# Temperature, Flow, Total Dissolved Solids, Thermal Stratification Impacts, and Aquatic Life Impacts in Lake Granbury during Winter Low Flow Conditions

Luminant

Prepared for
Luminant Inc.
Comanche Peak Nuclear Power Plant

MNES
Mitsubishi Nuclear Energy Systems

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Prepared by
Mitsubishi Nuclear Energy Systems
Enercon Services, Inc.

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**Objective**

Analyze the temperature, total dissolved solids (TDS), thermal stratification, low flow conditions, and aquatic impacts on Lake Granbury (LG) during full-power winter operations of Comanche Peak Nuclear Power Plant (CPNPP) Units 1 through 4, and withdrawals for makeup to Squaw Creek Reservoir (SQR) for CPNPP Units 1 and 2 operations and Wolf Hollow power plant operations, including minimum releases from De Cordova Bend Dam during the winter months.

**Areas of Interest to Substantiate Conclusion:**

1. *During the winter months, a comparison of the blowdown temperature of Units 3 and 4 discharges and ambient temperatures in LG indicate that there will be no heat buildup between the intake and the discharge in excess of the temperature criteria established in 30 TAC, Chapter 307 (Texas Surface Water Quality Standards).*

Blowdown Discharge Temperature

Monthly surface water temperatures on LG at the De Cordova Bend Dam were obtained from the Brazos River Authority (BRA) for the years 1998 through 2007. The temperature data obtained are sporadic, due to irregular measurement intervals; however, this data source was utilized for this investigation, because it provides the most accurate assessment of monthly temperature conditions in the vicinity of the CPNPP Units 3 and 4 cooling water intake and discharge lines on LG. The data collected from 1998 through 2007 are provided in ER Table 2.3-23, including the maximum, average-maximum, average, average-minimum, and minimum monthly temperatures. The average ambient surface water temperature from 1998 to 2007 for the winter months (December to February) is 50.21°F.

When cooling towers are planned for a specific location, the highest geographic wet bulb temperature is a contributing factor to the proposed design. This temperature will dictate the minimum performance available by the tower. The following table summarizes expected CPNPP Units 3 and 4 makeup and discharge flow rates and discharge temperatures based on a range of wet bulb temperatures. Each temperature "bin" provides the number of hours of operation expected annually under the given environmental conditions. The information was obtained from the Secondary Side Cooling Tower Optimization Study (Banerjee et al. 2007) prepared for CPNPP Units 3 and 4.

Secondary Side Heat Sink Evaluation

| | Bin 1 | Bin 2 | Bin 3 | Bin 4 | Bin 5 | Bin 6 | Bin 7 | Bin 8 | Bin 9 | Bin 10 | Bin 11 | Bin 12 | Bin 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Ambient Air Dry Bulb Temperature (°F) | 105 | 100 | 98 | 95 | 90 | 85 | 75 | 65 | 59 | 52 | 45 | 38 | 35 |
| Corresponding Ambient Air Wet Bulb Temperature (°F) | 81 | 78 | 77 | 76 | 75 | 73 | 89 | 55 | 52 | 80 | 40 | 34 | 32 |
| Number of Hours Annually in Temperature Bin | 35 | 53 | 88 | 263 | 438 | 876 | 2628 | 876 | 876 | 876 | 876 | 438 | 438 |
| Discharge Water Temperature in Cooling Tower Basin (°F) | 91 | 89 | 89 | 89 | 88 | 86 | 82 | 77 | 74 | 71 | 68 | 65 | 64 |
| Expected Make-Up Flow (gpm) | 63,634 | 62,792 | 62,536 | 62,262 | 61,702 | 60,896 | 57,904 | 54,170 | 51,690 | 49,182 | 46,406 | 43,754 | 42,616 |
| Expected Discharge Flow (gpm) | 26,256 | 25,904 | 25,798 | 25,684 | 25,450 | 25,116 | 23,868 | 22,312 | 21,280 | 20,234 | 19,078 | 17,972 | 17,498 |

LG Temperature Criteria

With regard to temperature elevations due to discharges, 30 TAC, Chapter 307 requires no more than a maximum temperature differential (rise over ambient) of 3°F for freshwater lakes and impoundments. Appendix A of 30 TAC, Chapter 307, provides additional temperature criteria for LG, which indicate a maximum temperature of 93°F to support designated water uses.

Heat Balance

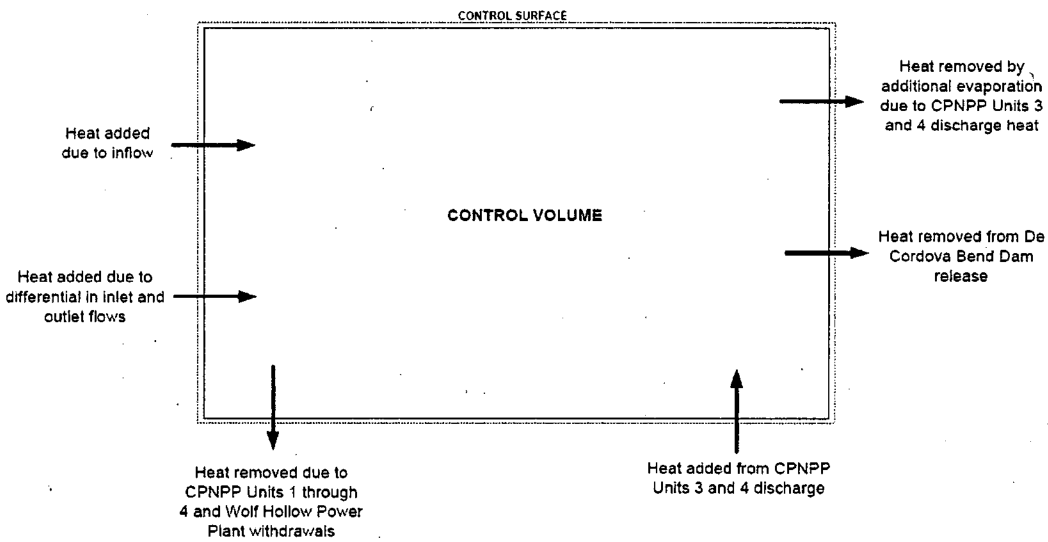
A first-order heat balance study was performed to analyze the thermal effects of CPNPP Units 3 and 4 discharges on the portion of LG between the CPNPP Units 3 and 4 intake and discharge lines. The goals of the evaluation were to determine if CPNPP Units 3 and 4 discharges would cause the ambient water temperature of Lake Granbury to rise above the maximum allowable temperature differential (rise over ambient) of 3°F during winter low flow conditions, and to explore the possibility of recirculation of the thermal plume.

To conservatively achieve these goals, the heat balance analysis was performed under the assumption that CPNPP Units 3 and 4 had been operating during a 65-day period of minimum dam releases from December 2001 to February 2002. This period was selected because it is centered in the winter months when ambient surface water temperatures in LG would be lowest, thus producing the highest temperature differential with respect to CPNPP Units 3 and 4 discharges. Inputs for the heat balance consist of the following meteorological and hydrological data:

- The volume of the lower portion of LG between the CPNPP Units 3 and 4 intake and discharge locations is estimated at 9,668 ac-ft (see aerial photo figure on page 5), based on an average January reservoir elevation of 691 feet msl (USGS 2009) and modified elevation-volume estimates from the 2007 LG bathymetry study (Boss 2009).
- The average ambient surface temperature of LG near the De Cordova Bend Dam is approximately 51.8°F, based on historical temperature data from four (4) measurements collected from December 11, 2001 to February 13, 2002.
- Historical dam release data for the 65-day consecutive period of low flow indicate minimal releases of approximately 28 cfs from December 11, 2001 to February 13, 2002.

- Historical wet bulb temperature data (average daily) (NOAA 2008), corresponding to each low flow day considered (December 11, 2001 to February 13, 2002), were used to assign expected CPNPP Units 3 and 4 discharge temperatures and flow rates (makeup from and discharge to LG). The expected flow rates and discharge temperatures were calculated in the Secondary Side Cooling Tower Optimization Study (Banerjee et al. 2007) and were selected by matching the appropriate temperature bin for the daily wet bulb temperatures observed during the period studied.
- Monthly withdrawal rates (December 2006 to February 2007) from LG for the operation of CPNPP Units 1 and 2 were used (TCEQ 2009).
- Monthly withdrawal rates (December 2006 to February 2007) from LG for the operation of the Wolf Hollow Power Plant were used (TCEQ 2009).

The evaluation used a control volume / energy balance approach based on the first law of thermodynamics, or conservation of energy, to determine the daily temperatures of LG between the intake and discharge lines. The figure below shows heating and cooling sources considered in the evaluation.

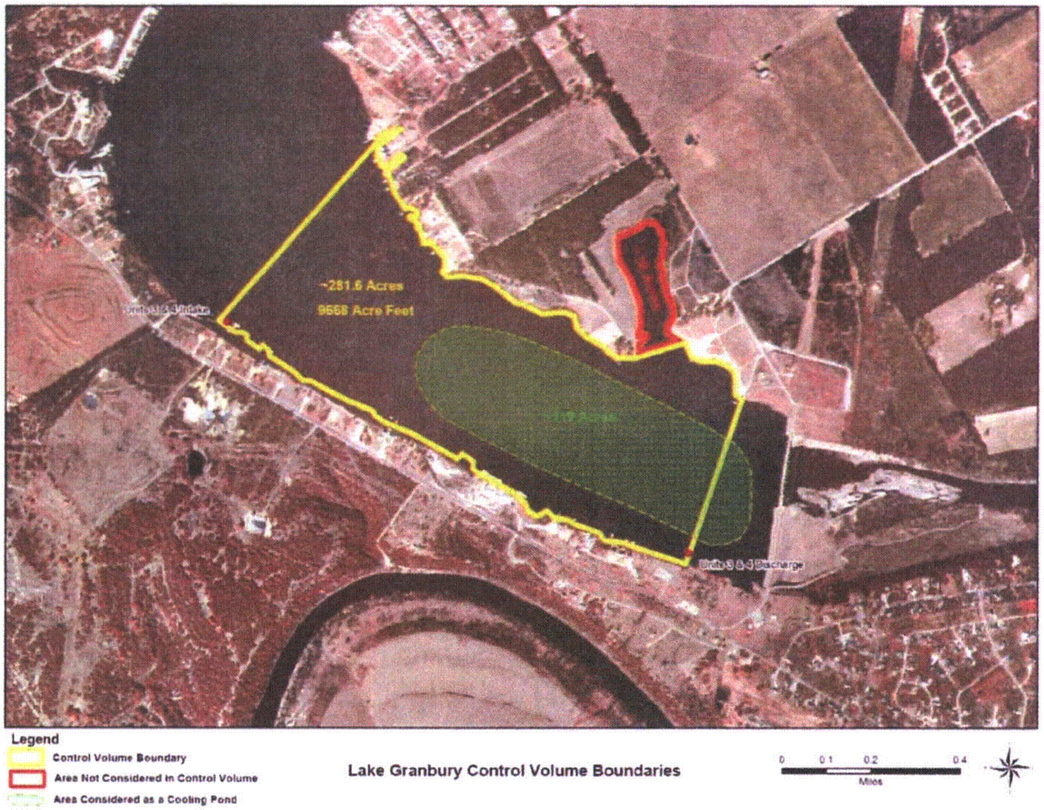



Because daily temperature data was not available for LG, the average temperature of 51.8°F was used as the baseline temperature during the 65-day period modeled. The daily energy transfer was calculated using historical dam release and surface water withdrawal data. The CPNPP Units 3 and 4 flow values and discharge temperatures used in the daily energy transfer calculations were determined by matching historic daily wet bulb temperatures to the appropriate temperature bin described in the Secondary Side Cooling Tower Optimization Study (Banerjee et al. 2007). Other key and conservative assumptions utilized in the evaluation include:

- For conservatism, surface or natural evaporation and solar loading were neglected within the formal evaluation but provided basis for the assumption that zero energy would be transferred across the control surface.

- Only four (4) temperature measurements were available for the period modeled. Consequently, the average temperature of 51.8°F for the period was used for conservatism.
- The highest differential lake temperatures, as compared to the cooling tower discharge, were assumed to be during the winter months.
- Actual permit conditions were not available; therefore, information was assumed using Texas Administrative Code. The permit condition for temperature change is assumed to be less than 3°F for the plant discharge.
- Conservatively assumed winds were 2 mph for the Lake Granbury area. From Table 2.7-45 of the ER, wind speeds for the area near CPNPP are > 7.5 mph verifying the conservatism of this assumption.
- No rain or snow was assumed for this period of evaluation.
- All work such as boating, actions of wildlife, etc. were negligible.
- No mass was gained or lost during the evaluation, but the mass flow rates provided weighted energy values crossing the control surface.

It was also assumed that discharges from CPNPP Units 3 and 4 would create a plume that is warmer than the ambient LG water temperature and therefore be buoyant. The buoyant plume is expected to spread across the surface of the control volume with enough energy to induce additional evaporation. It was determined that this additional evaporation provides the largest heat transfer from the control volume and was modeled by assuming the conservative 119-acre area of the control volume as a cooling pond (Perry and Green 1997). The size of the cooling pond was determined based on the expected CPNPP Units 3 and 4 discharge flow and temperature data. The evaluation estimated that for the 65-day period modeled, the temperature of the 9668 ac-ft control volume (see figure below) would have increased less than 1 °F above ambient. CPNPP Units 3 and 4 diffuser ports are designed to discharge downstream and away from the intake; therefore, the area considered as a cooling pond was shifted slightly downstream and out of the control volume. However, as shown below, the available control volume surface area (281.6 acres) is expected to adequately dissipate heat from CPNPP Units 3 and 4 discharges without recirculation to the intake structure.




Lake Granbury Control Volume Boundaries

This analysis was performed during a period of variable withdrawal from LG for SCR make-up and the Wolf Hollow plant operations when the combined intake flows for these two withdrawals varied from 1.6 to 71.3 cfs. It was determined that increased withdrawal rates would remove additional heat from the control volume. Additional heat transfer from LG to the atmosphere would be provided by natural evaporation which was not considered in this evaluation. Less than 1°F temperature increase of the control volume is conservative based on the large surface area of the lake beyond the control area and the historical natural evaporation rate of 1.73 to 2.38 inches (USACE 2007) during the winter months. With increased ambient lake temperatures, the thermal effects of CPNPP discharges would decrease. The thermal impacts from CPNPP Units 3 and 4 discharges during the winter months (December to February) on the lower portion of LG are expected to be minimal.

Therefore; correlation of the heat balance results with the historical low flow occurrences of December 2001 to February 2002 indicates that the 3°F ambient surface water temperature threshold is not exceeded for CPNPP Units 3 and 4 operation, even if comparable historical low flow winter conditions occur. Additionally, the available control volume surface area between the CPNPP Units 3 and 4 intake and discharge lines is expected to adequately dissipate heat from CPNPP Units 3 and 4 discharges without recirculation to the intake structure.

2. *The blowdown TDS concentrations of Units 3 and 4 discharges will not impact LG with respect to established numerical water quality standards.*

Discharge Effluent Modeling

A water chemistry analysis was used to estimate the analyte concentrations using a 2.4-cycle blowdown discharge into LG to evaluate the anticipated water quality at the effluent discharge point for the Combined Construction and Operating License (COL) Application as a part of the Environmental Report for CPNPP Units 3 and 4. This analysis included use of the tabulated quarterly monitoring data for surface water samples collected in year 2007 from LG to determine the mean and maximum concentrations for each analyte.

Final concentrations obtained from the analysis were compared to the Texas Commission on Environmental Quality (TCEQ) Criteria for Specific Metals in Water for Protection of Aquatic Life, Texas Surface Water Quality Standards (TSWQS), Human Health Criteria in Water, Screening Levels for Nutrient Parameters, and the CPNPP Texas Pollutant Discharge Elimination System (TPDES) permit.

The analysis indicated that the concentration of TDS is estimated to exceed the TSWQS for LG for maximum concentrations as a result of the 2.4-cycle cooling tower operation and when mixed with LG at low flow and annual mean flow; therefore, a blowdown treatment facility will be utilized to treat CPNPP Units 3 and 4 cooling tower blowdown prior to discharge to LG. The blowdown treatment facility and its operation, which is currently under conceptual design, will reduce blowdown TDS concentrations to ensure water quality standards on LG are met under any flow conditions.

3. *Based upon examination and evaluation of the existing intake structure for CPNPP Units 1 and 2, there is no persistent natural stratification that exists in the area of the intake structure. The aquatic ecology of the reservoir is not centered on a stratified environment due to weak and tenuous natural lake stratification.*

LG Vertical Structure

Flows into and out of the lake (i.e., throughflow), which is dominated by the flow in the Brazos River, vary widely in response to the storm-dominated climatology of North Texas. Typically, the higher annual flows are experienced in the late spring (April to June) and a secondary maximum occurs in the fall; however, this pattern is widely variable from year to year. This wide range in throughflow induces a Jekyll-Hyde dichotomy in the behavior of LG. Only when throughflow is low enough that the waters in the reservoir are quiescent and respond to the seasonal march of temperature and insolation does the reservoir behave like a subtropical lake. (Ward 2008)

In such a subtropical lake, the increased heating with the advance of spring produces a buoyant surface layer, called the epilimnion, that continues to collect warmed water and gradually deepens into summer. The zone of fall-off in temperature with depth (the thermocline) is a layer of vertical density gradient. Because the warm buoyant epilimnion water lies on top of the cool dense water below the thermocline (the hypolimnion), this stratification opposes vertical water movement and becomes self-stabilizing, resisting the exchange of water between epilimnion and hypolimnion. As the season advances from spring to summer, and epilimnion and hypolimnion become increasingly isolated, dissolved oxygen (DO) is retained in the epilimnion due to its continuing influx from surface re-aeration and from photosynthesis in the light-illuminated near-surface layer, but is no longer mixed downward into the hypolimnion. Here DO is consumed by microbiological respiration, until the hypolimnion becomes anoxic. A roll-off in DO with depth, called the oxycline, from high concentrations in the epilimnion to zero in the hypolimnion, occurs at, or just above, the level of the thermocline. (Ward 2008)

Aquatic Ecology and Thermal Stratification

Mobile zooplankton undergo daily vertical migration within the water column. Although zooplankton migrate through various strata and benefits of stratification are noted, migration appears to be largely dependent on light penetration through the water column rather than a temperature or DO differential. Predation in aquatic environments is visual and by migrating to deeper darker surroundings during daylight hours, predation is avoided. Conversely, surface phytoplankton on which zooplankton feed, synthesize proteins at night and carbohydrates during the day; therefore, the food quality available for zooplankton consumption increases at night. A benefit of a stratified environment is that growth efficiency is somewhat greater at lower temperatures. During the day, when food quality is poorer and predation higher at the surface, migrating zooplankton can take advantage of increased growth rates due to the temperature differential a stratified environment would provide. However, it is unclear to what extent a stratified environment would benefit zooplankton, because populations vary in a manner that cannot be linked to the presence of a stratified environment. (Wetzel 1983)

Persistence of LG Stratification

A disturbance of sufficient strength, such as a thunderstorm or influx of flood water, can disrupt the temperature stratification and mix the waters in the lake. The stability of the thermocline is the key parameter that dictates whether the vertical structure of the lake can withstand such an event. As the season progresses into fall, cooling of the epilimnion reduces the thermocline stability to the point that fall storms begin to mix out the vertical structure. In the case of LG, an inspection of field data indicates that summer stratification is not manifested under high flow conditions, even in the heat of summer. (Ward 2008)

In winter, there is vertical homogeneity in the temperature structure, then stratification develops through the spring. The vertical stratification is more apparent in DO, because the near-surface source combined with the DO consumption through the water column and at the lake bed enhances the vertical gradient. The stratification in LG is relatively weak. (Ward 2008)

Typical temperature structures of lakes in Texas during the winter months can be described as homogenous with the development of thermal stratification during spring and summer months. However, field data from LG indicate a weak thermal stratification during the spring and summer months that may occur and is easily disrupted by disturbances such as a thunderstorm or influx of flood water. Given these natural conditions within LG, the aquatic ecology of the reservoir would not be dependent upon a stratified environment, thus effects of CPNPP Units 3 and 4 on seasonal stratification and subsequent effects on aquatic ecology would be minimal.

LG Stratification Affect on Diffuser Performance

The weak thermal stratification that occurs during the spring and summer months in LG is not expected to disrupt CPNPP Units 3 and 4 diffuser performance with respect to adequate mixing of the thermal plume. The thermal plume would be warmer than the ambient water of LG and is expected to rise and spread across the surface of LG. During times of low flow through LG, the CPNPP Units 3 and 4 thermal plume is expected to have enough energy due to the temperature differential with respect to ambient to induce additional evaporation at the lake surface where a sufficient surface area is available to adequately dissipate the added heat.

4. *Induced velocity caused by withdrawals from LG during winter months for CPNPP Units 1 through 4, and makeup to SCR to support Units 1 and 2 operations and Wolf Hollow operations, does not create recirculation flow paths and does not affect blowdown diffuser performance or cause adverse impacts to LG.*

Expected Winter Month Withdrawal Rates

The withdrawal flow rates for three surface water intake points on the lower portion of LG were considered for the heat balance analysis. The intakes considered include CPNPP Units 3 and 4, SCR makeup (CPNPP Units 1 and 2), and the Wolf Hollow power plant.

CPNPP Units 3 and 4 makeup and discharge rates are controlled by atmospheric conditions. The Secondary Side Cooling Tower Optimization Study (Banerjee et al. 2007) provides the expected flow rates based on variable atmospheric conditions expected at the CPNPP site. As part of the heat balance study, the daily flow rates for the winter months were selected from 13 temperature bins based upon historical daily wet bulb temperatures. Based on the historical December 2001 to February 2002 daily wet bulb temperatures, the corresponding flow rates for CPNPP Units 3 and 4 were 94.95 to 130.69 cfs makeup and 38.99 to 49.71 cfs discharge. The table below shows the temperature bins utilized for the 65-day period modeled. These estimates do not account for discharge flow losses associated with the proposed blowdown treatment facility.

| CPNPP Units 3 and 4 Flow Rates and Discharge Temperatures from Cooling Tower Optimization Study | | | | | | |
|---|---|---|---|---|---|---|
| | Bin 8 | Bin 9 | Bin 10 | Bin 11 | Bin 12 | Bin 13 |
| Average Ambient Air Dry Bulb Temperature (°F) | 65 | 59 | 52 | 45 | 38 | 35 |
| Corresponding Ambient Air Wet Bulb Temperature (°F) | 58 | 52 | 80 | 40 | 34 | 32 |
| Number of Hours Annually in Temperature Bin | 876 | 876 | 876 | 876 | 438 | 438 |
| Discharge Water Temperature in Cooling Tower Basin (°F) | 77 | 74 | 71 | 68 | 65 | 64 |
| Expected Make-Up Flow (cfs) | 130.69 | 115.17 | 109.58 | 103.39 | 97.48 | 94.95 |
| Expected Discharge Flow (cfs) | 49.71 | 47.41 | 45.08 | 42.51 | 40.04 | 38.99 |

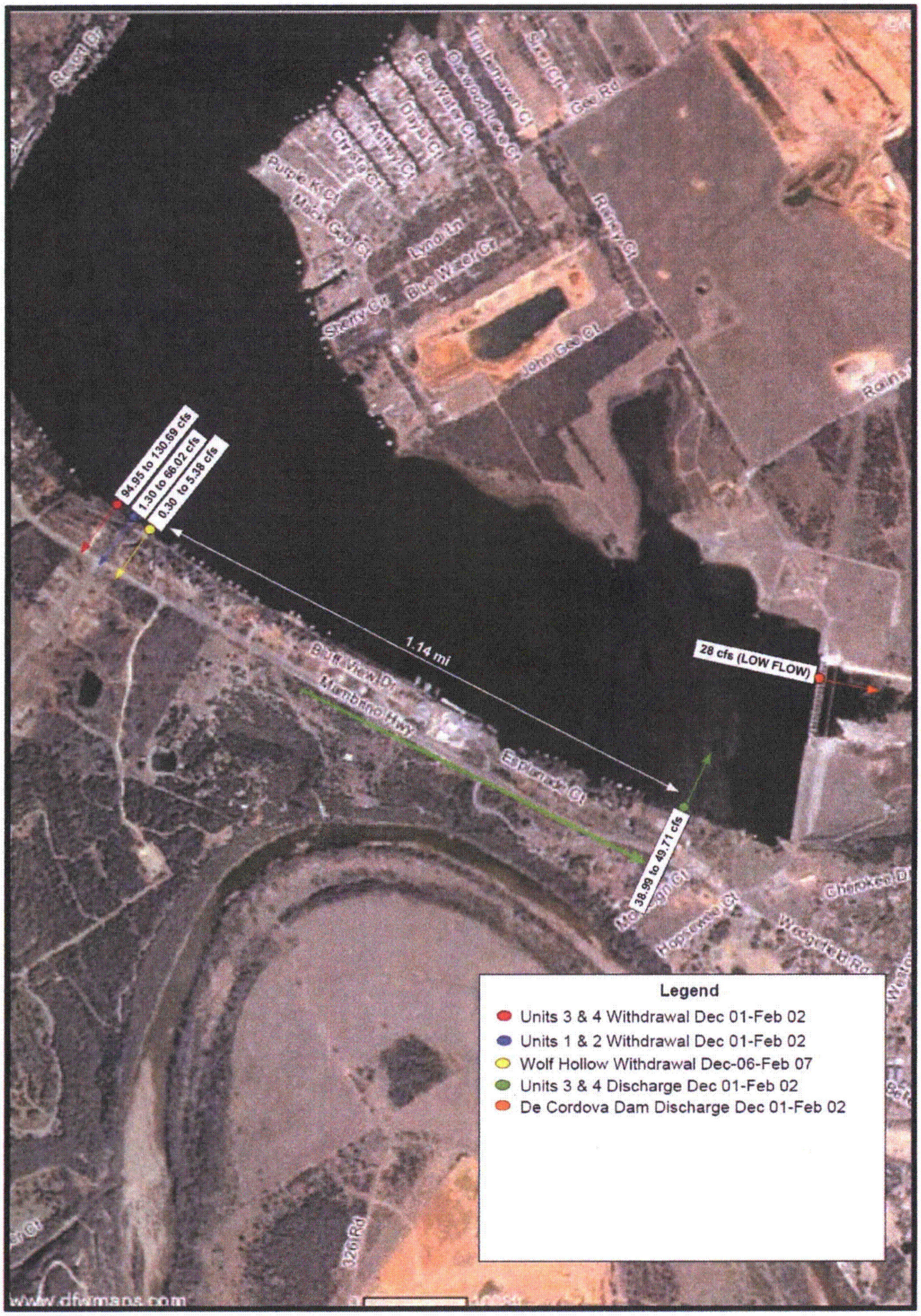
December 2001 to February 2002 withdrawal rates from LG for CPNPP Units 1 and 2 operations are provided below (TCEQ 2009).

| CPNPP Units 1 and 2 Diversions from Water Use Reports | | | | | | |
|---|---|---|---|---|---|---|
| Month | ac-ft/month | gallons/month | gallons/day | gallons/hour | gallons/minute | cubic feet/second |
| Dec-01 | 3925.00 | 1,278,965,175.00 | 42,632,172.50 | 1,776,340.52 | 29,605.67 | 66.02 |
| Jan-02 | 3483.20 | 1,135,004,203.00 | 37,833,473.44 | 1,576,394.72 | 26,273.24 | 58.59 |
| Feb-02 | 77.30 | 25,188,282.30 | 839,609.41 | 34,983.72 | 583.06 | 1.30 |

December 2006 to February 2007 withdrawal rates from LG for Wolf Hollow operation are provided below (TCEQ 2009).

| Wolf Hollow Power Plant Diversions from TCEQ Data | | | | | | |
|---|---|---|---|---|---|---|
| Month | ac-ft/month | gallons/month | gallons/day | gallons/hour | gallons/minute | cubic feet/second |
| Dec-06 | 320.00 | 104,272,320.00 | 3,475,744.00 | 144,822.67 | 2,413.71 | 5.38 |
| Jan-07 | 272.00 | 88,631,472.00 | 2,954,382.40 | 123,099.27 | 2,051.65 | 4.58 |
| Feb-07 | 18.00 | 5,865,318.00 | 195,510.60 | 8,146.28 | 135.77 | 0.30 |

Total withdrawals for the three intakes during the winter months for the period studied range from 96.55 to 202.09 cfs. The following figure shows the water input and withdrawal locations on LG considered in the heat balance analysis.


94.95 to 130.69 cfs
1.30 to 66.02 cfs
0.30 to 5.38 cfs
1.14 mi
28 cfs (LOW FLOW)
38.99 to 49.71 cfs
Legend
Units 3 & 4 Withdrawal Dec 01-Feb 02
Units 1 & 2 Withdrawal Dec 01-Feb 02
Wolf Hollow Withdrawal Dec-06-Feb 07
Units 3 & 4 Discharge Dec 01-Feb 02
De Cordova Dam Discharge Dec 01-Feb 02

## Conclusion

During the winter months, with minimal dam releases (<28 cfs or 28 cfs), with water being withdrawn for makeup to SCR for CPNPP Units 1 and 2 operations and Wolf Hollow operations, thermal and chemical impacts from CPNPP Units 3 and 4 withdrawals and discharges would not destabilize LG water quality or aquatic ecology.

## References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# Appendix

## Diffuser Location

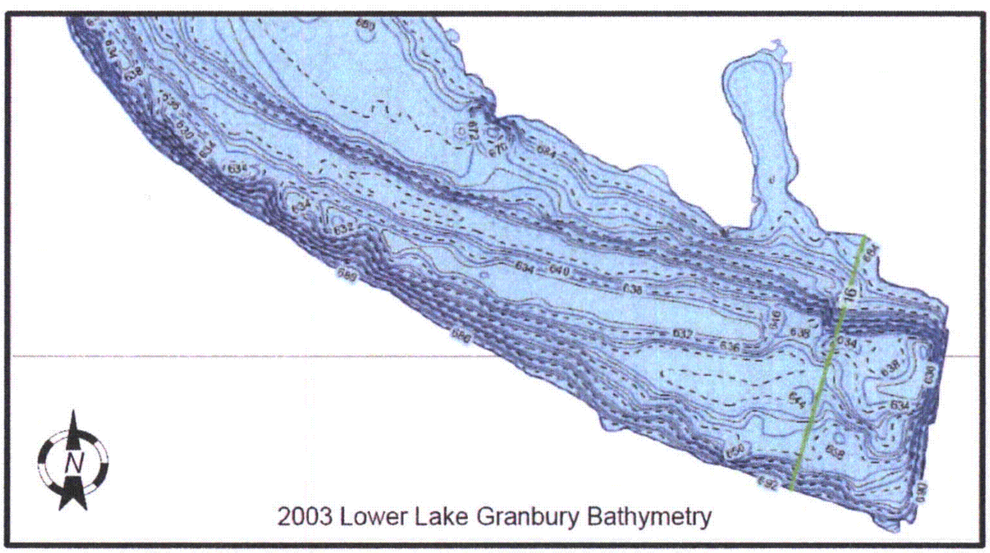
*Location of the diffuser used in the CORMIX calculation is conservative and the final location will have no effect on heat buildup back to the diffuser or in LG.*

**Diffuser Location Modeled in CORMIX**

The off-shore placement of the diffuser is in the conceptual stage and the exact depth and distance from the shoreline have not been determined. For the CORMIX mixing zone analysis, a conservative off-shore distance of 20 ft and a conservative low water level of 10 ft were used. The conservative placement of the diffuser in shallow water limits the volume of water above the diffuser and, thus, minimizes dilution of the thermal plume. To account for potential shoreline interference, the diffuser placement was modeled close to the shore. Placement of a diffuser in an area of shallow water close to the shore may cause eddies and/or vortices at the shoreline resulting in thermal accumulation. The results of the CORMIX analysis under these conditions indicated normal dilution of the plume without shoreline attachment.

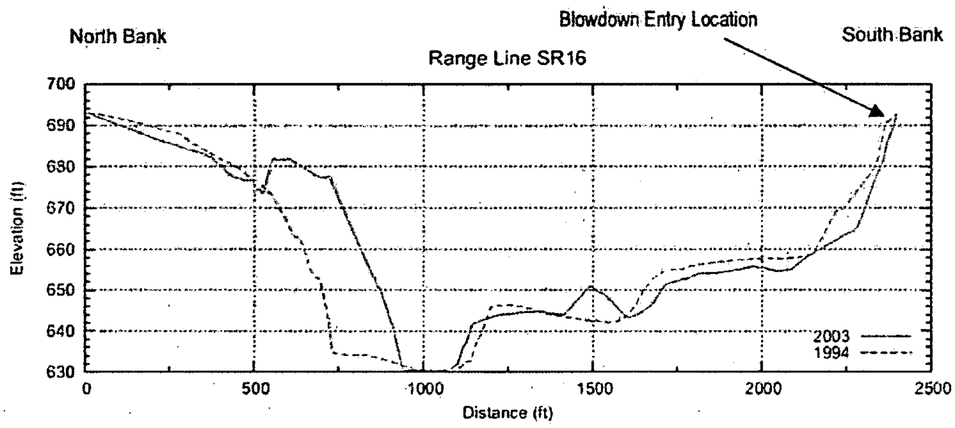
**Planned Diffuser Location**

The final placement of the diffuser will likely be in deeper water and further from the shoreline, allowing greater thermal dilution/dissipation and minimizing potential shoreline interference. A bathymetric map and bottom profile of the approximate planned location of the proposed CPNPP Units 3 and 4 outfalls are provided below.



2003 Lower Lake Granbury Bathymetry

Bottom Profile of Approximate Planned Location of CPNPP Units 3 and 4 Outfalls


North Bank
Blowdown Entry Location
South Bank
Range Line SR16
Elevation (ft)
700
690
680
670
660
650
640
630
0
500
1000
1500
2000
2500
Distance (ft)
2003
1994