Appendix A
Firm Yield Sensitivity for the Sulphur River Basin Reservoir Sites

Freese and Nichols

MEMORANDUM

TO: Texas Water Development Board

FROM: Andres Salazar, Ph.D., P.E.

SUBJECT: Firm Yield Sensitivity for the Sulphur River Basin Reservoir Sites

DATE: December 15, 2006

The initial screening process of the Reservoir Site Acquisition Study prepared for the Texas Water Development Board recommended 16 reservoirs for further detailed evaluation. Four of the reservoirs are located in the Sulphur River Basin. These reservoirs are Ralph Hall, George Parkhouse I, George Parkhouse II, and Marvin Nichols IA, and are shown on Figure 1.

Firm yield analyses were performed for each of these four reservoirs assuming stand-alone operations and excluding other potential reservoir sites identified in this study. However, if more than one of the proposed reservoirs are built, the firm yield of the reservoirs permitted with junior priority relative to the others may decrease substantially. This memorandum summarizes the results of a sensitivity analysis performed to assess the relative priority effects of various Sulphur River Basin reservoirs upon one another. The results of the stand alone yield analyses are discussed in Section 3.4 of the main report.

For the recommended conservation capacities shown in Table 1, the yields of Ralph Hall, Parkhouse I, Parkhouse II, and Marvin Nichols IA were determined assuming that all four reservoirs are built. Each reservoir was analyzed as the most junior in relation to the other three in at least one combination.

Four priority combinations were analyzed, which are listed in Table 2. In each combination, the yield of each reservoir was calculated assuming that senior reservoirs are operating at their firm yield. Ralph Hall Lake is already in the permitting process and very likely would be permitted before any of the other proposed reservoirs. Therefore, Ralph Hall is included as the most senior reservoir in three of the four scenarios. Scenario 4 has Ralph Hall with the most junior priority to obtain the worst case scenario for this reservoir.

Parkhouse I, Parkhouse II, and Marvin Nichols IA reservoirs are assumed to be passing inflows for environmental protection in accordance with the Texas Water Development Board's Consensus Criteria for Environmental Flow Needs. Lake Ralph Hall is assumed to be passing flows calculated with the Lyons method because this was the method used in the permit application. Environmental flow restrictions for each reservoir are listed in Attachment 1.

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Figure 1. Location Map

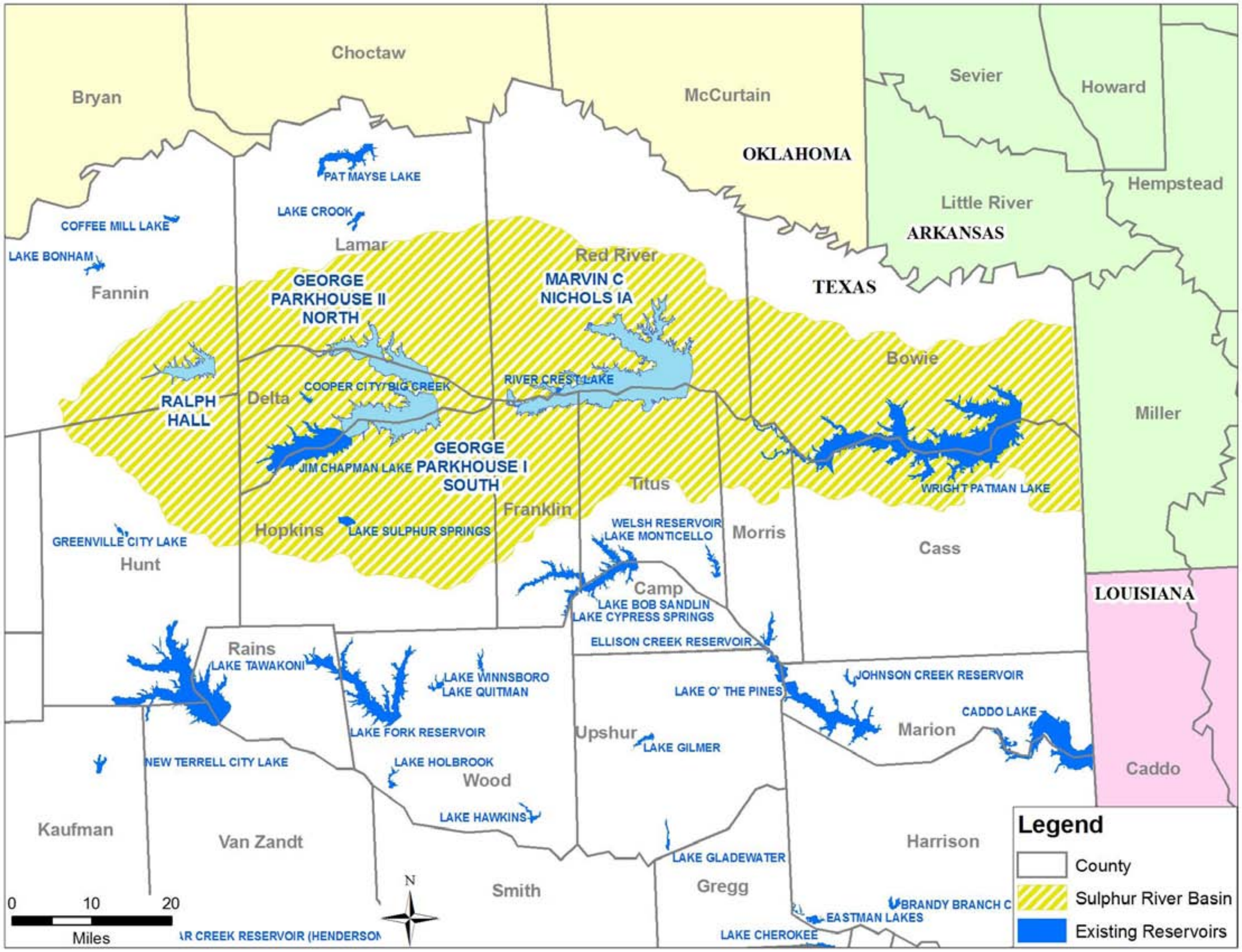

Table 1
Proposed Reservoirs in Sulphur River Basin

Reservoir	Conservation Elevation (msl)	Capacity (Acre-feet)	Area (Acres)
Ralph Hall	551.0	160,235	7,605
Parkhouse I	401.0	651,712	28,855
Parkhouse II	410.0	330,871	14,387
Marvin Nichols IA	328.0	1,562,669	67,392

Table 2
Relative Priority Combination Analyzed

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Most Senior	Ralph Hall	Ralph Hall	Ralph Hall	Parkhouse I
	Parkhouse I	Marvin Nichols IA	Parkhouse II	Parkhouse II
	Parkhouse II	Parkhouse I	Marvin Nichols IA	Marvin Nichols IA
Most Junior	Marvin Nichols IA	Parkhouse II	Parkhouse I	Ralph Hall

This sensitivity analysis used the permitting scenario (Run 3) of the Water Availability Model of the Sulphur River Basin (dated July 15, 2004) obtained from TCEQ (RJ Brandes 1999 and TCEQ 2006) and modified as necessary. A control point and reservoir were added at each dam location. These new control points were entered as primary control points, with known naturalized inflows.

In the WAM Models, flows at ungaged locations are usually calculated using the drainage area ratio method with known flows at gaged locations. The drainage areas of the Sulphur WAM were calculated by the University of Texas Center of Research in Water Resources (CRWR). These areas are different from values published from U.S. Geological Survey. In some cases, the difference is more than 10 percent. Preliminary yield studies conducted in this study determined that the flows calculated using the Sulphur WAM with the drainage area ratio method is different from previous hydrologic studies because of differences in the drainage areas. The USGS values are widely accepted and are more accurate than the CRWR values. Therefore, for purposes of estimating the firm yields under different priority scenarios, naturalized flows at the reservoir sites were calculated using the drainage area ratio method with drainage areas obtained from the USGS rather then CRWR.

The scope of work of this study does not include a verification or modification of the drainage areas of the Sulphur WAM Model. However, entering the naturalized flow at the reservoir sites is sufficient to produce accurate estimates of firm yields.

Evaporation rates are based on data from the Texas Water Development Board (2006), with adjustment to remove the portion of he precipitation on the surface area that is accounted for in the naturalized flows. Attachment 2 shows the gages and equations used for calculating the naturalized flows and evaporation rates.

Results

Table 3 shows the firm yield of each reservoir under the different combinations of priority. These results present the impacts of relative priorities of potential future water rights in the Sulphur River Basin. This sensitivity analysis does not include evaluation of the potential for increased yields through system operations with existing reservoir or other future reservoirs. Key results are summarized as follows:

1. The yield of Ralph Hall Lake could be reduced to 2,700 acre-feet per year (or a total reduction of 92%) if it is junior to all other proposed reservoirs.
2. Ralph Hall Lake would have minimal impact on Parkhouse I Lake, reducing the yield by 400 acre-feet per year.
3. Ralph Hall Lake would have substantial impact on Parkhouse II Lake, reducing the yield by 26,900 acre-feet per year, which is 18% of the stand-alone yield.
4. Ralph Hall Lake would reduce the yield of Marvin Nichols IA by 17,900 acre-feet per year, which is 3% of the stand-alone yield. This result assumes Parkhouse I and Parkhouse II are not built or have junior priority.
5. If Parkhouse I Lake is built as the most junior reservoir, its yield would be 48,400 acre-feet per year, which is 73,600 acre-feet per year less than the stand-alone yield (a reduction of 60%).
6. If Parkhouse II Lake is built as the most junior reservoir, its yield would be 32,100 acre-feet per year, which is 112,200 acre-feet per year less than the stand-alone yield (a reduction of 78%).
7. The yield of Marvin Nichols IA Reservoir would be reduced by 141,200 acre-feet per year (or a reduction of 23%) if all of the proposed upstream reservoirs are built with senior priority.

In summary, sequential development of these four reservoir sites in an upstream to downstream priority order provides the greatest total firm yield among the scenarios evaluated. Cooperative development and system operations of reservoirs at some or all of these sites will maximize total firm yield.

Table 3
Firm Yield of the Proposed Reservoir under Different Combination of Priority
(Values are Acre-Feet per Year)

	Stand Alone Yield	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Ralph Hall	33,700	33,700	33,700	33,700	2,700
Parkhouse I	122,000	121,600	60,600	48,400	122,000
Parkhouse II	144,300	117,400	32,100	117,400	140,400
Marvin Nichols IA	602,000	460,800	584,100	503,800	465,500
Total	**NA***	**733,500**	**710,500**	**703,300**	**730,600**

* Total does not apply because only one reservoir is operating and others are excluded.

References

RJ Brandes Company. 1999. *Water Availability Modeling for the Sulphur River Basin.*

Texas Commission on Environmental Quality. 2006. Input File of the Water Availability Models. http://www.tceq.state.tx.us/permitting/water_supply/water_rights/wam.html

Texas Water Development Board. 2006. Evaporation and Precipitation Data for the State of Texas. Available at http://hyper20.twdb.state.tx.us/Evaporation/evap.html

ATTACHMENT 1
Inflow Bypass for Environmental Protection

Table A1-1
Monthly Streamflow Statistics for Ralph Hall using the Lyons Method for Environmental Flow Needs

Month	AF	cfs
Jan	211	3.43
Feb	325	5.85
Mar	486	7.90
Apr	365	6.13
May	324	5.27
Jun	144	2.42
Jul	22	0.36
Aug	6	0.10
Sep	7	0.12
Oct	14	0.23
Nov	81	1.36
Dec	180	2.93
Total	2,164	
Average	180.4	3.00

Table A1-2
Monthly Streamflow Statistics for G. Parkhouse I (South) using the Consensus Criteria for Environmental Flow Needs

	Median		25th Percentile		7Q2	
Month	**AF**	**cfs**	**AF**	**cfs**	**AF**	**cfs**
Jan	1,919	31.2	318	5.2	0	0.0
Feb	3,596	64.2	794	14.2	0	0.0
Mar	3,748	60.9	800	13.0	0	0.0
Apr	2,697	45.3	638	10.7	0	0.0
May	4,687	76.2	741	12.0	0	0.0
Jun	1,854	31.1	294	4.9	0	0.0
Jul	233	3.8	22	0.4	0	0.0
Aug	47	0.8	0	0.0	0	0.0
Sep	72	1.2	0	0.0	0	0.0
Oct	180	2.9	9	0.2	0	0.0
Nov	696	11.7	88	1.5	0	0.0
Dec	1,916	31.1	177	2.9	0	0.0
Total	21,644		3,879		0	
Average	1,804	30.0	323	5.4	0	0.0

Table A1-3
Monthly Streamflow Statistics for G. Parkhouse II (North) using the Consensus Criteria for Environmental Flow Needs

	Median		25th Percentile		7Q2	
Month	**AF**	**cfs**	**AF**	**cfs**	**AF**	**cfs**
Jan	2,396	39.0	532	8.6	0	0.0
Feb	3,266	58.3	1,096	19.6	0	0.0
Mar	3,333	54.2	1,045	17.0	0	0.0
Apr	3,129	52.6	1,049	17.6	0	0.0
May	3,289	53.5	874	14.2	0	0.0
Jun	1,175	19.7	205	3.4	0	0.0
Jul	183	3.0	12	0.2	0	0.0
Aug	50	0.8	0	0.0	0	0.0
Sep	66	1.1	0	0.0	0	0.0
Oct	174	2.8	3	0.1	0	0.0
Nov	920	15.4	73	1.2	0	0.0
Dec	2,068	33.6	243	4.0	0	0.0
Total	20,046		5,132		0	
Average	1,671	27.8	428	7.2	0	0.0

Table A1-4
Monthly Streamflow Statistics for Marvin Nichols IA using the Consensus Criteria for Environmental Flow Needs

	Median		25th Percentile		7Q2	
Month	**AF**	**cfs**	**AF**	**cfs**	**AF**	**cfs**
Jan	13,845	225.1	3,419	55.6	69	1.1
Feb	21,947	391.6	6,659	118.8	63	1.1
Mar	31,133	506.2	8,975	145.9	69	1.1
Apr	19,656	330.2	6,143	103.2	67	1.1
May	32,113	522.1	6,092	99.0	69	1.1
Jun	11,994	201.5	3,110	52.3	67	1.1
Jul	2,564	41.7	552	9.0	69	1.1
Aug	911	14.8	220	3.6	69	1.1
Sep	1,011	17.0	123	2.1	67	1.1
Oct	1,562	25.4	251	4.1	69	1.1
Nov	5,055	84.9	1,083	18.2	67	1.1
Dec	11,641	189.3	2,201	35.8	69	1.1
Total	153,432		38,827		814	
Average	12,786	212.5	3,236	54.0	68	1.1

ATTACHMENT 2
Calculation of Naturalized Flows

Table A2-1 Gages Used in the Calculation of Naturalized Flows

Control Point	Name	USGS Drainage Area (sq. miles)	Sulphur WAM Drainage Area (sq. miles)
Existing Control Points			
A10	South Sulphur River near Cooper	527	541
B10	North Sulphur River near Cooper	276	311
C10	Sulphur River near Talco	1,365	1,381
D10	White Oak Creek near Talco	494	546
E10	Sulphur River near Darden	2,774	2,849
New Control Points			
B25	Ralph Hall	102	NA
C200	Parkhouse I	655	NA
C105	Parkhouse II	421	NA
E175	Marvin Nichols IA	1,889	NA

Derivation of Natural Flows and Evaporation Rates

1- Ralph Hall

Natural Flow (Calculated by the WRAP Model)

$$\text{Ralph Hall} = \frac{\text{B10}}{311\ \text{sq.miles}} \times 102\,\text{sq.miles}$$

Evaporation

Ralph Hall Evaporation = Control Point A70.
(Adjusted for effective runoff by the WRAP Model)

2- Parkhouse I

Natural Flow (Entered as primary control point)

$$\text{Parkhouse I} = \text{A10} + \frac{\text{C10} - \text{B10} - \text{A10}}{562\,\text{sq.miles}} \times 128\,\text{sq.miles}$$

Evaporation

Parkhouse I Evaporation = Net Quadrangle 412 + [Nat Flow C200] / 655

3- Parkhouse II

Natural Flow (Entered as primary control point)

$$\text{Parkhouse II} = \text{B10} + \frac{\text{C10} - \text{B10} - \text{A10}}{562\,\text{sq.miles}} \times 145\,\text{sq.miles}$$

Evaporation

Parkhouse II Evaporation = Net Quadrangle 412 + [Nat Flow C105] / 421

4- Marvin Nichols IA

Natural Flow (Entered as primary control point)

$$\text{Marvin Nichols IA} = \text{C10} + \frac{\text{E10} - \text{D10} - \text{C10}}{915\,\text{sq.miles}} \times 524\,\text{sq.miles}$$

Evaporation

Marvin Nichols Evaporation = 0.5 x (Net Quadrangle 412 + 413) + [Nat Flow E175] /1889