (less than 0.1% for 1992, the year of highest elevations during the period of comparison).

2.2.5 Negative Flows

Since flows are a calculated quantity in this methodology, negative inflows occasionally occur, especially during dry periods. In that case, negative flows were set to zero (0), and the flows for the other (positive) months adjusted such that the total annual flows were preserved. Both FNI and Franklin used the same procedure to adjust negative inflows. The negative values obtained in this study were relatively minor.

If Flow <0, Flow = 0

If Flow >0, $Flow_{(adjusted)}$ = $Flow_{(computed)}$ * total annual flow/total positive monthly flows for that year

Negative flows indicate some factor was not determined exactly in the measured data. There are numerous sources of potential error in calculation of inflows. These include:

- interaction between surface and groundwater, (either losses to groundwater or additions from groundwater),
- inaccuracy in estimating the areal extent of evaporation or rainfall (several point measurements aggregated into an areal value),
- inaccuracies in the elevation-volume relationships used to estimate the change in storage,
- inaccuracies in the discharge-gate opening relationships used to estimate releases,
- any lakeside use not reported, and
- any pipeline losses between Lakes Georgetown and Stillhouse Hollow.

Again, for this study, the negative flows were relatively minor. The negative flows did not dominate the dataset (<0.2%) and were negligible compared to the positive flows.

For Lakes Georgetown and Stillhouse Hollow, Franklin developed flow datasets for the period of January 1998 to December 2007. In addition, Franklin developed flow for the 1988 – 1997 dataset to compare to the FNI developed flow data for the same time period. The 1998 – 2007 dataset is the deliverable for the hydrologic extension task for the Williamson County Regional Raw Water Line project.

Since Lake Belton, did not have an existing flow dataset, Franklin developed the flow dataset for the period of January 1940 to December 2007 as part of this effort.

Section 3
Specifics on Data Sources and Procedures for Each Lake

3.1 Lake Georgetown

FNI developed a time series of inflows for Lake Georgetown for the period January 1941 through December 1997. This project required that the time series be extended to December 2007 in a manner consistent with the previous data. The lake began deliberate impoundment 1980, so it has been in existence for the entire period covered by this report. There is little water use under permit above Lake Georgetown so streamflow records provide a reasonably accurate record of flows. BRA holds the entire water right in Lake Georgetown, and keeps accurate records of withdrawals from and pipeline additions to that reservoir. Appendix B includes monthly data sets used in the water balance calculations for Lake Georgetown.

3.1.1 Change in Reservoir Storage

Consistent with FNI methodology, USGS reservoir storage values were used for the period available, January 1, 1988 through January 1, 2004. Change in storage was determined as the difference in storage at midnight of the first day of consecutive months. Because USGS records are only available through January 2004, COE reservoir records of the amount in storage at 0800 on the first day of consecutive months were used to estimate change in storage for the remainder of the period through December 2007.

In order to evaluate the impact of changing the input data from USGS storage to COE storage, a comparison of the USGS and COE reservoir storage on the first day of each month for the period 1988-2007 was conducted. It found little difference in values in the 1988 to approximately 1999 period. COE values began to have more substantial differences from USGS, both larger and smaller, after 2000. The monthly average difference between January 1988 and December 1999 was 0.01 foot. For the period January 2000 to January 2004 period, the COE data were greater by a monthly average of 0.23 acre-feet, with absolute differences from 98 acre-feet more to 65 acre-feet less. Any difference in change in reservoir storage translates directly into an equivalent change in inflow for that period.

This data was compared to computed storage using the 2005 TWDB area-elevation-capacity tables developed through a hydrographic survey of the lake. While the absolute values of storage differed, there was little difference in the change in storage between the two datasets.

3.1.2 Lakeside Use

BRA monthly records were used for the January 1988 through December 1997 period. BRA daily records for the period January 1998 through December 2007 were summed to produce monthly lakeside use.

3.1.3 Reservoir Spills and Releases

For the period March 1980 to December 1997, FNI used the stream gage immediately downstream of the dam (USGS gage 08104700, North Fork of the San Gabriel River near Georgetown), reduced by the drainage area ratio of the gage site to the dam site (247 square miles /248 square miles), to estimate reservoir spills.

Franklin followed the same procedures established by FNI and used the USGS North Fork gage adjusted by the drainage area ratio to estimate releases from Lake Georgetown for the period January 1997 to December 2007. It should be noted that the Oct, Nov, and Dec 2007 data was listed as provisional at the time it was obtained.

Since the reservoir exists for the entire period of interest, Franklin evaluated the impact had the COE record of spills been used, rather than the downstream stream gage. The COE reports 92,000 acre-feet less flow over the 1988-2007 time period (approximately 380 acre-feet less per month, on average) than measured at the USGS gage (when the gaged flows are reduced by the appropriate drainage area ratio). The stream gage records are a better reflection, in general, of flow conditions than the COE reported gate releases when gages are in close proximity downstream, such as at this site. COE spill releases are based on theoretical gate equations and tend to be less accurate than USGS gage readings.

3.1.4 Evaporation

TWDB publishes data on gross evaporation and precipitation based on quadrangles that are 1° latitude by 1° longitude. Using best professional judgment, FNI established a weighted evaporation based on the distance from the center of each of four (4) adjacent quadrangles. For Lake Georgetown, FNI computed the gross evaporation based on 5.05% of quadrangle 609, 13.13% of quadrangle 610, 59.09% of quadrangle 709 and 22.73% of quadrangle 710. At the request of Franklin, TWDB determined that the surface area of Lake Georgetown at the top of the conservation pool is 100% within quadrangle 710. During the time period studied, the lake is at or near the top of the conservation pool most of the time. Precipitation as measured at the lake was used to subtract from the gross evaporation to produce net evaporation. For months that have a negative net evaporation, precipitation exceeded evaporation.

The TWDB quadrangle data is only available through 2004. Franklin compared the effect of using the gross evaporation from the three datasets: (1) using only the gross evaporation from quadrangle 710, (2) using the gross evaporation with the FNI weighted data from four adjacent quadrangles and (3) using the COE gross evaporation as measured by a standard evaporation pan located at the dam site. There was very little difference between datasets (1) and (2). Dataset (3) correlated well with other gross evaporation estimates during the autumn, winter and spring months, but measured more gross evaporation than other estimates during the summer months. This is not surprising since the COE does not apply a pan factor to its reported evaporation. Franklin established monthly coefficients that reduced measured evaporation to more closely match the TWDB data, essentially deriving a pan factor for this data.

While net evaporation can represent a significant amount of water loss to a watercourse, comparison of the three above-described datasets showed there was not a large difference in the amount of water evaporated between those datasets. For this effort, Franklin used net evaporation reported by FNI for the period January 1988 through December 1997, the FNI process using four adjacent weighted TWDB quadrangles for the period January 1998 through December 2004, and the COE reported pan evaporation with the COE measured precipitation at the Lake for the January 2005 through December 2007 period. The COE pan evaporation was adjusted using the monthly coefficients derived by Franklin to match the FNI data in overlapping years as reported above.

3.1.5 Area-Elevation

The area of the lake exposed to evaporative effects was determined by the average lake elevation based on the first day of adjacent months (average elevation= (elevation day 1 month 2 – elevation day 1 month 1)/2). Franklin examined the difference between average area based solely on the elevation on the first of adjacent months and the average area using multiple periods during the month when there were large fluctuations within the month (a flood or drought period). There was little difference in the two methods, so the elevation on the first day of adjacent months was used for the full period.

FNI used the best available area-elevation information at the time of their report, the 1995 TWDB hydrographic survey. Franklin used the updated 2005 survey data. The difference between the two data sets are negligible (less than 0.1% during the year of highest flow, 1992).

3.1.6 Pipeline Deliveries

BRA records were used to determine the monthly volume of water delivered to Lake Georgetown from Lake Stillhouse Hollow. Water was delivered during the period January 2006 through March 2007. This volume was subtracted from the inflow since it was an input, not a release, to the Lake Georgetown reservoir. Therefore, the equation used to determine inflows is as follows:

Flow = change in reservoir storage + lakeside use + spills + net evaporation - pipeline deliveries

3.2 Lake Stillhouse Hollow

FNI developed a time series of inflows for Lake Stillhouse Hollow for the period January 1941 through December 1997. This project required that the time series be extended to December 2007 in a manner consistent with the previous data. The lake began deliberate impoundment in 1968 so it has been in existence the entire period covered by this report. There are few water rights upstream of Lake Stillhouse Hollow. BRA holds the water permit for all water in the reservoir, and keeps good records of withdrawals. Appendix C includes monthly data sets used in the water balance calculations for Lake Stillhouse Hollow.

3.2.1 Change in Reservoir Storage

It is unclear where FNI obtained the amount of water in storage so Franklin used that amount reported by the COE at 0800 on the first day of each month for the period 1988-2007. A comparison of the USGS and COE reservoir storage on the first day of each month for the period found little difference in values. This data was also compared to computed change in storage using the 2005 TWDB area-elevation-capacity tables developed through a hydrographic survey of the lake. While the absolute values of storage differed, there was little difference in the change in storage between the two datasets.

3.2.2 Lakeside Use

BRA monthly records were used for the January 1988 through December 1997 period. BRA daily records for the period January 1997 through 2007 were summed to produce monthly lakeside use.

3.2.3 Reservoir Spills and Releases

Consistent with the FNI methodology, Franklin used the downstream gage, USGS 08104100, Lampasas River near Belton, adjusted by the appropriate drainage area ratio (1313/1325 square miles) to estimate reservoir spills and releases for the time period January 1988 through September 1989. Consistent with the FNI methodology, Franklin used COE reported spills and releases from Lake Stillhouse Hollow for the period October 1989 through April 1999. COE records obtained from BRA for the period May 1999 through December 2007 were used to determine the reservoir spills and releases. This data was in daily increments, which were summed to produce monthly results.

Franklin conducted an analysis to determine the effect of using COE-reported reservoir spills and releases rather than estimating them with the downstream gage. USGS gage records were not available for the October 1989 through April 1999 time period. The COE reports 69,000 acre-feet less flow over the January 1988 through September 1989 plus May 1999 through December 2007 time periods (approximately 564 acre-feet less per month, on average) than measured with the USGS gage (when the gaged flows are reduced by the appropriate drainage area ratio).

3.2.4 Evaporation

TWDB publishes data on gross evaporation and precipitation based on quadrangles that are 1° latitude by 1°longitude. Using best professional judgment, FNI established a weighted evaporation based on the distance from the center of each of four (4) adjacent quadrangles. For Lake Stillhouse Hollow, FNI computed gross evaporation based on 17.5% of quadrangle 609, 32.9% of quadrangle 610, 16.8% of quadrangle 709 and 32.9% of quadrangle 710. At the request of Franklin, TWDB determined that the surface area of Lake Stillhouse Hollow at the top of the conservation pool is 93.13% in quadrangle 610 and 6.87% in quadrangle 710. During the time period studied, the lake is at or near the top of the conservation pool most of the time. Net evaporation was established as the TWDB quadrangle evaporation minus the TWDB quadrangle precipitation adjusted for the quadrangle proportions described above. For months that have a negative net evaporation, precipitation exceeded evaporation.

The TWDB quadrangle data is only available through 2004. Franklin compared the effect of using the gross evaporation from three datasets (1) using the weighted quadrangle proportions established by TWDB (using two adjacent quadrangles), (2) using the FNI weighted quadrangle proportions established (using four adjacent quadrangles) and (3) using the COE gross evaporation as measured by a standard evaporation pan at the dam site. The net evaporation was determined by subtracting the gross precipitation as determined by TWDB quadrangle data or measured at the dam site rain gage. There was very little difference between datasets (1) and (2). Dataset (3) correlated well with other net evaporation estimates during the autumn, winter and spring months, but it measured more net evaporation than other estimates during the summer months. This is not surprising since the COE does not apply a pan factor to its reported evaporation. Franklin established monthly coefficients that reduced measured evaporation to more closely match the TWDB data, essentially deriving a pan factor for this data.

For this effort, Franklin used the FNI reported values of net evaporation for the period January 1988 through December 1997, the FNI process using four quads proportioned as outlined above for the period January 1998 through December 2004 and COE reported pan evaporation with the COE measured precipitation at the Lake for the period January 2005 through December 2007. The COE pan evaporation was adjusted using the monthly coefficients derived by Franklin to match the FNI data in overlapping years as reported above.

3.2.5 Area-Elevation

The area of the lake exposed to evaporative effects was determined by the average lake elevation based on the first day of adjacent months (average elevation= (elevation day 1 month 2 – elevation day 1 month 1)/2). Franklin examined the difference between average area based solely on the elevation on the first of adjacent months and the average area using multiple periods during the month when there were large fluctuations within the month (a flood or drought period). There was little difference in the two methods, so the elevation on the first day of adjacent months was used for the full period.

FNI used the best available area-elevation information at the time of their report, the 1995 TWDB hydrographic survey. Franklin used the updated 2005 survey data. The difference between the two data sets are negligible (less than 0.1% during the year of highest flow, 1992).

3.2.6 Pipeline Deliveries

BRA records were used to determine the monthly volume of water delivered to Lake Georgetown from Lake Stillhouse Hollow. Water was removed during the period January 2006 through March 2007. This volume was added to the inflow to the reservoir. Therefore, the equation used to determine inflows is as follows:

> ***Flow = change in reservoir storage + lakeside use + spills + net evaporation + pipeline deliveries***

3.3 Lake Belton

The longest time series was developed for Lake Belton, January 1940 through December 2007. Construction was started on Lake Belton in 1949 and deliberate impoundment began March 1954. A small reservoir for the city of Temple existed at the site and was inundated when Lake Belton began impoundment. Little data exists on that small impoundment, and it was not considered in this analysis. The conservation pool of Lake Belton was raised on May 1, 1972 which is incorporated into the estimated flows. There is a multipurpose reservoir, Lake Proctor, and a number of irrigation water rights above Lake Belton. This study did not include the effect that the construction and operation of Lake Proctor or upstream water use would have on Lake Belton inflows. The major effect of Lake Proctor on the time series for Lake Belton is a mitigation of flood flows, spreading large releases over several months. While no direct comparison of Franklin derived flows to FNI derived flows was possible (FNI did not derive flows for Lake Belton), consideration of FNI methodology was given in data sources selected. Appendix D includes monthly data sets used in the water balance calculations for Lake Belton.

3.3.1 Drainage Area Ratio to Determine Flow

Prior to reservoir impoundment, for the period January 1940 through March 1954, flow was estimated by the drainage area ratio methodology for the USGS gage 08102500, Leon River near Belton. The drainage area for Lake Belton is 3570 square miles; the drainage area of the stream gage is 3580 square miles. Spills from the reservoir for the period January 1981 through September 1981 were also estimated using this method since the COE lacks flow data for this period.

3.3.2 Change in Reservoir Storage

Franklin used the amount of water in storage at 0800 on the first day of each consecutive month from COE records for the period March 1954 through December 2007. The change in storage during each month was computed by subtracting the storage on the first day of each consecutive month. This data was compared to USGS data and found to have only minor differences. This data was compared to computed change in storage using the 1995 TWDB area-elevation-capacity tables developed through a hydrographic survey of the lake. While the absolute values of storage differed, there was little difference in the change in storage between the two datasets.

3.3.3 Lakeside Use

The first reported lakeside use occurred in January 1969. Daily data from 1969 to 1984 was obtained directly from the COE, while data from 1985-2007 were obtained from BRA as reported to them by COE, and added to produce monthly totals. However, Bluebonnet Water Supply Corporation does not report its withdrawals from the lake to the COE, so that data came from BRA and was added to the monthly total lakeside use.

3.3.4 Reservoir Spills and Releases

Reservoir spills and releases reported by the COE were used for this analysis. Data prior to January 1985 were obtained from the COE website and data for 1985-2007 were obtained from BRA as reported to them by COE. These data were often in daily increments, which were summed to produce monthly results. For the period January 1983 through December 1984 one day of each week was missing from the COE data. The missing data were estimated as the average of adjacent days when summing to produce monthly totals. Note that, as mentioned above, spills from the reservoir for the period January 1981 through September 1981 were estimated using USGS gage records since the COE lacks flow data for this period.

An analysis was conducted to determine the effect of using COE-reported reservoir spills and releases rather than estimating them with the downstream gage USGS 08102500, Leon River near Belton. The COE reports 220,000 acre-feet more flows over the March 1954 through December 2007 time periods (approximately 340 acre-feet more per month, on average) than measured at the USGS gage (when the gaged flows are reduced by the appropriate drainage area ratio).

3.3.5 Evaporation

There is no COE pan evaporation or rain gage data for Lake Belton, therefore Franklin used the TWDB published data on gross and precipitation based on quadrangles that are 1° latitude by 1°longitude. The quadrangle data is based on measured data at numerous points across the state. At the request of Franklin, TWDB determined that the surface area of Lake Belton at the top of the conservation pool is 100% quadrangle 610. Net evaporation was established from the TWDB net evaporation tables for quadrangle 610. For months that have a negative net evaporation, precipitation exceeded evaporation.

Because the TWDB quadrangle data is only available through December 2004, for the period January 2005 through December 2007 the net evaporation as determined for Lake Stillhouse Hollow was used. These two lakes are near each other, and previous comparison of the effects of various estimates of net evaporation (see Lakes Georgetown and Stillhouse Hollow above) show this is a reasonable approximation.

3.3.6 Area-Elevation

The area of the lake exposed to evaporative effects was determined by the average lake elevation based on the first day of adjacent months (average elevation= (elevation day 1 month 2 – elevation day 1 month 1)/2). Franklin examined the difference between average area based solely on the elevation on the first of adjacent months and the average area using multiple periods during the month when there were large fluctuations within the month (a flood or drought period). There was little difference in the two methods, so the elevation on the first day of adjacent months was used for the full period. The area-elevation table published by TWDB from its May 2003 hydrographic survey was used to determine the average lake surface area during the month.

3.3.7 Net Evaporation Extension

For the Planning Simulation Model (see Part 1 of the "Williamson County Regional Raw Water System Transmission and Operations Models" report), a value for inflow and net evaporation is needed for each time step. Because the impoundment of Lake Belton began in March 1954, the net evaporation time series was not planned to be calculated for the period January 1941 – February 1954 by Franklin. In the interest of schedule and level of effort, the net evaporation over this period was estimated by CDM using a linear regression between the monthly net evaporation time series for Lake Belton and Lake Stillhouse Hollow over the period March 1954 – December 2007. Lake Stillhouse Hollow was used because regressions between the net evaporation for Lake Belton and the other two lakes (Georgetown and Granger) had lower values for the coefficient of determination (R^2) of the regression (0.749 for Lake Georgetown, 0.904 for Lake Granger, and 0.943 for Lake Stillhouse Hollow).

Figure 1 compares the monthly net evaporation time series for Lake Belton and Lake Stillhouse Hollow using the March 1954 – December 2007 time series calculated by Franklin. The linear regression shown in Figure 1 was used to calculate the net evaporation for Lake Belton for each month over the period January 1941 – February 1954 based on the monthly inflow time series for Lake Stillhouse Hollow calculated by Franklin. The resulting time series is also included in Figure 1to show that, except for the two highest net evaporation rates between March 1954 – December 2007, the linear regression was not extrapolated when generating the time series for Lake

Belton. Although the highest two inflows to Lake Stillhouse between March 1954 – December 2007 were greater than the highest rate between January 1941 – February 1954, the difference is considered relatively small. Therefore, extrapolation of the linear regression to calculate the net evaporation for Lake Belton for the two months corresponding to the two highest net evaporation rates for Lake Stillhouse Hollow between January 1941 – February 1954 was considered valid.

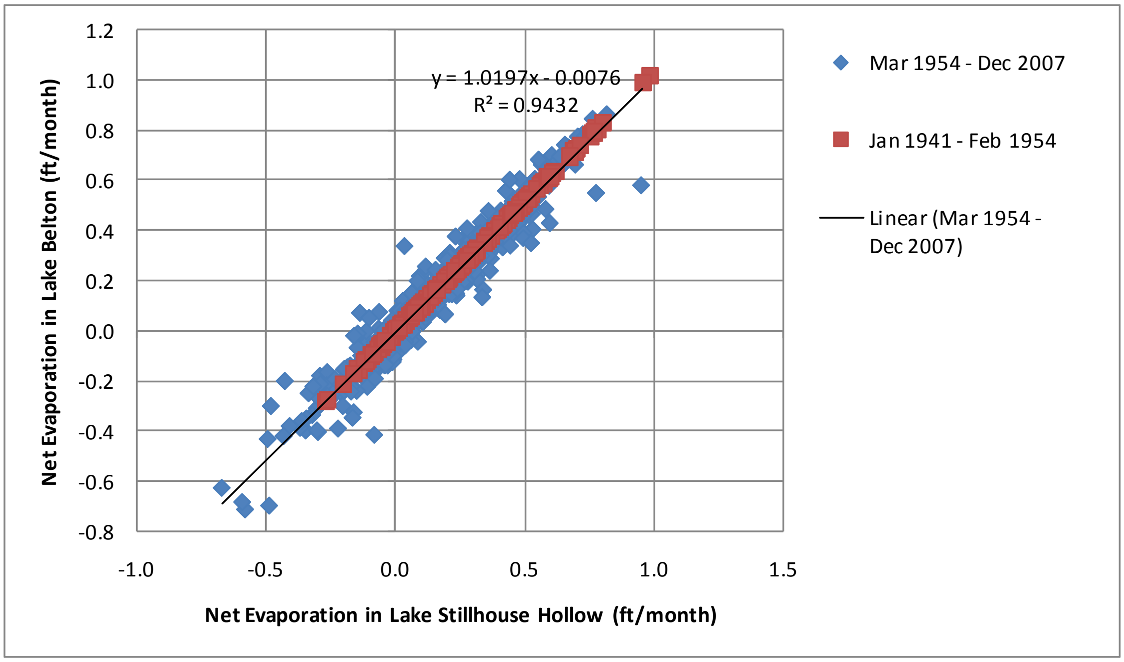

Figure 1. Comparison of Monthly Net Evaporation between Lake Belton and Lake Stillhouse Hollow

3.4 Lake Granger

At the start of this project effort, the project team did not believe data on Lake Granger was needed. However, after further discussion, a decision was made to add flows and net evaporation for Lake Granger to the Planning Simulation Model. FNI developed a time series of inflows for Lake Granger for the period January 1941 through December 1997. That time series as extended through December 2007. Because Lake Granger was not included in the scope of services for Franklin, CDM extended the inflow and net evaporation time series using linear regressions based on the 1941-1997 time series between Lake Granger and Lake Georgetown for inflow and between Lake Granger and Lake Stillhouse Hollow for net evaporation. Linear regression was used for these extensions in the interest of project schedule and level of effort required.

3.4.1 Inflow

A linear regression between the monthly inflows to Lake Granger and Lake Georgetown was generated to extend the inflow time series for Lake Granger through 2007. Lake Georgetown was used because regressions between Lake Granger and the other two lakes (Stillhouse Hollow and Belton) had lower values for the coefficient of determination (R^2) of the regression (0.528 for Lake Belton, 0.632 for Lake Stillhouse Hollow, and 0.823 for Lake Georgetown).

Figure 2 compares the monthly inflow time series for the two lakes using the 1941-1997 time series calculated by FNI. The linear regression shown in Figure 2 was used to calculate the inflow to Lake Granger for each month over the extension period 1998-2007 based on the monthly inflow time series calculated by Franklin over this period. The resulting time series for 1998-2007 is also included in Figure 2 to show that, except for the highest inflow between 1998-2007, the linear regression was not extrapolated when generating the extended inflow time series for Lake Granger. Although the highest inflow to Lake Georgetown between 1998-2007 was greater than that between 1941-1997 (74,522 versus 73,331 acft/mon, respectively), the difference is relatively small. Therefore, extrapolation of the linear regression to calculate the inflow to Lake Granger for the month corresponding to the highest inflow to Lake Georgetown between 1998-2007 was considered valid.

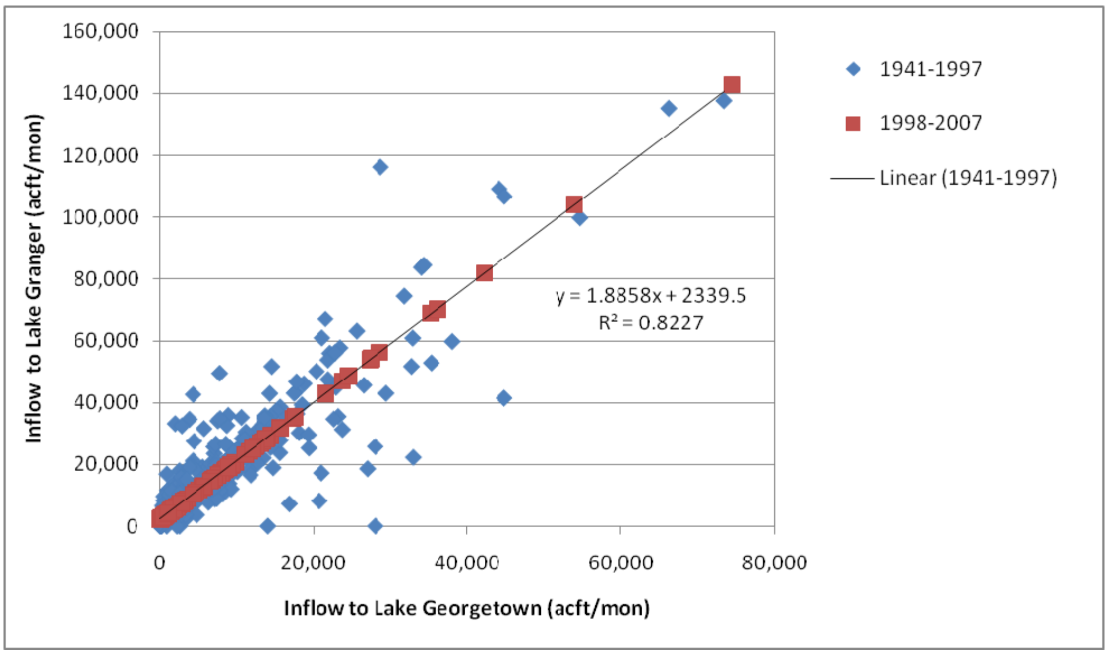

Figure 2. Comparison of Monthly Inflows between Lake Granger and Lake Georgetown.

3.4.2 Net Evaporation

A linear regression between the monthly net evaporation time series for Lake Granger and Lake Stillhouse Hollow was generated to extend the net evaporation time series for Lake Granger through 2007. Lake Stillhouse Hollow was used because regressions between Lake Granger and the other two lakes (Belton and Georgetown) had lower values for the coefficient of determination (R^2) of the regression (0.896 for Lake Belton, 0.878 for Lake Georgetown, and 0.960 for Lake Stillhouse).

Figure 3 compares the monthly net evaporation time series for the two lakes using the 1941-1997 time series calculated by FNI. The resulting linear regression shown in Figure 3 was used to calculate the net evaporation to Lake Granger for each month over the extension period 1998-2007 based on the monthly net evaporation time series calculated by Franklin over this period. The resulting time series for 1998-2007 is also included in Figure 3 to show that the linear regression was not extrapolated when generating the extended net evaporation time series to Lake Granger since all monthly net evaporation rates between 1998-2007 for Lake Stillhouse Hollow were within the range for 1941-1997.

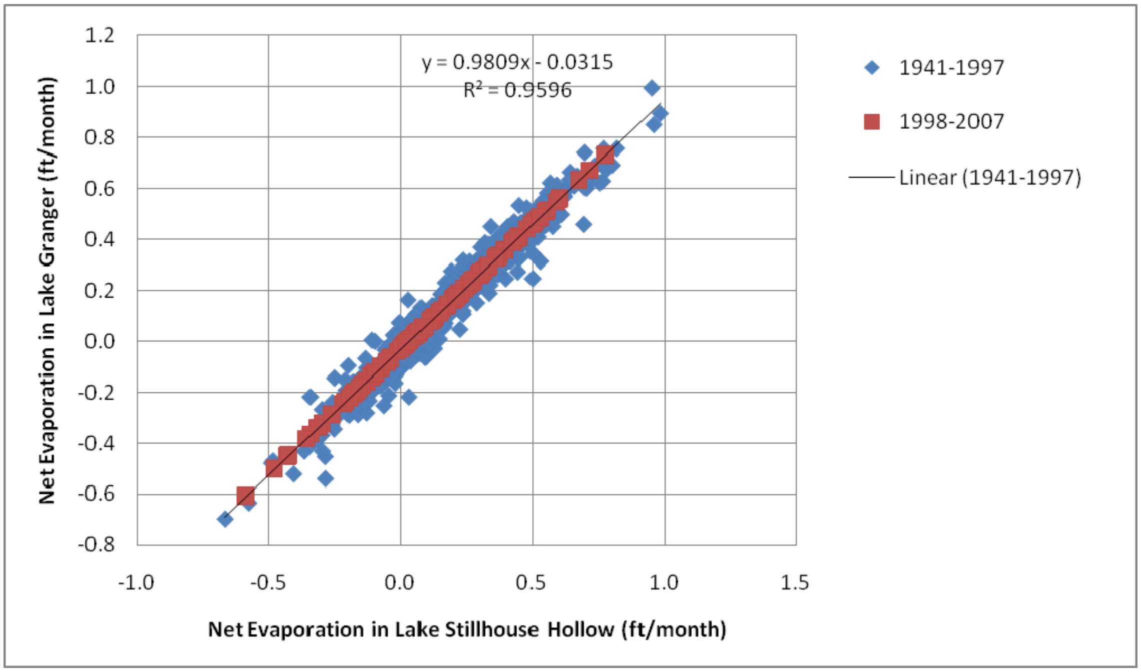

Figure 3. Comparison of Monthly Net Evaporation between Lake Granger and Lake Stillhouse Hollow.

Section 4
Comparison of Inflows

This section discusses the comparison of the historical flows developed by Franklin to those developed by FNI and the WAM/TR 340. The actual Franklin recommended data is included as Appendix A and the summary comparison with FNI included hereunder in tables. In absolute terms, Franklin inflows for the period January1998 through December 2007 were approximately 30% higher than long-term flows. TR 340 data show even higher percentage flows for this time period. This section also discusses a comparison conducted to ensure that the higher flows were reflected in adjacent streams.

4.1 General Comments – FNI and Franklin Comparison

While several years are comparable, there are larger differences between the FNI and Franklin datasets then would be expected from data generated through similar, if not the same, input data for other years. Some of the difference may be in the number of significant figures used in the change in storage values. USGS rounds to the nearest 100 acre-feet, while COE reports to the acre-foot. Any difference in the change in storage is directly related to the calculated inflow. Other minor differences may come from the method of computing average reservoir elevation to be used in determining net evaporation volume. FNI may also have used professional judgment to adjust data that was not reflected in the text of their report.

There are discontinuities in both FNI and Franklin datasets when FNI changed the source of stream data from one gage to another (even accounting for drainage area ratios and double mass curves) or from stream data to COE reported releases.

4.2 General Comments – WAM, TR 340, FNI and Franklin Comparison

The Water Availability Model (WAM) and the data used from TR 340 are datasets which represents estimated flows at a point without any artificial impacts such as water diversions, storages or releases. The datasets being estimated in this report represent historical flows with the effects of reservoir operations removed. A major difference in these two types of datasets are upstream water use and upstream reservoir operations, whether those reservoirs be small 'stock ponds' or large multipurpose reservoirs. Therefore, differences between the two types of datasets are to be expected, but comparison of the two can prove useful in understanding the limitations of historical flow estimates. BRA provided the WAM and TR 340 datasets used herein and requested a discussion of the differences.

Another useful insight that can be gained by comparing historically derived data such as those discussed in this report and the WAM/TR 340 is the evaluation of the impact of different sources of input data. For this data, there was a measurable difference in using USGS stream gage data and COE reported reservoir spills to estimate releases.

Much of the difference is likely due to the regular measuring of actual flows by USGS compared to the gate release equations used by the COE. Other sources of data differences such as net evaporation determinations or reservoir sedimentation over a decade, as identified through differences in area-elevation-capacity relationships did not contribute significantly to differences in flow estimate.

For all three reservoirs, the Franklin data matches the WAM data (for Belton: 1940-1997, for Stillhouse Hollow and Georgetown: 1988-1997) better than the TR 340 (1998 through 2007) data. Franklin examined all data and could find no difference in the Franklin source data between the pre-1998 and post-1998 period that could account for the difference. A next step could be to examine the methodology of the TR 340 dataset, but such work is beyond the scope of this project.

4.3 Comparison of Adjacent Streamflows to Validate Higher 1997-2007 Flow Values

The extended time series were compared to the original time series developed by FNI to ensure that the method yielded reservoir inflows that are consistent between the two time periods.

Figure 4 shows the frequency duration curves for inflows to Lakes Belton, Georgetown and Stillhouse Hollow for the original and extended periods (1951-1996 and 1997-2007, respectively). Although the inflow time series begin in 1941, the first 10 years (1941 – 1950) were excluded from this analysis in order to maintain a consistent time period between these time series and the streamflow time series described below. Although the inflow time series for Lake Belton was generated in its entirety by Franklin (as opposed to the inflow time series for Lakes Georgetown and Stillhouse Hollow which were extended from the original time series developed by FNI), Lake Belton was included in this analysis for comparison to the other two reservoirs. Figure 1 shows that inflows over the past 11 years have been higher than those over the previous 46 years indicating that the past decade has been wetter than usual. That this observation is evident in all three time series suggests that the difference between the extended and original time series for Lakes Georgetown and Stillhouse Hollow is due to real hydrologic variability and not differences in the methodology used by Franklin and FNI.

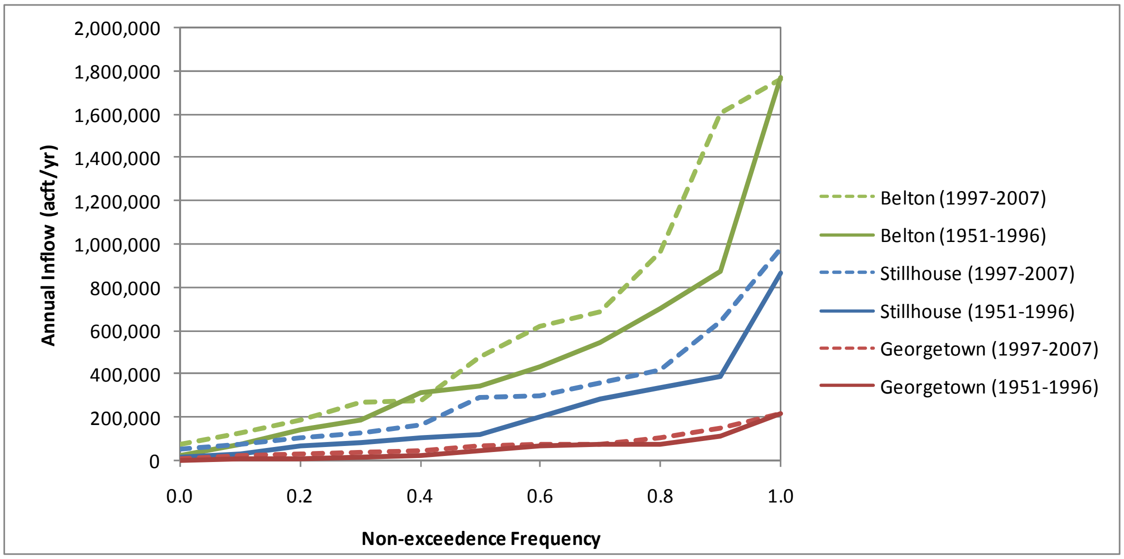

Figure 4. Frequency Duration Curves of Inflows to Lakes Belton, Georgetown and Stillhouse Hollow for original and extended time periods.

The difference in hydrology between the extension (1997-2007) and original (1951-1996) time periods was confirmed using daily streamflow data recorded at a USGS gage on Cowhouse Creek at Pidcoke, TX (Station ID: 08101000). This gage was chosen since it had a long record of daily streamflows (1951-present) and was not affected by upstream reservoir operations or any major water withdrawals. Figure 5 shows the frequency durations curves for streamflows at this gage over the two periods 1951-1996 and 1997-2007. This figure confirms that the past 11 years have been wetter than the previous 46 years validating the comparison between the original and extended inflow time series in Figure 4.

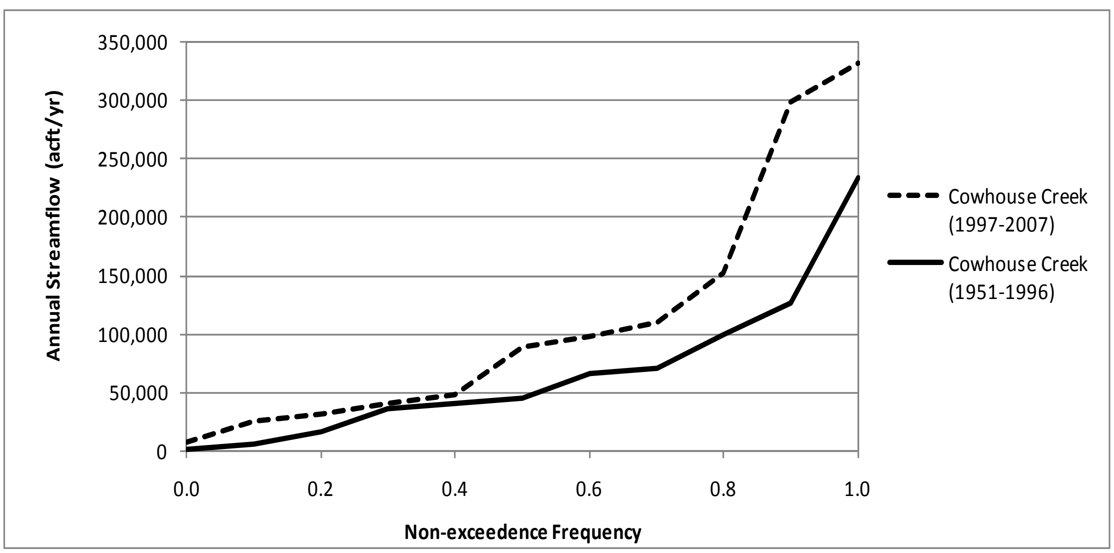

Figure 5. Frequency Duration Curves of USGS Gage 08101000 on Cowhouse Creek at Pidcoke, TX for the original and extended time periods.

Table 1 lists the annual average inflows to Lakes Belton, Georgetown and Stillhouse Hollow and the annual average streamflow at the USGS gage on Cowhouse Creek at

Pidcoke, TX for the two periods. The ratio of the average flows for the extension period to the average flows for the original period is consistent, although variable, between the three lake inflows and the historical streamflow. The variability in this ratio could be due to regional precipitation patterns, differences in baseflow contributions, or other spatial hydrologic differences. These ratios indicate that average flows over the past decade have been about 45-75% higher than the long-term averages. The WAM data values (prior to 1997) and TR 340 data values (post 1997) for the same time period are also presented. The increase in flows in the last ten years is even more pronounced when considering the TR 340 flows.

Table 1. Annual Average Inflows and Streamflow Comparison

Average Annual Inflow (acft/yr)			
	1941-1996	**1997-2007**	**Ratio**
Georgetown	53,147	78,291	1.47
Stillhouse Hollow	200,399	320,547	1.60
Belton	440,392	636,339	1.44
Average Annual Streamflow (acft/yr)			
	1951-1996	**1997-2007**	**Ratio**
USGS Gage Cowhouse Creek at Pidcoke, TX	63,859	111,106	1.74
WAM/TR 340 Reported Average Annual Streamflow (acft/yr)			
Georgetown	55,860	89,691	1.61
Stillhouse Hollow	221,667	451,161	2.04
Belton	483,530	828,408	1.71

4.4 Effect of Using Updated Hydrographic Surveys

The Brazos River Authority has contracted with the TWDB numerous times over the last fifteen years to conduct hydrographic surveys of various lakes to better establish the area-elevation-capacity relationships and to identify reservoir sedimentation trends. For this study, Franklin used data from TWDB surveys that were conducted at Lakes Georgetown and Stillhouse Hollow in the mid-1990s and mid-2000s. FNI used the best data available to them at the time, the 1995 hydrographic surveys. Franklin used the most recent surveys (2003 or 2005, depending on the reservoir).

Franklin examined the difference in inflow computations when using the TWDB 1995 and 2005 hydrographic survey for Lake Georgetown. For this comparison, Franklin used the 1995 data for the conservation pool and extrapolated into the flood pool assuming the same relationship between elevation and area. The hydrographic data were compared with the 2005 hydrographic survey with actual data on the flood pool. There is essentially no difference in the surface area, and hence evaporation, as long as the reservoir is in the conservation pool. Even in 1992, the year with the highest reservoir elevations and therefore the greatest potential difference between the two hydrographic surveys, the annual difference in flows was less than 0.1%.

For Lake Stillhouse Hollow, the 1995 TWDB hydrographic survey data were compared to both the 2005 survey data and the 2005 adjustment of the 1995 survey data. There were only minor differences in the resulting inflow calculations, so the 2005 data were used.

Franklin used the most recent hydrographic survey (2003) for Lake Belton since there was no comparison to an earlier dataset which had used earlier hydrographic surveys.

Section 5
Lake Georgetown

5.1 Comparison of FNI and Franklin Computed Inflows

As mentioned above, FNI applied an additional areal correction factor in their analysis. This factor is typically used to correct for direct precipitation on a lake surface when using a rainfall-runoff computation method. Since the inflows calculated here were based on operational flow data and not watershed runoff, the areal correction factor was not needed to generate the extended time series for this effort. The watershed areal correction factor was small (approximately 1.004). As shown in Appendix E, the total annual difference in flows over the ten year period as herein adjusted and compared to FNI shows 1,079 acre-feet less, (0.2%). Flows as thus adjusted are reported as Franklin "Recommended Flows" and are presented in Appendix A.

5.2 Comparison of WAM, TR 340, FNI and Franklin Computed Inflows

Comparing the WAM and TR 340 to the FNI and Franklin data shows the impacts of using different sources of data. Measureable discontinuities result whenever the source of the flow data is changed, either to another gage or to COE reported releases.

When compared to the WAM, the FNI dataset consistently underestimates flows by 12% during the period January 1941 through May 1968 when FNI used data from USGS gage 08105000, San Gabriel River at Georgetown scaled using the published drainage area ratio and a double mass curve slope developed in the 1998 report. When compared to the WAM, the FNI dataset for the period June 1968 through March 1980, which estimated flows based on the drainage area ratio of USGS gage 08104700, North Fork of the San Gabriel River near Georgetown, immediately below the future dam site, show strong similarity, with a difference of only 0.08%. When compared to the WAM, the FNI dataset for the period during reservoir operations, March 1980 through December 1997, show an average of 5% more flow, with variation from 26% more flow in 1990 to 10% less flow in 1984.

For the period January 1997 – December 2007, the Franklin "Recommended Flows" shows 11% less flow than the TR 340 data for the comparable period, with variation from 29% less in 2004 to 7% greater in 2002.

Section 6
Lake Stillhouse Hollow

6.1 Comparison of FNI and Franklin Computed Inflows

As with Lake Georgetown, since the inflows calculated here were based on operational flow data and not watershed runoff, the areal correction factor applied by FNI was not needed to generate the extended time series for this effort. The watershed areal correction factor is small (approximately 1.007). As shown in Appendix F, the total difference in flows over the ten year period as herein adjusted and compared to FNI shows 129,081 acre-feet less, (5%). Flows as thus adjusted are reported as Franklin "Recommended Flows" and are presented in Appendix A.

6.2 Comparison of WAM, TR 340, FNI and Franklin Computed Inflows

Comparing the WAM to the FNI and Franklin data shows the impacts of using different sources of data. Measureable discontinuities result whenever the source of the flow data is changed, either to another gage or to COE reported releases.

When compared to the WAM, the FNI dataset consistently underestimates flows by 3% during the period January 1941 to January 1968 when FNI used data from USGS gage 08104000, Lampasas River at Youngsport, scaled using the published drainage area ratio. When compared to the WAM, the FNI dataset for the period February 1968 to December 1980, which estimated flows based on the drainage area ratio of USGS gage 08104100, Lampasas River near Belton, immediately below the dam site adjusted by reservoir change in storage, lakeside use and net evaporation, show consistently less flow, 5% on average. FNI data show large differences from the WAM in 1981, when it used another stream gage, Lampasas River near Kempner and the Lampasas River near Belton.

From October 1981 through September 1989, which includes the period of FNI to Franklin comparisons, FNI used the Lampasas River at Belton, adjusted for drainage area, to remove change in reservoir storage, lakeside use and net evaporation. FNI used COE reported spills and releases for the period October 1989 through December 1997. This period showed the greatest differences from the WAM. When compared to the WAM, the FNI dataset for this period during reservoir operations show an average of 52,000 acre-feet per year (30%) less flow, with variation from 60,000 acre-feet less in March 1990 to 43,000 acre-feet more in March 1992.

The Franklin dataset consistently shows less flow than the WAM/TR 340, ranging from 15%-40% less flow, with an average of 30%. In 1997, Franklin calculates almost 433,000 acre-feet less flow than the WAM.

Section 7
Lake Belton

7.1 Comparison Of Wam, Tr 340 and Franklin Computed Inflows

Franklin developed historical flows for the period January 1940 through December 2007 for Lake Belton. There was no required comparison for Lake Belton data in the scope of work, but it does compare well to the Leon River at Belton stream gage.

The Franklin data consistently show approximately 0.5% higher flows prior to dam construction than does the WAM data. The reason is not entirely clear, since this data is simply the published USGS gage data proportioned by the USGS published drainage area ratio.

During initial filling of Lake Belton (approximately March 1954 through May 1956), COE reported spills result in approximately twice as much flow as would be the case if the USGS gage data for the Leon River at Belton were used. However, in either case the flows are small.

For the period May 1956 through December 1997, the annual flows show good comparison between Franklin and WAM for the period, with approximately 3% lower flows if a few anomalous months are removed from the record. The first anomalous month occurs in 1963, the year the upstream reservoir, Lake Proctor, began impounding flows. This starts a period where the effects of the flood control reservoir upstream are noticeable, reducing naturalized (WAM) large flows in one month and increasing flows in subsequent months as the flood pool is evacuated. However, there are a few months of large differences between the WAM and Franklin without an obvious explanation, but may be related to Lake Proctor operations. Franklin inspected all such instances and could find no data input or calculation errors which might have created this difference.

The TR 340 data are approximately 30% higher than Franklin data for the period January 1998 through December 2007. Since there were no changes to the Franklin data collection and analysis procedures that would account for such a sharp discontinuity, the source of this difference remains unclear, but may be related to the manner in which Lake Proctor was modeled in the TR 340 methodology, or other updates to methodology used in TR 340.

Section 8
Conclusion

Franklin Engineering Associates, LLC (Franklin) was engaged by CDM to develop a time series of monthly stream flows for the location of the dams impounding Lakes Georgetown, Stillhouse Hollow and Belton. The methodology for Lakes Georgetown and Stillhouse Hollow was to be consistent with the data sets developed by Freese and Nichols, Inc. (FNI) for the period January 1941 through December 1997 and presented in a 2001 report entitled "*Williamson County Water Supply Pipeline Model*". The time series for Lakes Georgetown and Stillhouse Hollow were developed for the period January 1998 through December 2007. The time series for Lake Belton was developed for the period January 1940 through December 2007 using the same general methodology. These time series are reported in acre-feet per month and attached as Appendix A.

The time series represent historical flows at these locations with the effect of the water supply and flood operations of those three reservoirs eliminated, but do not represent fully naturalized flows. The effects of upstream water use are not removed from this dataset. The effect of Lake Proctor operations on the inflows into Lake Belton has also not been removed from the dataset. The major effects this has on the time series for Lake Belton are a mitigation of flood flows, spreading large releases over several months, and the increased upstream water loss due to evaporation from the surface of Lake Proctor.

The extended time series developed for Lakes Georgetown and Stillhouse Hollow used the same methodology and source of the Freese and Nichols data. The data for the monthly time series for the period January 1988 to December 1997 were used as a comparison. While data for 1997 were similar (within 2% of the annual flows at Lakes Georgetown and Stillhouse Hollow), there were larger differences at other times. Franklin flows for Lake Georgetown show an annual average of 108 acre-feet per year (0.2%) less flow than the FNI data. Franklin flows for Lake Stillhouse Hollow were consistently lower than the flows derived by FNI, showing an average of 12,908 acre-feet per year (5%) less flow during this period.

The time series for Lake Belton was developed using the same methodology as the other lakes. It covers approximately 14 years prior to the deliberate impoundment of water in Lake Belton and the 64 years since impoundment. There was no direction in the scope of work to compare Lake Belton inflows with any other data developed by others, however, examination of historical flow at the Leon River near Belton shows the time series reproduces the low flows of the drought years and the flood periods well.

Section 9
References

1. Freese and Nichols, Inc., "*Williamson County Water Supply Pipeline Model,*" December 2001.

2. Freese and Nichols, Inc., *"Update of Lake Georgetown Hydrology,"* June 1998.

3. Brazos River Authority (BRA) – multiple data sets as shown below

   a. 2008. Customer Water Use Data 1940 – 2007. Unpublished data sets.

   b. 2008. Daily Reservoir Data of selected reservoirs 1940-2007. Unpublished data sets.

   c. 2009. Naturalized streamflows at selected locations 1940-1997, Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM). Fully naturalized run.

   d. 2009. Naturalized streamflows at selected locations 1998-2007. Wurbs, R. & Kim, T. "*Extending and Condensing the Brazos River Basin Water Availability Model,*" Texas Water Resources Institute Technical Report 340 (TR 340). December 2008.

4. U.S. Army Corps of Engineers (COE), Fort Worth District. (2008). *Daily reservoir level, releases, evaporation and rainfall as available for selected reservoirs.* Available from U.S. Army Corps of Engineers Database.

5. Texas Water Development Board (TWDB). (2008). *Evaporation/Precipitation Data for Texas.* Available from Texas Water Development Board Database.

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7. United States Geological Survey (USGS). (2008) *Streamflow, drainage area data, lake levels and daily volume for selected sites.* Available from United States Geological Survey Database.

APPENDIX A

Hydrologic Flow Extension Tables for Lake Georgetown, Lake Stillhouse Hollow and Lake Belton

Monthly Stream Flows for Lake Georgetown (AF/month)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1997	6861	15640	23725	28567	21504	35274	6538	884	273	69	364	14394
1998	15608	17255	27406	8405	2392	412	234	0	132	13055	7967	13352
1999	5734	2647	3151	2109	5435	3276	6707	615	0	26	415	465
2000	329	768	552	1102	232	2719	255	240	62	643	9234	5030
2001	12414	8064	13881	9727	5021	2041	596	1413	380	1077	17586	5483
2002	3535	2774	1826	1983	334	5650	36086	3157	2749	1888	3542	8580
2003	7867	13755	11596	4526	1493	1309	472	293	0	474	331	259
2004	1372	1092	2164	7524	4248	7132	2586	125	353	1777	42182	8897
2005	6525	9369	12587	5587	3047	789	903	2786	462	845	84	184
2006	528	434	365	2742	4690	515	134	301	180	288	225	390
2007	2763	1042	24556	11031	27515	74522	53917	12083	8849	4296	1024	1037

Monthly Stream Flows for Lake Stillhouse Hollow (AF/month)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1997	19846	150577	111564	90468	72251	109344	30882	5386	2204	552	3577	43995
1998	57001	64761	139019	40237	10304	3624	3862	2705	2717	27387	23759	46135
1999	20056	11798	33219	29279	20452	11091	3007	0	0	0	121	558
2000	1127	3103	3536	10885	1149	6183	0	0	930	2009	33828	15506
2001	36389	43428	66850	35823	31346	8814	2044	11416	6892	1643	29576	19521
2002	16422	19022	8205	9468	3758	5547	69900	6996	670	3820	2168	14663
2003	14938	23527	33357	12025	3418	12551	216	0	453	1406	611	512
2004	3701	4343	11342	26944	19814	50539	14728	26022	4441	7297	128706	54950
2005	44239	62155	75793	25029	16248	13203	2924	48253	10547	1301	1080	946
2006	2857	2282	9334	8500	22638	8851	950	929	134	1000	445	2008
2007	7301	3804	70397	49616	264657	273372	197420	45750	43931	12189	4757	4887

Monthly Stream Flows for Lake Belton (AF/month)

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1940	1110	1772	1104	29954	7051	99272	47918	8670	1982	5617	178488	211907
1941	85352	246838	217426	131433	414924	159560	83757	52621	41691	59176	18620	15047
1942	10896	9620	8124	288797	266356	187270	22276	27715	184481	146667	48989	29585
1943	22442	14593	20921	31473	20958	8835	3544	907	8331	7861	2682	4721
1944	47734	117760	108222	68417	536697	107580	21093	8682	10568	9584	8420	32730
1945	109817	111318	194984	399700	81305	64144	35802	7413	10349	43050	16294	39359
1946	48078	82962	154945	43839	146300	48295	9780	3041	26156	6990	26785	28561
1947	65363	25265	88908	42634	57048	11939	4985	1784	1187	687	3709	8180
1948	3342	20036	11392	7607	29775	10776	17132	1159	7981	12	0	53
1949	2030	4946	63646	84082	74499	54787	10988	1797	860	6794	3946	2851
1950	1919	11669	2667	13226	41934	24459	24066	1288	31028	354	5	9
1951	341	781	1331	2006	16071	28328	217	0	1934	32	0	0
1952	0	0	724	27824	67263	10212	2925	0	0	0	7577	18051
1953	5923	1373	17346	10532	158685	3287	10871	4819	3436	21589	5495	2851
1954	1741	1058	1263	7921	5704	0	0	0	27	1998	5715	0
1955	231	8825	3513	22233	73526	32034	4889	3406	19579	7794	57	0
1956	1254	2286	469	14407	111773	1883	0	1773	0	0	4327	6475
1957	829	1137	21615	327523	585587	91778	56444	20180	3270	117874	81301	33188
1958	29860	111523	115177	50740	179235	24831	6574	1067	1466	1303	945	659
1959	1613	3252	2587	3828	4153	44223	30874	13406	5417	369889	58827	78123
1960	147031	88202	41716	28124	16247	5840	3980	1045	485	43670	22020	117834
1961	236977	235937	100183	35632	16316	90956	100028	23433	11843	79085	27563	21917
1962	14960	10282	9458	13581	10433	13289	4924	5280	54544	14074	13840	12243
1963	2875	4128	4764	3854	10578	19830	5668	0	0	0	4127	87
1964	4321	13292	16782	48443	19010	81908	7669	17249	50656	63593	64477	22088
1965	37918	114040	90852	0	496470	99222	63786	44244	18059	10055	83200	24977
1966	15538	27626	25359	86741	71939	49631	24598	46040	70517	12335	4765	3218
1967	3306	2077	3034	9745	18236	8354	25691	0	6037	459	4840	3030
1968	164466	106528	155675	140322	231740	95999	53897	4493	3701	1136	3936	3792
1969	4853	6254	14965	98271	121372	16153	864	3507	191	10277	14055	24851
1970	37880	42291	203654	98048	75113	45040	2978	15392	17753	9488	3422	3552
1971	3237	3291	2926	4539	11976	425	113079	19345	6251	61505	27626	78471
1972	40403	18959	11801	4976	23187	6008	5853	1234	307	15053	1737	4945
1973	16715	19185	38546	49263	36103	48372	22732	1456	5161	45137	13171	5186
1974	7917	6725	6804	8731	3265	0	3731	27689	84003	153785	75972	40616
1975	62407	156226	52758	98297	90587	44421	18339	9045	1337	2799	852	0
1976	2598	4550	7210	26209	23971	20482	120473	5825	10682	19375	10734	44628
1977	14120	61750	54911	249311	136877	64520	10753	770	2032	1914	0	1211
1978	1748	6883	7054	5419	2506	2609	4616	1569	2087	1127	3476	2170
1979	17274	19402	67184	39192	112166	96430	22393	10406	338	0	0	4508

Monthly Stream Flows for Lake Belton (AF/Month), cont.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1980	3476	9103	8073	13136	130697	15199	6684	951	3919	0	1103	1985
1981	1340	2363	11237	11111	6810	135137	16036	6269	3802	12145	7070	2913
1982	2638	5016	16573	19175	63635	33268	35444	10948	0	0	179	1087
1983	1685	12772	29831	9768	19979	7571	393	2307	0	1488	0	0
1984	1178	525	10838	1800	1855	7370	3065	47	370	22047	5204	18183
1985	26047	29003	46839	26652	29328	31452	5479	4351	2092	57731	14988	53188
1986	13842	64100	12672	19745	52424	190273	85731	35087	101699	42922	41036	91763
1987	65472	57719	94603	33576	79768	218339	86684	39271	8185	1669	4576	11164
1988	5319	6711	7752	4870	5522	61644	19866	11954	4383	11262	0	1870
1989	11628	21102	40796	17070	79450	108425	41046	19366	12473	5510	1617	893
1990	3193	4399	34931	106740	356700	122829	82945	32667	17152	10289	8597	6046
1991	23503	16404	10361	15823	36969	47873	9634	14806	22942	30535	0	480250
1992	279306	448102	233832	131802	243401	122897	120073	85195	42894	14242	11779	35701
1993	36987	105646	133225	109735	69033	41150	9812	5110	8688	14968	23042	6740
1994	5963	26326	18239	9513	149550	95423	39527	8746	8203	16803	22628	45864
1995	39810	23991	57085	211344	133983	85705	26817	94864	39457	14949	5714	6711
1996	5818	6851	5733	8533	5433	19288	6247	59199	64470	27011	37280	70185
1997	53098	351651	306799	231087	235391	185928	99739	35418	8502	5350	7024	88403
1998	94717	85494	206486	95482	25078	10814	6028	7853	7890	39481	18804	90409
1999	33590	15293	25056	23840	14954	11582	7993	294	0	0	0	427
2000	2545	5296	6368	17055	3131	37711	1320	1123	4450	12270	76685	21641
2001	46334	68316	124959	47882	45342	17677	2666	27714	18432	6110	30962	40177
2002	24333	43658	30184	38274	7930	13053	53229	5088	2955	17903	14507	31087
2003	17118	39483	46318	17511	5002	22457	3293	12708	0	90561	9006	6190
2004	22936	36502	49667	111481	56410	108956	32273	63098	36437	25839	278057	102471
2005	86841	141260	160166	76589	28739	16548	2383	102718	6014	2429	1968	2636
2006	6335	6168	14837	8422	18712	4657	1564	2291	26	3852	2394	3747
2007	13929	4401	166562	82470	322445	407835	438750	145766	108694	16040	10162	9285

Monthly Stream Flows for Lake Granger (AF/Month)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	31758	34862	53995	18181	6846	3115	2780	2339	2588	26946	17355	27505
1999	13146	7327	8278	6313	12582	8513	14980	3498	2339	2388	3120	3214
2000	2958	3786	3379	4416	2776	7464	2820	2790	2455	3551	19744	11820
2001	25737	17538	28502	20674	11803	6186	3462	5003	3054	4368	35486	12673
2002	9001	7568	5781	6077	2967	12987	70356	8289	7520	5898	9015	18511
2003	17166	28265	24195	10869	5153	4806	3228	2890	2339	3232	2963	2827
2004	4925	4398	6418	16519	10346	15781	7213	2574	3004	5688	81845	19108
2005	14637	19997	26063	12869	8082	3826	4041	7589	3209	3932	2496	2685
2006	3334	3157	3027	7507	11180	3309	2591	2906	2677	2881	2762	3073
2007	7546	4303	48624	23131	54200	142802	103965	25113	19018	10437	4268	4293

APPENDIX B

Monthly Data Sets for Lake Georgetown Water Balance Calculations

Lake Georgetown
Data Sets for
Water Balance Calculations

		NF San Gab nr Georgetown (mean cfs)	Spills and Releases (AF)	Change in Storage (AF) USGS 98-04, COE 05-07	Lakeside Use (AF)	Water from Stillhouse (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1988	January	7.84	480	80	230		790.75	1280.5	0.16	207	997	965
	February	7.62	421	-40	109		790.72	1279.72	0.13	170	660	639
	March	7.33	449	-30	166		790.71	1279.46	0.20	252	836	810
	April	8.59	509	-560	213		790.52	1274.52	0.24	301	463	448
	May	5.76	353	-390	241		790.14	1264.64	0.16	199	402	390
	June	7.06	418	1580	301		791.36	1306.08	0.24	320	2619	2536
	July	5.41	331	-210	436		791.22	1298.66	0.46	598	1155	1118
	August	5.44	333	-1390	623		790.56	1275.56	0.40	509	75	72
	September	5.38	319	-1480	548		789.30	1246.3	0.39	483	-130	0
	October	5.88	360	-1230	383		788.20	1220.8	0.31	384	-103	0
	November	5.65	335	-1050	365		787.32	1198.32	0.30	361	11	11
	December	6.42	393	-740	344		786.52	1177.04	0.08	99	96	93
1989	January	4.66	285	30	242		786.06	1164.62	-0.18	-215	343	339
	February	4.73	262	70	213		786.16	1167.32	0.08	91	636	629
	March	5.38	329	2290	185		786.61	1179.47	0.02	21	2826	2799
	April	6.11	362	600	278		788.57	1229.68	0.33	410	1650	1634
	May	143.9	8812	4160	306		791.88	1333.64	0.16	216	13494	13366
	June	58.5	3467	-860	321		791.70	1324.1	0.24	321	3249	3218
	July	4.47	274	-1080	464		791.03	1288.59	0.58	745	403	399
	August	4.36	267	-1230	436		790.04	1262.04	0.41	519	-8	0
	September	3.47	206	-1500	567		788.97	1239.28	0.48	592	-135	0
	October	3.87	237	-1080	538		787.85	1212.1	0.30	368	63	62
	November	4.1	243	-880	438		787.03	1190.78	0.17	203	4	4
	December	3.93	241	-910	385		786.25	1169.75	0.18	211	-73	0
1990	January	4.27	261	-310	349		785.66	1153.48	0.04	46	347	346
	February	4.06	225	-350	236		785.41	1146.48	-0.02	-25	86	85
	March	4.95	303	330	259		785.48	1148.44	-0.21	-244	648	647
	April	5.6	332	70	276		785.48	1148.44	-0.06	-68	610	609
	May	6.46	396	1120	383		786.49	1176.23	0.12	138	2037	2033
	June	5.28	313	-1170	449		786.20	1168.4	0.56	658	249	249
	July	4.61	282	-1090	491		785.02	1135.56	0.36	403	87	87
	August	4.34	266	-1240	693		784.10	1108	0.45	497	215	215
	September	3.83	227	-770	514		783.09	1077.7	0.05	55	26	26
	October	3.78	231	-890	560		782.28	1054.84	0.09	90	-8	0
	November	4.12	244	-450	431		781.69	1038.94	-0.04	-38	188	187
	December	3.25	199	-760	546		780.98	1020.44	0.09	89	75	74

Lake Georgetown
Data Sets for
Water Balance Calculations

		NF San Gab nr Georgetown (mean cfs)	Spills and Releases (AF)	Change in Storage (AF) USGS 98-04, COE 05-07	Lakeside Use (AF)	Water from Stillhouse (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1991	January	4.3	263	3700	546		781.94	1045.44	-0.20	-210	4299	4299
	February	4.19	232	3340	471		785.77	1156.56	0.02	23	4065	4065
	March	2.95	181	1690	592		787.92	1213.92	0.22	264	2727	2727
	April	10.9	646	3420	535		790.02	1261.52	-0.22	-272	4329	4329
	May	129.1	7906	-120	539		791.59	1318.27	0.16	207	8532	8532
	June	85.5	5067	310	381		791.65	1321.45	0.17	229	5987	5987
	July	34.4	2107	-550	468		791.42	1309.26	0.58	762	2787	2787
	August	9.92	607	-1020	429		790.60	1276.6	0.37	470	487	487
	September	29.6	1754	1050	283		790.54	1275.04	0.19	240	3327	3327
	October	6.78	415	170	374		790.79	1281.54	0.43	556	1515	1515
	November	25.4	1505	-20	294		791.30	1302.9	0.21	270	2049	2049
	December	69.9	4281	41100	237		798.84	1603.6	-0.39	-621	44997	44997
1992	January	343.4	21030	11640	236		814.53	2221.2	-0.05	-106	32799	32799
	February	410.8	23534	42660	184		831.27	3066.2	-0.05	-141	66237	66237
	March	832.2	50964	-13600	179		833.68	3204	0.12	385	37928	37928
	April	574.1	34024	-25160	229		826.15	2787.5	0.31	875	9968	9968
	May	323	19780	2110	255		818.53	2396.5	-0.18	-443	21702	21702
	June	937.7	55572	-23710	264		821.60	2544	0.29	737	32863	32863
	July	740.8	45366	-34810	400		802.24	1739.6	0.43	754	11711	11711
	August	27.2	1666	-1160	388		790.92	1284.92	0.31	393	1287	1287
	September	15	889	-1060	382		790.05	1262.3	0.26	325	536	536
	October	2.19	134	-760	417		789.27	1245.67	0.41	510	301	301
	November	4.71	279	70	303		788.93	1238.32	-0.22	-270	382	382
	December	4.31	264	840	285		789.35	1247.35	-0.17	-211	1178	1178
1993	January	4.3	263	1020	351		790.03	1261.78	-0.11	-145	1490	1490
	February	53.8	2976	1000	406		791.26	1300.78	0.01	9	4391	4391
	March	131.8	8071	190	443		791.55	1316.15	-0.05	-70	8635	8635
	April	111.7	6620	310	451		791.33	1304.49	0.14	180	7561	7561
	May	127.4	7802	-490	464		791.64	1320.92	0.00	6	7782	7782
	June	210.7	12487	9450	442		793.13	1373.9	0.14	186	22565	22565
	July	231.2	14159	-9740	880		793.00	1370	0.78	1072	6371	6371
	August	7	429	-1700	1094		790.49	1273.74	0.90	1146	969	969
	September	9.45	560	-1130	620		789.31	1246.51	0.37	457	507	507
	October	9.69	593	-1030	466		788.43	1226.32	0.16	201	230	230
	November	8.77	520	-810	431		787.74	1209.24	0.13	153	294	294
	December	8.64	529	-710	497		787.04	1191.04	0.09	107	423	423

Lake Georgetown
Data Sets for
Water Balance Calculations

		NF San Gab nr Georgetown (mean cfs)	Spills and Releases (AF)	Change in Storage (AF) USGS 98-04, COE 05-07	Lakeside Use (AF)	Water from Stillhouse (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1994	January	10.9	668	-920	571		786.42	1174.34	0.04	50	368	368
	February	28.2	1560	-1140	414		785.33	1144.24	-0.02	-22	812	812
	March	28.6	1751	-1040	442		784.46	1118.8	0.05	53	1207	1207
	April	29.4	1742	-1620	593		783.15	1079.5	0.25	270	986	986
	May	7.15	438	1680	517		783.15	1079.5	0.01	15	2650	2650
	June	5.81	344	-600	704		783.92	1102.6	0.50	556	1005	1005
	July	5.61	344	-2220	1311		782.43	1059.04	0.82	865	299	299
	August	4.86	298	-1040	950		780.63	1010.64	0.32	325	532	532
	September	5	296	-1160	700		779.60	982.6	0.42	410	246	246
	October	5.52	338	1860	690		779.16	971.16	-0.32	-314	2574	2574
	November	5.69	337	160	617		780.96	1019.88	0.10	104	1218	1218
	December	6.08	372	3100	518		781.67	1038.42	-0.09	-91	3899	3899
1995	January	6.72	412	3020	492		785.64	1152.92	0.14	159	4082	4068
	February	6.75	373	1270	451		787.29	1197.54	0.10	115	2209	2201
	March	6.15	377	3560	500		789.35	1247.35	0.13	157	4594	4578
	April	70.5	4178	430	543		791.18	1296.54	-0.01	-15	5136	5118
	May	29.7	1819	1420	743		791.26	1300.78	-0.08	-109	3873	3859
	June	41.8	2477	-290	764		791.53	1315.09	0.39	511	3462	3450
	July	13.8	845	-1730	1179		791.31	1303.43	0.45	581	875	872
	August	8.79	538	-2080	1126		789.90	1258.9	0.27	337	-79	0
	September	13.8	818	-1650	905		788.22	1221.28	0.21	252	325	324
	October	13.8	845	-2030	952		786.66	1180.82	0.41	487	254	253
	November	13.4	794	-1550	798		785.15	1139.2	-0.05	-52	-10	0
	December	11.7	717	-1430	688		783.78	1098.4	0.13	144	118	118
1996	January	10.8	661	-1490	707		782.35	1056.8	0.21	225	104	104
	February	10.7	613	-1360	734		780.95	1019.6	0.27	273	260	260
	March	11.8	723	-1480	720		779.45	978.7	0.19	184	146	146
	April	11.6	687	-1670	933		777.83	937.75	0.41	380	330	330
	May	4.54	278	-1390	1266		775.92	891.16	0.21	187	341	341
	June	1.26	75	-1130	1108		774.68	862.64	0.27	232	284	284
	July	2.12	130	-2050	1588		772.67	815.07	0.62	505	173	173
	August	2.07	127	-810	1512		770.14	754.5	0.19	145	974	974
	September	5.5	326	2310	962		771.57	790.25	-0.55	-433	3165	3165
	October	3.37	206	1970	898		773.91	844.75	0.27	231	3306	3306
	November	9.78	580	200	701		776.03	893.72	-0.11	-100	1380	1380
	December	10.1	619	5920	687		779.07	968.82	0.04	38	7263	7263

Lake Georgetown
Data Sets for
Water Balance Calculations

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1997	January	7.1	435	5760	666		785.13	1138.64	0.00	0	6861	6861
	February	136.2	7534	7530	819		790.68	1278.68	-0.19	-243	15640	15640
	March	416.3	25494	-2680	801		793.21	1376.3	0.08	110	23725	23725
	April	274	16238	12550	744		797.07	1532.8	-0.63	-966	28567	28567
	May	543.5	33284	-12140	585		794.20	1410	-0.16	-226	21504	21504
	June	587.6	34824	-30	671		795.33	1463.2	-0.13	-190	35274	35274
	July	83	5083	-690	1459		791.59	1318.27	0.52	686	6538	6538
	August	8.33	510	-1540	1313		790.64	1277.64	0.47	600	884	884
	September	3.86	229	-1690	1335		789.34	1247.14	0.32	399	273	273
	October	3.2	196	-1020	929		788.19	1220.56	-0.03	-37	69	69
	November	4.64	275	-600	785		787.41	1200.66	-0.08	-96	364	364
	December	47.9	2933	10880	791		791.49	1312.97	-0.16	-210	14394	14394
1998	January	303.3	18574	-3660	750		792.79	1363.7	-0.03	-45	15619	15608
	February	269.4	14901	1960	663		792.32	1349.6	-0.19	-258	17267	17255
	March	480.7	29438	-2840	740		792.20	1346	0.06	87	27425	27406
	April	143.2	8487	-1420	958		791.28	1301.84	0.30	387	8411	8405
	May	14.3	876	-490	1469		791.06	1290.18	0.42	538	2393	2392
	June	5.48	325	-2050	1700		790.09	1263.34	0.35	438	412	412
	July	3.82	234	-2540	1871		788.37	1224.88	0.55	669	234	234
	August	5.39	330	-2610	1847		785.94	1161.32	0.31	361	-72	0
	September	5.1	302	-1550	1249		787.07	1191.82	0.11	131	133	132
	October	36.4	2229	10230	988		787.19	1194.94	-0.32	-383	13064	13055
	November	126	7467	-340	962		791.89	1334.17	-0.09	-117	7972	7967
	December	207.5	12707	-200	795		791.67	1322.51	0.04	59	13361	13352
1999	January	87.3	5346	-540	744		791.32	1303.96	0.14	186	5736	5734
	February	31.5	1742	-90	740		791.18	1296.54	0.20	255	2648	2647
	March	24.3	1488	910	782		791.33	1304.49	-0.02	-28	3152	3151
	April	26.3	1559	-360	665		791.32	1303.96	0.19	246	2109	2109
	May	65.5	4011	540	961		791.66	1321.98	-0.06	-75	5437	5435
	June	48	2845	-550	1189		791.60	1318.8	-0.16	-207	3277	3276
	July	86.7	5309	-150	1231		791.59	1318.27	0.24	319	6710	6707
	August	5.79	355	-2630	2062		790.41	1271.66	0.65	829	616	615
	September	6.25	370	-3130	2165		788.04	1216.96	0.48	582	-13	0
	October	4.6	282	-2370	1828		785.57	1150.96	0.25	287	26	26
	November	9.3	551	-1830	1344		783.81	1099.3	0.32	349	415	415
	December	9.64	590	-1350	1102		782.30	1055.4	0.12	123	465	465

Lake Georgetown
Data Sets for
Water Balance Calculations

Year	Month	NF San Gab nr Georgetown (mean cfs)	Spills and Releases (AF)	Change in Storage (AF) USGS 98-04, COE 05-07	Lakeside Use (AF)	Water from Stillhouse (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
2000	January	2.35	144	-850	967		781.32	1029.32	0.07	68	329	329
	February	3	172	-560	981		780.48	1006.44	0.17	175	768	768
	March	2.5	153	-770	1023		779.95	991.7	0.15	146	552	552
	April	5.23	310	-570	1088		779.28	974.28	0.28	274	1102	1102
	May	2.1	129	-1140	1162		778.57	956.25	0.08	81	232	232
	June	2.55	151	1200	1135		778.68	959	0.24	233	2719	2719
	July	1.76	108	-2910	2347		777.56	931	0.76	711	255	255
	August	1.52	93	-3090	2604		774.22	852.06	0.74	633	240	240
	September	5.35	317	-2580	2106		770.52	764	0.29	219	62	62
	October	6.17	378	-820	1286		768.10	702.5	-0.29	-201	643	643
	November	7.67	455	8110	1041		773.87	843.75	-0.44	-371	9234	9234
	December	7.27	445	3700	971		779.17	971.42	-0.09	-86	5030	5030
2001	January	4.13	253	11410	921		785.50	1149	-0.15	-170	12414	12414
	February	130	7191	-80	869		791.95	1337.35	0.06	85	8064	8064
	March	171.7	10515	2990	864		791.91	1335.23	-0.37	-489	13881	13881
	April	185.9	11017	-2690	1197		792.04	1341.2	0.15	203	9727	9727
	May	43.9	2688	800	1369		791.78	1328.34	0.12	163	5021	5021
	June	9.61	570	-640	1519		791.65	1321.45	0.45	593	2041	2041
	July	3.81	233	-2790	2367		790.67	1278.42	0.61	786	596	596
	August	3.39	208	-1940	2674		787.99	1215.74	0.39	472	1413	1413
	September	3.83	227	-1760	1582		787.12	1193.12	0.28	331	380	380
	October	9.66	592	-1380	1747		785.72	1155.16	0.10	118	1077	1077
	November	85.9	5091	11490	1389		790.79	1281.54	-0.30	-384	17586	17586
	December	127	7777	-3160	1090		792.09	1342.7	-0.17	-225	5483	5483
2002	January	46.6	2854	-660	1207		791.43	1309.79	0.10	134	3535	3535
	February	31.3	1731	-210	1090		791.31	1303.43	0.12	163	2774	2774
	March	5.75	352	-120	1389		791.11	1292.83	0.16	206	1826	1826
	April	6.83	405	-570	1711		791.10	1292.3	0.34	438	1983	1983
	May	4.77	292	-3050	2770		789.31	1246.51	0.26	321	334	334
	June	6.9	409	2700	2149		787.15	1193.9	0.33	392	5650	5650
	July	496.1	30381	3970	1702		798.48	1589.2	0.02	34	36086	36086
	August	18.5	1133	-1270	2583		793.15	1374.5	0.52	711	3157	3157
	September	19.4	1150	-560	1923		792.39	1351.7	0.17	236	2749	2749
	October	13.3	814	350	1361		791.71	1324.63	-0.48	-637	1888	1888
	November	56.1	3325	-920	1019		792.03	1340.9	0.09	118	3542	3542
	December	130.6	7998	-170	943		791.81	1329.93	-0.14	-191	8580	8580

Lake Georgetown
Data Sets for
Water Balance Calculations

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2003	January	99.8	6112	840	878		792.01	1340.3	0.05	69	7899	7867
	February	241.4	13353	-100	830		791.99	1339.47	-0.20	-271	13811	13755
	March	170.7	10454	-460	1434		792.16	1344.8	0.16	216	11643	11596
	April	38	2252	-560	2333		791.25	1300.25	0.40	519	4544	4526
	May	5.88	360	-1420	2268		790.67	1278.42	0.23	291	1499	1493
	June	5.51	327	-890	1816		789.97	1260.37	0.05	62	1314	1309
	July	4.67	286	-2680	2362		788.42	1226.08	0.41	506	474	472
	August	4.18	256	-2940	2545		785.88	1159.64	0.37	433	294	293
	September	3.77	223	-2360	1862		783.43	1087.9	0.09	102	-173	0
	October	4.64	284	-1820	1844		781.77	1041.02	0.16	168	476	474
	November	3.22	191	-1750	1680		779.97	992.22	0.21	212	333	331
	December	4.81	295	-1720	1499		778.15	945.75	0.20	187	260	259
2004	January	4.11	252	130	1194		777.16	921	-0.22	-204	1372	1372
	February	3.07	176	325	808		777.36	926	-0.23	-216	1092	1092
	March	2.87	176	556	1340		778.03	942.75	0.10	92	2164	2164
	April	3.19	189	6033	1437		780.26	1000.28	-0.14	-135	7524	7524
	May	1.53	94	2253	1723		785.52	1149.56	0.16	178	4248	4248
	June	3.29	195	5876	1646		787.65	1206.9	-0.48	-585	7132	7132
	July	5.81	356	-463	2295		791.01	1287.53	0.31	398	2586	2586
	August	1.89	116	-2057	1981		789.56	1251.76	0.07	85	125	125
	September	1.53	91	-2547	2371		787.80	1210.8	0.36	438	353	353
	October	2.4	147	379	1713		786.52	1177.04	-0.39	-462	1777	1777
	November	15.1	895	40725	1275		796.89	1525.6	-0.47	-713	42182	42182
	December	665.7	40767	-33364	1296		801.81	1722.4	0.11	198	8897	8897
2005	January	98	6001	-516	1157		791.85	1332.05	-0.09	-118	6525	6525
	February	169	9348	-873	1012		791.52	1314.56	-0.09	-118	9369	9369
	March	199.5	12217	-909	1164		791.45	1310.85	0.09	115	12587	12587
	April	61.1	3621	-78	1539		791.63	1320.39	0.38	505	5587	5587
	May	7.6	465	353	1975		791.22	1298.66	0.20	254	3047	3047
	June	2.22	132	-2538	2509		790.57	1275.82	0.54	687	789	789
	July	1.1	67	-2514	2941		788.18	1220.32	0.34	409	903	903
	August	2.25	138	383	2456		788.11	1218.64	-0.16	-191	2786	2786
	September	1.04	62	-3054	2856		786.49	1176.23	0.51	598	462	462
	October	1.06	65	-1937	2452		784.39	1116.7	0.24	265	845	845
	November	1.12	66	-2245	2093		782.19	1052.32	0.16	169	84	84
	December	1.69	103	-1876	1784		780.19	998.32	0.17	172	184	184

Lake Georgetown
Data Sets for
Water Balance Calculations

		NF San Gab nr Georgetown (mean cfs)	Spills and Releases (AF)	Change in Storage (AF) USGS 98-04, COE 05-07	Lakeside Use (AF)	Water from Stillhouse (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
2006	January	1.69	103	-1690	1901	23.40	778.21	947.25	0.25	237	528	528
	February	1.44	80	-499	1635	888.59	777.24	923	0.12	107	434	434
	March	1.45	89	-365	1909	1399.61	776.70	909.8	0.15	132	365	365
	April	1.59	94	1733	1932	1189.83	776.49	904.76	0.19	173	2742	2742
	May	0.851	52	2186	2132	0.00	780.82	1015.96	0.32	320	4690	4690
	June	0.103	6	-2205	2480	0.00	779.41	977.66	0.24	234	515	515
	July	0.581	36	-1813	2543	805.34	777.49	929.25	0.19	173	134	134
	August	0.084	5	-2760	3856	1344.13	774.94	868.62	0.63	544	301	301
	September	0.501	30	-1138	2570	1350.21	772.60	813.6	0.08	68	180	180
	October	1.09	67	-471	2187	1448.94	771.46	787.5	-0.06	-46	288	288
	November	1.7	101	-818	2064	1353.66	770.74	769.5	0.30	231	225	225
	December	1.84	113	347	1740	1735.76	770.12	754	-0.10	-74	390	390
2007	January	1.69	103	3983	1468	2548.06	772.98	821.58	-0.30	-244	2763	2763
	February	0.379	21	586	1564	1316.42	775.88	890.24	0.21	188	1042	1042
	March	2.74	168	23046	2032	500.05	782.55	1062.4	-0.18	-189	24556	24556
	April	231.5	13720	-4794	1825	0	793.31	1379.3	0.20	280	11031	11031
	May	204.1	12499	13563	1964	0	794.45	1422.5	-0.36	-511	27515	27515
	June	600.3	35576	37464	1903	0	799.96	1648.4	-0.26	-421	74522	74522
	July	722.7	44258	9201	1863	0	824.05	2672.5	-0.53	-1404	53917	53917
	August	524.3	32108	-23353	2640	0	819.10	2424	0.28	688	12083	12083
	September	501.1	29697	-23312	2279	0	808.33	1959.9	0.09	185	8849	8849
	October		15832	-14316	2487	0	794.86	1443	0.20	293	4296	4296
	November		362	-1522	2043	0	791.27	1301.31	0.11	141	1024	1024
	December		228	-1284	1967	0	790.30	1268.8	0.10	126	1037	1037

APPENDIX C

Monthly Data Sets for Lake Stillhouse Hollow Water Balance Calculations

Lake Stillhouse Hollow
Data Sets for
Water Balance Calculations

		Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Water to Georgetown (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1988	January	4883	-1294	409		622.17	6512	0.16	1042	5040	5032
	February	1188	2138	364		622.44	6556	0.10	656	4346	4339
	March	6125	-2203	397		622.27	6528	0.16	1045	5363	5355
	April	1783	-1225	467		622.14	6507	0.32	2082	3107	3103
	May	14420	-15630	505		621.49	6383	0.21	1340	635	634
	June	1650	3844	546		620.06	6199	0.17	1054	7094	7083
	July	48700	-47261	614		616.03	5522	0.33	1822	3876	3870
	August	0	-2747	679		611.75	4908	0.51	2503	435	435
	September	0	-2205	608		611.18	4840	0.32	1549	-48	0
	October	0	-1880	547		610.76	4787	0.30	1436	103	103
	November	0	-1513	460		610.47	4754	0.26	1236	183	183
	December	0	302	440		610.39	4744	0.05	237	979	978
1989	January	0	3244	422		610.53	4760	-0.13	-619	3047	2975
	February	0	3707	407		611.31	4856	-0.03	-146	3968	3874
	March	0	5729	437		612.02	4952	0.05	248	6414	6262
	April	0	2515	498		613.13	5100	0.30	1530	4543	4435
	May	0	25656	502		615.51	5447	-0.04	-218	25940	25325
	June	0	11597	549		618.89	6104	0.09	549	12695	12394
	July	0	-1789	733		619.66	6181	0.49	3029	1973	1926
	August	0	-2940	669		619.29	6119	0.37	2264	-7	0
	September	0	-4357	618		618.64	6047	0.42	2540	-1199	0
	October	0	-2094	531		618.04	5911	0.31	1832	269	263
	November	0	-1605	410		617.78	5797	0.21	1217	22	22
	December	0	-1830	491		617.47	5749	0.20	1150	-189	0
1990	January	0	1002	426		617.38	5735	0.04	229	1657	1657
	February	0	710	354		617.56	5763	-0.04	-231	833	833
	March	0	10622	393		618.76	6075	-0.11	-668	10347	10347
	April	20	23875	412		620.40	6241	-0.05	-312	23995	23995
	May	10752	28171	462		626.68	6982	0.06	419	39804	39804
	June	25849	-24214	686		626.29	6935	0.58	4022	6343	6343
	July	6952	-9102	637		622.84	6622	0.28	1854	341	341
	August	0	-3349	646		622.16	6510	0.48	3125	422	422
	September	1406	1735	481		622.16	6510	0.10	651	4273	4273
	October	0	1097	440		622.18	6514	0.10	651	2188	2188
	November	2789	646	370		622.53	6571	-0.04	-263	3542	3542
	December	908	-388	422		622.27	6528	0.08	522	1465	1465

Lake Stillhouse Hollow
Data Sets for
Water Balance Calculations

		Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Water to Georgetown (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1991	January	17203	-710	412		622.63	6587	-0.29	-1910	14994	14994
	February	11921	840	329		622.30	6533	0.04	261	13351	13351
	March	6724	-905	399		622.23	6522	0.27	1761	7979	7979
	April	3995	-451	404		622.24	6523	0.04	261	4209	4209
	May	54896	903	417		623.71	6580	0.01	66	56282	56282
	June	24547	2593	463		622.90	6632	0.16	1061	28664	28664
	July	3519	-2334	637		622.44	6556	0.49	3213	5034	5034
	August	0	-2063	578		622.14	6507	0.31	2017	532	532
	September	1265	708	435		622.14	6507	0.12	781	3189	3189
	October	0	1804	479		621.93	6439	0.18	1159	3442	3442
	November	3844	-1160	376		622.19	6515	0.17	1108	4168	4168
	December	16832	211610	395		630.74	7437	-0.67	-4983	223854	223854
1992	January	79261	-814	387		648.91	9498	-0.19	-1805	77030	77030
	February	137131	195341	354		663.05	11358	-0.32	-3634	329192	329192
	March	205125	-34267	374		666.34	11881	0.02	238	171469	171469
	April	218916	-145070	432		658.66	10696	0.21	2246	76524	76524
	May	91337	-10634	454		646.71	9225	-0.23	-2122	79035	79035
	June	85333	-23253	466		650.21	9623	0.11	1059	63604	63604
	July	144387	-128524	668		638.74	8321	0.45	3745	20275	20275
	August	71933	-65033	671		625.73	6868	0.41	2816	10386	10386
	September	492	-708	570		622.16	6510	0.31	2018	2372	2372
	October	0	-1540	571		621.80	6422	0.34	2184	1215	1215
	November	980	2312	404		621.86	6430	-0.10	-643	3053	3053
	December	7335	0	406		622.30	6533	-0.11	-719	7022	7022
1993	January	6875	903	383		622.14	6507	-0.07	-455	7705	7705
	February	29887	3177	346		622.48	6563	-0.06	-394	33016	33016
	March	20311	32543	389		625.36	6823	-0.03	-205	53038	53038
	April	42776	-707	415		627.37	7051	0.09	635	43118	43118
	May	85057	-33719	452		625.13	6796	0.11	748	52538	52538
	June	27245	16494	486		623.30	6557	0.15	984	45208	45208
	July	31021	-18498	745		622.52	6569	0.77	5058	18327	18327
	August	0	-3017	886		621.95	6442	0.82	5282	3151	3151
	September	0	1089	598		621.64	6402	0.37	2369	4056	4056
	October	0	0	467		621.88	6433	0.06	386	853	853
	November	0	385	419		621.89	6434	0.10	643	1447	1447
	December	0	964	430		621.90	6435	0.10	644	2038	2038

Lake Stillhouse Hollow
Data Sets for
Water Balance Calculations

		Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Water to Georgetown (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1994	January	1258	64	419		622.11	6502	0.04	260	2001	1916
	February	7133	902	376		622.29	6532	-0.05	-327	8084	7740
	March	6232	-580	432		622.11	6502	0.13	845	6929	6635
	April	1712	-193	484		622.16	6510	0.16	1042	3044	2915
	May	7884	15915	456		623.10	6546	-0.20	-1309	22946	21970
	June	20537	-14948	602		623.21	6552	0.47	3079	9270	8876
	July	135	-4747	836		621.91	6436	0.70	4506	729	698
	August	0	-3110	730		621.24	6351	0.44	2794	414	397
	September	0	-5456	595		620.83	6293	0.30	1888	-2973	0
	October	0	7738	543		621.76	6417	-0.14	-898	7383	7069
	November	0	2937	450		621.65	6403	-0.01	-64	3323	3182
	December	1521	4969	451		622.05	6492	-0.18	-1169	5773	5527
1995	January	12071	-3234	442		622.28	6530	0.00	0	9279	9198
	February	4181	2390	403		622.16	6510	0.00	0	6974	6913
	March	22493	-2068	450		622.52	6569	-0.04	-263	20612	20430
	April	32955	387	478		622.79	6614	-0.01	-66	33754	33457
	May	16746	2720	563		622.38	6546	-0.18	-1178	18851	18685
	June	9604	260	651		622.54	6573	0.20	1315	11829	11725
	July	4596	-2657	788		622.61	6584	0.42	2765	5492	5444
	August	2168	-3343	777		622.06	6494	0.23	1494	1096	1086
	September	60	-1150	506		621.63	6401	0.16	1024	440	436
	October	61	-3367	646		621.24	6351	0.39	2477	-183	0
	November	60	-1765	488		620.86	6297	0.07	441	-777	0
	December	61	-566	484		620.70	6277	0.09	565	544	540
1996	January	61	-1254	466		620.54	6258	0.20	1252	525	485
	February	58	-813	537		620.40	6241	0.27	1685	1467	1355
	March	61	-936	541		620.23	6220	0.22	1368	1035	956
	April	60	-1305	526		620.12	6207	0.28	1738	1018	941
	May	61	-1116	614		619.86	6214	0.33	2051	1610	1488
	June	36169	-35375	609		617.24	5713	0.28	1600	3002	2774
	July	61	-2860	784		612.44	5006	0.55	2753	739	683
	August	61	9576	637		612.98	5076	0.00	0	10274	9495
	September	60	-3568	411		615.46	5440	-0.05	-272	-3369	0
	October	61	726	443		615.84	5494	0.11	604	1835	1696
	November	60	4629	368		616.20	5547	-0.04	-222	4835	4468
	December	61	17810	384		618.29	5968	-0.03	-179	18076	16705

Lake Stillhouse Hollow
Data Sets for
Water Balance Calculations

		Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Water to Georgetown (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1997	January	1924	17334	398		621.23	6349	0.03	190	19846	19846
	February	52984	99455	321		629.43	7277	-0.30	-2183	150577	150577
	March	106498	4524	380		636.54	8079	0.02	162	111564	111564
	April	98717	-7174	376		636.38	8062	-0.18	-1451	90468	90468
	May	116420	-44303	442		633.06	7697	-0.04	-308	72251	72251
	June	87336	22531	456		631.67	7534	-0.13	-979	109344	109344
	July	102815	-76524	689		627.77	7094	0.55	3902	30882	30882
	August	3965	-2194	683		622.20	6517	0.45	2933	5386	5386
	September	60	-1347	594		621.93	6438	0.45	2897	2204	2204
	October	61	-256	489		621.80	6422	0.04	257	552	552
	November	60	3086	366		622.03	6488	0.01	65	3577	3577
	December	21578	23523	360		624.04	6664	-0.22	-1466	43995	43995
1998	January	78125	-20996	383		624.23	6687	-0.08	-511	57001	57001
	February	48990	16416	312		623.89	6590	-0.15	-957	64761	64761
	March	113998	24338	343		626.82	6998	0.05	340	139019	139019
	April	79373	-41663	377		625.51	6841	0.31	2151	40237	40237
	May	5794	1494	539		622.63	6587	0.38	2477	10304	10304
	June	2019	-2336	600		622.57	6577	0.51	3341	3624	3624
	July	6190	-6594	690		621.87	6431	0.56	3576	3862	3862
	August	5950	-5747	607		620.89	6301	0.30	1895	2705	2705
	September	2146	-309	531		620.41	6241	0.06	349	2717	2717
	October	15064	13881	452		621.48	6381	-0.32	-2011	27387	27387
	November	23621	195	423		622.59	6581	-0.07	-479	23759	23759
	December	47480	-1556	450		622.49	6564	-0.04	-239	46135	46135
1999	January	18244	907	485		622.44	6556	0.11	713	20349	20056
	February	9771	454	459		622.54	6573	0.20	1288	11971	11798
	March	33007	0	473		622.57	6577	0.03	225	33705	33219
	April	28215	-519	541		622.53	6571	0.22	1470	29707	29279
	May	17526	2406	557		622.68	6596	0.04	262	20751	20452
	June	11092	-2600	602		622.67	6593	0.33	2160	11253	11091
	July	1267	-1552	747		622.34	6540	0.40	2588	3050	3007
	August	484	-5370	901		621.80	6422	0.60	3876	-109	0
	September	60	-4821	821		621.00	6313	0.43	2737	-1203	0
	October	61	-2535	490		620.41	6241	0.22	1402	-581	0
	November	60	-1903	391		620.05	6197	0.25	1576	123	121
	December	61	-245	351		619.87	6216	0.06	398	566	558

Lake Stillhouse Hollow
Data Sets for
Water Balance Calculations

		Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Water to Georgetown (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
2000	January	61	367	556		619.89	6219	0.02	155	1139	1127
	February	6728	-4068	542		619.58	6167	-0.01	-65	3137	3103
	March	61	1814	507		619.39	6136	0.19	1192	3575	3536
	April	60	9126	508		620.28	6226	0.21	1311	11005	10885
	May	61	-313	663		621.00	6313	0.12	750	1161	1149
	June	60	4355	598		621.32	6360	0.19	1239	6251	6183
	July	61	-5915	1070		621.18	6343	0.72	4542	-242	0
	August	5814	-11166	540		619.80	6204	0.68	4195	-617	0
	September	280	-2319	784		618.70	6061	0.36	2196	940	930
	October	61	1305	527		618.61	6040	0.02	137	2031	2009
	November	12371	23499	472		620.61	6266	-0.34	-2142	34200	33828
	December	12165	2929	493		622.73	6603	0.01	90	15676	15506
2001	January	34859	1769	470		623.09	6545	-0.11	-709	36389	36389
	February	45844	-2878	401		623.09	6545	0.01	62	43428	43428
	March	56588	10777	440		623.68	6578	-0.15	-955	66850	66850
	April	45144	-11233	483		623.57	6572	0.22	1429	35823	35823
	May	31480	-1559	590		622.60	6582	0.13	836	31346	31346
	June	3830	1689	707		622.60	6582	0.39	2588	8814	8814
	July	3499	-6197	895		622.26	6526	0.59	3847	2044	2044
	August	61	9073	840		622.48	6562	0.22	1441	11416	11416
	September	13416	-8048	568		622.55	6574	0.15	956	6892	6892
	October	61	0	571		621.93	6439	0.16	1011	1643	1643
	November	27620	2836	492		622.15	6509	-0.21	-1371	29576	29576
	December	17074	2727	461		622.58	6579	-0.11	-741	19521	19521
2002	January	12284	3141	444		623.03	6542	0.08	553	16422	16422
	February	24928	-6837	379		622.75	6606	0.08	552	19022	19022
	March	4461	2525	447		622.42	6553	0.12	772	8205	8205
	April	10621	-3428	466		622.35	6541	0.28	1808	9468	9468
	May	61	1290	701		622.18	6514	0.26	1705	3758	3758
	June	60	3048	683		622.52	6568	0.27	1756	5547	5547
	July	71080	-1105	580		622.67	6593	-0.10	-654	69900	69900
	August	6641	-3876	828		622.28	6530	0.52	3403	6996	6996
	September	125	-1856	645		621.84	6427	0.27	1756	670	670
	October	1476	3079	525		621.93	6439	-0.20	-1259	3820	3820
	November	190	775	462		622.23	6522	0.11	741	2168	2168
	December	15431	-259	452		622.28	6529	-0.15	-960	14663	14663

Lake Stillhouse Hollow
Data Sets for
Water Balance Calculations

		Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Water to Georgetown (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
2003	January	13976	65	444		622.26	6527	0.07	455	14940	14938
	February	18563	5726	379		622.71	6600	-0.17	-1139	23530	23527
	March	38471	-6694	447		622.63	6587	0.17	1137	33361	33357
	April	7841	1355	466		622.22	6519	0.36	2364	12026	12025
	May	2622	-1483	701		622.21	6518	0.24	1578	3419	3418
	June	11207	515	683		622.13	6505	0.02	148	12553	12551
	July	61	-2760	580		621.96	6443	0.36	2334	216	216
	August	61	-3611	828		621.46	6379	0.42	2709	-12	0
	September	60	-503	645		621.13	6337	0.04	252	453	453
	October	61	566	525		621.14	6337	0.04	254	1406	1406
	November	60	-1192	462		621.09	6331	0.20	1281	611	611
	December	61	-1249	452		620.89	6301	0.20	1248	512	512
2004	January	61	3765	472		621.09	6332	-0.09	-597	3701	3701
	February	58	4984	389		621.78	6420	-0.17	-1088	4343	4343
	March	17601	-7124	436		621.60	6397	0.07	429	11342	11342
	April	14698	12907	438		622.05	6491	-0.17	-1098	26944	26944
	May	24119	-5654	522		622.63	6587	0.13	828	19814	19814
	June	40582	12261	513		623.13	6547	-0.43	-2816	50539	50539
	July	23821	-12196	677		623.13	6547	0.37	2425	14728	14728
	August	16243	8085	736		622.82	6618	0.14	958	26022	26022
	September	12113	-10464	614		622.64	6589	0.33	2178	4441	4441
	October	4092	3995	479		622.15	6508	-0.19	-1268	7297	7297
	November	22959	109675	400		629.93	7332	-0.59	-4328	128706	128706
	December	124560	-70917	432		632.78	7655	0.11	875	54950	54950
2005	January	78508	-34720	446		625.62	6854	0.00	6	44239	44239
	February	55178	6942	380		623.61	6574	-0.05	-345	62155	62155
	March	86404	-12596	419		623.17	6550	0.24	1566	75793	75793
	April	21788	-387	507		622.18	6513	0.48	3121	25029	25029
	May	10854	3106	581		622.38	6546	0.26	1707	16248	16248
	June	11480	-1945	742		622.47	6561	0.45	2926	13203	13203
	July	2047	-1355	825		622.22	6519	0.22	1407	2924	2924
	August	42895	4015	632		622.43	6554	0.11	711	48253	48253
	September	12204	-5557	645		622.31	6535	0.50	3255	10547	10547
	October	61	-1723	595		621.74	6415	0.37	2368	1301	1301
	November	60	-1016	498		621.52	6387	0.24	1538	1080	1080
	December	61	-1011	490		621.36	6366	0.22	1406	946	946

Lake Stillhouse Hollow
Data Sets for
Water Balance Calculations

		Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Water to Georgetown (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
2006	January	61	758	577	23.4	621.34	6364	0.23	1437	2857	2857
	February	56	-505	538	888.593	621.36	6366	0.21	1305	2282	2282
	March	61	6136	592	1399.614	621.80	6422	0.18	1145	9334	9334
	April	60	5204	656	1189.829	622.69	6596	0.21	1391	8500	8500
	May	27239	-7266	721	0	622.53	6570	0.30	1944	22638	22638
	June	3921	772	934	0	622.02	6487	0.50	3224	8851	8851
	July	61	-4341	1044	805.344	621.74	6415	0.53	3381	950	950
	August	61	-6743	1368	1344.133	620.86	6297	0.78	4899	929	929
	September	58	-4410	887	1350.212	619.96	6231	0.36	2250	134	134
	October	61	-1696	775	1448.935	619.46	6147	0.07	410	1000	1000
	November	60	-3535	715	1353.656	619.03	6074	0.31	1853	445	445
	December	61	-654	713	1735.757	618.68	6055	0.03	151	2008	2008
2007	January	61	6189	696	2548.063	619.14	6093	-0.36	-2193	7301	7301
	February	56	182	591	1316.418	619.67	6182	0.27	1659	3804	3804
	March	1498	69476	693	500.054	624.83	6760	-0.26	-1769	70397	70397
	April	98015	-51365	649	0	626.27	6932	0.33	2317	49616	49616
	May	64350	203432	685	0	635.36	7950	-0.48	-3810	264657	264657
	June	198767	78091	696	0	652.13	9834	-0.43	-4183	273372	273372
	July	134493	63916	700	0	658.91	10735	-0.16	-1689	197420	197420
	August	210180	-171460	1051	0	653.34	9981	0.60	5978	45750	45750
	September	190060	-148183	906	0	635.68	7985	0.14	1147	43931	43931
	October	37057	-28706	866	0	624.26	6691	0.44	2972	12189	12189
	November	1787	1226	805	0	622.21	6518	0.14	940	4757	4757
	December	3991	-581	895	0	622.26	6526	0.09	582	4887	4887

APPENDIX D

Monthly Data Sets for Lake Belton Water Balance Calculations

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1940	January	18.1	1110								1110	1110
	February	30.9	1772								1772	1772
	March	18	1104								1104	1104
	April	504.8	29954								29954	29954
	May	115	7051								7051	7051
	June	1673	99272								99272	99272
	July	781.5	47918								47918	47918
	August	141.4	8670								8670	8670
	September	33.4	1982								1982	1982
	October	91.6	5617								5617	5617
	November	3008	178488								178488	178488
	December	3456	211907								211907	211907
1941	January	1392	85352								85352	85352
	February	4457	246838								246838	246838
	March	3546	217426								217426	217426
	April	2215	131433								131433	131433
	May	6767	414924								414924	414924
	June	2689	159560								159560	159560
	July	1366	83757								83757	83757
	August	858.2	52621								52621	52621
	September	702.6	41691								41691	41691
	October	965.1	59176								59176	59176
	November	313.8	18620								18620	18620
	December	245.4	15047								15047	15047
1942	January	177.7	10896								10896	10896
	February	173.7	9620								9620	9620
	March	132.5	8124								8124	8124
	April	4867	288797								288797	288797
	May	4344	266356								266356	266356
	June	3156	187270								187270	187270
	July	363.3	22276								22276	22276
	August	452	27715								27715	27715
	September	3109	184481								184481	184481
	October	2392	146667								146667	146667
	November	825.6	48989								48989	48989
	December	482.5	29585								29585	29585

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1943	January	366	22442								22442	22442
	February	263.5	14593								14593	14593
	March	341.2	20921								20921	20921
	April	530.4	31473								31473	31473
	May	341.8	20958								20958	20958
	June	148.9	8835								8835	8835
	July	57.8	3544								3544	3544
	August	14.8	907								907	907
	September	140.4	8331								8331	8331
	October	128.2	7861								7861	7861
	November	45.2	2682								2682	2682
	December	77	4721								4721	4721
1944	January	778.5	47734								47734	47734
	February	2053	117760								117760	117760
	March	1765	108222								108222	108222
	April	1153	68417								68417	68417
	May	8753	536697								536697	536697
	June	1813	107580								107580	107580
	July	344	21093								21093	21093
	August	141.6	8682								8682	8682
	September	178.1	10568								10568	10568
	October	156.3	9584								9584	9584
	November	141.9	8420								8420	8420
	December	533.8	32730								32730	32730
1945	January	1791	109817								109817	109817
	February	2010	111318								111318	111318
	March	3180	194984								194984	194984
	April	6736	399700								399700	399700
	May	1326	81305								81305	81305
	June	1081	64144								64144	64144
	July	583.9	35802								35802	35802
	August	120.9	7413								7413	7413
	September	174.4	10349								10349	10349
	October	702.1	43050								43050	43050
	November	274.6	16294								16294	16294
	December	641.9	39359								39359	39359

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1946	January	784.1	48078								48078	48078
	February	1498	82962								82962	82962
	March	2527	154945								154945	154945
	April	738.8	43839								43839	43839
	May	2386	146300								146300	146300
	June	813.9	48295								48295	48295
	July	159.5	9780								9780	9780
	August	49.6	3041								3041	3041
	September	440.8	26156								26156	26156
	October	114	6990								6990	6990
	November	451.4	26785								26785	26785
	December	465.8	28561								28561	28561
1947	January	1066	65363								65363	65363
	February	456.2	25265								25265	25265
	March	1450	88908								88908	88908
	April	718.5	42634								42634	42634
	May	930.4	57048								57048	57048
	June	201.2	11939								11939	11939
	July	81.3	4985								4985	4985
	August	29.1	1784								1784	1784
	September	20	1187								1187	1187
	October	11.2	687								687	687
	November	62.5	3709								3709	3709
	December	133.4	8180								8180	8180
1948	January	54.5	3342								3342	3342
	February	349.3	20036								20036	20036
	March	185.8	11392								11392	11392
	April	128.2	7607								7607	7607
	May	485.6	29775								29775	29775
	June	181.6	10776								10776	10776
	July	279.4	17132								17132	17132
	August	18.9	1159								1159	1159
	September	134.5	7981								7981	7981
	October	0.19	12								12	12
	November	0	0								0	0
	December	0.865	53								53	53

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1949	January	33.1	2030								2030	2030
	February	89.3	4946								4946	4946
	March	1038	63646								63646	63646
	April	1417	84082								84082	84082
	May	1215	74499								74499	74499
	June	923.3	54787								54787	54787
	July	179.2	10988								10988	10988
	August	29.3	1797								1797	1797
	September	14.5	860								860	860
	October	110.8	6794								6794	6794
	November	66.5	3946								3946	3946
	December	46.5	2851								2851	2851
1950	January	31.3	1919								1919	1919
	February	210.7	11669								11669	11669
	March	43.5	2667								2667	2667
	April	222.9	13226								13226	13226
	May	683.9	41934								41934	41934
	June	412.2	24459								24459	24459
	July	392.5	24066								24066	24066
	August	21	1288								1288	1288
	September	522.9	31028								31028	31028
	October	5.77	354								354	354
	November	0.08	5								5	5
	December	0.152	9								9	9
1951	January	5.56	341								341	341
	February	14.1	781								781	781
	March	21.7	1331								1331	1331
	April	33.8	2006								2006	2006
	May	262.1	16071								16071	16071
	June	477.4	28328								28328	28328
	July	3.54	217								217	217
	August	0	0								0	0
	September	32.6	1934								1934	1934
	October	0.526	32								32	32
	November	0	0								0	0
	December	0	0								0	0

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1952	January	0	0								0	0
	February	0	0								0	0
	March	11.8	724								724	724
	April	468.9	27824								27824	27824
	May	1097	67263								67263	67263
	June	172.1	10212								10212	10212
	July	47.7	2925								2925	2925
	August	0	0								0	0
	September	0	0								0	0
	October	0	0								0	0
	November	127.7	7577								7577	7577
	December	294.4	18051								18051	18051
1953	January	96.6	5923								5923	5923
	February	24.8	1373								1373	1373
	March	282.9	17346								17346	17346
	April	177.5	10532								10532	10532
	May	2588	158685								158685	158685
	June	55.4	3287								3287	3287
	July	177.3	10871								10871	10871
	August	78.6	4819								4819	4819
	September	57.9	3436								3436	3436
	October	352.1	21589								21589	21589
	November	92.6	5495								5495	5495
	December	46.5	2851								2851	2851
1954	January	28.4	1741								1741	1704
	February	19.1	1058								1058	1035
	Start of Impoundment - March	4.62	283	575	718		488.80	7	0.29	1.94	1295	1267
	April	1.7	101	452	7612		503.00	267	0.22	57.41	8122	7946
	May	0.868	53	278	5430		517.65	1003	0.14	140.43	5848	5722
	June	0.053	3	486	-1320		519.75	1194	0.66	783.73	-50	0
	July	0.258	16	587	-1740		518.40	1074	0.79	843.40	-309	0
	August	1.86	114	841	-1610		516.75	898	0.78	695.76	-73	0
	September	0.25	15	708	-1140		515.20	782	0.59	461.91	30	29
	October	3.01	185	635	1220		515.25	785	0.25	193.57	2048	2004
	November	1.07	63	422	5360		518.45	1079	0.07	77.34	5860	5733
	December	0.674	41	401	-770		520.60	1251	0.19	240.78	-129	0

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1955	January	2.51	154	464	-250		520.20	1220	0.02	18.29	232	231
	February	8.99	498	724	8310		522.82	1417	-0.12	-166.49	8867	8825
	March	2.56	157	587	2640		526.23	1686	0.18	303.51	3531	3514
	April	5.86	348	744	21190		531.33	2069	0.20	406.85	22341	22233
	May	8.51	522	722	73350		544.94	3556	-0.05	-189.63	73882	73526
	June	5.74	341	601	30600		556.93	5141	0.19	989.71	32191	32036
	July	4.95	304	827	1600		559.85	5483	0.45	2485.76	4913	4889
	August	7.59	465	861	900		560.07	5517	0.30	1664.35	3425	3409
	September	5.48	325	833	17700		561.56	5736	0.20	1142.43	19675	19581
	October	4.36	267	904	4500		563.36	6038	0.40	2430.18	7835	7797
	November	3.82	227	801	-2700		563.53	6068	0.32	1956.81	58	58
	December	6.03	370	768	-2500		563.13	5998	0.15	879.76	-853	0
1956	January	8.15	500	704	500		562.97	5952	0.01	74.40	1279	1254
	February	7.32	420	706	1300		563.11	5995	0.05	324.73	2331	2286
	March	6.58	403	772	-2600		563.01	5978	0.39	2306.46	478	469
	April	4.6	273	674	11900		563.73	6101	0.35	2115.00	14689	14408
	May	1,312	80446	81472	31300		566.89	6512	0.18	1177.60	113950	111765
	June	58	3442	3951	-6200		568.70	6940	0.60	4181.29	1932	1895
	July	13.2	809	1726	-7500		567.75	6702	0.78	5210.42	-564	0
	August	21.2	1300	1997	-5000		566.87	6509	0.74	4795.29	1793	1758
	September	11.1	659	1224	-6000		566.07	6406	0.67	4276.07	-500	0
	October	21.7	1331	1565	-5600		565.22	6295	0.36	2271.35	-1764	0
	November	897.2	53238	53715	-49900		560.63	5588	0.11	596.09	4411	4327
	December	321.4	19707	19984	-13700		555.17	4949	0.06	317.57	6601	6475
1957	January	2.68	164	385	400		553.92	4827	0.01	44.25	829	829
	February	3.56	197	415	1000		554.05	4830	-0.06	-277.71	1137	1137
	March	4.76	292	442	21800		556.16	5057	-0.12	-627.97	21614	21614
	April	144.2	8557	6649	327000		576.50	8591	-0.71	-6121.09	327528	327528
	May	3,928	240849	212211	377400		606.99	15599	-0.28	-4302.64	585308	585308
	June	6,002	356146	355025	-266900		611.12	16548	0.24	3930.10	92055	92055
	July	6,287	385493	395575	-345400		587.49	10841	0.58	6278.52	56454	56454
	August	669.1	41026	42058	-27000		570.13	7320	0.70	5130.17	20188	20188
	September	26.7	1584	1708	800		568.43	6880	0.11	762.56	3270	3270
	October	1,858	113925	115420	4600		568.80	6961	-0.31	-2151.96	117868	117868
	November	1,392	82598	85550	-2700		568.91	6985	-0.22	-1548.45	81302	81302
	December	453.3	27794	30094	2200		568.87	6977	0.13	895.35	33189	33189

Lake Belton
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Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1958	January	459.2	28156	30580	-900		568.96	6996	0.03	180.74	29860	29860
	February	485.4	27843	27414	85600		574.00	8150	-0.18	-1494.17	111520	111520
	March	3054	187259	200784	-86400		573.95	8142	0.10	793.83	115178	115178
	April	678	40231	39658	11100		569.54	7138	0.00	-17.84	50740	50740
	May	3135	192225	191154	-12400		569.45	7116	0.07	480.33	179234	179234
	June	386.9	22958	23140	100		568.62	6923	0.23	1592.18	24832	24832
	July	18.8	1153	1684	300		568.65	6929	0.66	4596.27	6580	6580
	August	7.89	484	1063	-2700		568.49	6893	0.39	2711.34	1074	1074
	September	8.22	488	837	800		568.36	6865	-0.03	-171.63	1465	1465
	October	9.44	579	853	-100		568.41	6876	0.08	550.07	1303	1303
	November	6.4	380	623	-300		568.38	6869	0.09	623.97	947	947
	December	6.99	429	690	-300		568.33	6860	0.04	268.67	659	659
1959	January	6.44	395	651	300		568.34	6861	0.10	663.20	1614	1614
	February	9.61	532	417	4000		568.63	6925	-0.17	-1165.66	3251	3251
	March	8.06	494	833	-800		568.85	6971	0.37	2556.17	2589	2589
	April	36	2136	2313	900		568.86	6974	0.09	616.00	3829	3829
	May	32.5	1993	2384	1000		568.99	7003	0.11	770.31	4154	4154
	June	586.8	34819	35475	9000		569.66	7164	-0.04	-250.73	44224	44224
	July	645.2	39561	39726	-10300		569.57	7143	0.20	1446.51	30872	30872
	August	33	2023	2444	9300		569.50	7129	0.23	1663.32	13407	13407
	September	173.3	10283	10582	-6500		569.69	7170	0.19	1332.52	5414	5414
	October	3918	240235	248788	124500		576.28	8552	-0.40	-3399.53	369889	369889
	November	3058	181455	188674	-130800		575.86	8478	0.11	953.81	58828	58828
	December	1119	68612	69587	9500		569.04	7024	-0.14	-965.81	78121	78121
1960	January	2278	139677	143254	4200		569.96	7232	-0.06	-421.85	147032	147032
	February	1713	94869	99165	-11100		569.49	7126	0.02	136.59	88202	88202
	March	703.3	43123	43203	-2400		568.59	6916	0.13	916.37	41719	41719
	April	337.5	20027	21846	4600		568.74	6949	0.24	1679.24	28126	28126
	May	308.4	18910	19520	-5100		568.70	6940	0.26	1833.29	16253	16253
	June	5.31	315	865	2700		568.54	6905	0.33	2278.71	5844	5844
	July	8.13	498	1146	300		568.75	6951	0.37	2537.02	3983	3983
	August	30.1	1846	2097	-3500		568.53	6903	0.36	2450.57	1047	1047
	September	17.4	1032	1474	-3800		568.03	6793	0.41	2813.61	487	487
	October	549.4	33687	23036	21900		569.23	7067	-0.18	-1266.21	43670	43670
	November	374.3	22210	32178	-11000		569.98	7236	0.12	838.21	22017	22017
	December	1924	117972	119196	1500		569.35	7094	-0.40	-2861.43	117835	117835

Lake Belton
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Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1961	January	2964	181740	182454	57100		572.94	7958	-0.33	-2586.49	236968	236968
	February	2902	160719	161895	75700		580.35	9492	-0.18	-1661.12	235934	235934
	March	3601	220798	222331	-123600		577.47	8850	0.16	1452.91	100183	100183
	April	861.6	51126	51636	-18600		569.43	7111	0.36	2589.76	35626	35626
	May	200	12263	13063	1300		568.27	6846	0.29	1956.67	16320	16320
	June	822.7	48817	49195	43200		571.12	7547	-0.19	-1440.22	90955	90955
	July	1623	99516	99588	100		574.20	8190	0.04	341.26	100029	100029
	August	1018	62420	64862	-45200		571.35	7601	0.50	3775.20	23438	23438
	September	176.2	10455	10096	700		568.28	6849	0.15	1050.14	11846	11846
	October	1218	74683	74869	3400		568.58	6914	0.12	818.14	79087	79087
	November	468.4	27794	26349	1800		568.84	6970	-0.08	-586.67	27562	27562
	December	446.4	27371	26648	-4800		568.58	6914	0.01	69.14	21917	21917
1962	January	222.5	13643	15366	-900		568.19	6828	0.07	495.04	14961	14961
	February	140	8030	7829	1400		568.22	6836	0.15	1053.84	10283	10283
	March	121.7	7462	7785	-200		568.31	6854	0.27	1873.48	9459	9459
	April	114.1	6770	6736	6400		568.73	6945	0.06	445.66	13582	13582
	May	113.3	6947	7188	700		569.21	7062	0.36	2542.15	10430	10430
	June	257.9	15303	14696	-1800		569.13	7045	0.06	393.32	13289	13289
	July	123.6	7579	7922	-7300		568.44	6883	0.63	4307.91	4930	4930
	August	5.94	364	1049	-500		567.91	6729	0.70	4704.93	5254	5254
	September	767	45512	45162	8100		568.51	6898	0.19	1281.80	54544	54544
	October	353.4	21669	22281	-9300		569.04	7023	0.16	1094.41	14075	14075
	November	70.6	4189	4175	9600		569.06	7027	0.01	64.42	13840	13840
	December	192.6	11809	12613	-300		569.08	7032	-0.01	-70.32	12243	12243
1963	January	171.3	10503	9352	-7000		568.57	6912	0.10	679.65	3032	2876
	February	13.1	726	1023	2400		568.26	6844	0.14	929.70	4353	4130
	March	103.9	6371	5599	-2900		568.23	6838	0.34	2324.89	5024	4767
	April	33.3	1976	2071	600		568.07	6803	0.21	1394.65	4065	3857
	May	195.3	11975	10132	-100		568.11	6811	0.16	1118.10	11150	10578
	June	330.8	19629	16271	1600		568.10	6810	0.45	3041.67	20912	19840
	July	137.4	8425	7002	-6000		568.10	6810	0.73	4988.11	5990	5683
	August	3.58	220	787	-6600		567.79	6708	0.58	3868.55	-1944	0
	September	6.43	382	700	-3400		567.01	6573	0.39	2568.85	-131	0
	October	6.54	401	716	-4400		566.29	6435	0.43	2734.75	-949	0
	November	7.23	429	623	3500		565.72	6360	0.04	227.90	4351	4128
	December	6.44	395	613	-600		565.66	6352	0.01	79.40	92	88

Lake Belton
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		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1964	January	6.29	386	734	4100		566.17	6419	-0.08	-513.53	4320	4320
	February	18.8	1041	1388	11700		567.25	6615	0.03	203.95	13292	13292
	March	143.5	8799	9245	7100		568.57	6912	0.06	437.74	16783	16783
	April	526.6	31247	32071	15400		570.07	7304	0.13	973.85	48445	48445
	May	539.4	33074	33111	-15600		570.06	7300	0.21	1502.55	19013	19013
	June	1065	63195	62258	18000		570.21	7340	0.23	1651.58	81910	81910
	July	410.2	25152	25748	-23200		569.85	7207	0.71	5098.82	7647	7647
	August	131.9	8088	8771	5800		568.71	6942	0.39	2678.48	17250	17250
	September	138.3	8206	7896	43100		571.82	7712	-0.04	-340.59	50656	50656
	October	1530	93813	101700	-40000		573.41	8031	0.24	1894.03	63594	63594
	November	1101	65331	67009	-2100		570.57	7439	-0.06	-433.94	64475	64475
	December	526.7	32295	23060	-1700		568.93	6990	0.10	728.11	22088	22088
1965	January	583.3	35766	35961	2300		569.17	7052	-0.04	-264.47	37996	37918
	February	901.6	49932	50423	65100		573.27	8003	-0.16	-1247.10	114275	114039
	March	1688	103501	103781	-13600		574.66	8282	0.10	862.67	91043	90855
	April	795.3	47191	48066	-52100		570.67	7466	0.24	1785.59	-2248	0
	May	337.5	20694	19625	485800		590.06	11367	-0.70	-7928.15	497497	496466
	June	5736	340362	347983	-253600		601.91	13946	0.37	5159.93	99543	99337
	July	3172	194494	195248	-138100		586.59	10663	0.64	6779.61	63927	63795
	August	2202	135017	135729	-95200		574.68	8286	0.46	3818.32	44347	44255
	September	308	18276	18942	-2500		568.93	6989	0.24	1654.00	18096	18059
	October	114.5	7021	7224	2200		568.91	6984	0.09	651.88	10076	10055
	November	1387	82302	83868	300		569.08	7033	-0.11	-797.09	83371	83199
	December	403.1	24716	25016	600		569.14	7046	-0.08	-587.14	25029	24977
1966	January	258.3	15838	16021	-600		569.14	7046	0.02	117.43	15538	15538
	February	433.8	24883	24540	3400		569.33	7089	-0.04	-313.09	27627	27627
	March	406.7	24937	25331	-1700		569.44	7114	0.24	1725.08	25356	25356
	April	181.7	10782	11040	77300		573.93	8138	-0.20	-1600.43	86740	86740
	May	1673	102581	103084	-32300		576.74	8632	0.13	1150.98	71935	71935
	June	1576	93517	94133	-47000		571.99	7753	0.32	2506.69	49640	49640
	July	324.3	19885	20924	-400		569.03	7021	0.58	4077.84	24602	24602
	August	672	41204	42498	3200		569.22	7064	0.05	341.42	46040	46040
	September	1182	70137	70898	2600		569.61	7152	-0.42	-2968.22	70530	70530
	October	247.4	15170	15192	-5400		569.40	7106	0.36	2546.25	12338	12338
	November	54.6	3240	3634	-1100		568.96	6996	0.32	2232.99	4767	4767
	December	29.2	1790	2116	100		568.91	6985	0.14	1001.25	3218	3218

Lake Belton
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		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1967	January	21.3	1306	1628	200		568.93	6990	0.21	1485.33	3314	3306
	February	20.4	1130	1466	-800		568.89	6980	0.20	1419.28	2085	2080
	March	18.4	1128	1559	-1000		568.77	6954	0.36	2486.06	3045	3038
	April	513	30440	30835	-22100		567.13	6594	0.16	1033.00	9768	9746
	May	249.1	15274	15485	2000		565.71	6358	0.13	794.74	18280	18238
	June	128.5	7625	8392	-3100		565.62	6347	0.49	3083.57	8376	8356
	July	350	21461	22193	1000		565.48	6328	0.41	2562.95	25756	25697
	August	192.5	11803	12748	-16600		564.31	6187	0.59	3655.55	-196	0
	September	20.4	1210	1502	4500		563.39	6044	0.01	50.36	6052	6038
	October	9.36	574	871	-700		563.68	6093	0.05	289.43	460	459
	November	3.39	201	524	4200		563.94	6138	0.02	127.87	4852	4840
	December	3.07	188	440	2700		564.46	6211	-0.02	-103.52	3037	3030
1968	January	18.9	1159	1117	166900		574.48	8246	-0.43	-3559.73	164457	164457
	February	2431	134634	140495	-34000		582.62	9932	0.00	33.11	106528	106528
	March	2390	146545	147519	8100		581.35	9698	0.01	56.57	155675	155675
	April	3522	208988	210154	-70400		577.93	8960	0.06	567.49	140321	140321
	May	3098	189956	189914	43700		576.55	8600	-0.22	-1870.46	231744	231744
	June	3006	178370	178991	-83800		574.02	8153	0.10	808.51	96000	96000
	July	904.8	55479	55344	-3200		568.81	6963	0.25	1752.28	53896	53896
	August	25.4	1557	2358	-1400		568.50	6897	0.51	3545.95	4504	4504
	September	6.09	361	795	1400		568.51	6899	0.22	1506.21	3702	3702
	October	2.79	171	579	-1700		568.47	6890	0.33	2262.21	1141	1141
	November	1.92	114	536	3400		568.66	6930	0.00	0.00	3936	3936
	December	4.66	286	744	2300		569.05	7026	0.11	749.48	3793	3793
1969	January	62.3	3820	4397	-1400	739	569.05	7025	0.16	1118.18	4855	4855
	February	142.5	7892	8267	-2800	718	568.76	6953	0.01	69.53	6254	6254
	March	131.6	8069	8309	5600	794	568.94	6992	0.04	262.20	14965	14965
	April	1148	68120	68407	29100	858	571.18	7562	-0.01	-94.53	98271	98271
	May	2087	127966	128628	-8400	1085	572.52	7864	0.01	58.98	121372	121372
	June	638.1	37864	38373	-28100	1459	570.16	7327	0.61	4432.74	16164	16164
	July	159	9749	10552	-16400	1820	567.15	6597	0.74	4898.35	870	870
	August	21.1	1294	2037	-2200	1461	565.83	6373	0.35	2209.45	3508	3508
	September	4.41	262	716	-3300	1038	565.42	6321	0.28	1738.32	192	192
	October	6.68	410	726	8600	962	565.81	6371	0.00	-10.62	10277	10277
	November	13.8	819	952	11500	860	567.25	6615	0.11	744.13	14056	14056
	December	290	17782	18165	6100	810	568.49	6893	-0.03	-224.03	24851	24851

Lake Belton
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		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1970	January	591.1	36244	36256	500	827	568.94	6991	0.04	297.11	37880	37880
	February	407.1	23351	22663	19600	725	570.25	7353	-0.10	-698.49	42289	42289
	March	1978	121283	123056	80100	852	576.08	8516	-0.04	-354.84	203654	203654
	April	2406	142767	141862	-46600	1011	578.09	9011	0.20	1779.75	98053	98053
	May	1681	103072	103348	-30000	1158	573.77	8105	0.08	607.90	75114	75114
	June	1040	61711	62040	-22100	1390	570.55	7432	0.50	3722.27	45053	45053
	July	10.9	668	1470	-4700	1795	568.79	6958	0.64	4424.35	2989	2989
	August	9.02	553	1642	7200	1809	568.95	6994	0.68	4744.37	15395	15395
	September	311.8	18502	19359	-2000	1140	569.31	7085	-0.11	-743.96	17755	17755
	October	82.7	5071	5554	2500	1014	569.35	7093	0.06	419.69	9487	9487
	November	62.6	3715	4243	-4000	953	569.24	7069	0.32	2226.89	3423	3423
	December	21.4	1312	1728	-400	838	568.95	6993	0.20	1386.96	3553	3553
1971	January	17.4	1067	1353	-1000	1015	568.85	6972	0.27	1870.94	3239	3239
	February	14.1	781	1222	-200	944	568.77	6954	0.19	1327.06	3293	3293
	March	18.6	1140	1484	-3000	1190	568.55	6906	0.47	3257.45	2931	2931
	April	277	16437	17447	-16000	1396	567.21	6608	0.26	1695.94	4539	4539
	May	261.5	16034	16409	-7600	1378	565.52	6333	0.28	1789.20	11976	11976
	June	562.7	33389	34459	-38800	1646	561.79	5770	0.54	3125.60	431	431
	July	132.5	8124	9017	101100	1914	565.98	6393	0.16	1049.59	113081	113081
	August	298.4	18297	18903	-2400	1255	573.19	7987	0.20	1590.66	19348	19348
	September	98.3	5833	6198	-3500	1258	572.83	7932	0.29	2300.41	6257	6257
	October	633.8	38862	38986	22500	1094	573.86	8124	-0.13	-1076.37	61504	61504
	November	344.5	20442	19958	5300	1016	575.74	8457	0.16	1353.14	27628	27628
	December	580.4	35588	35509	43100	937	578.46	9104	-0.12	-1077.25	78468	78468
1972	January	629.6	38604	37331	2200	1031	580.67	9560	-0.02	-159.33	40403	40403
	February	67.2	3722	1367	14400	996	581.51	9731	0.23	2197.60	18960	18960
	March	124.5	7634	7744	-1500	1354	582.17	9846	0.43	4209.24	11806	11806
	April	76.1	4516	3658	-3700	1614	581.91	9812	0.35	3409.82	4982	4982
	May	228	13980	13644	7100	1273	582.08	9829	0.12	1171.31	23189	23189
	June	16.8	997	1523	-1300	1696	582.37	9884	0.41	4093.62	6013	6013
	July	16.5	1012	1537	-500	1680	582.28	9867	0.32	3140.99	5858	5858
	August	14	858	1537	-5800	1651	581.96	9824	0.39	3855.83	1244	1244
	September	13.2	783	1488	-4900	1527	581.42	9713	0.23	2193.41	308	308
	October	19	1165	1630	12100	1429	581.78	9787	-0.01	-106.02	15053	15053
	November	29.4	1745	1666	-1500	1103	582.32	9875	0.05	469.04	1738	1738
	December	29.2	1790	1722	1400	1107	582.31	9874	0.07	715.84	4945	4945

Lake Belton
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		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1973	January	33	2023	1722	15100	1229	583.12	10020	-0.13	-1335.99	16715	16715
	February	33.4	1850	1555	16800	1035	584.66	10296	-0.02	-205.92	19184	19184
	March	40.4	2477	1722	34600	1167	587.03	10752	0.10	1057.26	38546	38546
	April	36.7	2178	1666	46400	1207	590.59	11468	0.00	-9.56	49263	49263
	May	386.8	23717	24107	8300	1564	593.34	12016	0.18	2132.77	36104	36104
	June	805.7	47809	48263	-2100	1532	594.02	12138	0.06	677.69	48372	48372
	July	233.5	14317	15075	2900	1794	594.05	12143	0.24	2964.97	22734	22734
	August	41	2514	3189	-10900	2089	593.72	12087	0.59	7080.76	1460	1460
	September	18.5	1098	1670	1000	1520	593.32	12012	0.08	970.96	5161	5161
	October	524.3	32148	32095	14900	1323	593.96	12132	-0.26	-3184.52	45133	45133
	November	284	16852	17050	-7100	1182	594.28	12185	0.17	2041.04	13173	13173
	December	32.1	1968	2311	-500	1103	593.97	12133	0.19	2275.01	5189	5189
1974	January	121.2	7431	7678	-900	1233	593.92	12123	-0.01	-90.92	7920	7917
	February	34.9	2002	1757	1200	1105	593.93	12126	0.22	2667.70	6730	6728
	March	25.4	1557	1722	-300	1427	593.97	12132	0.33	3963.27	6812	6810
	April	20.8	1234	1666	1100	1787	594.00	12138	0.35	4187.63	8741	8738
	May	18.6	1140	1722	-3100	1696	593.92	12123	0.24	2949.96	3267	3266
	June	191.2	11345	12383	-20700	1991	592.94	11973	0.52	6185.92	-140	0
	July	160.8	9860	11008	-16800	2398	591.38	11615	0.61	7133.47	3739	3738
	August	20.4	1251	1706	26100	1736	591.76	11688	-0.16	-1840.80	27701	27692
	September	295.6	17540	18080	66400	1451	595.91	13188	-0.15	-2000.25	83930	83902
	October	1116	68428	67465	86900	1380	601.65	13908	-0.14	-1947.05	153798	153746
	November	890.5	52840	52860	21900	1241	605.10	14772	0.00	0.00	76001	75976
	December	1553	95223	95589	-56300	1203	603.89	14348	0.01	143.48	40635	40622
1975	January	2600	159421	161038	-100600	1268	598.14	13302	0.08	1008.74	62716	62436
	February	2174	120401	121120	35400	1298	595.73	13092	-0.07	-938.24	156881	156181
	March	1447	88724	88488	-39200	1543	595.58	13006	0.17	2265.21	53097	52860
	April	1551	92033	92705	4000	1476	594.20	12172	0.05	557.87	98738	98298
	May	478.4	29333	29485	63100	1559	596.79	13072	-0.25	-3257.05	90887	90482
	June	1587	94169	95160	-57100	1774	597.03	13145	0.38	4951.25	44785	44586
	July	400	24526	24752	-12400	1680	594.35	12198	0.36	4391.33	18423	18341
	August	71.8	4402	5076	-2700	2270	593.74	12090	0.37	4443.21	9089	9048
	September	18.6	1104	1759	-5100	1697	593.42	12031	0.25	2987.58	1344	1338
	October	15.5	950	1722	-4300	1535	593.04	11959	0.32	3856.63	2814	2801
	November	22.1	1311	1700	-5300	1427	592.64	11906	0.26	3036.14	863	859
	December	11.7	717	1845	-5700	1508	592.42	11857	-0.01	-59.28	-2406	0

Lake Belton
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		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1976	January	14	858	1845	-3800	1268	592.25	11820	0.28	3289.97	2603	2603
	February	10.4	576	1726	-1700	1298	592.02	11769	0.27	3226.78	4551	4551
	March	9.52	584	1845	1900	1543	592.03	11772	0.16	1922.70	7211	7211
	April	16.7	991	1785	26200	1476	593.18	11986	-0.27	-3256.10	26205	26205
	May	395.4	24244	24534	-2000	1559	594.17	12166	-0.01	-121.66	23971	23971
	June	237.1	14069	14735	2200	1774	594.18	12168	0.15	1774.49	20484	20484
	July	1995	122325	122560	-3200	1680	594.14	12161	-0.05	-567.50	120473	120473
	August	37.6	2305	2815	-5400	2270	593.77	12096	0.51	6148.79	5833	5833
	September	47.2	2801	3084	5800	1697	593.79	12099	0.01	100.82	10682	10682
	October	247.9	15200	14954	4100	1535	594.03	12140	-0.10	-1213.96	19375	19375
	November	211.1	12526	12316	-4000	1427	594.03	12140	0.08	991.47	10734	10734
	December	725.5	44485	44684	-1100	1508	594.01	12137	-0.04	-465.25	44627	44627
1977	January	317.6	19474	12940	200	1485	593.98	12134	-0.04	-495.48	14130	14119
	February	946.4	52414	59721	0	1299	593.98	12135	0.06	778.68	61798	61752
	March	452.7	27758	28695	23800	1463	594.92	12303	0.08	994.52	54953	54911
	April	1942	115234	115485	135300	1553	600.76	13809	-0.21	-2923.01	249416	249227
	May	3665	224722	225589	-92000	1541	602.40	14053	0.14	1897.12	137027	136923
	June	2116	125559	125913	-68400	1918	596.51	13012	0.41	5302.22	64733	64684
	July	20.1	1232	2301	-2100	2496	593.79	12099	0.67	8075.95	10773	10765
	August	18.1	1110	2091	-9300	2377	593.32	12012	0.47	5605.53	773	772
	September	5.68	337	1137	-7700	2163	592.63	11903	0.54	6447.53	2047	2046
	October	17.2	1055	1686	-5600	1908	592.08	11782	0.33	3927.19	1921	1919
	November	12.8	760	1726	-4800	1531	591.64	11664	0.09	1088.64	-454	0
	December	12.8	785	1783	-5000	1504	591.22	11586	0.25	2925.36	1212	1211
1978	January	8.65	530	1783	-2400	1520	590.92	11531	0.07	845.58	1748	1748
	February	11.4	654	1611	4800	1338	591.02	11547	-0.08	-866.01	6883	6883
	March	16.3	999	1783	1400	1554	591.27	11595	0.20	2319.01	7056	7056
	April	16	949	1726	-1500	1835	591.27	11594	0.29	3362.28	5423	5423
	May	7.6	466	1783	-2900	1968	591.08	11559	0.14	1656.81	2508	2508
	June	283.7	16834	17352	-22100	2105	590.00	11355	0.46	5261.15	2618	2618
	July	639.1	39187	38892	-44600	2412	586.99	10735	0.74	7917.24	4622	4622
	August	45.4	2784	3612	-10100	2331	584.45	10258	0.56	5727.44	1571	1571
	September	18.4	1092	1833	-4100	1756	583.76	10137	0.26	2601.85	2090	2090
	October	13.4	822	1833	-6200	1907	583.26	10045	0.36	3590.97	1131	1131
	November	17.1	1015	1494	2500	1515	583.08	10012	-0.20	-2035.72	3473	3473
	December	20.5	1257	1537	-1500	1424	583.13	10021	0.07	709.81	2171	2171

Lake Belton
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Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1979	January	25.2	1545	1537	14600	1700	583.76	10137	-0.05	-515.30	17321	17273
	February	37.9	2099	1388	17000	1423	585.28	10423	-0.03	-356.11	19455	19401
	March	36.6	2244	1537	65400	1503	588.98	11153	-0.10	-1068.82	67372	67185
	April	52.1	3092	1894	34500	1479	593.29	12006	0.12	1430.74	39304	39195
	May	1018	62420	58569	56800	1615	598.58	13364	-0.35	-4632.93	112351	112039
	June	2701	160272	154388	-61800	1954	598.38	13336	0.17	2222.60	96765	96496
	July	389.8	23901	20797	-3500	2313	594.15	12162	0.23	2848.04	22458	22396
	August	81.3	4985	7026	-1300	2246	593.96	12132	0.20	2466.74	10438	10410
	September	17.9	1062	1190	-6200	1992	593.67	12076	0.28	3361.25	343	342
	October	21.3	1306	1537	-7000	1773	593.13	11975	0.29	3452.90	-237	0
	November	22.2	1317	1488	-6000	1534	592.59	11895	0.18	2131.26	-847	0
	December	23.1	1416	1537	3100	1314	592.47	11869	-0.12	-1434.16	4517	4504
1980	January	27.8	1705	1537	1000	1267	592.64	11906	-0.03	-307.58	3497	3476
	February	28.7	1589	1438	5300	1293	592.90	11964	0.09	1126.60	9158	9103
	March	17.9	1098	1000	4100	1511	593.29	12005	0.13	1510.67	8121	8073
	April	5.37	319	833	9000	1596	593.82	12104	0.15	1785.40	13214	13136
	May	1774	108774	110124	21800	1674	595.04	12710	-0.17	-2118.35	131479	130697
	June	578.1	34303	34432	-28100	2420	594.79	12279	0.53	6538.38	15290	15199
	July	216.5	13275	18250	-24000	3101	592.68	11915	0.79	9373.35	6724	6684
	August	19.6	1202	3261	-12800	3052	591.15	11571	0.64	7444.27	957	951
	September	10.8	641	1797	-3900	2182	590.35	11421	0.34	3864.19	3943	3919
	October	11.2	687	1797	-8700	1817	589.73	11317	0.35	3923.24	-1163	0
	November	18.3	1086	1607	-3200	1815	589.30	11225	0.08	888.67	1110	1103
	December	14.3	877	1299	-800	1619	589.00	11163	-0.01	-120.93	1997	1985
1981	January	3.92	240	—	-1400	1560	589.00	11163	0.08	939.55	1340	1340
	February	2.19	121	—	800	1461	589.00	11163	0.00	-18.61	2363	2363
	March	3.33	204	—	9600	1656	589.00	11163	-0.02	-223.26	11237	11237
	April	41.2	2445	—	5200	1792	589.00	11163	0.15	1674.45	11111	11111
	May	6.94	426	—	3400	1924	589.00	11163	0.10	1060.49	6810	6810
	June	123.2	7310	—	130200	1943	589.00	11163	-0.39	-4316.36	135137	135137
	July	1390	85229	—	-77100	2595	589.00	11163	0.48	5311.73	16036	16036
	August	141.9	8701	—	-9500	2808	589.00	11163	0.38	4260.55	6269	6269
	September	58.5	3471	—	-4000	2042	589.00	11163	0.21	2288.42	3802	3802
	October	138.8	8511	9110	3900	1790	594.14	12160	-0.22	-2654.87	12145	12145
	November	25.5	1513	2380	1600	1493	594.36	12200	0.13	1596.16	7070	7070
	December	15	920	1942	-2400	1461	594.33	12194	0.16	1910.47	2913	2913

Lake Belton
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1982	January	10.9	668	1353	-1400	1565	594.17	12166	0.09	1145.64	2663	2638
	February	12.4	711	924	1600	1353	594.18	12167	0.10	1186.28	5063	5016
	March	142.3	8725	9126	5500	1555	594.46	12219	0.05	549.86	16731	16573
	April	362.6	21516	22537	-5900	1531	594.45	12216	0.10	1191.10	19358	19175
	May	1079	66160	66778	-3700	1639	594.06	12146	-0.04	-475.72	64241	63635
	June	266.1	15790	15914	13500	1911	594.45	12217	0.19	2260.21	33585	33268
	July	570.5	34981	35893	-8700	2512	594.65	12253	0.50	6075.46	35781	35444
	August	43.3	2655	3689	-3100	3092	594.18	12167	0.61	7371.19	11053	10948
	September	24.2	1436	2124	-10700	2370	593.62	12067	0.47	5661.44	-544	0
	October	6.48	397	1123	-7300	1891	592.88	11959	0.25	3039.70	-1247	0
	November	8.4	498	867	-500	1577	592.56	11889	-0.15	-1763.50	180	179
	December	13.9	852	893	-1000	1502	592.50	11876	-0.03	-296.89	1098	1087
1983	January	13.8	846	922	-700	1618	592.43	11860	0.00	0.00	1840	1685
	February	7.65	424	833	12900	1344	592.93	11971	-0.09	-1127.22	13950	12772
	March	264.2	16200	17397	13400	1502	594.00	12135	0.02	283.15	32582	29831
	April	148.8	8829	10798	-6700	1717	594.27	12184	0.40	4853.46	10669	9768
	May	138.6	8498	8097	13000	1887	594.52	12230	-0.10	-1161.87	21822	19979
	June	188.5	11185	12738	-10300	2024	594.63	12250	0.31	3807.80	8269	7571
	July	8.06	494	1628	-9000	2512	593.86	12112	0.44	5288.86	430	393
	August	18	1104	1908	-4700	2380	593.30	12008	0.24	2931.98	2520	2307
	September	10.2	605	1105	-8800	2141	592.75	11930	0.13	1600.56	-3954	0
	October	3.89	239	1103	-3400	1795	592.24	11818	0.18	2127.25	1625	1488
	November	10.4	617	1057	-4600	1511	591.91	11715	0.08	878.63	-1154	0
	December	10.3	632	932	-6600	1720	591.43	11625	0.10	1143.15	-2805	0
1984	January	22.5	1380	934	-2800	1715	591.03	11550	0.12	1328.21	1178	1178
	February	11.8	654	724	-3700	1556	590.76	11500	0.17	1945.41	525	525
	March	9.01	552	613	7600	1655	590.93	11533	0.08	970.66	10838	10838
	April	13	771	809	-6300	2068	590.98	11543	0.45	5223.28	1800	1800
	May	17.4	1067	1976	-6500	2596	590.43	11438	0.33	3783.93	1855	1855
	June	207.8	12330	12964	-12300	2357	589.62	11294	0.39	4348.12	7370	7370
	July	382.4	23447	23719	-29900	3032	587.72	10886	0.57	6214.07	3065	3065
	August	45.2	2771	2678	-11800	3023	585.80	10523	0.58	6146.98	47	47
	September	102.1	6058	8517	-14800	2423	584.53	10273	0.41	4229.22	370	370
	October	107.8	6610	7075	17000	1883	584.64	10292	-0.38	-3911.07	22047	22047
	November	6.54	388	863	2500	1614	585.57	10479	0.02	227.05	5204	5204
	December	15.4	944	893	18300	1583	586.54	10653	-0.24	-2592.32	18183	18183

Lake Belton
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Water Balance Calculations

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1985	January	15.5	950	922	21600	2587	588.37	11029	0.09	937.42	26047	26047
	February	8.97	497	831	26900	2022	590.20	11394	-0.07	-750.12	29003	29003
	March	14.2	871	922	44100	2525	593.10	11971	-0.06	-708.28	46839	46839
	April	243.5	14449	15039	7000	2618	595.46	12944	0.15	1995.57	26652	26652
	May	749.7	45968	45352	-21500	3177	595.04	12710	0.18	2298.41	29328	29328
	June	310.5	18424	18778	6700	3729	595.25	12828	0.18	2244.88	31452	31452
	July	140.9	8639	9884	-15500	4706	593.96	12132	0.53	6389.30	5479	5479
	August	43.1	2643	4157	-13500	5268	592.78	11938	0.71	8426.05	4351	4351
	September	41.2	2445	3529	-7200	3938	591.88	11710	0.16	1824.87	2092	2092
	October	393.5	24128	24748	32000	2771	593.17	11984	-0.15	-1787.66	57731	57731
	November	115.9	6877	5474	7500	3221	594.21	12173	-0.10	-1207.13	14988	14988
	December	318.8	19547	21433	30400	2473	596.60	13031	-0.09	-1118.53	53188	53188
1986	January	761	46661	47094	-37800	2287	596.08	12920	0.18	2261.06	13842	13842
	February	1128	64702	62354	900	2182	596.12	12928	-0.10	-1335.94	64100	64100
	March	154.4	9467	10409	-4900	2897	594.14	12160	0.35	4266.08	12672	12672
	April	15.1	896	2180	12700	3155	594.03	12140	0.14	1709.66	19745	19745
	May	800.2	49065	46647	4300	3747	595.73	13093	-0.17	-2269.44	52424	52424
	June	1348	79987	85220	102900	3103	601.63	13904	-0.07	-950.10	190273	190273
	July	2416	148139	163033	-92100	5253	600.29	13717	0.70	9544.90	85731	85731
	August	663	40652	42440	-17100	4763	594.66	12256	0.41	4983.99	35087	35087
	September	1657	98323	105870	-7100	2864	596.96	13110	0.01	65.55	101699	101699
	October	525.1	32197	37041	5200	2700	594.57	12239	-0.17	-2019.38	42922	42922
	November	614.6	36469	42250	-3200	2455	594.55	12235	-0.04	-469.00	41036	41036
	December	647.5	39702	44047	48000	2559	595.69	13071	-0.22	-2842.98	91763	91763
1987	January	1415	86762	98529	-36000	2587	596.21	12949	0.03	356.09	65472	65472
	February	666.5	36912	42779	14000	2236	594.61	12247	-0.11	-1296.18	57719	57719
	March	1462	89644	103737	-13400	2583	596.18	12942	0.13	1682.46	94603	94603
	April	789.4	46841	52449	-26700	3220	594.38	12205	0.38	4607.28	33576	33576
	May	208	12754	14698	62600	3300	594.84	12288	-0.07	-829.43	79768	79768
	June	982.4	58294	67759	150400	3124	606.13	15230	-0.19	-2944.48	218339	218339
	July	3015	184867	185395	-110100	4305	605.05	14759	0.48	7084.43	86684	86684
	August	1780	109142	117481	-91200	5279	596.52	13014	0.59	7710.78	39271	39271
	September	107.9	6403	6238	-3800	3183	594.14	12161	0.21	2563.99	8185	8185
	October	23.1	1416	1511	-7800	3194	593.57	12059	0.40	4763.31	1669	1669
	November	12.8	760	1279	2400	2530	593.37	12022	-0.14	-1632.98	4576	4576
	December	5.24	321	1228	6800	4554	593.57	12058	-0.12	-1416.86	11164	11164

Lake Belton
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Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1988	January	3.67	225	1230	-200	2707	594.03	12140	0.15	1841.17	5578	5319
	February	4.74	263	1150	2600	2538	594.09	12152	0.06	749.35	7037	6711
	March	82.1	5034	5528	-1700	2758	594.24	12180	0.13	1542.75	8129	7752
	April	29.4	1745	2196	-4200	3302	593.93	12125	0.31	3809.40	5107	4870
	May	94.7	5807	7859	-9300	3650	593.29	12007	0.30	3581.95	5790	5522
	June	595.8	35354	39828	19600	3900	595.05	12715	0.10	1313.91	64642	61644
	July	391.7	24017	27322	-15900	4129	594.16	12164	0.43	5281.15	20832	19866
	August	629.9	38623	44690	-43500	4838	591.04	11552	0.56	6507.52	12535	11954
	September	36.2	2148	3199	-5300	4391	589.20	11205	0.21	2306.42	4596	4383
	October	33.4	2048	2910	2600	3687	588.82	11119	0.24	2612.99	11810	11262
	November	15.9	943	1878	-13800	2881	588.30	11014	0.20	2175.33	-6865	0
	December	15.2	932	1537	-2100	2661	588.06	10964	-0.01	-137.05	1961	1870
1989	January	9.92	608	1135	9300	2472	588.03	10959	-0.12	-1278.50	11628	11628
	February	3.28	182	833	19400	2425	589.42	11251	-0.14	-1556.38	21102	21102
	March	27.1	1662	1091	36800	2819	590.88	11524	0.01	86.43	40796	40796
	April	5.3	314	1190	9000	3235	594.08	12149	0.30	3644.62	17070	17070
	May	889.5	54540	54416	23400	3278	596.39	12986	-0.13	-1644.92	79450	79450
	June	2020	119863	122493	-17100	3591	596.04	12912	-0.04	-559.52	108425	108425
	July	512.2	31406	32678	-2100	4869	594.70	12263	0.46	5600.15	41046	41046
	August	227.6	13955	16489	-4100	4042	594.53	12231	0.24	2935.47	19366	19366
	September	75.2	4462	6371	-3100	4243	594.19	12169	0.41	4958.91	12473	12473
	October	46.3	2839	3622	-6000	3665	593.77	12096	0.35	4223.43	5510	5510
	November	26.9	1596	2210	-6300	2716	593.30	12007	0.25	2991.82	1617	1617
	December	27.2	1668	2279	-7300	3039	592.76	11934	0.24	2874.04	893	893
1990	January	15.8	969	1853	-1000	2705	592.40	11853	-0.03	-365.46	3193	3193
	February	22.4	1285	1593	1200	2358	592.46	11866	-0.06	-751.51	4399	4399
	March	184.7	11325	11512	23400	2721	593.78	12097	-0.22	-2701.71	34931	34931
	April	616	36552	36008	68800	2773	595.15	12773	-0.07	-840.89	106740	106740
	May	4560	279600	280469	73500	3315	606.08	15208	-0.04	-582.96	356700	356700
	June	4086	242455	245066	-136600	6037	599.53	13557	0.61	8326.54	122829	122829
	July	1171	71801	73698	-500	4502	595.24	12819	0.41	5245.08	82945	82945
	August	400.5	24557	25642	-4000	4700	594.91	12301	0.51	6324.82	32667	32667
	September	215.2	12770	13117	-600	3469	594.83	12287	0.10	1167.22	17152	17152
	October	90.5	5549	6680	-300	2901	594.45	12218	0.08	1007.96	10289	10289
	November	51	3026	4641	2200	2500	594.55	12235	-0.06	-744.32	8597	8597
	December	64.6	3961	6184	-3600	2820	594.46	12218	0.05	641.47	6046	6046

Lake Belton
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Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1991	January	366.9	22497	24153	-600	2725	594.44	12215	-0.21	-2595.61	23682	23503
	February	241.2	13358	13997	-300	2071	594.22	12174	0.06	760.90	16529	16404
	March	73.2	4488	5861	-1500	2595	594.09	12151	0.29	3483.30	10440	10361
	April	163.5	9702	10748	1800	2643	594.28	12186	0.06	751.50	15943	15823
	May	571.7	35054	35207	300	2857	594.62	12248	-0.09	-1112.49	37251	36969
	June	236.2	14016	35207	5800	2887	614.44	17855	0.24	4344.82	48239	47873
	July	72.8	4464	6252	-6800	4471	594.58	12241	0.47	5783.69	9707	9634
	August	52.2	3201	4895	2700	4425	594.16	12165	0.24	2899.28	14919	14806
	September	323	19166	21685	-3400	3146	594.31	12191	0.14	1686.41	23117	22942
	October	68.7	4212	5460	20100	3400	594.25	12181	0.15	1806.84	30768	30535
	November	1239	73520	5460	-16500	3383	614.06	17735	0.13	2246.43	-5410	0
	December	1136	69655	66543	423700	2587	603.27	14229	-0.63	-8916.64	483914	480250
1992	January	5066	310626	324293	-43600	2743	618.86	19139	-0.22	-4130.84	279306	279306
	February	2179	120677	129792	323700	2289	628.28	22865	-0.34	-7678.80	448102	448102
	March	6134	376111	371682	-141000	2692	631.72	23867	0.02	457.45	233832	233832
	April	5170	306777	307206	-183400	2975	623.19	20426	0.25	5021.27	131802	131802
	May	3773	231345	236717	8000	3116	616.50	18405	-0.24	-4432.57	243401	243401
	June	3766	223466	224547	-106400	3680	617.95	18885	0.06	1070.17	122897	122897
	July	4439	272181	273697	-166000	4606	608.17	15884	0.49	7769.68	120073	120073
	August	3084	189098	189891	-114700	4347	598.01	13283	0.43	5656.31	85195	85195
	September	641.4	38059	39160	-4100	3749	594.34	12196	0.34	4085.80	42894	42894
	October	122.6	7517	8116	-1700	3831	594.00	12136	0.33	3994.65	14242	14242
	November	36.1	2142	2680	8200	2663	594.15	12163	-0.15	-1763.65	11779	11779
	December	34	2085	2483	32800	2436	595.73	13092	-0.15	-2018.27	35701	35701
1993	January	41.1	2520	2767	33200	2671	598.09	13294	-0.12	-1650.71	36987	36987
	February	40.7	2254	2731	102400	2268	603.70	14312	-0.12	-1753.27	105646	105646
	March	3008	184438	184598	-53200	2811	604.50	14568	-0.07	-983.34	133225	133225
	April	3721	220796	222504	-116600	2876	599.14	13487	0.07	955.35	109735	109735
	May	1090	66834	68493	-4400	3406	594.27	12185	0.13	1533.26	69033	69033
	June	230.8	13695	16612	18900	3590	594.53	12232	0.17	2048.89	41150	41150
	July	283.8	17401	19359	-25200	5350	594.25	12182	0.85	10303.58	9812	9812
	August	44.7	2741	3812	-15400	6360	593.06	11962	0.86	10337.54	5110	5110
	September	14	831	2023	-2600	4433	592.20	11809	0.41	4831.72	8688	8688
	October	23	1410	2221	10000	2838	535.09	2444	-0.04	-91.64	14968	14968
	November	71.2	4225	5066	13900	3097	593.85	12111	0.08	978.97	23042	23042
	December	38.6	2367	2460	300	2865	594.17	12166	0.09	1115.17	6740	6740

Lake Belton
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Water Balance Calculations

Year	Month	Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1994	January	28.5	1748	2460	0	2824	594.12	12157	0.06	678.79	5963	5963
	February	333.6	19135	19904	5200	2506	594.51	12228	-0.11	-1283.99	26326	26326
	March	279	17107	17548	-3500	2922	594.26	12183	0.10	1269.10	18239	18239
	April	67.8	4023	4707	-400	3369	594.26	12182	0.15	1837.46	9513	9513
	May	2232	136857	136651	13300	3461	595.34	12874	-0.30	-3862.32	149550	149550
	June	1539	91321	91263	-5600	4197	594.50	12226	0.46	5562.78	95423	95423
	July	277.4	17009	22374	2800	5766	595.47	12946	0.66	8587.72	39527	39527
	August	73.8	4525	5718	-9700	5338	594.72	12266	0.60	7390.33	8746	8746
	September	129.1	7661	8434	-8400	4036	594.12	12156	0.34	4133.16	8203	8203
	October	241	14777	16385	-3100	3648	593.16	11982	-0.01	-129.80	16803	16803
	November	119.7	7103	8450	12600	2959	593.78	12098	-0.11	-1381.14	22628	22628
	December	530.3	32516	32995	12700	2677	594.81	12283	-0.20	-2507.86	45864	45864
1995	January	860.6	52768	52744	-15700	2765	594.45	12217	0.00	0.00	39810	39810
	February	296.5	16421	15860	5500	2631	594.14	12160	0.00	0.00	23991	23991
	March	1001	61377	61985	-6600	2947	594.73	12268	-0.10	-1247.26	57085	57085
	April	3473	206080	209351	600	3027	597.09	13161	-0.12	-1634.10	211344	211344
	May	1841	112882	116727	15300	3811	595.06	12721	-0.15	-1855.17	133983	133983
	June	1314	77970	79537	-1000	4172	595.02	12701	0.24	2995.21	85705	85705
	July	473.1	29009	30292	-13500	5942	594.63	12251	0.33	4083.61	26817	26817
	August	1380	84616	86674	1500	4819	594.74	12270	0.15	1871.25	94864	94864
	September	494.4	29337	30605	2700	3952	594.47	12222	0.18	2199.88	39457	39457
	October	216.8	13293	13906	-9100	5400	594.15	12163	0.39	4743.70	14949	14949
	November	111.7	6628	7140	-6300	3056	593.53	12052	0.15	1817.84	5714	5714
	December	98.1	6015	6561	-3700	3181	593.13	11976	0.06	668.67	6711	6711
1996	January	78	4783	5538	-5200	3424	592.71	11923	0.17	2056.66	5818	5818
	February	21.9	1213	2684	-2900	3655	592.46	11867	0.29	3411.75	6851	6851
	March	22.6	1386	3074	-4000	3787	592.16	11801	0.24	2871.49	5733	5733
	April	25.6	1519	2975	-1500	4027	592.02	11769	0.26	3030.49	8533	8533
	May	172.9	10602	12712	-17100	5284	591.48	11635	0.39	4537.78	5433	5433
	June	554.4	32897	34298	-23600	4920	590.13	11380	0.32	3670.04	19288	19288
	July	87.1	5341	7662	-13400	6166	587.68	10877	0.54	5819.43	6247	6247
	August	80.3	4924	6579	48600	5098	586.76	10694	-0.10	-1078.28	59199	59199
	September	543.2	32232	33985	26900	3616	594.19	12170	0.00	-30.43	64470	64470
	October	281.8	17279	17720	3900	3594	594.23	12177	0.15	1796.12	27011	27011
	November	610.2	36208	36422	-200	2734	594.30	12190	-0.14	-1676.12	37280	37280
	December	1185	72659	72012	-3900	3122	594.45	12218	-0.09	-1048.71	70185	70185

Lake Belton
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Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
1997	January	853.5	52333	52094	-2000	3157	594.44	12215	-0.01	-152.69	53098	53098
	February	2566	142110	142711	211500	2828	599.51	13553	-0.40	-5387.46	351651	351651
	March	6621	405972	407698	-104200	3128	607.89	15999	0.01	173.32	306799	306799
	April	3860	229044	227296	2700	3499	602.23	14025	-0.17	-2407.59	231087	231087
	May	3752	230057	242332	-10900	3912	601.53	13890	0.00	46.30	235391	235391
	June	3123	185312	180954	100	3882	600.89	13837	0.07	991.64	185928	185928
	July	3040	186400	173470	-87400	5899	597.53	13263	0.59	7770.18	99739	99739
	August	509.3	31228	34744	-10900	6001	594.25	12181	0.46	5572.72	35418	35418
	September	44.4	2635	3566	-6600	5521	593.86	12112	0.50	6015.57	8502	8502
	October	19.8	1214	2035	-600	3784	593.64	12071	0.01	130.77	5350	5350
	November	20	1187	996	2500	3367	593.63	12069	0.01	160.92	7024	7024
	December	701.2	42995	43644	46700	3182	595.81	13138	-0.39	-5123.99	88403	88403
1998	January	1887	115703	136336	-42200	3097	595.90	13184	-0.19	-2515.96	94717	94717
	February	961.3	55140	53486	31300	2707	594.89	12298	-0.16	-1998.46	85494	85494
	March	2598	159298	149091	53700	3117	598.41	13341	0.04	578.09	206486	206486
	April	2867	170122	169563	-82200	3802	596.08	12919	0.33	4317.19	95482	95482
	May	228.9	14035	18583	-3700	5450	594.17	12167	0.39	4745.08	25078	25078
	June	81.8	4854	6962	-8300	5760	593.78	12098	0.53	6391.87	10814	10814
	July	57.3	3513	5494	-14200	6569	592.83	11949	0.68	8165.25	6028	6028
	August	31.2	1913	4304	-5900	5473	591.94	11722	0.34	3975.64	7853	7853
	September	28.5	1691	3834	-700	4367	591.63	11664	0.03	388.79	7890	7890
	October	46.1	2827	5661	32800	3681	592.88	11959	-0.22	-2660.97	39481	39481
	November	112.9	6699	18274	-1300	3031	594.44	12215	-0.10	-1201.10	18804	18804
	December	555.1	34036	84089	5000	2990	594.87	12294	-0.14	-1669.92	90409	90409
1999	January	296.9	18205	33658	-2800	3018	594.30	12190	0.04	426.63	34302	33590
	February	201.7	11171	12490	-2000	2773	594.22	12176	0.19	2354.04	15617	15293
	March	330.6	20271	20481	1300	3030	594.58	12241	0.06	775.26	25586	25056
	April	273.3	16217	17746	800	3333	594.53	12232	0.20	2466.81	24345	23840
	May	117.8	7223	7636	3100	3913	594.50	12227	0.05	621.52	15271	14954
	June	81	4806	5494	-2100	4095	594.47	12221	0.36	4338.52	11828	11582
	July	41.6	2551	3064	-5300	4872	594.42	12212	0.45	5526.00	8162	7993
	August	40.8	2502	2997	-17200	7236	593.41	12028	0.60	7267.18	300	294
	September	56.3	3341	4259	-17100	5991	591.97	11727	0.41	4817.64	-2032	0
	October	57.7	3538	3987	-12100	4844	590.63	11477	0.22	2505.76	-763	0
	November	28.7	1703	1781	-8000	3765	589.85	11343	0.21	2429.29	-24	0
	December	28.1	1723	2221	-5000	3308	589.24	11214	-0.01	-93.45	436	427

Lake Belton
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2000	January	27.6	1692	2398	-3200	3393	588.90	11136	0.00	-46.40	2545	2545
	February	26.2	1451	2192	-700	3334	588.61	11077	0.04	470.77	5296	5296
	March	25.4	1557	2118	-1000	3586	588.68	11090	0.15	1663.56	6368	6368
	April	33.4	1982	2083	9400	3930	589.17	11198	0.15	1642.42	17055	17055
	May	34.5	2115	2035	-4100	4607	589.24	11214	0.05	588.73	3131	3131
	June	27.1	1608	1565	31100	4283	591.26	11593	0.07	763.23	37711	37711
	July	28.5	1748	2164	-16300	7018	591.14	11571	0.73	8437.46	1320	1320
	August	32.9	2017	2604	-16900	7653	589.63	11295	0.69	7765.44	1123	1123
	September	43.1	2557	2793	-8700	6186	588.35	11024	0.38	4170.76	4450	4450
	October	36.2	2220	3074	4300	4276	587.95	10930	0.06	619.35	12270	12270
	November	77	4569	4296	73300	3295	593.34	12016	-0.35	-4205.56	76685	76685
	December	179.4	11000	10639	7800	3375	594.59	12244	-0.01	-173.45	21641	21641
2001	January	907	55613	45894	-1400	3410	594.94	12307	-0.13	-1569.11	46334	46334
	February	1197	66292	56279	9000	3198	595.44	12932	-0.01	-161.65	68316	68316
	March	2563	157152	129604	-6400	3602	596.99	13116	-0.14	-1847.23	124959	124959
	April	953.3	56567	52495	-11500	3898	594.61	12246	0.24	2990.11	47882	47882
	May	743.3	45576	44868	-5400	4642	594.98	12314	0.10	1231.40	45342	45342
	June	69.4	4118	4314	3500	5487	594.26	12183	0.36	4375.73	17677	17677
	July	25.3	1551	2765	-14700	6947	593.80	12102	0.63	7654.26	2666	2666
	August	49.5	3035	2733	16200	7032	592.72	11925	0.15	1749.02	27714	27714
	September	278	16496	19083	-6900	4381	594.62	12249	0.15	1867.90	18432	18432
	October	51.3	3146	4427	-4700	4498	593.76	12094	0.16	1884.62	6110	6110
	November	324.5	19255	19367	10100	4098	594.35	12200	-0.21	-2602.59	30962	30962
	December	663.1	40659	40994	-2900	3991	594.96	12311	-0.16	-1908.17	40177	40177
2002	January	115	7051	8313	11000	3953	594.29	12188	0.09	1066.45	24333	24333
	February	950.9	54544	51439	-12100	3613	594.70	12264	0.06	705.16	43658	43658
	March	270.5	16586	17215	8000	3849	594.49	12224	0.09	1120.54	30184	30184
	April	642.9	38148	39564	-8000	4278	594.42	12211	0.20	2432.03	38274	38274
	May	16.2	993	2097	-2700	6192	593.86	12113	0.19	2341.82	7930	7930
	June	9.59	569	1964	1300	5885	593.66	12076	0.32	3904.57	13053	13053
	July	926.1	56785	43390	4000	5174	595.32	12866	0.05	664.74	53229	53229
	August	22.2	1361	2325	-11300	7122	593.83	12107	0.57	6941.54	5088	5088
	September	24.3	1442	2797	-9500	6088	592.91	11966	0.30	3569.87	2955	2955
	October	17.7	1085	2297	13800	4660	592.75	11930	-0.24	-2853.28	17903	17903
	November	16.5	979	1726	7000	3995	594.25	12181	0.15	1786.49	14507	14507
	December	577.5	35410	29532	1900	3905	613.85	17768	-0.24	-4249.52	31087	31087

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
2003	January	263.8	16175	13285	-900	3899	594.29	12188	0.10	1157.88	17443	17118
	February	378	20934	18476	19800	3717	595.09	12740	-0.14	-1762.33	40231	39483
	March	1253	76829	63753	-22500	3739	594.91	12302	0.18	2204.10	47196	46318
	April	64.3	3815	5974	3600	4541	594.30	12189	0.31	3727.91	17843	17511
	May	29.2	1790	3114	-6200	6146	594.13	12159	0.17	2036.62	5097	5002
	June	287.7	17072	14497	4200	4806	594.37	12204	-0.05	-620.35	22883	22457
	July	53.7	3293	1904	-11100	6767	593.76	12094	0.48	5785.19	3356	3293
	August	3.42	210	1968	-600	7008	592.87	11958	0.38	4574.01	12949	12708
	September	3.18	189	1904	-11600	5100	592.47	11868	-0.04	-514.29	-5110	0
	October	1140	69900	67561	20800	4632	594.73	12269	-0.06	-715.67	92278	90561
	November	34.3	2035	3035	-1300	4023	594.02	12138	0.28	3418.95	9177	9006
	December	26.4	1619	3136	-3100	3882	593.77	12097	0.20	2389.12	6307	6190
2004	January	60.2	3691	4582	15968	3635	594.28	12187	-0.10	-1249.13	22936	22936
	February	549.1	30410	27134	9181	2928	594.75	12272	-0.22	-2740.66	36502	36502
	March	1012	62052	60885	-14225	3039	595.20	12796	0.00	-31.99	49667	49667
	April	1246	73935	74229	37284	3062	595.13	12760	-0.24	-3094.23	111481	111481
	May	1509	92526	90109	-38412	3822	594.80	12282	0.07	890.46	56410	56410
	June	1312	77851	74075	36565	3808	595.70	13075	-0.42	-5491.54	108956	108956
	July	998.8	61242	60730	-38065	5598	595.01	12696	0.32	4009.77	32273	32273
	August	617.6	37869	39269	15956	6291	595.09	12737	0.12	1581.52	63098	63098
	September	775	45987	45503	-18696	5509	594.24	12180	0.34	4120.76	36437	36437
	October	294.7	18070	16296	6750	4644	594.38	12205	-0.15	-1851.05	25839	25839
	November	934.1	55428	56311	227583	3564	600.49	13758	-0.68	-9400.99	278057	278057
	December	4619	283218	281567	-183602	3485	604.56	14584	0.07	1020.85	102471	102471
2005	January	1893	116071	118953	-35615	3503	595.59	13017	0.00	0.00	86841	86841
	February	1878	104007	103206	35482	3214	595.26	12832	-0.05	-641.59	141260	141260
	March	3497	214421	205226	-50722	3581	576.95	8671	0.24	2080.96	160166	160166
	April	790.1	46883	62011	-868	4696	634.09	25000	0.43	10750.01	76589	76589
	May	214.5	13152	13131	7868	4941	594.19	12169	0.23	2798.97	28739	28739
	June	275.3	16336	16483	-9724	5646	594.27	12184	0.34	4142.43	16548	16548
	July	36.3	2226	1906	-8318	6504	593.55	12055	0.19	2290.36	2383	2383
	August	1312	80446	78797	17162	5201	596.35	12978	0.12	1557.37	102718	102718
	September	140.8	8355	8497	-13022	5806	594.01	12136	0.39	4733.17	6014	6014
	October	25.4	1557	1906	-9067	5637	593.15	11981	0.33	3953.60	2429	2429
	November	35.1	2083	1845	-7460	4739	592.40	11853	0.24	2844.73	1968	1968
	December	32.7	2005	1906	-6215	4372	591.80	11695	0.22	2572.89	2636	2636

Lake Belton
Data Sets for
Water Balance Calculations

		Leon R near Belton (mean csf)	Monthly Flows (AF)	Spill and Releases (AF)	Change in Storage (AF)	Lakeside Use (AF)	Mean Elev (ft)	Avg Surface Area (acres)	Net Evap (ft)	Net Evap (AF)	Raw Inflow (AF) (includes negatives)	Recommended Inflows (AF) (negative flows accounted for)
2006	January	67.3	4127	4219	-5228	4681	591.19	11579	0.23	2663.21	6335	6335
	February	53.4	3063	2805	-2885	3826	590.93	11534	0.21	2422.09	6168	6168
	March	35.1	2152	2029	6391	4343	590.88	11523	0.18	2074.22	14837	14837
	April	27.4	1626	1964	-839	5093	591.30	11601	0.19	2204.13	8422	8422
	May	27.3	1674	2029	8187	5429	592.15	11799	0.26	3067.72	18712	18712
	June	17.4	1032	2406	-8536	6469	591.66	11668	0.37	4317.32	4657	4657
	July	13	797	2388	-11966	7106	590.93	11533	0.35	4036.68	1564	1564
	August	7.89	484	2414	-15335	9000	589.62	11295	0.55	6212.01	2291	2291
	September	16.4	973	2039	-11367	5994	589.19	11203	0.30	3360.93	26	26
	October	10.1	619	1448	-3595	5346	587.69	10880	0.06	652.80	3852	3852
	November	20.8	1234	1190	-7980	5843	587.16	10778	0.31	3341.22	2394	2394
	December	8.37	513	1313	-2671	4658	605.52	14903	0.03	447.09	3747	3747
2007	January	26.7	1637	1190	11412	3790	568.25	6842	-0.36	-2463.03	13929	13929
	February	20.2	1119	1111	-3685	4050	587.46	10835	0.27	2925.40	4401	4401
	March	53.9	3305	1678	163337	4465	589.29	11223	-0.26	-2918.09	166562	166562
	April	2456	145734	146670	-74151	4399	616.88	18506	0.30	5551.87	82470	82470
	May	2251	138022	139862	181443	5156	598.73	13386	-0.30	-4015.88	322445	322445
	June	2862	169825	172992	233170	4844	608.07	15860	-0.20	-3171.91	407835	407835
	July	4039	247655	249096	185226	4885	627.89	22845	-0.02	-456.90	438750	438750
	August	5830	357471	354813	-224954	6761	624.84	21272	0.43	9146.79	145766	145766
	September	4689	278235	272741	-172710	6172	614.25	17795	0.14	2491.25	108694	108694
	October	3626	222331	215685	-211033	5875	600.63	13784	0.40	5513.59	16040	16040
	November	95.8	5685	5141	-1103	4975	574.28	8206	0.14	1148.80	10162	10162
	December	19.3	1183	1369	2581	4584	575.14	8351	0.09	751.63	9285	9285

APPENDIX E

Lake Georgetown
Differences in Acre-Feet between
Historical Monthly Flows Determined by FNI
and Franklin "Recommended Flows"

(Note - Negative flows represent greater estimates
by Franklin than by FNI)

Lake Georgetown Flow Comparison

		Jan	Feb	Mar	Apr	May	Jun	Jul	Auf	Sep	Oct	Nov	Dec	Annual
1988	FNI	1015	723	831	499	451	2790	1269	266	0	0	19	132	7995
	Franklin	965	639	810	448	390	2536	1118	72	0	0	11	93	7082
	Difference	50	84	21	51	61	254	151	194	0	0	8	39	913
	% Diff	5%	12%	3%	10%	14%	9%	12%	73%	--	--	43%	29%	11%
1989	FNI	342	593	2832	1608	13579	3285	472	103	0	126	53	0	22993
	Franklin	339	629	2799	1634	13366	3218	399	0	0	62	4	0	22451
	Difference	3	-36	33	-26	213	67	73	103	0	64	49	0	542
	% Diff	1%	-6%	1%	-2%	2%	2%	15%	100%	--	51%	92%	--	2%
1990	FNI	383	0	632	628	1952	356	220	387	156	92	285	149	5240
	Franklin	346	85	647	609	2033	249	87	215	26	-8	187	74	4550
	Difference	37	-85	-15	19	-81	107	133	172	130	100	98	75	690
	% Diff	10%	-100%	-2%	3%	-4%	30%	61%	44%	84%	109%	34%	50%	13%
1991	FNI	4250	3968	2725	4278	8523	5979	2772	433	3322	1531	2073	44779	84633
	Franklin	4299	4065	2727	4329	8532	5987	2787	487	3327	1515	2049	44997	85101
	Difference	-49	-97	-2	-51	-9	-8	-15	-54	-5	16	24	-218	-468
	% Diff	-1%	-2%	0%	-1%	0%	0%	-1%	-12%	0%	1%	1%	0%	-1%
1992	FNI	32853	66165	38006	9936	21834	32934	11767	1400	648	378	411	1199	217531
	Franklin	32799	66237	37928	9968	21702	32863	11711	1287	536	301	382	1178	216894
	Difference	54	-72	78	-32	132	71	56	113	112	77	29	21	637
	% Diff	0%	0%	0%	0%	1%	0%	0%	8%	17%	20%	7%	2%	0%
1993	FNI	1495	4389	8647	7332	7772	22596	6345	857	486	211	274	415	60819
	Franklin	1490	4391	8635	7561	7782	22565	6371	969	507	230	294	423	61217
	Difference	5	-2	12	-229	-10	31	-26	-112	-21	-19	-20	-8	-398
	% Diff	0%	0%	0%	-3%	0%	0%	0%	-13%	-4%	-9%	-7%	-2%	-1%
1994	FNI	373	815	1230	907	2617	966	252	475	219	2550	1206	3890	15500
	Franklin	368	812	1207	986	2650	1005	299	532	246	2574	1218	3899	15796
	Difference	5	3	23	-79	-33	-39	-47	-57	-27	-24	-12	-9	-296
	% Diff	1%	0%	2%	-9%	-1%	-4%	-19%	-12%	-12%	-1%	-1%	0%	-2%
1995	FNI	4075	2198	4590	5110	3830	3437	839	0	185	242	0	0	24506
	Franklin	4068	2201	4578	5118	3859	3450	872	0	324	253	0	118	24839
	Difference	7	-3	12	-8	-29	-13	-33	0	-139	-11	0	-118	-333
	% Diff	0%	0%	0%	0%	-1%	0%	-4%	--	-75%	-5%	--	-100%	-1%
1996	FNI	0	0	0	0	0	0	0	871	2818	3086	1485	7272	15532
	Franklin	104	260	146	330	341	284	173	974	3165	3306	1380	7263	17727
	Difference	-104	-260	-146	-330	-341	-284	-173	-103	-347	-220	105	9	-2,195
	% Diff	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-12%	-12%	-7%	7%	0%	-14%
1997	FNI	6898	16220	23537	28661	22209	35460	6452	958	238	73	336	15037	156079
	Franklin	6861	15640	23725	28567	21504	35274	6538	884	273	69	364	14394	154092
	Difference	37	580	-188	94	705	186	-86	74	-35	4	-28	643	1,987
	% Diff	1%	4%	-1%	0%	3%	1%	-1%	8%	-15%	6%	-8%	4%	1%

10-yr Total	**Diff**	**1,079**
	% Diff	**0.2%**

APPENDIX F

Lake Stillhouse Hollow
Differences in Acre-Feet between
Historical Monthly Flows Determined by FNI
and Franklin "Recommended Flows"

(Note - Negative flows represent greater estimates
by Franklin than by FNI)

Lake Stillhouse Hollow Flow Comparison

		Jan	Feb	Mar	Apr	Mau	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1988	FNI	5288	5763	6566	4575	3868	9446	4654	2523	1647	1342	521	1214	47407
	Franklin	5032	4339	5355	3103	634	7083	3870	435	0	103	183	978	31114
	Difference	256	1,424	1,211	1,472	3,234	2,363	784	2,088	1,647	1,239	338	236	16,293
	% Diff	5%	25%	18%	32%	84%	25%	17%	83%	100%	92%	65%	19%	34%
1989	FNI	2976	3753	7367	6481	27805	14320	4067	1634	697	767	644	0	70511
	Franklin	2975	3874	6262	4435	25325	12394	1926	0	0	263	22	0	57477
	Difference	1	-121	1,105	2,046	2,480	1,926	2,141	1,634	697	504	622	0	13,034
	% Diff	0%	-3%	15%	32%	9%	13%	53%	100%	100%	66%	97%	--	18%
1990	FNI	1,779	2,467	10,931	25,504	41,416	9,593	918	2,416	3,737	1,432	3,599	1,165	104,957
	Franklin	1,657	833	10,347	23,995	39,804	6,343	341	422	4,273	2,188	3,542	1,465	95,211
	Difference	122	1,634	584	1,509	1,612	3,250	577	1,994	-536	-756	57	-300	9,746
	% Diff	7%	66%	5%	6%	4%	34%	63%	83%	-14%	-53%	2%	-26%	9%
1991	FNI	15,257	13,605	9,262	6,024	54,041	29,163	6,832	2,753	2,574	3,133	3,815	224,950	371,409
	Franklin	14,994	13,351	7,979	4,209	56,282	28,664	5,034	532	3,189	3,442	4,168	223,854	365,699
	Difference	263	254	1,283	1,815	-2,241	499	1,798	2,221	-615	-309	-353	1,096	5,710
	% Diff	2%	2%	14%	30%	-4%	2%	26%	81%	-24%	-10%	-9%	0%	2%
1992	FNI	110,574	302,539	178,181	81,319	71,125	76,035	21,435	8,026	3,893	1,971	3,095	7,392	865,585
	Franklin	77,030	329,192	171,469	76,524	79,035	63,604	20,275	10,386	2,372	1,215	3,053	7,022	841,177
	Difference	33,544	-26,653	6,712	4,795	-7,910	12,431	1,160	-2,360	1,521	756	42	370	24,408
	% Diff	30%	-9%	4%	6%	-11%	16%	5%	-29%	39%	38%	1%	5%	3%
1993	FNI	7,173	32,984	54,679	38,941	57,838	50,417	15,792	3,902	3,496	1,220	1,499	2,010	269,951
	Franklin	7,705	33,016	53,038	43,118	52,538	45,208	18,327	3,151	4,056	853	1,447	2,038	264,495
	Difference	-532	-32	1,641	-4,177	5,300	5,209	-2,535	751	-560	367	52	-28	5,456
	% Diff	-7%	0%	3%	-11%	9%	10%	-16%	19%	-16%	30%	3%	-1%	2%
1994	FNI	2,745	9,075	7,519	4,733	23,945	9,236	2,191	1,408	1,866	5,663	3,902	5,106	77,389
	Franklin	1,916	7,740	6,635	2,915	21,970	8,876	698	397	0	7,069	3,182	5,527	66,924
	Difference	829	1,335	884	1,818	1,975	360	1,493	1,011	1,866	-1,406	720	-421	10,465
	% Diff	30%	15%	12%	38%	8%	4%	68%	72%	100%	-25%	18%	-8%	14%
1995	FNI	10,412	8,045	22,046	35,099	21,319	12,294	6,593	3,109	986	0	269	590	120,762
	Franklin	9,198	6,913	20,430	33,457	18,685	11,725	5,444	1,086	436	0	0	540	107,912
	Difference	1,214	1,132	1,616	1,642	2,634	569	1,149	2,023	550	0	269	50	12,850
	% Diff	12%	14%	7%	5%	12%	5%	17%	65%	56%	--	100%	9%	11%
1996	FNI	980	2,364	1,825	3,033	3,425	12,621	2,733	5,939	1,415	2,576	3,505	18,694	59,110
	Franklin	485	1,355	956	941	1,488	2,774	683	9,495	0	1,696	4,468	16,705	41,047
	Difference	495	1,009	869	2,092	1,937	9,847	2,050	-3,556	1,415	880	-963	1,989	18,063
	% Diff	50%	43%	48%	69%	57%	78%	75%	-60%	100%	34%	-27%	11%	31%
1997	FNI	20,679	150,818	116,640	90,855	70,859	115,517	30,391	6,036	2,094	1,374	3,217	45,221	653,701
	Franklin	19,846	150,577	111,564	90,468	72,251	109,344	30,882	5,386	2,204	552	3,577	43,995	640,646
	Difference	833	241	5,076	387	-1,392	6,173	-491	650	-110	822	-360	1,226	13,055
	% Diff	4%	0%	4%	0%	-2%	5%	-2%	11%	-5%	60%	-11%	3%	2%

10-yr Total	**Diff**	**129,081**
	% Diff	**5%**