TECHNICAL MEMORANDUM

Task 2: Wasteload Allocation Study

Wastewater Treatment Plant Discharge Permit

(OPDES Permit No. OK0037893)

City of Shawnee, Oklahoma

Prepared For:

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CITY OF SHAWNEE, OKLAHOMA

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1.0 INTRODUCTION AND BACKGROUND

This Wasteload Allocation (WLA) study is based on the ODEQ-approved approach put forth in the WLA Scoping Study (S2E/Tetra Tech, 2020) which recommended using a QUAL2K model to determine the water quality impacts of planned changes to the City of Shawnee treated wastewater discharges to the North Canadian River. The City of Shawnee currently discharges its treated wastewater effluent at two locations along the North Canadian River - Southside (NPDES ID OK0026051, Facility ID S-20548) and Northside (NPDES ID OK0037893, Facility ID S-20590) Wastewater Treatment Plants (WWTPs), operated by the Shawnee Municipal Authority (Figure 2).

As part of the proposed changes, the City intends to cease effluent discharge at the Southside WWTP while increasing discharge at the Northside WWTP. Existing permitted flow limits at the Southside and Northside outfalls are 3 million gallons per day (MGD) each. The proposed effluent flow limit for the Northside outfall is 4.5 MGD, reflecting a net decrease in total permitted flow for the City of 1.5 MGD due to the elimination of the Southside discharge. In other words, the total permitted flow will be decreasing from 6 MGD to 4.5 MGD. The City intends for this WLA study to aid DEQ in its decisions pertaining to its National Pollution Discharge Elimination System (NPDES) permit modification for the Northside facility, and for amending the Oklahoma Water Quality Management 208 Plan.

The Northside facility discharges into the North Canadian River approximately 5 kilometers downstream of the crossing of I-40, northeast of Shawnee (Figure 1). The North Canadian River in the vicinity of the Northside WWTP outfall (Waterbody ID OK520510000110 - North Canadian River from State Hwy 377/99 Bridge to Portland Street Bridge, Oklahoma City) is classified for the following beneficial uses: Aesthetics, Agriculture, Recreation (Primary Body Contact), Water Supply (Emergency Water Supply), and Fish and Wildlife (Warm Water Aquatic Community; WWAC). Based on the WWAC categorization of this portion of the North Canadian River, specific seasonal water quality standards apply relative to minimum dissolved oxygen (DO) concentrations (Table 1).

The WLA analyses conducted in this report are focused on the proposed changes at the Northside WWTP and the ability of the North Canadian River to demonstrate assimilative capacity for dissolved oxygen demanding substances in meeting seasonal water quality standards. QUAL2K modeling efforts were not fully calibrated, however available data was used to help setup and check reasonableness of results and an appropriate margin of safety (MOS) of 20% is included to account for uncalibrated model.

Table 1. Dissolved Oxygen Criteria to Protect Fish and Wildlife Propagation for Warm Water Aquatic Community Subcategory (OK Water Quality Standards, Chapter 45).

Fishery Class	Dates Applicable	Minimum DO Criteria (mg/l) ***	Seasonal Temperature (C)
Early Life Stages (Spring)	4/1 – 6/15	6.0 *	25 **
Other Life Stages: Summer Conditions	6/16 – 10/15	5.0 *	32
Other Life Stages Winter Conditions	10/16 – 3/31	5.0	18

* Because of natural diurnal DO fluctuation, a 1.0 mg/l DO concentration deficit shall be allowed for not more than eight (8) hours during any twenty-four (24) hour period.

** Discharge limits necessary to meet summer conditions will apply from June 1 of each year. However, where discharge limits based on Early Life Stage (Spring) conditions are more restrictive, those limits may be extended to July 1.

*** DO shall not exhibit concentrations less than the criteria magnitudes expressed above in greater than 10% of the samples as assessed across all life stages and seasons.

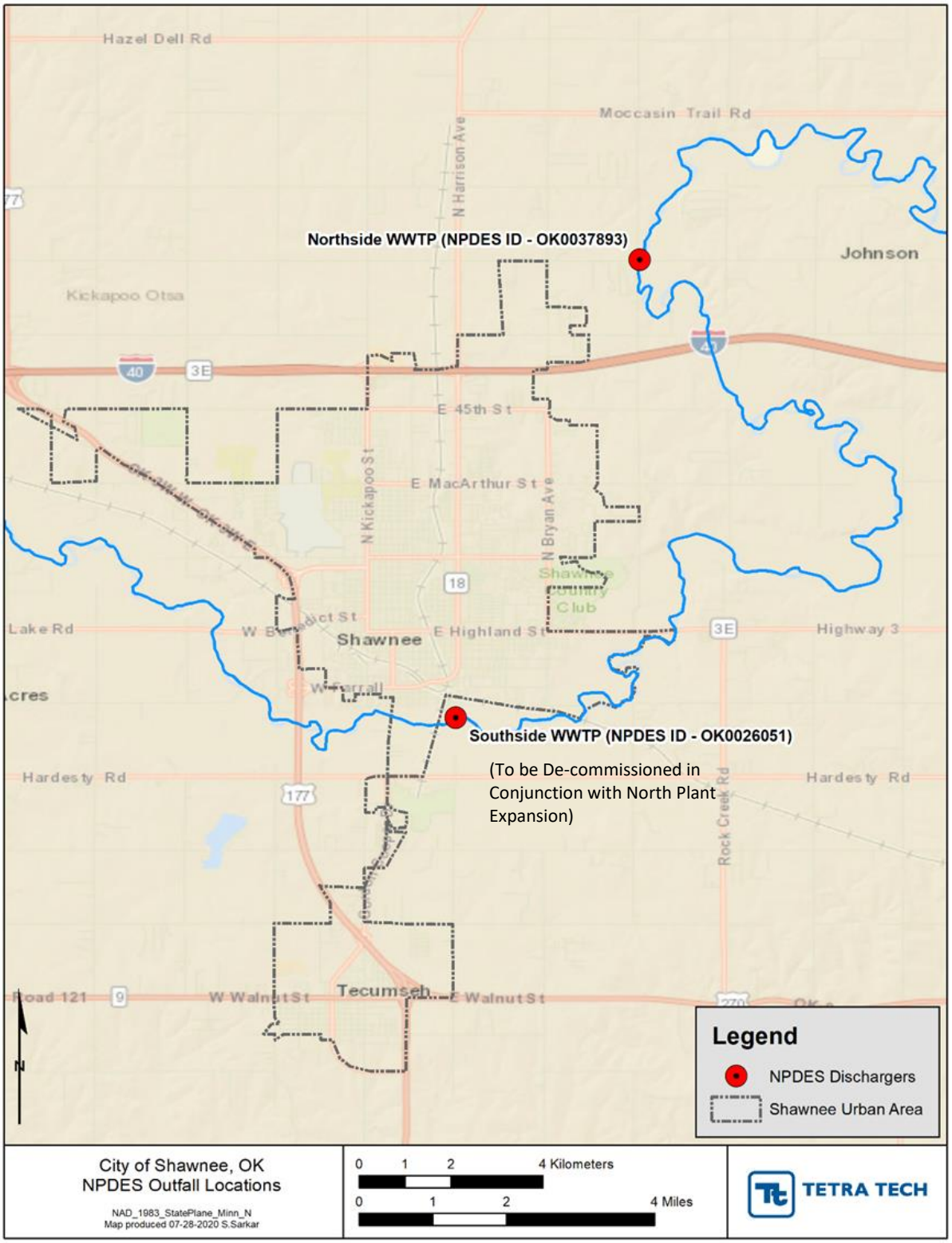

Figure 1. Location of Existing Southside and Northside WWTP Outfall Locations.

2.0 QUAL2K MODEL SETUP

For this WLA application, the primary modeling objective is to establish waste load allocations for biochemical oxygen demand (BOD) and ammonia relative to maintaining the DO criteria below a single source discharge. For these parameters, Oklahoma standards apply under seasonal steady-state low flow conditions. Given the single point of discharge and steady-state conditions of interest, a relatively simple QUAL2K model was developed for critical conditions in each regulatory season, macro-level calibration was performed, and the WLA study was conducted.

The QUAL2K model is a one-dimensional steady-state river water quality model specifically designed for applications such as the waste load allocation studies needed for Shawnee (Chapra et al., 2012). QUAL2K was developed as a modernized and updated version of QUAL2E (Brown and Barnwell, 1987). The model has been extensively peer-reviewed and is supported nationally by the United States Environmental Protection Agency (USEPA). QUAL2K assumes well-mixed stream channels (both vertically and laterally) and can employ a diel, or 24-hour period, heat budget. DO processes in QUAL2K are based on the Streeter-Phelps model but also include implicit calculation of reaeration rate, temperature effects on BOD decay and reaeration, sediment oxygen demand and phytoplankton photosynthesis and respiration.

The key model inputs required for building a desktop level QUAL2K model to support WLA studies for Shawnee are summarized below.

2.1 MODEL EXTENT

The Northside WWTP is located along and near the upstream end of Oklahoma stream reach OK520510000110_05, a 21.91-mile stretch of the North Canadian River that extends from just north of I-40 east of Shawnee to OK-99. This entire stream reach was selected as the QUAL2K model extent as it begins just upstream of the Northside outfall and extends more than sufficiently needed downstream to capture the potential impact on water quality (i.e., DO sag).

2.2 MODEL SEGMENTATION AND REACH HYDRAULICS

The QUAL2K model extent of the North Canadian River was segmented for simulation at inflow points of five small tributaries. Reach characteristics are summarized in Table 2.

Cross-sections for the modeled reaches were based on the Federal Emergency Management Agency (FEMA) Hydrologic Engineering Center (HEC) River Analysis Package (RAS) model effective May 5, 2014 (FEMA Case Number 11-06-2177S Product CID 40063-Hughes County-wide). Selected cross-sections in the HEC-RAS model in the QUAL2K model extent (Figure 3) were extracted and converted to idealized trapezoidal cross-sections. For a given HEC-RAS cross-section, the bottom width and side slope for the equivalent trapezoidal cross-sections were determined by setting the top width, hydraulic depth and wetted perimeter of the trapezoid equal to those reported by HEC-RAS for the lowest flow rate (10-year return interval storm). Reach lengths were determined in GIS, and longitudinal slopes for each reach were calculated using the HEC-RAS model cross-sections based on surveyed channel bed elevations. The channel-weighted Manning's constant reported by HEC-RAS for each cross-section was used in the QUAL2K model. Dimensions of the trapezoidal and physical properties of the model reaches in the QUAL2K model are summarized in Table 2.

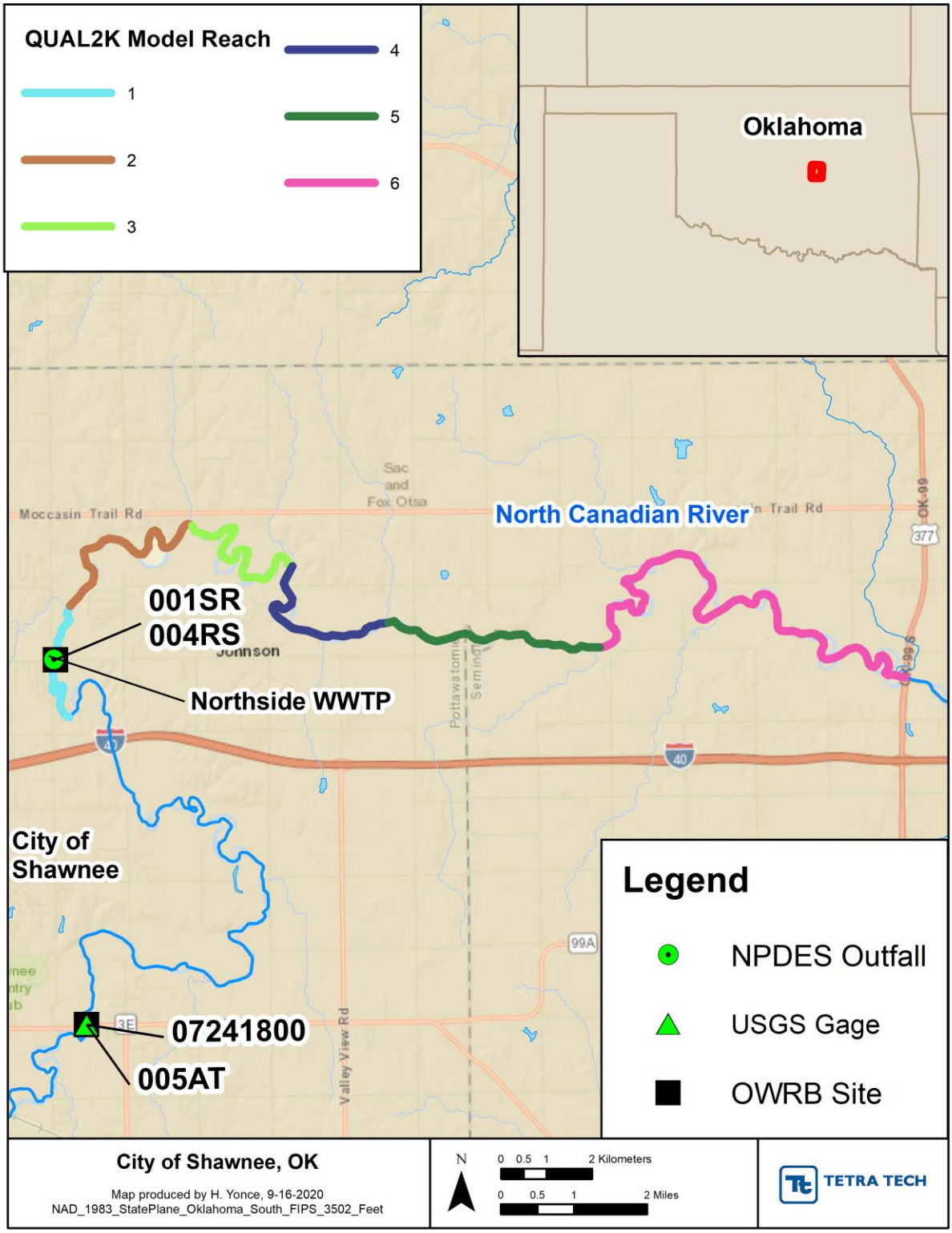

Figure 2. QUAL2K Model Extent of the North Canadian River near Shawnee, Oklahoma.

Table 2. QUAL2K Model Segmentation and Hydraulic Inputs.

Reach	Description	Length (km)	Channel Slope (ft/mi)	Manning's n	Bottom Width (m)	Side Slopes (ft/ft)
1	I-40 to Rock Creek	3.82	1.48	0.05	89.1	1.85
2	Rock Creek to Squaw Creek	6.10	2.60	0.05	136.0	1.59
3	Squaw Creek to Stamp Dance Creek	5.76	1.81	0.05	92.1	2.42
4	Stamp Dance Creek to Painter Creek	5.35	2.73	0.05	68.9	2.76
5	Painter Creek to Deer Creek	6.14	2.44	0.05	54.7	6.67
6	Deer Creek to OK-99	16.18	2.49	0.05	51.2	3.56

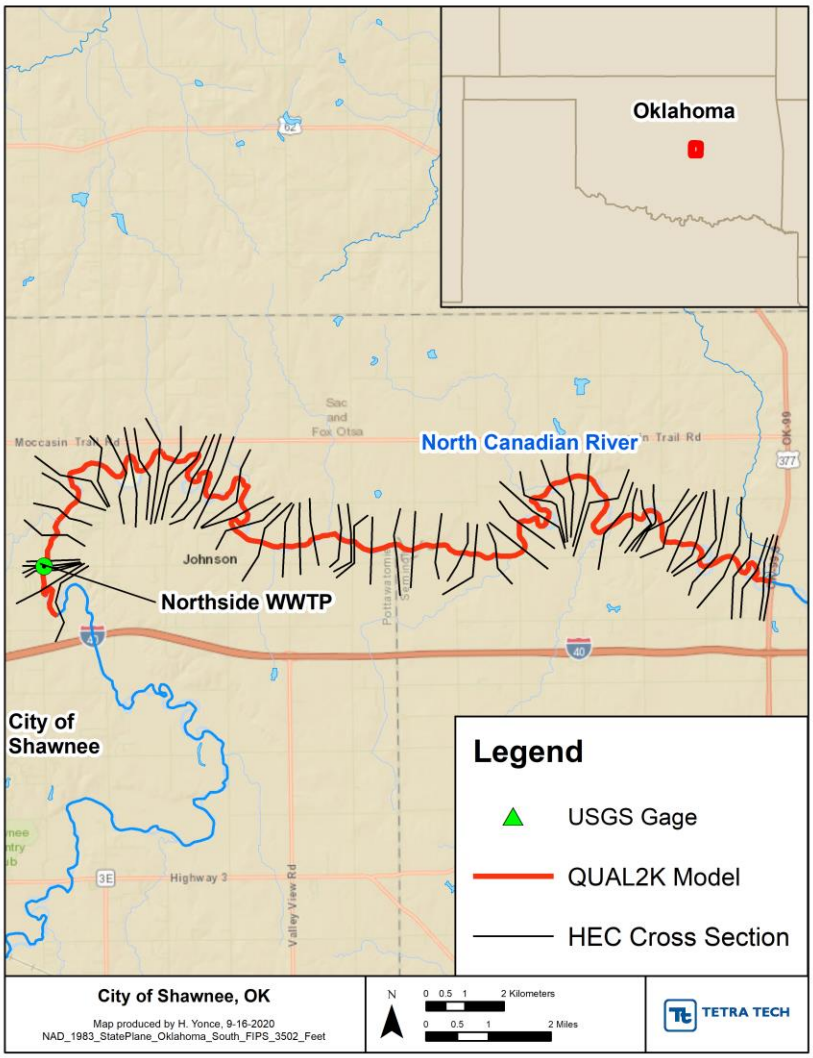

Figure 3. FEMA HEC Cross-Sections within the QUAL2K Model Extent.

2.3 CRITICAL CONDITIONS

As specified in the Oklahoma Water Quality Standards (OK WQS) [Oklahoma Water Resources Board, 1991, Chapter 45], critical conditions are defined as both critically low flows and critically warm temperatures for each season. Seasonal temperatures for Warm Water Aquatic Community fishery classes are 25 °C, 32 °C, and 18 °C for spring, summer, and winter periods respectively. These seasonal temperatures were used directly for the seasonal model inputs for water temperature boundary conditions. Simulation dates for the three seasonal QUAL2K models were selected as the approximate central date of the spring and summer periods during which each water quality standard is applied for the Warm Water Aquatic Community fishery class (May 1 and August 1, respectively). November 1 was selected for the winter as being more reflective of likely critical flow and temperature conditions as specified by the OK WQS.

Seasonal low-flow conditions are defined as the seasonal seven-day, two-year low flow (7Q2) statistics which identify the 7-day low flow of a stream likely to occur with a 50% probability each year. With continuous USGS gage flow data from North Canadian River at Shawnee, OK (07241800), the USGS Stormwater Toolbox (SWToolbox; Kiang et al., 2018) was used to calculate seasonal 7Q2 flows. Calculations were made using full seasons of record 2001 – 2019 (Table 3). Seasonal 7Q2 flows were calculated as 175 cfs for spring, 96 cfs for summer, and 113 cfs for winter. Under these three flow conditions, the Northside WWTP proposed flow of 4.5 MGD represents 4%, 7%, or 6% of the total streamflow during each respective season. The SWToolbox output files associated with the 7Q2 flow analysis are included in Appendix A.

Table 3. Seasonal Critical Conditions Based on Protection of Fish and Wildlife Propagation for Warm Water Aquatic Community Subcategory (OK Water Quality Standards, Chapter 45).

Season	Fishery Class	Dates Applicable	QUAL2K Simulation Date	Minimum DO WQS (mg/l)	Seasonal Critical Temperature (°C)	Seasonal 7Q2 (cfs)
Spring	Early Life Stages	4/1 – 6/15	May 1	6	25	175
Summer	Other Life Stages	6/16 – 10/15	August 1	5	32	96
Winter	Other Life Stages	10/16 – 3/31	November 1	5	18	113

2.4 METEOROLOGICAL FORCING AND SHADE

The seasonal critical temperatures of 25°C, 32°C, and 18°C were applied as air temperature to each seasonal model. Dew point temperature inputs were approximated based on air temperatures to ensure that instream water temperatures stayed at the seasonally specific critical temperatures. Inputs for wind and cloud cover are typically assumed to be zero under critical conditions. Inputs for stream shading (which is interpreted by QUAL2K as shading of the stream centerline) are also assumed to be zero as this portion of the North Canadian River appears almost entirely unshaded based on aerial imagery due to topography, and stream channel width, and lack of significant riparian vegetation.

However, because receiving stream ambient data indicate that photosynthetic activity is frequently responsible for increasing DO levels instream, there is justification to assume that a cloudy and/or shaded condition may be more representative of critical conditions when the photosynthetic response is dampened. This appears to be the case for this section of the North Canadian River due to the observed DO supersaturation particularly during the summer period, therefore cloud and shade were introduced for all seasonal critical condition simulations (see Section 4 Model Applications for details).

2.5 BOUNDARY CONDITIONS

Flow at the headwaters of the modeled segment of the North Canadian River drives the boundary conditions for this application of the QUAL2K model. The seasonal 7Q2 flows calculated for the USGS gage 07241800 were applied at the headwaters of the modeled segment. Additionally, by area-weighting the 7Q2 flows to the downstream end of the model, it was determined that the overall impact of groundwater and small tributary inflows to this portion of the North Canadian River are negligible (approximately 1% of total flow) during critically low flow conditions and are therefore not simulated.

Water quality conditions associated with the headwaters were developed largely using the Oklahoma Water Resources Board (OWRB) sampling site co-located with USGS gage 07241800, site 520510000110-005AT ("005AT"; North Canadian River, SH 3E, Shawnee). This site is part of the State's Beneficial Use Monitoring Program (BUMP), with 85 sampling dates from 2002 – 2012. BUMP data were not available after 2012. The USGS gage site has water quality sampling for 6 dates in 2012. Average water quality concentrations for measured constituents were used to parameterize the headwaters for QUAL2K (Table 4).

In the absence of field data, background concentration of ultimate carbonaceous biochemical oxygen demand ($CBOD_{ult}$) was approximated using the Streeter-Phelps equation recommended by the QUAL2K User's Manual (Chapra, 2012). The equation approximates $CBOD_{ult}$ as a function of $CBOD_5$ and CBOD decay rate: $CBOD_{ult} = CBOD_5 / (1-\exp(-k \times 5))$, such that k is 0.3 and $CBOD_5$ is recommended by ODEQ to be 2 mg/l. Based on these inputs, $CBOD_{ult}$ for the headwaters was input as 2.57 mg/l. In the absence of instream CBOD data, all CBOD forms in the model were represented as a single pool using the parameter fastCBOD, which is characteristic of rapidly-oxidizing (i.e., labile) CBOD.

Table 4. Headwater inputs for each seasonal QUAL2K Model.

Input Parameter	Spring	Summer	Winter	Rationale
Flow (cfs)	175	96	113	Seasonal 7Q2 calculated with USGS SWToolbox
Temperature (°C)	25	32	18	Seasonal Temperature from OK WQS Chapter 45
Dissolved Oxygen (mg/l)	7.68	6.24	7.45	Seasonal 25th percentile DO saturation at OWRB site 005AT applied to seasonal critical temperatures (spring 93%, summer 86%, winter 79%).
Conductivity (µmhos)	825	830	898	Seasonal average observed at OWRB site 005AT
fastCBOD (mg/l)	2.57	2.57	2.57	Assumed background concentration of 2 mg/l $CBOD_5$ converted to $CBOD_{ult}$
Ammonia (µg/l)	141	119	245	Seasonal average observed at OWRB site 005AT
Organic N (µg/l)	2115	1979	1522	Seasonal average observed TKN minus NH3 at OWRB site 005AT
Nitrate (µg/l)	1719	1611	3935	Seasonal average observed at OWRB site 005AT
Organic P (µg/l)	380	447	467	Half of seasonal average observed TP at OWRB site 005AT
Inorganic P (µg/l)	380	447	467	Half of seasonal average observed TP at OWRB site 005AT
Inorganic Suspended Solids (mg/L)	95	71	30	80% of seasonal average observed TSS at OWRB site 005AT
Detritus (mg/l)	24	18	7	20% of seasonal average observed TSS at OWRB site 005AT

Input Parameter	Spring	Summer	Winter	Rationale
Phytoplankton (µg/l)	124	106	58	Seasonal average observed at OWRB site 005AT
Alkalinity (mg/l)	193	154	192	Seasonal average observed at OWRB site 005AT
pH	8.38	8.47	8.05	Seasonal average observed at OWRB site 005AT

2.6 RATES AND KINETICS

Reaeration was simulated in QUAL2K using a user-defined formula of the "Texas Equation" which ODEQ prefers to apply for "larger streams" with flow over approximately 3 cfs: Reaeration Rate (K2) = 4.022 x Velocity ^ 0.273 / Depth ^ 0.894 (Long, 1984).

Sediment oxygen demand (SOD) was simulated as the rate 0.11 g/ft^2/d (1.18 g/m^2/d) which is the ODEQ-recommended literature-based instream approximation in the absence of SOD field measurements.

All other rates and kinetics were largely held to QUAL2K model default values, except for phytoplankton growth, respiration, and death rates which were parameterized as part of the macro-level calibration process outlined in Section 3 below.

2.7 POINT SOURCE INPUTS

The Northside WWTP provides secondary treatment using conventional extended aeration. The WWTP is currently permitted to discharge a maximum of 3 MGD of treated effluent. The existing effluent discharge permit limits are summarized by monitored parameter in Table 5 alongside the average monthly mean conditions by season as shown in the facility's discharge monitoring reports (DMRs) acquired from the USEPAs Integrated Compliance Information System (ICIS).

DMR data include average monthly flow and concentrations for the permitted parameters such as flow, five-day biological oxygen demand (BOD_5), five-day carbonaceous biological oxygen demand ($CBOD_5$), ammonia (NH_3), pH, and total suspended solids (TSS). Note that there is currently no NH3 limit from November – May, and parameters such as total phosphorus (TP) and DO are not regulated and are therefore not monitored and reported. The months summarized for each season were determined based on guidance provided in the Continuing Planning Process document (ODEQ, 2012).

Table 5. Seasonal Summary of Discharge Monitoring Report Data for Northside WWTP (Average of Monthly Mean by Parameter for 2015-2019) and Seasonal Permit Limits.

Parameter	Spring		Summer		Winter	
	Permit Limit (4/1 – 6/15)	Average (Apr – May)	Permit Limit (6/16 – 10/15)	Average (Jun – Oct)	Permit Limit (10/16 – 3/31)	Average (Nov -Mar)
BOD_5 (mg/l)	30.0	4.1	N/A	N/A	30.0	3.9
$CBOD_5$ (mg/l)	N/A	N/A	20.0	2.4	N/A	N/A
Flow (MGD)	3.0	1.8	3.0	1.5	3.0	1.2
NH_3 (mg/l)	No limit	1.8	10.0	0.9	No limit	0.8

Parameter	Spring		Summer		Winter	
	Permit Limit (4/1 – 6/15)	Average (Apr – May)	Permit Limit (6/16 – 10/15)	Average (Jun – Oct)	Permit Limit (10/16 – 3/31)	Average (Nov -Mar)
pH (s.u.)	6.5 – 9.0	7.2	6.5 – 9.0	7.1	6.5 – 9.0	7.1
TSS (mg/l)	30.0	5.3	30.0	3.3	30.0	4.6

QUAL2K model inputs for the Northside WWTP were setup based on the existing permit limits for water quality constituents and an expanded flow, increased from 3 MGD to 4.5 MGD as proposed. For water quality parameters not permitted or monitored, assumptions were made based on literature values for WWTPs of this size and treatment type (EPA 1995). Despite the effluent flow increase modeled, the overall loads to the North Canadian River associated with these assumptions will be decreased because of the elimination of the currently permitted 3 MGD from the Southside facility.

$CBOD_{ult}$ concentrations associated with the effluent were approximated using the Streeter-Phelps equation as described in the Boundary Conditions Section 2.5. BOD_5 and $CBOD_5$ permit limits are 30 and 20 mg/l respectively depending on the time of year. As detailed in the Continuing Planning Process document, a BOD_5 limit of 30 mg/l is to be treated equivalent as a $CBOD_5$ limit of 25 mg/l (ODEQ, 2012). Using the Streeter-Phelps equation and a rapidly oxidizing CBOD decay rate of 0.3 /d, $CBOD_{ult}$ permit limits for QUAL2K model input are 32.18 and 25.74 mg/l respectively.

Table 6. Summary of QUAL2K Model Inputs for Northside WWTP.

Input Parameter	Spring	Summer	Winter	Rationale
Flow (MGD)	4.5			Proposed flow expansion
fastCBOD (mg/l)	32.18	25.74	32.18	Based on permitted monthly average maximum BOD_5 (Nov to May) is 30 mg/l, and $CBOD_5$ (Jun to Oct) is 20 mg/l.
Ammonia (mg/l)	20	10	20	Permit limit for ammonia for summer. No permit limit exists currently for spring and winter; conservatively assumed to be double that of summer.
Organic N (mg/l)	7.1			Approximate median effluent concentrations based on treatment level from literature, specifically examples provided related to “activated sludge” and “activated sludge/nitrification, single stage” treatment types as summarized from various literature sources in the *Technical Guidance Manual for Developing Total Maximum Daily Loads* (USEPA, 1995)
Nitrate (mg/l)	7.9			
Organic P (mg/l)	1.2			
Inorganic P (mg/l)	4.6			
Inorganic Suspended Solids (mg/l)	15			Permit limit for TSS of 30 mg/l split 50/50 as inorganic and organic particulate matter.
Detritus (mg/l)	15			
Dissolved Oxygen (mg/l)	0	0	0	Conservative assumption in the absence of a DO permit limit
Temperature (°C)	25	32	18	Seasonal Temperature from OK WQS Chapter 45

3.0 MACRO-LEVEL CALIBRATION

In order to check the reasonableness of this QUAL2K model setup, a macro-level calibration was performed based on observed conditions instream. Instream DO conditions observed at OWRB site 005AT (upstream of the Northside facility) and site 004RS (near the Northside facility discharge location) were compared to identify patterns that the model could be set up to replicate. There were 12 instances from 2002-2003 where sampled DO and DO saturation at these two sites were conducted on the same date at similar times. The median difference in DO between these two sites was 0.1 mg/l, while the median difference in DO saturation was 0.8 percent. Based on this analysis, phytoplankton parameters were approximated to ensure that the same general DO concentrations are simulated along the model extent such that simulated reaeration, SOD, and phytoplankton are in equilibrium based on observed DO levels.

A summer date was selected from the paired-DO sampling analysis for a macro-level calibration effort. August 12, 2002 was selected as the recorded flow recorded at the USGS gage was 91.3 cfs which is very close to the summer 7Q2 flow of 96 cfs. DO was measured at 12.82 mg/l (DO saturation 170.5 percent) at site 005AT and 10.97 mg/l (DO saturation 142.8 percent) at site 004RS. Since these samples were taken around 12:30-1:00pm when DO levels are likely near daily maximum, headwater inputs for this model run were setup based on the median DO saturation observed for all summer data, which was 98 percent. For the observed water temperature at site 005AT on 8/12/2002 of 28 °C, average DO at the headwaters was set to 8.88 mg/l based on these assumptions of DO saturation and water temperature.

The Southside WWTP discharge was present for this simulation date, and its impact on instream flow and water quality is captured implicitly by the USGS gage and site 005AT which are downstream of that site. The Northside WWTP discharge is simulated for this model run using long-term seasonal average effluent concentrations.

Meteorological inputs for this simulation were based on historical climate date available from Weather Underground (wunderground.com). Conditions on this date included an average air temperature of 27 °C, dew point of 20 °C, and partly cloudy conditions which were input to the model as 50 percent cloud cover. Assumptions for wind and stream shade were both set to zero.

All hydraulics, rates, and kinetics were setup as they were for the seasonal critical models, while phytoplankton parameters were considered the focus for the macro-level calibration—the rates for which would be applied for all subsequent seasonal critical condition WLA applications.

Table 7. Headwater inputs for the macro-level calibration model.

Input Parameter	Input	Rationale
Flow (cfs)	91.3	Flow observed at USGS gage on 8/12/2002
Temperature (°C)	28	Observed at OWRB site 005AT on 8/12/2002
Dissolved Oxygen (mg/l)	8.88	Seasonal median percentile DO saturation 98% at OWRB site 005AT applied to water temperature.
Conductivity (µmhos)	823	Observed at OWRB site 005AT on 8/12/2002
fastCBOD (mg/l)	2.57	Assumed background concentration of 2 mg/l $CBOD_5$ converted to $CBOD_{ult}$

Input Parameter	Input	Rationale
Ammonia (µg/l)	100	Observed at OWRB site 005AT on 8/12/2002
Organic N (µg/l)	3020	Observed TKN minus NH3 at OWRB site 005AT on 8/12/2002
Nitrate (µg/l)	6250	Observed at OWRB site 005AT on 8/12/2002
Organic P (µg/l)	283	Half of observed TP at OWRB site 005AT on 8/12/2002
Inorganic P (µg/l)	283	Half of observed TP at OWRB site 005AT on 8/12/2002
Inorganic Suspended Solids (mg/L)	71	80% of seasonal average observed TSS at OWRB site 005AT
Detritus (mg/l)	18	20% of seasonal average observed TSS at OWRB site 005AT
Phytoplankton (µg/l)	106	Seasonal average observed at OWRB site 005AT
Alkalinity (mg/l)	146	Observed at OWRB site 005AT on 8/12/2002
pH	9.12	Observed at OWRB site 005AT on 8/12/2002

Table 8. Northside WWTP inputs for the macro-level calibration model.

Input Parameter	Input	Rationale
Flow (MGD)	1.5	Average summer effluent flow from DMRs
fastCBOD (mg/l)	3.09	Based on average summer $CBOD_5$ 2.4 mg/l from DMRs
Ammonia (mg/l)	0.9	Average summer concentration from DMRs
Organic N (mg/l)	7.1	Approximate median effluent concentrations based on treatment level from literature (see Table 6)
Nitrate(mg/l)	7.9	
Organic P (mg/l)	1.2	
Inorganic P (mg/l)	4.6	
Inorganic Suspended Solids (mg/l)	1.65	Average summer observed TSS of 3.3 mg/l split 50/50 as inorganic and organic particulate matter.
Detritus (mg/l)	1.65	
Dissolved Oxygen (mg/l)	5	Seasonal WQS from OK WQS Chapter 45
Temperature (°C)	32	Seasonal Temperature from OK WQS Chapter 45

The results of the macro-level calibration analysis for the QUAL2K model of this section of the North Canadian River are shown in Figure 4. The phytoplankton parameterization that best predicted typical summer low-flow instream DO conditions included a maximum growth rate of 2 /d, and rates of respiration, excretion, and death all set to 0.1 /d. These calibrated phytoplankton parameter values fall within the range of reasonably acceptable values based on an assessment of peer-reviewed literature of QUAL2K model application (USEPA, 2019).

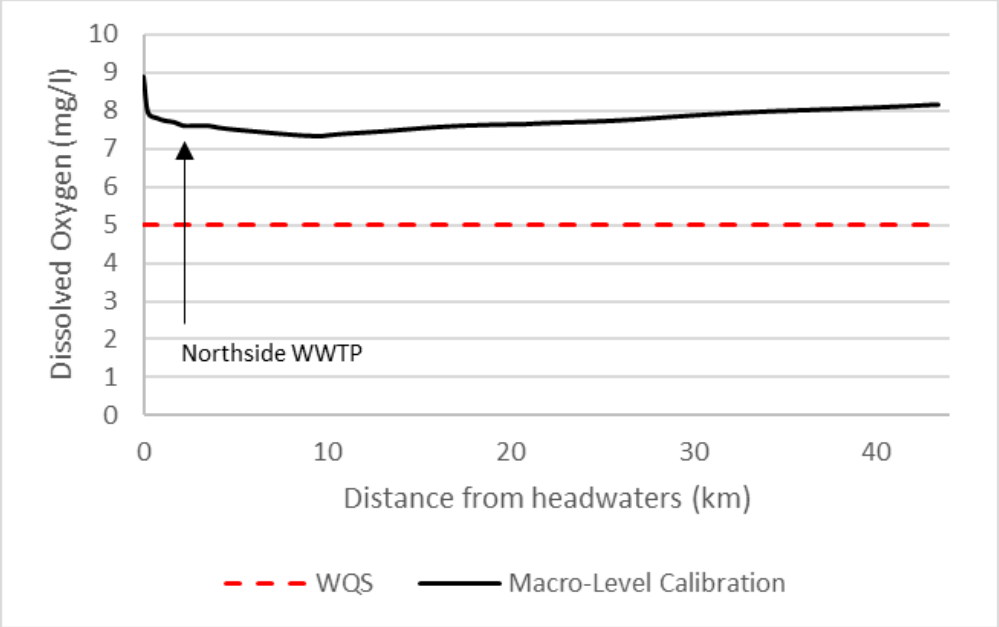

Figure 4. Longitudinal DO Predicted by the Macro-Level Calibration on 8/12/2002.

4.0 MODEL APPLICATION

The purpose of the WLA assessment is to determine through modeling whether the receiving water has the capacity to assimilate the effluent at proposed permit limits for flow and water chemistry. Assimilative capacity is identified by instream water quality conditions not exceeding water quality criteria for DO with an appropriate margin of safety (MOS). In this case, the North Canadian River is being assessed for its capacity to assimilate 4.5 MGD of flow from the Northside WWTP. The model was run with existing permit limits for parameters other than flow and assumptions for other constituents as outlined in Section 2.7 of this report. Results for each critical condition seasonal application of QUAL2K are summarized below in Table 9, with longitudinal DO plots present in Figure 5, Figure 6 and Figure 7. As described in the Continuing Planning Process document, an uncalibrated model of a single source discharge is required to meet the water quality criteria within a MOS of 20 percent to account for uncertainty in the determination of pollutant loading requirements and the effect on water quality (ODEQ, 2012).

These seasonal models were run with conservative assumptions for cloud cover and stream shading of 75% and 10% respectively to ensure a dampening of the photosynthetic activity which can typically boost DO concentrations instream. Although a conservative assumption of DO concentration from the Northside WWTP was made seasonally of 0.0 mg/l, in order to meet the WQS with MOS during the spring season, a minimum DO concentration of 4.0 mg/l is required.

Table 9. WLA study QUAL2K Results of Seasonal Critical Condition Minimum DO Concentrations.

Model Application	Fishery Class	Minimum DO Criteria (mg/l)	Minimum DO + 20% MOS (mg/l)	Simulated Minimum DO (mg/l)
Spring	Early Life Stages (Spring)	6.0	7.2	7.2
Summer	Other Life Stages: Summer Conditions	5.0	6.0	6.3
Winter	Other Life Stages Winter Conditions	5.0	6.0	7.5

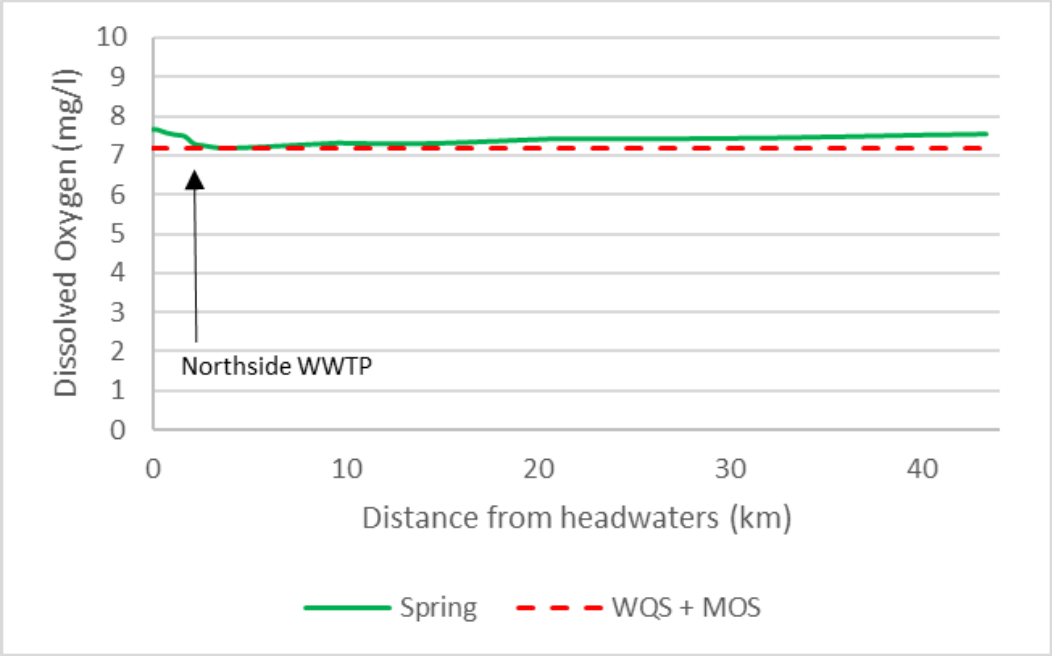

Figure 5. Longitudinal DO Results for the Spring WLA Study.

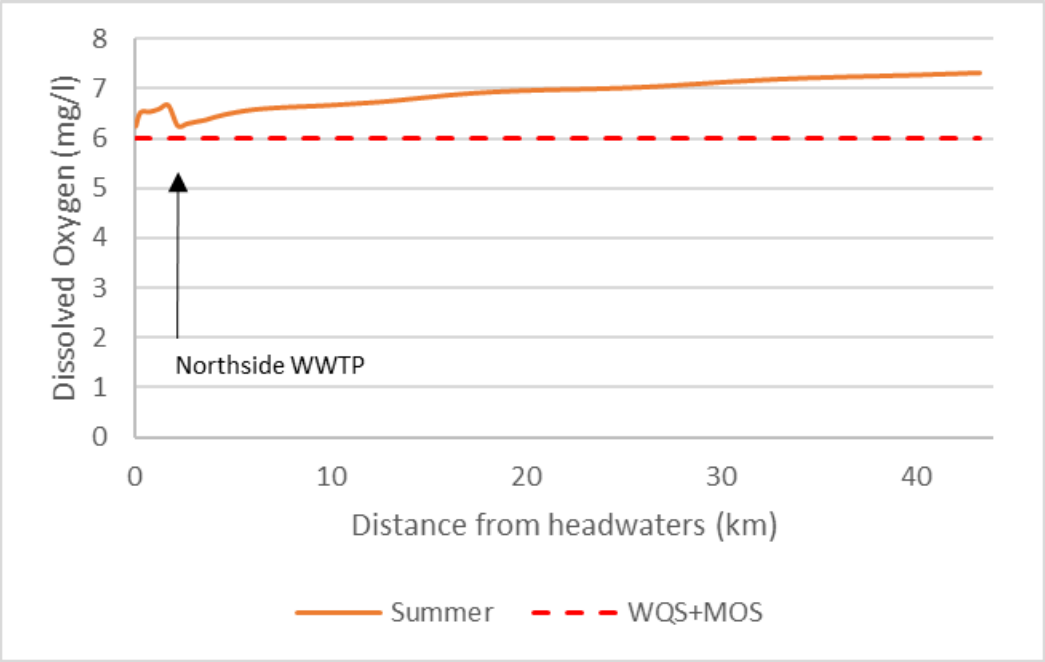

Figure 6. Longitudinal DO Results for the Summer WLA Study.

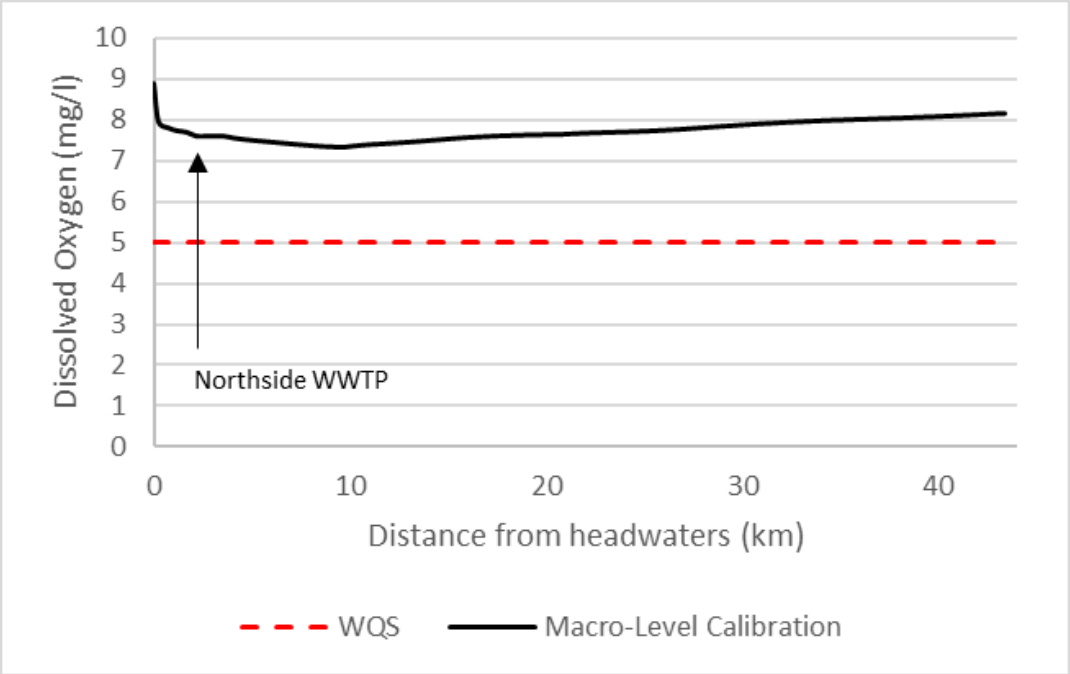

Figure 7. Longitudinal DO Results for the Winter WLA Study.

5.0 RECOMMENDATIONS

The model predicts that the Northside WWTP discharge can be increased by 1.5 MGD using current permit limits without significant impact on downstream DO during summer and winter. During spring, current permit limits work well with the exception of adding a minimum DO concentration limit of 4.0 mg/l to ensure the water quality standard is met under critical conditions within the required margin of safety. Note that these results do not include any credit for the removal of the 3 MGD Southside WWTP discharge upstream, so actual results may be better than shown as overall loading is decreased to the North Canadian River from the City. Based on model results and the level of dilution achieved instream under 7Q2 conditions, it is recommended that the Northside WWTP be permitted to increase its effluent flow to 4.5 MGD with existing limits for all seasons except that a DO limit of 4 mg/L be added during the Spring period.

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APPENDIX A. 7Q2 FLOW CALCULATIONS

The 7Q2 low-flow calculations were conducted using SWToolbox for USGS gage 07241800. The outputs of each seasonal flow analysis are included below (Figure 8, Figure 9, and Figure 10)

```
Program SWStat          U.S. GEOLOGICAL SURVEY              Seq 00001
Ver. 5.0       Log-Pearson & Pearson Type III Statistics    Run Date / Time
03/13/2018            based on USGS Program A193            9/1/2020 10:03 AM

 Notice -- Log-Pearson Type III or Pearson Type III distributions are used
           for these computations. Users are responsible for assessment
           and interpretation.


       Description:  07241800 North Canadian River at Shawnee, OK
    Year Boundaries:  April  1 - May 31
   Period in report:  April  1, 2001 - May 31, 2020
          Parameter:  7-day low
    Non-zero values:    20
        Zero values:     0
    Negative values:     0  (ignored)

Input time series (zero and negative values not included in listing.)

   390.430   203.290   167.570   148.290   125.710    70.614   143.000   388.000
   266.430   224.430    90.457   122.660   242.430    85.729   219.570   145.140
   161.000    96.471   733.710   444.710

  LOG PEARSON TYPE III Frequency Curve Parameters
  (based on logs of the non-zero values)

  Mean (logs)                                 2.267
  Variance (logs)                             0.070
  Standard Deviation (logs)                   0.264
  Skewness (logs)                             0.533
  Standard Error of Skewness (logs)           0.512
  Serial Correlation Coefficient (logs)       0.158
  Coefficient of Variation (logs)             0.117


Frequency Curve - Parameter values at selected probabilities

    Non-                                 Variance    95-Pct Confidence
 exceedance     Recurrence  Parameter       of          Intervals
 Probability     Interval     Value     Estimate    Lower      Upper
 -----------    ----------  ---------   --------  ---------  ---------
      0.5000         2.00     175.150      1.049    131.300    241.760
```

Figure 8. Spring 7Q2 Flow Calculation Output from SWToolbox.

```
Program SWStat          U.S. GEOLOGICAL SURVEY              Seq 00001
Ver. 5.0       Log-Pearson & Pearson Type III Statistics    Run Date / Time
03/13/2018             based on USGS Program A193           9/1/2020 10:03 AM

 Notice -- Log-Pearson Type III or Pearson Type III distributions are used
           for these computations. Users are responsible for assessment
           and interpretation.


      Description:  07241800 North Canadian River at Shawnee, OK
  Year Boundaries:  June  1 - October 31
 Period in report:  June  1, 2001 - October 31, 2019
        Parameter:  7-day low
  Non-zero values:    18
      Zero values:     0
  Negative values:     1  (ignored)

Input time series (zero and negative values not included in listing.)

   133.000    94.700    74.843   117.430   113.990    44.871   416.140   117.570
   120.290   101.260    50.214    32.000   129.290    54.957   117.430    76.900
   126.570   181.710


  LOG PEARSON TYPE III Frequency Curve Parameters
  (based on logs of the non-zero values)

  Mean (logs)                                 1.995
  Variance (logs)                             0.063
  Standard Deviation (logs)                   0.250
  Skewness (logs)                             0.283
  Standard Error of Skewness (logs)           0.536
  Serial Correlation Coefficient (logs)      -0.141
  Coefficient of Variation (logs)             0.126


Frequency Curve - Parameter values at selected probabilities

   Non-                                 Variance    95-Pct Confidence
 exceedance     Recurrence  Parameter      of          Intervals
 Probability     Interval     Value     Estimate    Lower      Upper
 -----------    ----------  ---------   --------  ---------  ---------
      0.5000         2.00      96.125      1.032     71.899    131.220
```

Figure 9. Summer 7Q2 Flow Calculation Output from SWToolbox.

```
Program SWStat          U.S. GEOLOGICAL SURVEY              Seq 00001
Ver. 5.0      Log-Pearson & Pearson Type III Statistics     Run Date / Time
03/13/2018            based on USGS Program A193            9/1/2020 10:04 AM

 Notice -- Log-Pearson Type III or Pearson Type III distributions are used
           for these computations. Users are responsible for assessment
           and interpretation.


       Description:  07241800 North Canadian River at Shawnee, OK
    Year Boundaries:  November  1 - March 31
   Period in report:  November  1, 2001 - March 31, 2020
          Parameter:  7-day low
    Non-zero values:    19
        Zero values:     0
    Negative values:     0  (ignored)

Input time series (zero and negative values not included in listing.)

   145.430   125.290   109.290   211.570    86.043    70.200   190.430    91.371
   169.710    83.114    83.557    43.186    84.400    93.486   142.000    90.029
   113.260   167.100   257.000


  LOG PEARSON TYPE III Frequency Curve Parameters
  (based on logs of the non-zero values)

  Mean (logs)                                  2.055
  Variance (logs)                              0.036
  Standard Deviation (logs)                    0.189
  Skewness (logs)                             -0.054
  Standard Error of Skewness (logs)            0.524
  Serial Correlation Coefficient (logs)        0.109
  Coefficient of Variation (logs)              0.092


Frequency Curve - Parameter values at selected probabilities

   Non-                                  Variance    95-Pct Confidence
 exceedance     Recurrence  Parameter       of          Intervals
 Probability     Interval     Value     Estimate    Lower      Upper
 -----------    ----------  ---------   --------  ---------  ---------
      0.5000         2.00     113.920      1.010     91.340    141.630
```

Figure 10. Winter 7Q2 Flow Calculation Output from SWToolbox.