

Under Drought Conditions, Use of Analytical and Modeling Methodologies Helps an Indirect Potable Reuse Project Move Forward

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In 2011, Texas entered an unprecedented drought period. While the entire state experienced significant drought, the City of Wichita Falls, located approximately 150 mi northwest of Dallas, was particularly hard hit. Wichita Falls experienced record temperatures that year, exceeding 100°F on more than 100 days (when 28 days is typical) and received only 13 in. of rain, less than half of the average rainfall of 28.5 in. This made 2011 the most extreme year on record for the city in terms of temperature and rainfall, and the drought continued through 2015. Levels in the city's

Lake Arrowhead drinking water supply reservoir dropped precipitously to only 23.5 percent reservoir capacity available. This put the city within one year of running out of water.

To minimize water shortfalls, the city implemented a short-term solution to the emergency: direct potable reuse (DPR), which involves the introduction of reclaimed water directly into a drinking water treatment plant. For the city, this involved piping the effluent from the River Road Wastewater Treatment Plant (WWTP) to its Cypress water treatment plant, which has advanced treatment capabil-

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ities, including microfiltration and reverse osmosis. This short-term strategy allowed the city time to implement a long-term indirect potable reuse (IPR) solution. The IPR involves supplementing a drinking water source with reclaimed water, but differs from DPR in that it uses an environmental buffer prior to drinking water treatment. Implementation of IPR for the city focused on piping wastewater effluent to Lake Arrowhead, which served as the environmental buffer prior to withdrawal from the lake and treatment at the city's Jasper water treatment plant. A map of Lake Arrowhead and its pipeline routes is shown in Figure 1.

Early in the project, one of the concerns raised regarding this approach was related to total dissolved solids (TDS), which are a natural component of surface waters throughout the world. The TDS is comprised of cations and anions (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are water soluble. Preliminary discussions with the state regulatory agency, the Texas Commission on Environmental Quality (TCEQ), indicated that there was the potential for a TDS permit limit. This would require membrane treatment of the effluent prior to reuse and ultimately would have made the project cost-prohibitive for the city.

The city, in conjunction with CDM Smith, determined that advanced analytical and modeling methodologies could be used to effectively evaluate the need for a permit limit for a discharge from the River Road WWTP into Lake Arrowhead for the purposes of indirect potable reuse. This ultimately led

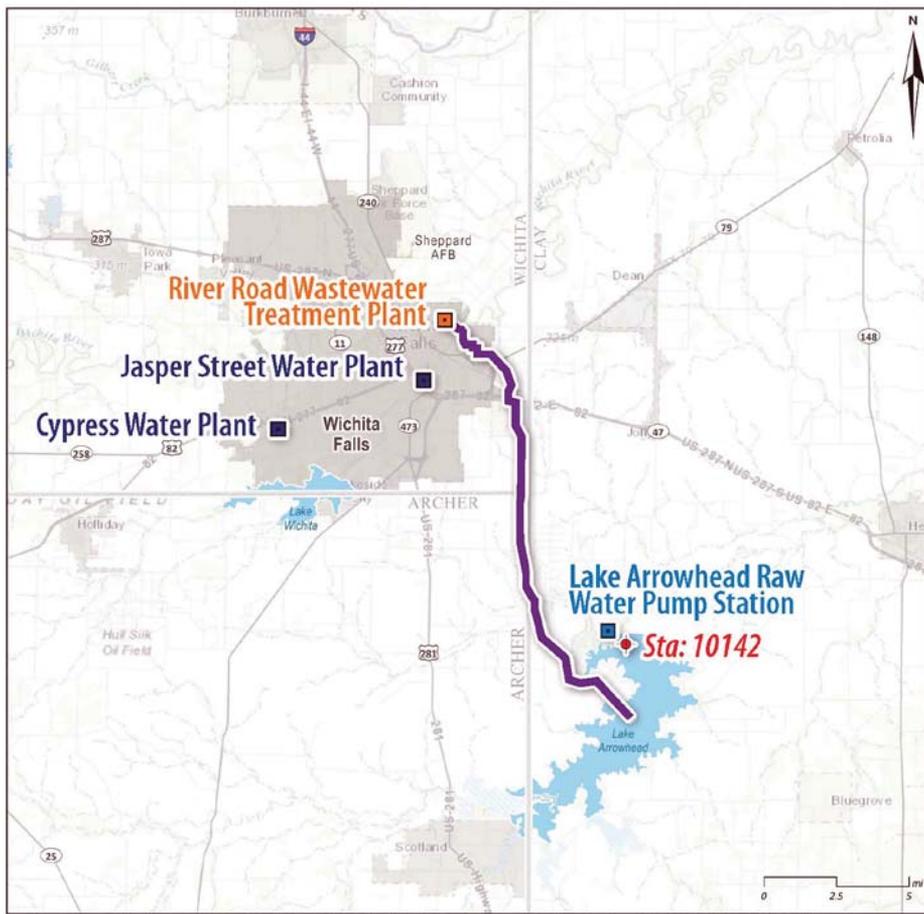


Figure 1. Pipeline Route for Lake Arrowhead

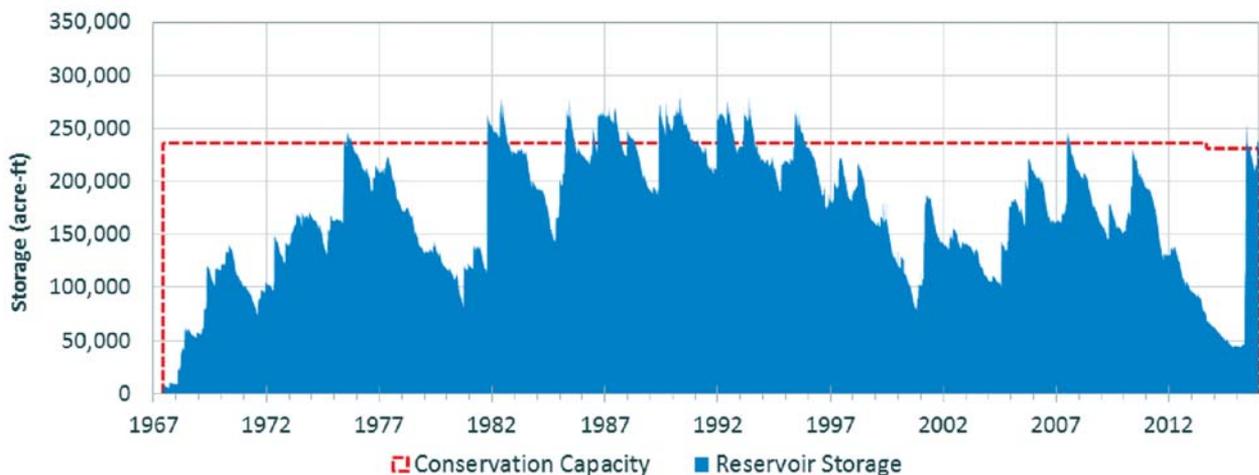


Figure 2. Volume of Lake Arrowhead from 1968 to present (Texas Water Development Board, 2015)

to a negotiation to avoid a TDS limit on the discharge.

Is a Total Dissolved Solids Permit Limit Necessary?

Lake Arrowhead is currently one of three drinking water sources for the City of Wichita Falls. It also serves as a sole source of drinking water for several communities in the area. The lake was primarily designed and constructed for water supply and recreational purposes. A permit to construct the reservoir was issued in 1962 and deliberate impoundment began in October 1966. The city owns the water rights to Lake Arrowhead and also owns and maintains the dam and appurtenant structures. When full, Lake Arrowhead holds 230,359 acre-ft (more than 75 bil gal) of water. Storage over time for Lake Arrowhead is shown in Figure 2.

While the Lake is currently 100 percent full, as of Dec. 21, 2015, the situation was much different only seven months prior, when the drought was at its worst. In April 2015, the Lake was only 19 percent full—the lowest levels since deliberate impoundment. Following torrential rainfall that was experienced across Texas in May and June 2015, the drought was broken and the lake dramatically rebounded to 100 percent of the conservation pool.

Water Quality Standards

Lake Arrowhead is considered to be suitable for primary contact recreation, high aquatic life, and domestic public water supply uses. The corresponding Texas water

quality standards are shown in table format in Figure 3.

In addition to TDS, water quality criteria are established for sulfate and chloride, which are considered individual constituents of TDS. These parameters are typically evaluated when they are determined to be a potential concern. For Lake Arrowhead, based on the limited available data, there was no reason to consider either parameter a potential concern; thus, the analysis focused on TDS only. As noted previously, one of the major concerns raised early on by TCEQ was related to the potential need for TDS limits. The TCEQ has an established screening process to evaluate WWTP discharges to a classified lake as defined in its implementation procedures (2011) and has incorporated these procedures into a series of screening spreadsheets.

To evaluate the discharge from the River Road WWTP into Lake Arrowhead, the TCEQ implementation procedures dictate that the effluent load is calculated based on the effluent TDS concentration (CE) and the effluent fraction (EF) at the edge of the human health (HH) mixing zone, based on critical conditions. Then, the concentration at the edge of the mixing zone within the lake is calculated based on the ambient TDS concentration (CA). These values are then compared to the TDS criterion (CC) as shown in Equation 1:

Equation 1

$$CC \geq (EF) * (CE) + (1 - EF) * (CA)$$

A permit limit may be assigned if the effluent concentration is more than 70 percent of the estimated daily average TDS in the lake, which is defined in Equation 2:

Equation 2

$$\text{Daily Average} = \frac{[CC - (1 - EF) * (CA)] * 1.37}{EF}$$

Therefore, the permit limit evaluation requires an understanding of ambient water quality, the effluent water quality, and the mixing characteristics within the lake.

Ambient Water Quality

Water quality in Lake Arrowhead is monitored frequently by TCEQ. The primary monitoring point is near the city's raw water intake at monitoring station 10142. The TDS has been monitored in Lake Arrowhead since the early 1970s and the TDS values over time are shown in Figure 4.

The TCEQ screening procedures include recommended site-specific values for TDS concentrations, among other parameters. The values for TDS are typically based on the median concentration for the segment. In some cases, the state chose to use a conversion between specific conductance and TDS to supplement the dataset used to calculate the median TDS concentration, which for the Lake Arrowhead segment was calculated to be 494 mg/L. This is shown in Figure 4 as a solid red line. This value, however, is not representative of recent ambient conditions. Additionally, using this value in a permit screening evaluation would not provide adequate assimilative capacity for the proposed discharge.

Fortunately, the implementation procedures allow the permittee to propose an alternative ambient TDS concentration based on the most recent five years of TDS in the water

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quality monitoring database. This value of 360 mg/L is shown in Figure 4 as a red dashed line, and is more representative of current lake water quality and was therefore used in the permit screening evaluation.

Effluent Total Dissolved Solids Characteristics

As previously discussed, the city maintains the River Road WWTP, located north of Arrowhead Lake on the Little Wichita River. Historically, the plant has been permitted to discharge a daily average of up to 19.91 mil gal per day (mgd) to the river and a two-hour peak flow of 43.86 mgd. The plant uses an activated sludge process with fine bubble diffusion, followed by chlorination, dechlorination, and re-aeration. For permitting of the new indirect potable reuse discharge to Lake Arrowhead, a maximum flow of 16 mgd was requested.

Wastewater effluent monitoring data were collected by the city from August to No-

vember 2012 to support the IPR permitting efforts. Based on that monitoring, TDS concentrations ranged between 640 and 937 mg/L, with a median TDS concentration of 721 mg/L.

Mixing Characteristics

Based on TCEQ screening evaluations, using the ambient TDS concentrations and effluent flow and TDS concentration, it was determined that the discharge needs to achieve an EF of 0.09 or greater to ensure adequate mixing within the lake and obviate the need for a TDS permit limit. To achieve the required mixing, a diffuser has been proposed at the end of the WWTP outfall.

The CORMIX model, which is a U.S. Environmental Protection Agency (USEPA)-supported mixing zone model and decision support system for environmental impact assessment of regulatory mixing zones resulting from continuous point source discharges, is most commonly used to design diffusers and

evaluate mixing near outfalls, and this model was applied to evaluate conditions from the River Road WWTP into Lake Arrowhead and propose an initial diffuser design.

The CORMIX model input includes the following categories:

- ◆ Ambient conditions defining the current, density, and water depth conditions at the outfall structure.
- ◆ Effluent characteristics, including density and discharge rate.
- ◆ Configuration of outfall diffuser, including the discharge orientation and dimensions.

The ambient conditions evaluated in the diffuser design included normal pool elevation of the lake (826 ft), which corresponds to a lake depth of 30 ft at the diffuser location. Runs were also conducted at a historically low water level of 912 ft, which corresponds to a lake depth of 16 ft to evaluate the mixing under low water conditions. For both lake level conditions, runs were conducted for summer and winter water density conditions, considering both the 5th and 95th percentile seasonal values based on available lake data. For the winter condition, there was little variation between top and bottom values, and therefore, an unstratified condition was evaluated. In contrast, the summer data did show some stratification and so separate density values for top and bottom water were specified.

Several effluent flow rates for the diffuser design were considered, ranging from 10 mgd, which is reflective of current discharge rate, to 20 mgd, which is the permitted flow rate for the original WWTP. The buildout flow rate was used in the design of the diffuser. The effluent density for winter and summer were calculated based on the average measured TDS concentration of the effluent (721 mg/l) and the average seasonal effluent temperature (18.3°C in winter, 28.2°C in summer).

Configuration of Outfall Diffuser

The diffuser that was designed for the outfall discharge includes the following characteristics:

- ◆ *Port openings.* The number and size of port openings were established such that the velocity of discharge from each port is less than 8 ft/s for a 20 mgd discharge. The resulting design included five openings, each with a 12-in. (0.305 meter) diameter.
- ◆ *Port opening orientation.* To avoid bottom scour by the effluent jets, the port openings are directed upward at a 45 degree angle to the lake bottom.

Figure 3. Water Quality Standards for Lake Arrowhead

Parameter	Criterion
TDS	500 mg/L
Sulfate	50 mg/L
Chloride	250 mg/L
Dissolved oxygen	5.0 mg/L
pH range	6.5 to 9 standard units
Indicator bacteria (<i>E. coli</i>)	126 cfu per 100 mL
Chlorophyll <i>a</i>	In negotiation with US EPA

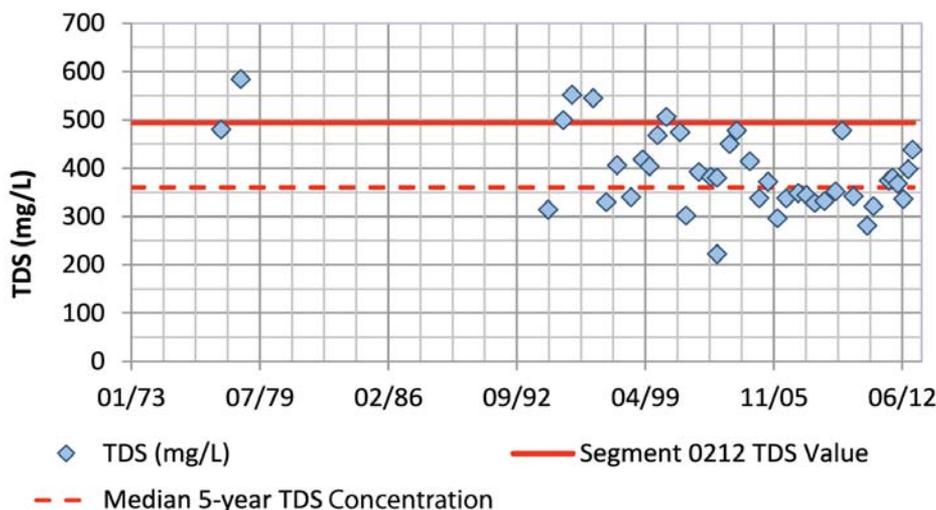


Figure 4. Total Dissolved Solids Values in Lake Arrowhead

- ◆ **Diffuser length.** To accommodate these openings, a diffuser length of 30 ft (4 meters) was established.
- ◆ **Diffuser location.** The diffuser is located about 1100 ft offshore, where the lake bottom elevation is between 898 and 899 ft National Geodetic Vertical Datum (NGVD). Accounting for revetment of the lake bottom with a riprap pad, the pipe invert elevation is assumed to be at 899 ft NGVD 29.
- ◆ **Diffuser orientation.** The diffuser is mounted horizontally above the lake bed such that the ports discharge downstream towards the dam.
- ◆ **Diffuser pipe diameter.** A pipe diameter of 36 in. (0.92 meters) would be appropriate for conveying the flow and distributing flow among the ports.

When a diffuser is implemented, it is anticipated that the mixing zone will be rectangular in shape and centered about the diffuser, as shown in Figure 5. In this case, with the diffuser directing the discharge away from the diffuser in a parallel direction to the lake shoreline, the rectangular mixing zone was assumed to begin at the diffuser and extend downstream, with dimensions specified such that the width of the rectangle represented a downstream distance and the length of the rectangle represented the diffuser length plus twice the downstream distance.

The model results were evaluated to determine the minimum amount of dilution at the edge of the mixing zone.

Model Results

The model results for the CORMIX simulations are summarized in table format in Figure 6. For each simulation, the table presents the EF for each mixing zone. The value of EF is the inverse of the dilution value S that is presented in the CORMIX output. For example, a CORMIX output value of 2 represents a condition with one part effluent and one part ambient lake water, which would be equivalent to an EF value of half, or 0.5.

In the table, both the winter- and summer-month evaluations included consideration of the following scenarios for establishing the range of EF values:

- ◆ 5T or 95T = based on 5th or 95th percentile water temperature
- ◆ 5S or 95S = based on 5th or 95th percentile salinity (calculated from TDS)
- ◆ Q1-Q3 = effluent flow (Q1 = 10, Q2 = 16.49, Q3 = 19.91 mgd)

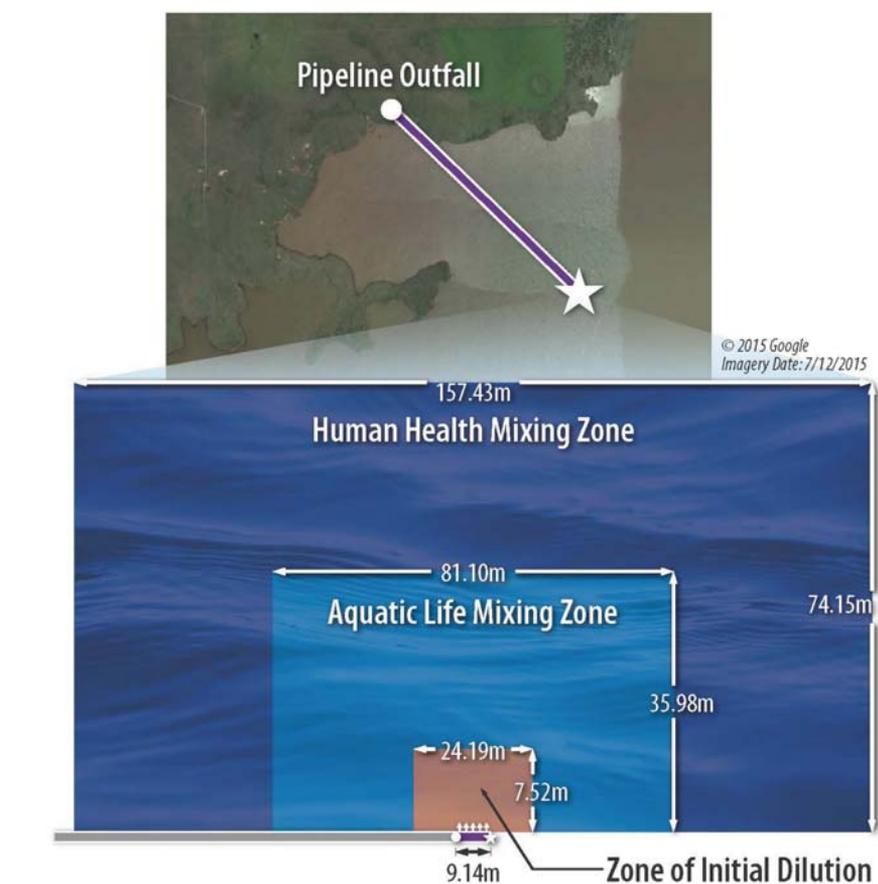


Figure 5. Lake Arrowhead Proposed Diffuser Location and Regulatory Mixing Zones

Figure 6. Lake Arrowhead CORMIX Results Summary

CORMIX Scenario	Range of Calculated Effluent Fraction (EF) at Mixing Zone Boundary		
	ZID	AL	HH
Winter Runs at Normal Pool Elevation	0.104 – 0.105	0.072- 0.073	0.056
Summer Runs at Normal Pool Elevation	0.104 – 0.105	0.072- 0.073	0.056
Winter Runs at Historically Low Pool Elevation	0.143 – 0.205	0.099	0.076
Summer Runs at Historically Low Pool Elevation	0.143	0.099	0.076

The table presents EF values at the downstream end of the mixing zone, as results showed that the dilution at that point was the critical value (i.e., dilution at the point that the plume passes through the rectangular mixing zone either to the left or right of the diffuser was greater than the downstream dilution).

The table shows that the modeled dilution (EF) at the edge of the HH mixing zone is always greater than the required mixing based on the screening evaluation. For both summer

and winter conditions, there is little or no difference in results for the different ambient conditions and different WWTP flows.

When the low lake depth is considered, the modeled EF value for the AL and HH mixing zones is greater than corresponding values with the lake at normal pool elevation. However, the resulting EF values are still achieving the required mixing based on the screening spreadsheet.

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Project Takeaways

There were several key lessons learned throughout the project that may be useful to others facing similar permitting challenges. First, site-specific data is key to ensure that the data sets are representative of the current ambient water quality. Another key lesson is that mixing models are important tools for the evaluation process. Through the use of the CORMIX model, the project team was able to demonstrate that proper mixing was achieved during both normal pool and historic low pool elevations. This provided confidence that the discharge will be protective of HH and aquatic life based on standards that have been set by TCEQ. Finally, maintaining open

lines of communication with the regulators helps ensure clear understandings and can increase project success. For this project, the magnitude of the drought required quick reaction times. Close coordination with regulators provided the opportunity to hear feedback prior to the evaluations being completed, and this helped advance the process more quickly.

Employing advanced analytical and modeling methodologies to evaluate the need for a permit limit for a discharge from the River Road WWTP into Lake Arrowhead for the purposes of indirect potable reuse helped the city avoid TDS permit limits on the discharge. The potential for a TDS limit to be imposed on this discharge would have required membrane treatment and caused the IPR strategy to become too expensive, putting

the future water supply for the city at risk. The process used by the project team to successfully negotiate and avoid TDS permit limits on the discharge allowed the IPR project to move forward at a critical time while under extreme drought conditions. It has also served to improve the reliability and resilience of the city's water supply.

References

- Texas Commission on Environmental Quality, 2011. Procedures to Implement the Texas Surface Water Quality Standards. RG-194.
- Texas Water Development Board, 2015. Lake Arrowhead. <<<http://www.twddb.state.tx.us/surface-water/rivers/reservoirs/arrowhead/ndex.asp>>. Accessed Dec. 19, 2015. ◊