Technical Memorandum ECO-4

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Subject: *Water Quality Assessment of the Fort Worth Central City Project*

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1.0 Executive Summary

This technical memorandum summarizes the assessment of the water quality characteristics of the proposed Central City project in downtown Fort Worth, Texas. The Central City project proposes to develop an urban waterway resulting from flood channel improvements at the confluence of the Clear Fork and West Fork of the Trinity River which will include the construction of a dam and flood control gates. The key water quality requirements for the project are that the resulting waterway must meet public expectations for aesthetics as well as the State of Texas water quality standards for its designated uses.

The State of Texas designated uses for the Trinity River associated with this project are: high aquatic life support, contact recreation, public water supply, and fish consumption. The State of Texas establishes water quality standards based on these uses and continually measures waterways to determine whether or not they meet these standards. This assessment evaluated whether the waterways associated with this project currently meet State standards and assessed how the waterway resulting from the proposed project would affect compliance with State standards. Water quality characteristics for the proposed waterway were evaluated under low flow conditions as required by the State. Median flow conditions were evaluated as well.

The water quality characteristics of the proposed waterway will be essentially the same as the characteristics currently observed with the existing impoundments on the Clear and West Forks within the project area.

1.1 Aquatic Life Support

Determining whether a waterway can support a high level of aquatic life requires assessing the level of dissolved oxygen (DO) in the waterway during low-flow, warm weather conditions. The State of Texas has set DO standards appropriate for high aquatic life support for the waterways associated with the proposed project. The State of Texas 2002 and draft

2004 biennial water quality assessments indicated that all waterways associated with the proposed project are meeting the DO standards (TCEQ 2002 and 2004a).

To assess the impact of the proposed project on DO concentrations, this assessment utilized the USEPA Water Quality Analysis Simulation Program (WASP) and a steady-state spreadsheet model and compared the results to existing conditions. The flow conditions modeled were the statistical low flow condition stipulated by the State of Texas for compliance with water quality standards (the seven-day, two-year low-flow, abbreviated as 7Q2) . In addition, the median flow condition was assessed. Oxygen demanding substances were entered as loads in models based on median concentrations observed in the system based on a historical dataset. Temperature and wind speed are directly related to DO levels in waterways. Higher summer temperatures reduce the amount of DO that water can hold. Summer water temps average 28.5 degrees C (83 degrees F). Mean summer wind speed is 9.6 mph. Wind increases the amount of DO in a waterway through surface reaeration.

The analysis indicates that both during the 7Q2 and median flows, with summer temperatures and wind speed, the water quality standard for DO (5.0 mg/L) would be easily maintained in the proposed waterway. This assumes a completely-mixed system which would present the most difficult conditions for standards compliance. In the case of stratification, the State of Texas requires measurements of DO for standards compliance to be conducted at the surface (i.e., in the epilimnion) where DO is highest. Stratification has been observed at times in other impoundments within the area and historical data from these impoundments demonstrate compliance with the DO standard in the epilimnion, further reinforcing that the proposed project would meet the State of Texas water quality standards for DO and would support a high level of aquatic life.

By the time the proposed project is constructed, it is anticipated that the State of Texas will have promulgated nutrient standards for the State of Texas river segments of the Trinity River encompassed by the proposed project. Absent a specific standard, it is not possible to determine whether the proposed project would result in compliance with such standards. However, analyses show that the project would not significantly change the nutrient dynamics of the river segments involved for either flow regime.

1.2 Contact Recreation

Support for contact recreation (i.e., recreational activities that involve a substantial risk of ingesting water, including wading by children, swimming, water skiing, etc.) is gauged by a waterway's compliance with water quality standards for indicator bacteria. Waterways in urban areas often have difficulty meeting water quality standards for bacteria (USEPA 1992). Historically, the bacteria test was done by a count of fecal coliform bacteria, which are an indirect and often imprecise indicator of pathogens and viruses which may be present.

Because health implications are unclear from this test, the State of Texas has recently converted to a different bacteria indicator – *E. Coli.*

The project is encompassed within two of the State of Texas river segments of the Trinity River: Segments 0806 (West Fork Trinity River Below Lake Worth) and 0829 (Clear Fork Below Benbrook Lake). Significant portions of these segments are listed as meeting the bacteria water quality standard (upper 11 miles of Segment 0806 and all of Segment 0829), although these reaches are also listed as having not been completely assessed (TCEQ 2002). The lower 22 miles of Segment 0806, of which a small portion (1.4 miles) is within the project area, is listed as not meeting the State's water quality for bacteria and this is not expected to change for the pending biennial update (TCEQ 2004a). As a result, the State will develop a Total Maximum Daily Load (TMDL) plan that includes this reach of the Trinity.

There are currently no municipal wastewater treatment facilities discharging upstream of the project area. As such, bacteria currently contributed to these reaches of the Trinity River come from urban and rural runoff. The changes resulting from the proposed project would not result in any increase in bacteria within the affected waterways. It is anticipated that, over the long-term, the project may even reduce bacterial loads through improved urban runoff management practices and upgraded wastewater collection systems within the project area. TRWD currently monitors waterways associated with the proposed project for bacteria and posts signs in public access points warning against contact recreation when bacterial counts exceed State criteria.

1.3 Fish Consumption

There are currently fish consumption advisories by the State of Texas for a number of river segments and waterbodies of the Trinity River in the North Central Texas area including a one mile reach of the Clear Fork of the Trinity encompassed by the proposed project. Consumption advisories in the region result from elevated levels of PCBs and/or chlordane in fish tissue. PCBs and chlordane are considered "legacy" pollutants because they persist in the environment for a very long time, slowly degrading. These legacy pollutants are addressed in a State and USEPA approved Total Maximum Daily Load program which calls for continued monitoring of fish tissue in the anticipation that contaminant levels will continue to decrease over time (TCEQ 2001). This assessment found no reason that the proposed project would increase the likelihood of legacy pollutants in the waterway.

1.4 Public Water Supply

The previously discussed water quality parameters also factor into determining whether a waterbody supports the use of its water as a raw water supply for public drinking water. The City of Fort Worth currently draws water from the Clear and West Forks of the Trinity as raw water for treatment to State drinking water standards at the Holly Water Treatment Plant. The State's biennial 305b assessments, which encompass all known water quality data, have indicated historical compliance for all water quality parameters relevant to public water supplies. The proposed project is not expected to change this for any parameter.

1.5 Water Aesthetics

All evidence developed through these analyses indicates that public expectations of water quality associated with the project would be met – including aesthetic appeal. It is anticipated that water quality within the system would not be significantly different than that in the current impoundments that exist within system, and that improved urban runoff management practices associated with the redevelopment efforts of land areas adjacent to the project would likely contribute to both aesthetic and water quality improvements. Additional information regarding options for water quality and aesthetic management for the proposed project can be found in Technical Memorandum ECO-5 (TRWD 2005).

1.6 Recommendations

Because the proposed project would create a hydraulically complex waterway, it is recommended that a more robust and long-term water quality monitoring program be developed and employed. In addition, further refinement of the water quality model should be undertaken to better employ the model as an operational tool for the proposed waterway.

2.0 Introduction and Background

The Tarrant Regional Water District (TRWD) is participating with the U.S. Army Corps of Engineers (USACE), Tarrant County, and the City of Fort Worth in evaluating flood channel improvements in the "Central City '' segment of the Clear Fork and West Fork of the Trinity River. The Community-Based Alternative (CBA) calls for creating a bypass channel to handle flood flows and to create a quiescent river segment on the Trinity adjacent to downtown Fort Worth. The quiescent river segment would begin at the confluence of the Clear Fork and the West Fork of the Trinity River to just upstream (south) of the Northside Drive Bridge, generally following the existing river channel. This area is within the Central City river segment of the Trinity River Vision Master Plan.

This technical memorandum was developed to assist in the preliminary design of the Central City project and to provide concurrent review and assessment by the USACE as a part of their regulatory responsibilities. The USACE is assisting in the evaluation of the project and will produce Draft and Final Environmental Impact Statements (EIS) for the project.

2.1 Goals of Analysis and Target Constituents

The key goals for the project are that the resulting waterway must meet public expectations for aesthetics as well as the State of Texas water quality standards for its designated uses The principal State criteria of interest for this assessment include dissolved oxygen (DO) and bacteria (E. coli and fecal coliform). Other water quality parameters of interest include nutrients (due to the potential of nutrient standards being promulgated by the State in the near future) and any parameters associated with current fish consumption advisories. The State of Texas water quality inventory (305b assessment) encompasses all known water quality data and provides the basis for determining compliance with water quality standards. Except for bacteria and legacy pollutants, this biennial inventory indicates historical compliance with standards for all water quality parameters under a range of flow conditions. The proposed project is not expected to change this trend. For example, water temperature can often be impacted by impoundments, particularly at low flow. However, historical monitoring at existing impoundments has not identified any compliance violations. For this reason, temperature, or any other parameter beyond those noted above, is not included in the analysis presented here.

From this assessment, the project will be able to accomplish the following:

- Provide the necessary material to the USACE for inclusion in the Draft EIS regarding the water quality impacts of the CBA;
- Assess the current water quality characteristics of the waterbodies associated with the CBA;
- Assess the potential for water quality standards violations to occur as a result of implementing the CBA; and
- Recommend any additional data collection and/or analyses necessary to monitor water quality and provide operational guidance for water quality in the implemented project;

Potential waterway management practices/strategies that might be necessary to achieve water quality expectations and standards and which could then be evaluated and incorporated into future projects are addressed in Technical Memorandum ECO-5 (TRWD 2005).

2.2 Supporting Data

Interviews were conducted with TRWD staff regarding available water quality data and on appropriate evaluation approaches. TRWD staff provided CDM with the following:

- Measured historical water quality data for a range of parameters, including DO, nutrients, carbonaceous biochemical oxygen demand (CBOD)[1], chlorophyll *a*, and temperature at various upstream and downstream locations, as summarized in **Table 1** (TRWD 2004);

- A list of calibrated water quality model parameters from past modeling of regional reservoirs using EPA's Water Quality Analysis Simulation Program (WASP).

Hydraulic and hydrologic data for both the proposed and existing systems was provided through simulations of recently-developed HEC-RAS models as a part of the preliminary design of the proposed project. HEC-RAS calculates reach hydraulics (velocities, depths, widths, and volumes) for given flow rates at cross-sections located throughout the Clear Fork, West Fork, Central City, and downstream reaches.

Low river flow for the models was determined by assessing the State of Texas requirements (TAC 2000) and by assessing low flows using DFLOW (USEPA 2000). The State of Texas requires water quality standards attainment to be evaluated at the seven-day, two-year low flow (7Q2). The 7Q2 flow was developed by the State of Texas was 9.3 cfs for the most applicable US Geological Survey gauge: 08048000 - West Fork of the Trinity River at Fort Worth, Texas (USGS 2004) which is embedded within the proposed project area (shown on **Figure 6**). Current State water quality standards (TAC 2004) cite a 30-year period of record (1966 to 1996) for determining the 7Q2 for this gauge. The 7Q2 flow calculated by DFLOW was 6.8 cfs. The smaller flow value (6.8 cfs) was used to be conservative. Median flow was determined from the same flow data using a spreadsheet and was calculated to be 31 cfs.

Historical wind speed data from the Dallas-Fort Worth Airport were also used to support the analysis described here. Mean wind speed during summer was calculated to be 9.6 mph.

The proposed project creates an additional 113 acres of water surface and an additional 2,114 ac-ft of volume within the system. Using the mean annual evaporation (59.32 inches, 4.94 feet), the project would result in an additional 558 ac-ft of evaporative losses. This is offset by 283 ac-ft of mean annual precipitation (30 inches, 2.5 feet) that falls on the water surface directly. Therefore, the additional loss of water that results from the proposed project is 558 ac-ft minus 283 ac-ft, or 275 ac-ft. This is not an appreciable amount to change flow through the project and, regardless, the project would secure additional water to compensate for these losses.

[1] Unless otherwise noted in the document, all carbonaceous biochemical oxygen demand concentrations are ultimate CBOD values

2.3 Pollutant Sources

The sources of pollutant contributing to the waterways in the study area result from runoff from urban and rural (undeveloped and agriculture) lands and from releases from Lake Worth (West Fork) and Benbrook Lake (Clear Fork). There are permitted point source discharges within or upstream of the study area. There are small point source discharges upstream of Lake Worth and Benbrook Lake, but their pollutant loads are completely assimilated above or in these reservoirs.

The pollutant load characteristics of runoff from contributing land uses has been developed by a regional Stormwater monitoring program through the North Central Texas Council of Governments (NCTCOG). Developed to assist local governments in complying with the Federal Clean Water Act requirements for Stormwater discharges, the program has been collecting data for over a decade from watersheds across the Dallas/Fort Worth metropolitan area (NCTCOG 2002). Representative results from this monitoring effort are showing **Table 2**.

The proposed project would induce a change in land use within the project area, converting commercial and industrial land uses to predominately residential and commercial land use. It is anticipated that the change in land use, along with improved stormwater quality management practices being implemented in the City of Fort Worth, would result in an improvement to stormwater pollutant loads contributing directly to the water way created by the project.

2.4 Water Quality Standards Overview

As discussed above, DO and fecal coliform are the water quality parameters of primary interest for the waterways associated with the Central City project. The Texas Commission on Environmental Quality (TCEQ) has assigned the following designated uses for the waterways in the Central City area:

- Segment 0806 West Fork Trinity River below Lake Fort Worth – contact recreation, high aquatic life use, public water supply

- Segment 0829 Clear Fork Trinity River below Benbrook Lake – contact recreation, high aquatic life use, public water supply

Table 3 contains the associated water quality criteria for DO to achieve the high aquatic life designated use. The mean DO standard is applied as a minimum average over a 24-hour period and the daily minima are not to extend beyond 8 hours per a 24-hour day. In addition to the criteria presented in **Table 3**, lower DO minima may apply on a site-specific basis, when natural daily fluctuations below the mean are greater than the difference between the mean and minima of the appropriate criteria.

To achieve the contact recreation designated use for the Central City waterways, the geometric mean concentration of E. coli should not exceed 126 colonies per 100 mL and single sample concentrations of *E. coli* should not exceed 394 colonies per 100 mL. Similarly, fecal coliform can be used an indicator and its geometric mean should not exceed 200 colonies per 100 mL and single sample concentrations should not exceed 400 colonies per 100 mL.

TCEQ assesses attainment of water quality standards by comparing available water quality data with the water quality criteria presented in the above discussion. When the assessment of a given waterbody shows non-attainment of one or more water quality standards, the waterbody is added to the State's 303(d) list, which then requires the development and implementation of a Total Maximum Daily Load (TMDL) process specific to the waterway and its impairment. The waterways in Central City are currently listed on the State of Texas 2002 and draft 2004 303(d) lists (TCEQ 2004) for the following constituents:

- Segment 0806 West Fork Trinity River below Lake Fort Worth – PCBs in fish tissue (2002 and 2004), PCBs and chlordane in fish tissue (2004) and bacteria (2002 and 2004) in the lower 22 miles of the segment and therefore designated as Not Supporting the fish consumption and contact recreation uses for this length. Approximately 1.4 miles of the proposed project area is within this reach. The remaining 11 miles of stream segment, some of which is included in the project area, is shown as Fully Supporting its designated uses.

- Segment 0829 Clear Fork Trinity River below Benbrook Lake – chlordane in fish tissues (2002 and 2004) and PCBs and chlordane in fish tissue (2004)

The non-attainment resulting from chlordane in fish tissue has been addressed though the TMDL for Legacy Pollutants in Streams and Reservoirs in Fort Worth (TCEQ 2001). TCEQ has prepared an implementation document for this TMDL and will continue to monitor legacy pollutants in the Fort Worth area. The State has established as a high priority to develop a TMDL for PCBs in these segments.

Organochlorine insecticides and PCBs were widely used in the U.S. prior to EPA restriction, and are common environmental contaminants (Moore and Ramamoorthy 1984; Schmitt et al.1985, 1990; Smith et al. 1988; USGS 2000). These substances are a frequent cause of fish consumption advisories in the U.S. (EPA 1999a,b), and elevated concentrations of some of these contaminants are frequently found in game fish tissue (Kuehl et al. 1994). Continuing decreases in environmental legacy pollutant levels are expected, although the necessary time frame is subject to debate (TCEQ 2001).

2.5 Summary of Existing Water Quality Data

Historical water quality data for the system, as outlined in **Table 1**, are further summarized in **Figures 1 – 5** for key parameters. Median concentrations are plotted for each sampling station, with bars corresponding to minimum and maximum values. Data for Lake Worth and Benbrook Lake were collected at two depths: the top layer and bottom layer. 4th Street Bridge and Beach Street Dam data shown correspond to mid-depth samples only.

As can be seen, at certain locations in the system dissolved oxygen levels have fallen below 3 mg/ in the past and have risen to over 11 mg/L. Excursions below 3 mg/L, for bottom layer and mid-depth sampling, are believed to have occurred during periods of stratification, and therefore should not be compared to the water quality standard which applies to the epilimnon only (see Section 5.0). Downstream chlorophyll a concentrations (up to 50 – 90 μg/l) are indicative of possible eutrophication in these areas (Chapra 1998). Assuming an average internal plant tissue N:P mass ratio of 7.2 (Stumm and Morgan 1981), instream nitrogen to phosphorus ratios (on average: 9 – 15) are indicative of phosphorus limitation to plant growth in the system. However, the range of values indicates that the system may, at times, change to nitrogen limitation.

3.0 Methodology

The methodologies used to assess the water quality impacts of the proposed project are described below.

3.1 Available Approaches for Assessing Water Quality Impacts of Proposed Project

A number of options exist for assessing the water quality changes resulting from the proposed project. One option considered was statistical evaluation of existing data sets. The amount of available water quality data was not seen as sufficient to support this approach. The collection and analysis of additional water quality data was not seen as practical given time constraints. As such, deterministic water quality models were deemed better suited to predicting likely water quality conditions of the proposed project.

A number of published water quality models were evaluated for possible use in this analysis, including QUAL2E, BATHTUB, and WASP. QUAL2E is a one-dimensional stream and river water quality model, BATHTUB is designed for modeling multi-layer lakes and reservoirs, and WASP can be used to simulate either rivers or lakes in single or multiple layers. In addition to these published models, a steady-state spreadsheet model using lumped oxygen demand and reaeration was considered.

3.2 Selected Approach for Assessing Water Quality Impacts of Proposed Project

The USEPA Water Quality Analysis Simulation Program (WASP) version 6.0.0.12 (USEPA 2004) was selected to perform the majority of the analyses. WASP has the flexibility required to model both river segments and reservoir-like impoundments. WASP has been used extensively in the past by TRWD for modeling local reservoirs and, as such, TRWD, has a high level of familiarity with the model and has developed extensive experience with model parameters on local reservoirs. In addition, TRWD's stated long-term goal is to continue the development of a WASP model of the proposed waterway, combining it with a hydrodynamic model to create a tool better suited to operational aspects of water quality management for the implemented project.

Additionally, a simplified spreadsheet model was constructed to provide for rapid comparison of the proposed project to existing conditions for key water quality constituents and to check WASP model results for reasonableness. While QUAL-TX could have been used for this purpose, the spreadsheet model allowed a more rapid assessment of alternatives. Since the environmental impact analysis is concerned with relative impacts between proposed and existing conditions, the development and use of a spreadsheet model was seen as appropriate. Both the WASP model and the spreadsheet model are described further below.

3.3 Constructed Models

WASP was used to simulate DO, nutrients, CBOD, and phytoplankton (as measured by chlorophyll *a*) as functions of stream hydrology and hydraulics, upstream loadings, instream kinetics, and environmental conditions (temperature, light levels, and wind speed). WASP is a surface water quality model maintained by the EPA capable of dynamically simulating the fate and transport of solutes in up to three dimensions. The model calculates solute concentrations in specified computational elements or "segments" throughout the water body of interest and at each time step in the simulation period. WASP simulates, potentially time-varying, advection, dispersion, diffusion and point mass loading, and boundary exchange.

Flows are calculated for each point in space and time based on user-specified headwater and tributary inflows. Stream hydraulics (velocity, depth, and width) can either be calculated with a separate dynamic flow package (e.g. HEC-RAS), and then input to WASP, or can be calculated within WASP through user-defined power equations.

In addition to the WASP model, a simplified spreadsheet model was constructed to simulate DO (including wind and hydraulic reaeration) and lumped ultimate biochemical oxygen demand (carbonaceous + nitrogenous). This model allows for rapid comparison of existing and proposed conditions and provides a check of WASP model results.

The modeled system is shown in **Figure 6**. The system includes Clear and West Fork reaches upstream of the proposed interior impoundment, a short downstream reach, and the proposed bypass channel. The Clear Fork segment extends approximately 1.6 miles upstream of the West Fork confluence. The West Fork segment extends approximately 0.7 miles upstream of the Clear Fork confluence. The downstream segment extends approximately 0.8 miles downstream of the end of the interior impoundment. The bypass channel length is approximately 1.6 miles.

As described above, a 7Q2 flow of 6.8 cfs and median flow of 31 cfs were calculated from daily streamflow data from the USGS gauge on the West Fork of the Trinity River at Fort Worth. Based on analysis of the flow at the West Fork gauge and a Clear Fork USGS streamflow gauge below Benbrook Dam (station 08047500) , a 2:1 split of the 7Q2 and median flows was assumed for the Clear and West Forks, respectively, as well as for the interior impoundment and the bypass channel, respectively. Flow distributions are summarized in **Table 4** and shown in **Figure 6**.

As described above, river hydraulic characteristics for all modeling efforts were calculated in HEC-RAS. The mean summer water temperature is 28.5 degrees C. The assumed stream temperature for the baseline models was 30 degrees C.

Mass loadings for both models were the median concentrations from observed data (**Table 1** and **Figures 1-5**) and are consistent with regional stormwater runoff concentrations (Table 2). For the WASP model of the proposed project, median measured nutrient and CBOD concentrations from Lake Worth and Benbrook Lake observed data were used. Median DO concentrations of 7.9 mg/L and 8.5 mg/L from observed data at Clear Fork at Trinity Park and the Lake Worth outfall respectively were assumed for the headwater concentrations of the simulated reaches. The median measured chlorophyll *a* concentration at the Lake Worth outfall was assumed for the headwater concentrations of both reaches as measured data appropriate for the Clear Fork was not available.

Additional descriptions of the two models are provided below.

3.3.1 WASP Model

The WASP model developed for these analyses is a steady-state (flows and loadings do not change with time) and one-dimensional model. Although maximum flow depths up to approximately 35 feet are anticipated for the modeled scenario, vertical stratification in the model was not simulated due to a lack of additional data. Specifically, exchange rates between layers would not be able to be quantified or calibrated with the available data. Furthermore, a single layer is deemed adequate for providing the analysis needed to support the EIS.

A segment length of 1000 feet was used throughout the model domain, except in the vicinity of flow changes, where segment lengths were altered slightly to ensure that flow changes occurred at the start of a model segment. Average velocities and depths, as well as total segment volumes were calculated for each segment using the HEC-RAS output described above. Multiple HEC-RAS cross-sections were generally contained in each WASP segment. HEC-RAS velocities and depths were averaged for each WASP segment.

Flow volumes are reported as cumulative values at each HEC-RAS cross section. Therefore, WASP segment volumes were estimated as the difference between the cumulative volume at the bottom of the segment and the cumulative volume at the top of the segment. Linear interpolation of the HEC-RAS cumulative volumes was sometimes required to get top and bottom of segment estimates. Approximate model segmentation is shown in **Figure 6**.

Channel longitudinal dispersion is simulated in WASP to capture the exchange of solute particles between segments due to turbulence, random movement, or other non-advective forms of transport. Total effective dispersion in WASP is a combination of user-input hydrodynamic dispersion and model numerical dispersion. In the model constructed here, numerical dispersion dominates, and the total effective dispersion coefficient varies from approximately 3 to 55 m^2/s for the proposed project. This range is appropriate for this type of water body (Chapra 1998). Cross-sectional areas through which the dispersive exchanges take place were set using HEC-RAS output.

The following water quality state variables were simulated in WASP: DO, CBOD, organic nitrogen, ammonium, nitrate, orthophosphate, organic phosphorus, and phytoplankton. The key processes associated with these variables are reaeration, organic nitrogen mineralization, nitrification, and phytoplankton growth and respiration/decay.

Kinetic parameters associated with these processes were set based on previous calibrated model simulations performed by TRWD on area reservoirs. The balance between phytoplankton growth and respiration was adjusted, however, due to unrealistically high phytoplankton biomass predictions using the TRWD parameters. Growth rates were therefore adjusted until simulated phytoplankton concentrations roughly matched historical observed values. These changes are justified since the TRWD calibration was for purely lentic systems. A different species of phytoplankton, for example, may be dominant in the TRWD reservoirs compared to the reaches targeted in this project, resulting in the differences in growth parameters. Reaeration rates were calculated in the model as a function of stream hydraulics and wind speed. This is the most rigorous option for estimating reaeration rates in rivers. **Table 5** provides a summary of model parameter values.

3.3.2 Spreadsheet Model

The spreadsheet model simulates lumped nitrogenous and carbonaceous biochemical oxygen demand (BOD) dynamics and oxygen reaeration using analytical solutions and assuming plug flow (longitudinal dispersion = 0). The steady-state analytical solutions used in the spreadsheets are given as (Chapra 1998):

$$L(x) = L_0 e^{-\frac{k_L}{U}x} \qquad (1)$$

$$D = D_0 e^{-\frac{k_a}{U}x} + \frac{k_L L_0}{k_a - k_n}\left(e^{-\frac{k_L}{U}x} - e^{-\frac{k_a}{U}x}\right) \qquad (2)$$

where L = lumped biochemical oxygen demand (mg/L); D = DO deficit (relative to saturation in mg/L); L_0 and D_0 = starting L and D, respectively; k_L = BOD decay rate constant (1/day); k_a = reaeration rate constant (1/day); U = segment velocity (m/day); and x = distance downstream (m).

Lumped first-order decay rate constants were selected based on typical values. Both hydraulics-induced and wind-induced reaeration rate constants were calculated using published equations (Chapra 1998), with the final rate constant set equal to the higher of the two. Reach segmentation used in this model corresponds to the segmentation used in the HEC-RAS hydraulics model. Segment velocities and depths are set equal to those calculated for the upstream cross-section. The impacts of low flow dams (which exist in the current system, but would not in the proposed system) on reaeration are simulated in the model using the following empirical equation (Butts and Evans 1983):

$$r = 1 + 0.38abH(1 - 0.11H)(1 + 0.046T) \qquad (3)$$

where r = ratio of the DO deficit above and below the dam, H = change in water elevation (m), T = water temperature (ºC), and a and b = coefficients that correct for water quality and dam type (a = 1.0 and b = 0.45 for this application).

The spreadsheet model was used to compare DO concentrations of the existing system against the proposed condition of the Central City impoundment. BOD loadings, biological kinetics, and environmental parameters were maintained at the values used in the WASP model described above.

3.4 Limitations of Approach for Assessing Water Quality Impacts of Proposed Project

The models developed for this assessment are adequate for prediction of fundamental changes that would result from the proposed project. Additional detail will need to be incorporated into the model to adequately simulate subtle water quality changes associated with operational strategies or to analyze highly site-specific characteristics. This cannot be done at this time because of the limited amount of data available on which to construct and calibrate water quality models. For instance, the models could not be used to investigate changes resulting from water circulation differences within the proposed system.

The models are currently single-layer and are modeled as completely mixed systems. Therefore, they do not attempt to simulate thermal stratification in the system or the impacts of such stratification on water quality parameters. All simulated model concentrations can be thought of as depth-averaged values associated with a well-mixed water body. While thermal stratification would likely occur during summer, maintaining DO at or above the State standard of 5.0 mg/L is more challenging in a completely-mixed system as opposed to a stratified system, for reasons discussed in Section 5.0.

4.0 Results

4.1 WASP Simulation of Proposed Conditions

The results of the WASP model simulation of the proposed project using 7Q2 flow, median loads, median starting DO, a mean summer wind speed of 4.3 mph, and a summer water temperature of 30° C are shown in **Figure 7**. The potential DO sag under these conditions is minor and is not significant enough to result in non-attainment of the segments water quality standard for DO (5 mg/L).

The governing reach in the system is the reach that experiences the largest DO sag, in this case the slow-moving reach of the West Fork which is the segment depicted Q2-Q6-Q7-Q8 sequence in **Figure 6** and is the reach illustrated in **Figures 7-12.** The lowest DO (6.2 mg/L) in this reach is caused by the oxidation of upstream pollutant loadings (**Figure 7**). Downstream recovery of DO occurs after the oxidation of the bulk of the pollutants occurs (**Figure 8**) and wind-induced reaeration begins to dominate over oxygen demand. **Figure 9** shows resulting chlorophyll *a* concentrations for the 7Q2 model run. The Bypass Channel and Clear Fork were modeled as well, but results are not represented in the graph because the DO sags in these reaches are even less pronounced.

Figures 10 – 12 show DO, pollutant oxidation, and chlorophyll *a* concentrations for the proposed project using median flow (31 cfs) and the same loads, starting DO, wind speed, and water temperature. As with the 7Q2 flow, the lowest DO under these conditions in the

West Fork reach, but the sag is not significant enough to result in non-attainment of the DO standard. However the sag is slightly larger (lowest DO of 5.7 mg/L) and occurs nearly a mile further downstream of the minimum DO point in the model with 7Q2 flow and, while somewhat counter-intuitive, is the result of accelerated DO uptake resulting from the additional mixing associated with the higher flow. These differences are slight, as is the difference in flow rates used (25 cfs). As with the 7Q2 condition, the Bypass Channel and Clear Fork were modeled as well, but results are not represented in the graph because the DO sags in these reaches are even less pronounced.

4.2 Proposed vs. Existing Comparisons (Spreadsheet Model)

Figures 13 and 14 show a comparison of simulated DO in the existing system versus the proposed system using the simplified spreadsheet model under the 7Q2 and median flow conditions. The intent of this analysis is to show relative changes in system DO and pollutant assimilative capacity as a function of proposed hydraulic alterations. This simulation shows proposed conditions reduce system DO by a maximum of 0.25 mg/L for the 7Q2 flow regime (6.0 mg/L vs. 6.25 mg/L) and by a maximum of 0.9 mg/L (6.2 mg/L vs. 7.1 mg/L) for the median flow regime.

4.3 Sensitivity Analysis

A sensitivity analysis was performed for the WASP model to help quantify some of the uncertainty associated with the simulations shown in **Figures 10-12**. Conservative baseline values for flow (5.0 cfs which is lower than the 7Q2 flow of 6.8 cfs) and beginning DO (3.8 mg/L) were used. Key model parameters were then individually varied and the resulting minimum DO concentration was recorded. The results of this analysis are provided in **Table 6**. Model parameters are ranked, in descending order of D.O. sensitivity, in **Table 7.** The sensitivity analysis demonstrated that changes in wind speed induce the greatest variability in DO as would be expect in a lentic (lake-like) system.

5.0 Discussion and Conclusions

Modeling results show that, under low (7Q2) and median flow conditions, the resulting DO concentrations within the waterway proposed under the Central City project would be maintained above the State of Texas standard of 5 mg/L with median pollutant loads, median starting DO, mean summer wind speed, and summer water temperatures. This is consistent with what is currently observed with the existing impoundments on the Clear and West Forks within the project area.

Model results also show that relative water quality differences between the existing and proposed simulated systems are slight. However, small reductions in dissolved oxygen are predicted for the proposed system versus the existing. Figure 13 shows a greater DO sag just downstream of the loading for the proposed vs. the existing for low flow. These lower DO concentrations are due to a higher residence time in this area of the system (and thus greater pollutant assimilation) and lower reaeration, both the result of hydraulic changes. In Figure 14, slightly lower DO concentrations for the proposed system are also predicted, at median flow, for more downstream portions of the reach. While the proposed changes in hydraulics appear to have minimal affect on the DO sag under this flow regime, DO recovery is aided by grade control structures in the existing system that are absent in the proposed system. In neither case, however, are the predicted differences enough to cause a violation of standards.

This assessment simulates a completely-mixed regime. However, it is likely that the system would stratify thermally during the low flow conditions. This should have no bearing on the ability of the system to maintain adequate DO concentrations. Texas surface water quality standards state that, for impoundments, "representative samples shall be collected from the entire water column in the absence of thermal stratification… representative samples shall be confined to the epilimnion when an impoundment is thermally stratified" (TCEQ 2004). Because wind reaeration dominates in the proposed system, during stratification epilimnon DO concentrations are expected to be at or above the DO concentrations simulated for the completely-mixed regime. Therefore, water quality standards are expected to be easily met during stratification periods.

At this time, these analyses are unable to determine specifically where or when stratification would occur in the proposed system. However, based on observed DO and temperature for impoundments in the area, stratification would likely occur during summer low flow conditions. These data show occurrences of apparent stratification at the 4th Street Bridge and the Beach Street Dam, as well as in the upstream reservoirs (Lake Worth and Benbrook) during summer months.

By the time the proposed project is constructed, it is anticipated that the State of Texas will promulgate nutrient standards for the State of Texas river segments of the Trinity River encompassed by the proposed project. Absent a specific standard, it is not possible to determine whether the proposed project would result in compliance with such standards. Current model simulations indicate rapid downstream assimilation of nutrients for both the existing and proposed systems. As such, it is anticipated that the project would not significantly change the nutrient dynamics of the river segments. The predicted level of chlorophyll *a* in the proposed waterway (average of approximately 20 ug/L) is consistent with currently observed average concentrations measured at the 4th Street low water dam (23.5 ug/L).

Approximately 1.4 miles of the West Fork of the Trinity River within the proposed project area, does not meet water quality standards for contact recreation – a portion of the lower 22 miles of Segment 0806 is listed as not meeting the State's water quality for bacteria. The State is in the process of developing a Total Maximum Daily Load (TMDL) plan for this reach of the Trinity. Waterways in urban areas often have difficulty meeting water quality standards for bacteria particularly during wet weather as runoff from urban areas often contain high levels of bacteria (USEPA 1992). Historically, the bacteria test was done by a count of fecal coliform bacteria, which are an indirect and often imprecise indicator of pathogens and viruses which may be present. Because health implications are unclear from this test, the State of Texas has recently converted to a different bacteria indicator – *E. Coli.*

There are currently no municipal wastewater treatment facilities discharging upstream of the project area. As such, bacteria currently contributed to these reaches of the Trinity River come from urban and rural runoff. The changes resulting from the proposed project would not result in any increase in bacteria within the affected waterways. It is anticipated that, over the long-term, the project may even reduce bacterial loads through improved urban runoff management practices and upgraded wastewater collection systems within the project area. TRWD currently monitors waterways associated with the proposed project for bacteria and posts signs in public area prohibiting contact recreation when bacterial counts exceed State criteria..

There are currently fish consumption advisories for a portion of the Clear Fork of the Trinity River encompassed by the proposed project for chlordane and for PCBs. Chlordane and PCBs are "legacy" pollutants which are substances whose uses have been banned or severely restricted by the U.S. Environmental Protection Agency (EPA). Because of their slow rate of decomposition, these substances frequently remain at elevated levels in the environment for many years after their widespread use has ended.

Chlordane has been addressed in a State and EPA approved Total Maximum Daily Load (TMDL) program which calls for continued monitoring of fish tissue in the anticipation that contaminant levels will continue to decrease over time. A TMDL is being developed for PCBs in these segments. This assessment found that the proposed project would comply with the legacy pollutant TMDL, will not increase the likelihood of legacy pollutants in the waterway, and would therefore have no impact.

The project would result in significant construction activities that would involve extensive grading and earth-moving activities. The design of the project will be done to include compliance with the Texas Pollutant Discharge Elimination System (TPDES) requirements for stormwater water pollution prevention during construction.

5.1 Downstream Water Quality Impacts

Simulations show that pollutant assimilation occurs rapidly within the Central City impoundment, with rapid recovery of dissolved oxygen in downstream segments of the system. The modeling presented here focuses on this critical area of assimilation and does not extend downstream of the Central City area. However, results do indicate that required dissolved oxygen levels would be maintained in downstream reaches. Furthermore, the proposed project is not expected to significantly impact flow or hydraulics downstream of the modeled area (existing flows would be maintained), nor is it expected to generate additional nutrient or BOD loads. Existing water quality is therefore expected to be maintained in downstream reaches of the Trinity River.

6.0 Recommendations

6.1 Future Monitoring and Modeling Recommendations

Continued long-term monitoring before, during, and after implementation of the proposed project is recommended. The purpose of this monitoring would be to monitor parameters relevant to the maintenance of the designated uses of the waterway, to help verify model predictions, and establish a modeling system capable of evaluating of water quality operational strategies for the waterway. The exact nature of the long-term monitoring program will be specified as a part of the continuing design process, but would likely include monitoring of: dissolved oxygen, nutrients (nitrogen and phosphorus), biochemical oxygen demand (BOD), temperature, bacteria (E. coli and fecal coliform), and other parameters associated with the State's water quality inventory.

Continued refinement of the models developed under this assessment is seen as important in order to provide TRWD with the ability to simulate operational strategies relating to water quality. As such, vertical stratification should be incorporated into the model, and should be guided by measured data collected over an extended period. Conversion of the model from steady-state to dynamic is also seen as necessary to achieve an effective operational tool.

6.2 Waterway Management and Strategy Recommendations

Assessment of the proposed project indicates that water quality would be maintained within the waterway. However, because the project is hydraulically complex, operational strategies should be assessed and refined in order determine if any water quality management practices are potentially warranted to ensure maintenance of water quality throughout the proposed impoundment. Waterway management issues that would be addressed during the design phase of the project are discussed in Technical Memorandum ECO-5 (TRWD 2005).

7.0 References

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8.0 Attachments

8.1 Tables

- Table 1 – Summary of supporting water quality data
- Table 2: Summary of North Central Texas stormwater data for Sep2000 to Aug2001
- Table 3 – Dissolved oxygen criteria for waterways in the Central City area
- Table 4 – Modeled distribution of flows
- Table 5 –Baseline WASP model kinetics and environmental parameters for the Trinity River/Central City impoundment
- Table 6 – Results of sensitivity analysis with baseline WASP model
- Table 7 – Model parameter ranking (in descending order of dissolved oxygen sensitivity)

8.2 Figures

- Figure 1 – Historical dissolved oxygen for the Clear and West Forks of the Trinity River (stream segments 0806 and 0829)
- Figure 2 – Historical total kjeldhal nitrogen (TKN) for the Clear and West Forks of the Trinity River (stream segments 0806 and 0829)
- Figure 3 – Historical total phosphorous for the Clear and West Forks of the Trinity River (stream segments 0806 and 0829)
- Figure 4 – Historical carbonaceous biochemical oxygen demand (CBOD) for the Clear and West Forks of the Trinity River (stream segments 0806 and 0829)
- Figure 5 – Historical chlorophyll *a* for the Clear and West Forks of the Trinity River (State stream segments 0806 and 0829)
- Figure 6 – Schematic of the Trinity Rover/Central City WASP model
- Figure 7 – Results of WASP analysis for low flow conditions for dissolved oxygen
- Figure 8 – Results of WASP analysis for low flow conditions for oxidizing pollutants
- Figure 9 - Results of WASP analysis for low flow conditions for chlorophyll *a*

- Figure 10 – Results of WASP analysis for median flow conditions for dissolved oxygen
- Figure 11 – Results of WASP analysis for median flow conditions for oxidizing pollutants
- Figure 12 – Results of WASP analysis for median flow conditions for chlorophyll *a*
- Figure 13 – Comparison of modeled dissolved oxygen concentrations between existing and proposed conditions for low flow
- Figure 14 – Comparison of modeled dissolved oxygen concentrations between existing and proposed conditions for median flow

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Table 1 – Summary of supporting water quality data

Station name	Description	Location relative to modeled system (described below)	Period of record, sampling frequency
Benbrook Lake	Reservoir (upstream on Clear Fork)	Approximately 11 miles upstream of modeled Clear Fork reach	1990, 1992, 3/00 – 6/04, quarterly
Clear Fork at Trinity Park	Instream (Clear Fork)	Approximately at the top of modeled Clear Fork reach	8/03 – 7/04, monthly
Lake Worth Reservoir	Reservoir (upstream on West Fork)	Approximately 9 miles upstream of modeled West Fork reach	1990, 1996, 1997 10/01 – 7/04, quarterly
4th Street Bridge	Instream (Trinity River)	Approximately 2.3 miles downstream of modeled system	9/00 – 6/04, quarterly
Beach Street Dam	Instream (Trinity River)	Approximately 4.5 miles downstream of modeled system	12/01 – 7/04, quarterly

Table 3 – Dissolved oxygen criteria for waterways in the Central City area

Mean (mg/L)	Minimum (mg/L)	Spring Mean (mg/L)	Spring Minimum (mg/L)
5.0	3.0	5.5	4.5

Source: Texas Comission on Environmental Quality Chapter 307: Texas Surface Water Quality Standards

Table 4 – Modeled distribution of flows

Reach	Low (7Q2) Flow (cfs)	Median Flow (cfs)	Upstream Reaches
Upstream Clear Fork	4.5	20.5	Headwater
Upstream West Fork	2.3	10.5	Headwater
Interior	4.5	20.4	Clear Fork & West Fork
Bypass Channel	2.3	10.5	Clear Fork & West Fork
Downstream Trinity River	6.8	31.0	Bypass Channel & Interior

Table 5 –Baseline WASP model kinetics and environmental parameters for the Trinity River/Central City impoundment

Nitrification rate constant (1/day)	Nitrogen processing rate temperature correction coeff. (unitless)	Nitrification ½ saturation constant for DO limitation (mg/L)	Denitrification rate constant (1/day)	Denitrification ½ saturation constant for DO limitation (mg/L)
0.1	1.08	1.2	0.02	1.9
Organic nitrogen (ON) mineralization rate constant (1/day)	**Calculated reaeration rate constants (1/day)**	**Fraction of phytoplankton (phyto) death recycled to nitrogen**	**Phyto max growth rate constant (1/day)**	**Phyto growth temperature correction coeff. (unitless)**
0.04	0.2 - 1.0	1	0.3	1.06
Phyto Carbon: chlorophyll a ratio (unitless)	**Phyto optimal light saturation (langleys/day)**	**Phyto ½ saturation constant for nitrogen (mg/L)**	**Phyto ½ saturation constant for phosphorus (mg/L)**	**Phyto respiration rate constant (1/day)**
50	200	0.025	0.001	0.125
Phyto death rate constant, predation (1/day)	**Phyto nitrogen to carbon ratio (unitless)**	**Phyto phosphorus to carbon ratio (unitless)**	**Sediment oxygen demand (g/m2/d)**	**Net settling rates (for all particulates, m/d)**
0	0.25	0.025	0.5	0
Stream temperature (ºC)	**Daily solar radiation (langleys/day)**	**Non-algal light extinction coefficient (1/m)**	**Wind speed (m/s)**	**CBOD decay rate constant (1/d)**
30	300	5	4.3	0.1

Table 7 – Model parameter ranking (in descending order of dissolved oxygen sensitivity)

Wind speed
Phytoplankton growth/respiration balance
CBOD settling velocity
CBOD decay rate constant
CBOD upstream loading
Sediment oxygen demand (SOD)
Organic nitrogen mineralization rate constant
Phytoplankton (chlorophyll a) upstream loading
TKN upstream loading
Stream temperature
(all other parameters impact D.O. within ± 0.2 mg/L)

Table 1 – Summary of supporting water quality data

Station name	Description	Location relative to modeled system (described below)	Period of record, sampling frequency
Benbrook Lake	Reservoir (upstream on Clear Fork)	Approximately 11 miles upstream of modeled Clear Fork reach	1990, 1992, 3/00 – 6/04, quarterly
Clear Fork at Trinity Park	Instream (Clear Fork)	Approximately at the top of modeled Clear Fork reach	8/03 – 7/04, monthly
Lake Worth Reservoir	Reservoir (upstream on West Fork)	Approximately 9 miles upstream of modeled West Fork reach	1990, 1996, 1997 10/01 – 7/04, quarterly
4th Street Bridge	Instream (Trinity River)	Approximately 2.3 miles downstream of modeled system	9/00 – 6/04, quarterly
Beach Street Dam	Instream (Trinity River)	Approximately 4.5 miles downstream of modeled system	12/01 – 7/04, quarterly

Table 2: Summary of North Central Texas Storm Water Data for Sep2000 to Aug2001 (NCTCOG 2002)

Parameter	Commercial 4-Stations	Highway 3-Stations	Industrial 4-Stations	Residential 4-Stations	In-stream 3-Stations	Mixed 4-Stations
COD (mg/L)						
Sample Size	14	9	9	12	23	34
Minimum	10	21	11	10	6	1
Maximum	56	79.5	43	67	113	87
Mean	30.2	50.8	22.4	41.9	32.3	26
Median	32	54	17	45	24	23
Std. Dev.	13.7	21.8	11.0	18.2	25.8	19.1
BOD (mg/L)						
Sample Size	14	8	8	12	22	34
Minimum	2.5	4	2.7	3.1	3	1
Maximum	12	14	11	14	23	20
Mean	5.8	7.7	5.4	7.1	7.9	6.0
Median	5.0	6.4	4.4	6.2	6.4	5.7
Std. Dev.	2.8	3.5	3.0	3.7	5.0	3.6
Fecal Streptococci (Colonies/100 mL)						
Sample Size	15	11	9	15	24	32
Minimum	180	100	1800	3500	33	300
Maximum	840000	520000	110000	160000	600000	270000
Mean (geom)	8866	5375	9193	22674	20666	12848
Median	6800	6500	10000	25000	21000	16000
Std. Dev.	219881	154070	35023	36954	172190	54940
Fecal Coliform (Colonies/100 mL)						
Sample Size	15	11	9	15	24	32
Minimum	33	33	50	260	33	50
Maximum	600000	370000	61000	200000	200000	100000
Mean (geom)	2060	2173	2226	8911	5242	1581
Median	3000	900	3500	10000	4950	1000
Std. Dev.	153802	114119	19640	53464	55168	25215
Total Dissolved Solids (mg/L)						
Sample Size	14	9	9	12	22	34
Minimum	14	45	31	42	30	14
Maximum	116	1980	238	176	789	664
Mean	67.4	453	144.3	112.9	304.7	160.2
Median	66	258	130	110	262	129.5
Std. Dev.	29.5	591.4	68.8	45.8	176.9	124.2
Total Suspended Solids (mg/L)						
Sample Size	14	9	9	12	22	34
Minimum	20	14	38	14	18	1
Maximum	239	1114	241	280	686	216
Mean	80.1	268.3	84.6	114.2	213.7	73.0
Median	58.5	134	68	123.5	155	62
Std. Dev.	68.0	363.3	61.8	71.8	172.5	55.8

Table 2 (continued): Summary of North Central Texas Storm Water Data for Sep2000 to Aug2001 (NCTCOG 2002)

Parameter	**Commercial** 4-Stations	**Highway** 3-Stations	**Industrial** 4-Stations	**Residential** 4-Stations	**In-stream** 3-Stations	**Mixed** 4-Stations
Cadmium (µg/L)						
Sample Size	14	12	9	12	22	34
Minimum	1	1	1	1	1	1
Maximum	1	3	1	10	10	5
Mean	1	1.2	1	1.8	1.5	1.1
Median	1	1	1	1	1	1
Std. Dev.	0	0.6	0	2.6	2.0	0.7
Chromium (µg/L)						
Sample Size	14	12	9	12	22	34
Minimum	1	1	1	1	1	1
Maximum	25	30	11	7	30	14
Mean	5.9	9	4.1	4.1	6.6	4.7
Median	3.5	6.5	3	4.5	3.5	4
Std. Dev.	6.6	9.1	3.2	2.4	7.0	3.5
Arsenic (µg/L)						
Sample Size	14	12	9	12	22	34
Minimum	5	5	5	5	5	5
Maximum	40	10	20	10	40	40
Mean	11.1	8.8	9.4	7.9	14.5	11.5
Median	10	10	10	10	10	10
Std. Dev.	9.2	2.3	4.6	2.6	11.8	7.3
Lead (µg/L)						
Sample Size	14	12	9	12	22	34
Minimum	2	2	2	2	2	2
Maximum	120	61	22	50	100	40
Mean	17.9	18.2	8.6	11.7	16.6	10.1
Median	5.5	8.5	5	7	5	5
Std. Dev.	31.0	20.5	6.7	13.2	23.2	10.0
Copper (µg/L)						
Sample Size	14	12	9	12	22	34
Minimum	1	6	3	2	2	1
Maximum	24	40	18	41	190	33
Mean	9.5	18	9.1	10.9	19.0	10.0
Median	6	17	7	8.5	8.5	8.5
Std. Dev.	7.2	11.0	5.0	10.5	39.4	8.0
Zinc (µg/L)						
Sample Size	14	12	9	12	22	34
Minimum	2	30	40	16	14	1
Maximum	290	332	207	260	2400	220
Mean	75.9	123.2	77. 8	79.8	399.5	69.8
Median	49	106.5	52	60	48.5	70.7
Std. Dev.	71.4	94.0	56.2	65.9	681.7	48.4

Table 2 (continued): Summary of North Central Texas Storm Water Data for Sep2000 to Aug2001 (NCTCOG 2002)

Parameter	**Commercial** 4-Stations	**Highway** 3-Stations	**Industrial** 4-Stations	**Residential** 4-Stations	**In-stream** 3-Stations	**Mixed** 4-Stations
Dissolved Phosphorous (mg/L)						
Sample Size	14	10	9	15	23	34
Minimum	0.01	0.01	0.01	0.01	0.01	0.01
Maximum	0.14	0.07	0.09	0.49	0.2	0.244
Mean	0.04	0.03	0.04	0.14	0.04	0.07
Median	0.02	0.02	0.04	0.08	0.02	0.04
Std. Dev.	0.04	0.02	0.03	0.16	0.05	0.07
Total Phosphorous (mg/L)						
Sample Size	14	10	9	15	22	34
Minimum	0.01	0.01	0.06	0.1	0.01	0.01
Maximum	0.4	2.29	0.39	0.66	0.84	0.69
Mean	0.17	0.44	0.19	0.39	0.39	0.20
Median	0.15	0.28	0.18	0.34	0.42	0.13
Std. Dev.	0.12	0.67	0.11	0.18	0.22	0.17
Kjeldahl Nitrogen (mg/L)						
Sample Size	14	10	9	15	22	34
Minimum	0.1	0.1	0.1	0.1	0.1	0.1
Maximum	3.66	5.24	2.9	10	6.33	3.7
Mean	1.09	1.77	0.84	1.79	1.19	0.86
Median	0.92	1.66	0.28	1.1	0.1	0.34
Std. Dev.	1.00	1.76	0.98	2.62	1.70	1.00
Total Nitrogen (mg/L)						
Sample Size	14	10	9	15	23	34
Minimum	0.41	0.25	0.64	0.44	0.62	0.48
Maximum	4.05	8.64	3.29	10.87	7.11	4.68
Mean	1.48	2.90	1.56	2.35	2.07	1.60
Median	1.28	1.97	1.62	1.45	1.3	1.28
Std. Dev.	1.00	2.75	0.82	2.65	1.67	1.03
Diazinon (µg/L)						
Sample Size	14	11	9	12	22	35
Minimum	0.005	0.005	0.005	0.005	0.005	0.002
Maximum	5.800	0.010	0.098	9.097	1.500	0.685
Mean	0.679	0.006	0.024	0.801	0.091	0.030
Median	0.006	0.006	0.005	0.006	0.005	0.005
Std. Dev.	1.617	0.001	0.037	2.615	0.3185	0.116
Oil and Grease (mg/L)						
Sample Size	15	10	9	12	22	35
Minimum	2	0.5	2	14	0.5	0.5
Maximum	559	236	408	419	376	480
Mean	180	105	164	153	120	168
Median	157	96	159	77	98	142
Std. Dev.	174	77	166	143	113	147

Table 3 – Dissolved oxygen criteria for waterways in the Central City area

Mean (mg/L)	Minimum (mg/L)	Spring Mean (mg/L)	Spring Minimum (mg/L)
5.0	3.0	5.5	4.5

Source: Texas Comission on Environmental Quality Chapter 307: Texas Surface Water Quality Standards

Table 4 – Modeled distribution of flows

Reach	Low (7Q2) Flow (cfs)	Median Flow (cfs)	Upstream Reaches
Upstream Clear Fork	4.5	20.5	Headwater
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0.1	1.08	1.2	0.02	1.9
Organic nitrogen (ON) mineralization rate constant (1/day)	**Calculated reaeration rate constants (1/day)**	**Fraction of phytoplankton (phyto) death recycled to nitrogen**	**Phyto max growth rate constant (1/day)**	**Phyto growth temperature correction coeff. (unitless)**
0.04	0.2 - 1.0	1	0.3	1.06
Phyto Carbon: chlorophyll a ratio (unitless)	**Phyto optimal light saturation (langleys/day)**	**Phyto ½ saturation constant for nitrogen (mg/L)**	**Phyto ½ saturation constant for phosphorus (mg/L)**	**Phyto respiration rate constant (1/day)**
50	200	0.025	0.001	0.125
Phyto death rate constant, predation (1/day)	**Phyto nitrogen to carbon ratio (unitless)**	**Phyto phosphorus to carbon ratio (unitless)**	**Sediment oxygen demand (g/m2/d)**	**Net settling rates (for all particulates, m/d)**
0	0.25	0.025	0.5	0
Stream temperature (ºC)	**Daily solar radiation (langleys/day)**	**Non-algal light extinction coefficient (1/m)**	**Wind speed (m/s)**	**CBOD decay rate constant (1/d)**
30	300	5	4.3	0.1

Table 6 – Results of sensitivity analysis with baseline WASP model

Sensitivity Analysis
baseline flow (cfs) = 5.0
baseline DO min (mg/l) = 3.8

parameter	baseline value	high perturbation	new DO min (mg/L)	low perturbation	new DO min (mg/L)	source for perturbation range
wind speed (m/s)	4.3	8.7	**6.6**	1.7	**0.9**	DFW Airport measured wind speeds: summer 2 day min, 2 day max
stream temperature (C)	30	31	**3.7**	22	**4.3**	measured summer instream temperatures (Clear Fork at Trinity, 4th St., Beech St.)
ON upstream concentrations (mg/l: CF, WF)	2.3, 1.2	2.3, 2.3	**3.5**	0.06	**4.1**	measured range at instream and reservoir wq stations
NH4 upstream concentrations (mg/l: CF, WF)	0.2, 0.1	0.2, 0.2	**3.7**	0.02, 0.02	**3.8**	measured range at instream and reservoir wq stations
$CBOD_{ult}$ upstream concentrations (mg/l: CF, WF)	20	42	**3.5**	10	**5.0**	measured range at instream and reservoir wq stations
chl a upstream concentrations (ug/l: CF, WF)	45	94	**2.9**	1	**3.7**	measured range at instream and reservoir wq stations
OP upstream concentrations (ug/l: CF, WF)	0.3, 0.09	0.3, 0.3	**3.8**	0.02, 0.02	**3.8**	measured range at instream and reservoir wq stations
DPO4 upstream concentrations (ug/l: CF, WF)	0.07, 0.02	0.2, 0.2	**3.8**	0.0025, 0.0025	**3.8**	measured range at instream and reservoir wq stations
ON mineralization rate constant (1/d)	0.04	0.4	**3.2**	0.02	**4.0**	QUAL2E recommended ranges
ON settling velocity (m/d)	0	1.8, with f = 0.5	**4.0**	0	**3.8**	QUAL2E recommended ranges
NH4 nitrification rate constant (1/d)	0.1	1	**3.6**	0.05	**3.8**	QUAL2E recommended ranges
NO3 denitrification rate (1/d)	0.02	0.04	**3.8**	0	**3.7**	WASP recommended = 0.09, model stability error above 0.04
CBOD decay rate constant (1/d)	0.1	0.5	**2.6**	0.05	**4.5**	Chapra, p. 356
CBOD settling velocity (m/d)	0	1.8, with f = 0.5	**5.9**	0	**3.8**	QUAL2E recommended ranges, for phytoplankton
sediment oxygen demand (SOD, g/m2/d)	0.5	0.07	**4.1**	1.5	**3.1**	Chapra, p.452
phytoplankton max growth rate (1/d)	0.3	3	**4.7**	0	**2.8**	WASP recommended range
phytoplankton respiration rate (1/d)	0.125	0.5	**2.6**	0	**7.1**	WASP recommended range
phytoplankton settling velocity (m/d)	0	1.8	**3.7**	0	**3.8**	QUAL2E recommended ranges

ON = organic nitrogen; CBOD = carbonaceous biochemical oxygen demand; DPO4 = dissolved othrophosphate; chl a = cholorphyll a

Table 7 – Model parameter ranking (in descending order of dissolved oxygen sensitivity)

Wind speed
Phytoplankton growth/respiration balance
CBOD settling velocity
CBOD decay rate constant
CBOD upstream loading
Sediment oxygen demand (SOD)
Organic nitrogen mineralization rate constant
Phytoplankton (chlorophyll a) upstream loading
TKN upstream loading
Stream temperature
(all other parameters impact D.O. within ± 0.2 mg/L)

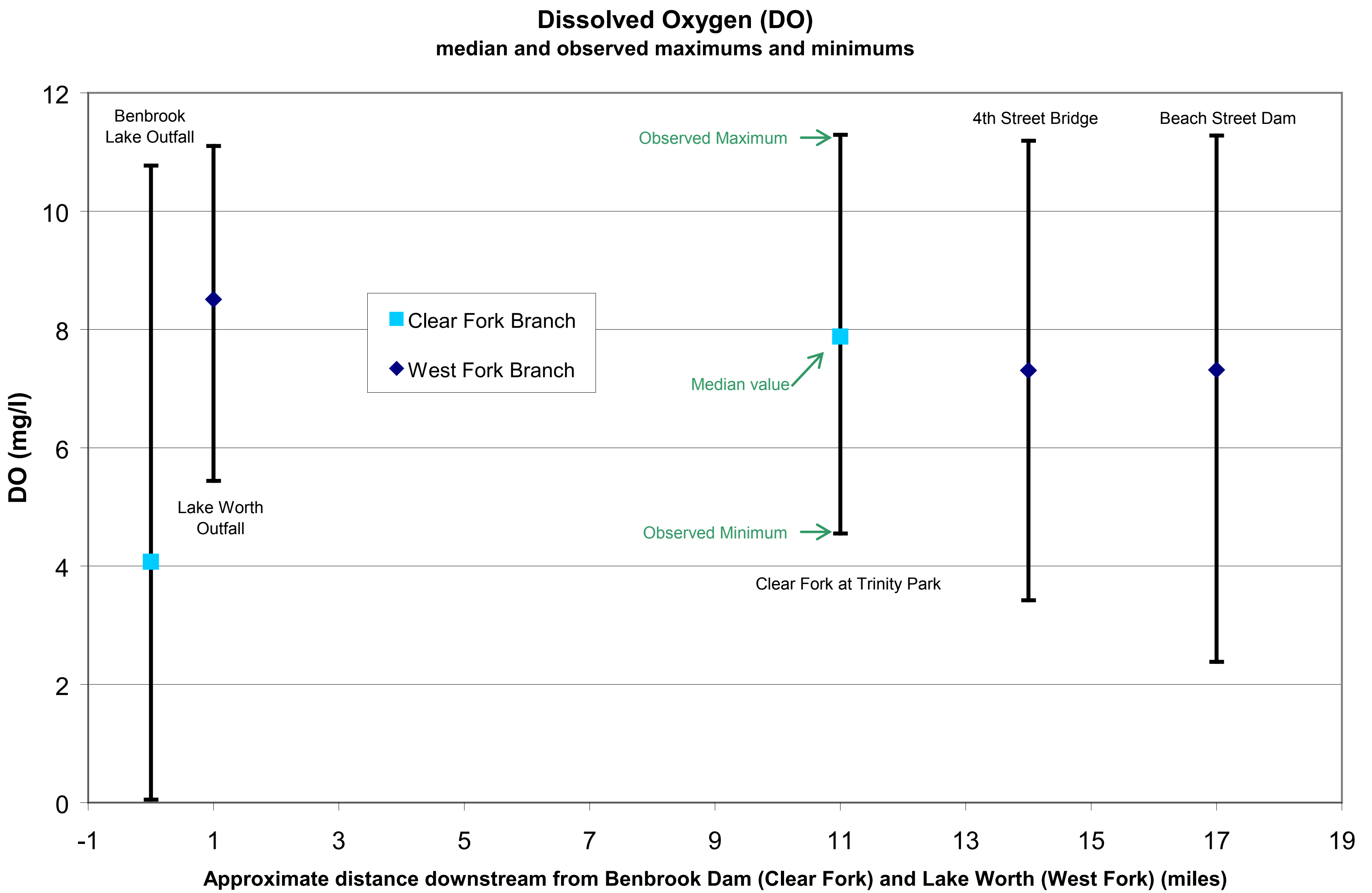


Figure 1 – Historical dissolved oxygen for the Clear and West Forks of the Trinity River (State Stream Segments 0806 and 0829)

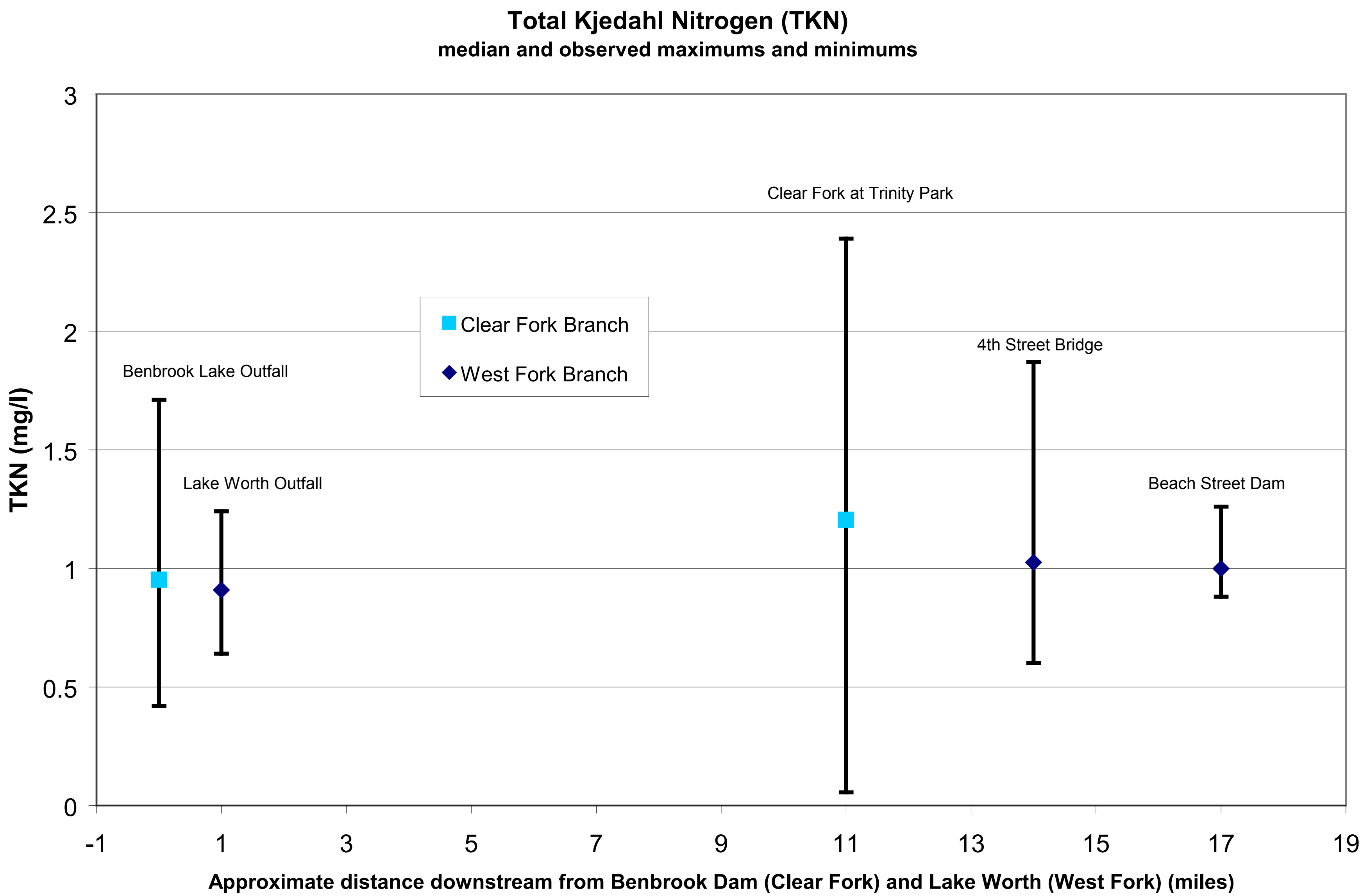


Figure 2 – Historical total kjeldhal nitrogen (TKN) for the Clear and West Forks of the Trinity River (State Stream Segments 0806 and 0829)

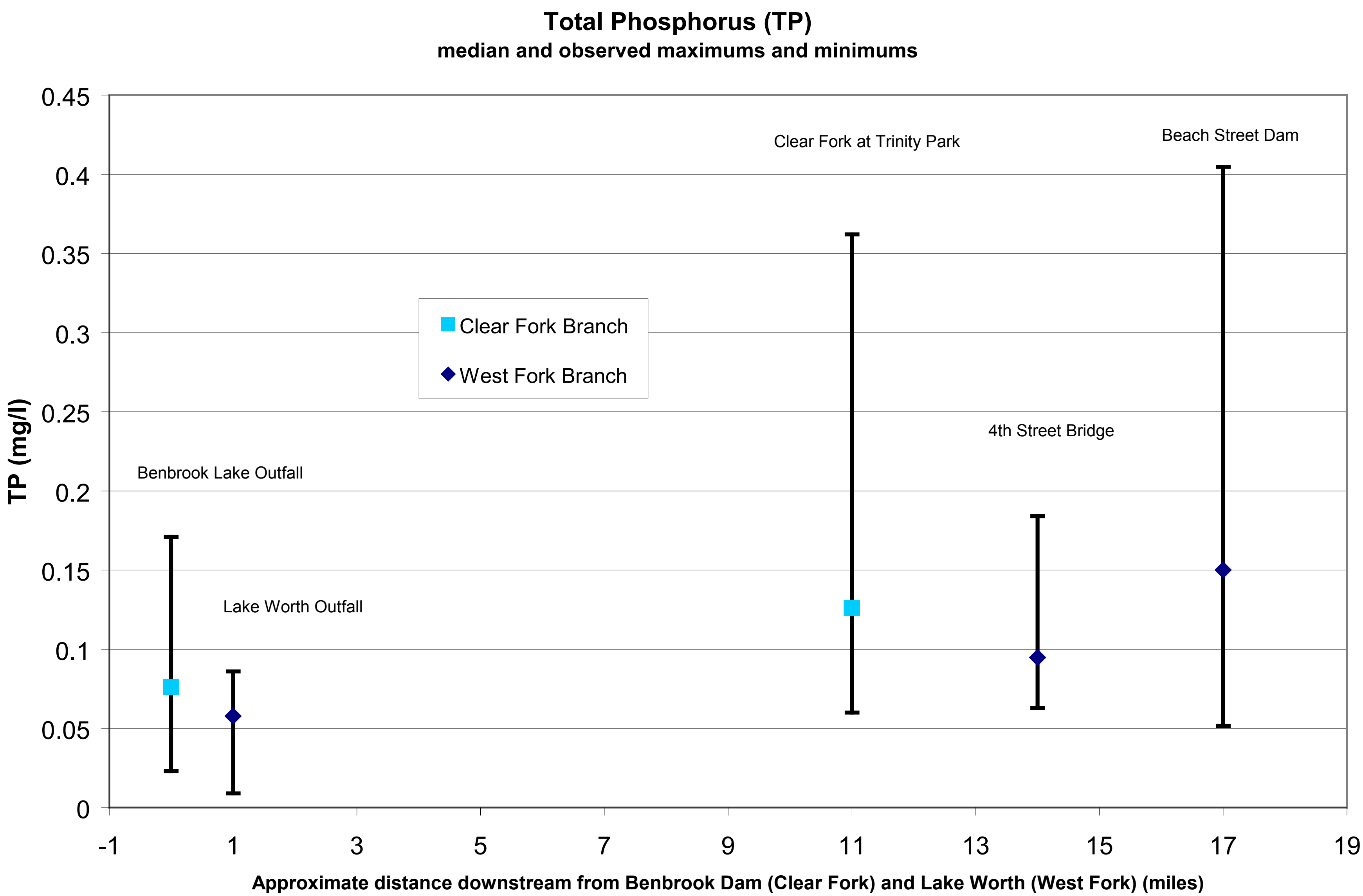


Figure 3 – Historical total phosphorous for the Clear and West Forks of the Trinity River (State Stream Segments 0806 and 0829)

CDM

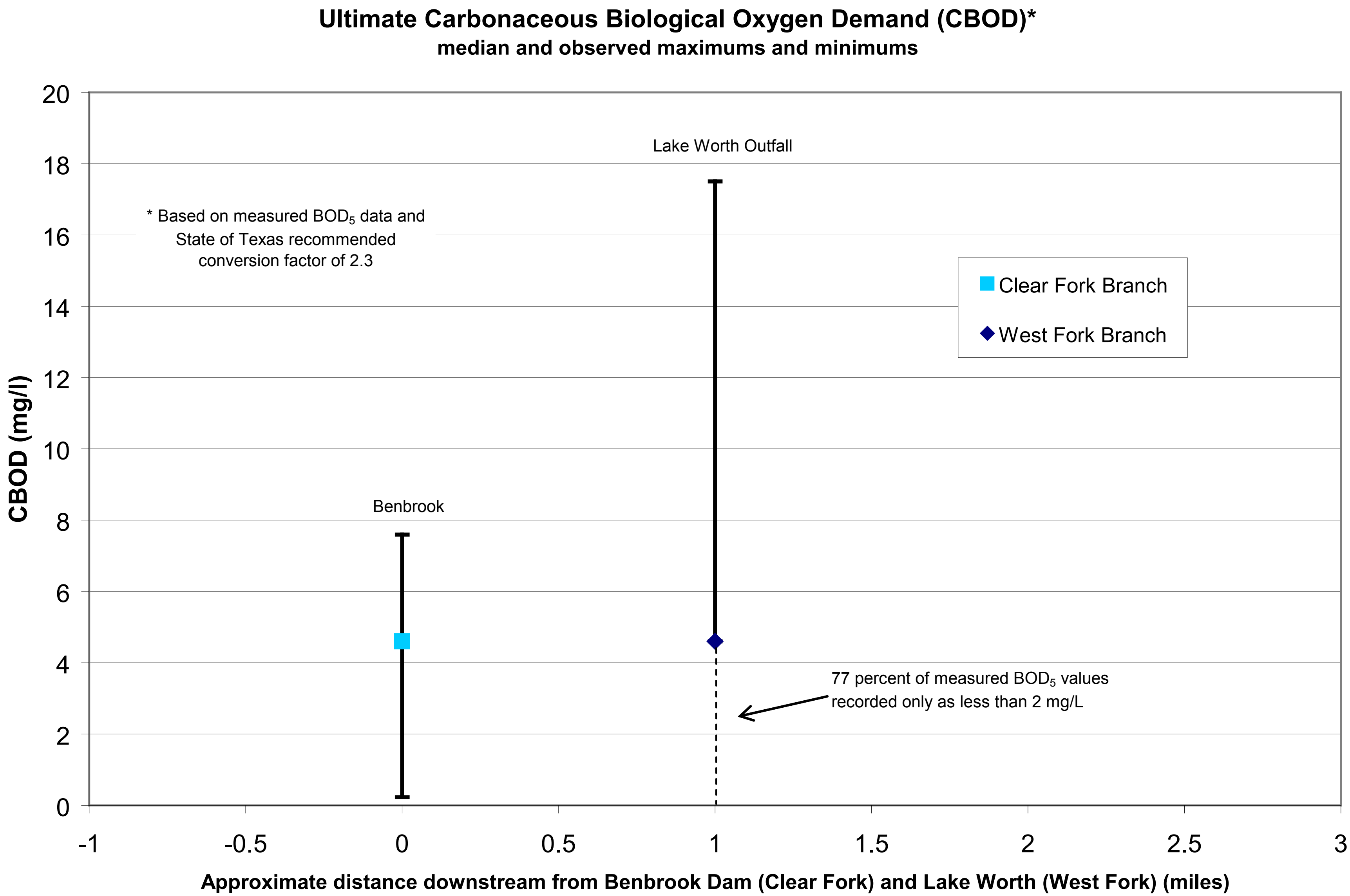


Figure 4 - Historical carbonaceous biochemical oxygen demand (CBOD) for the Clear and West Forks of the Trinity River (State Stream Segments 0806 and 0829)

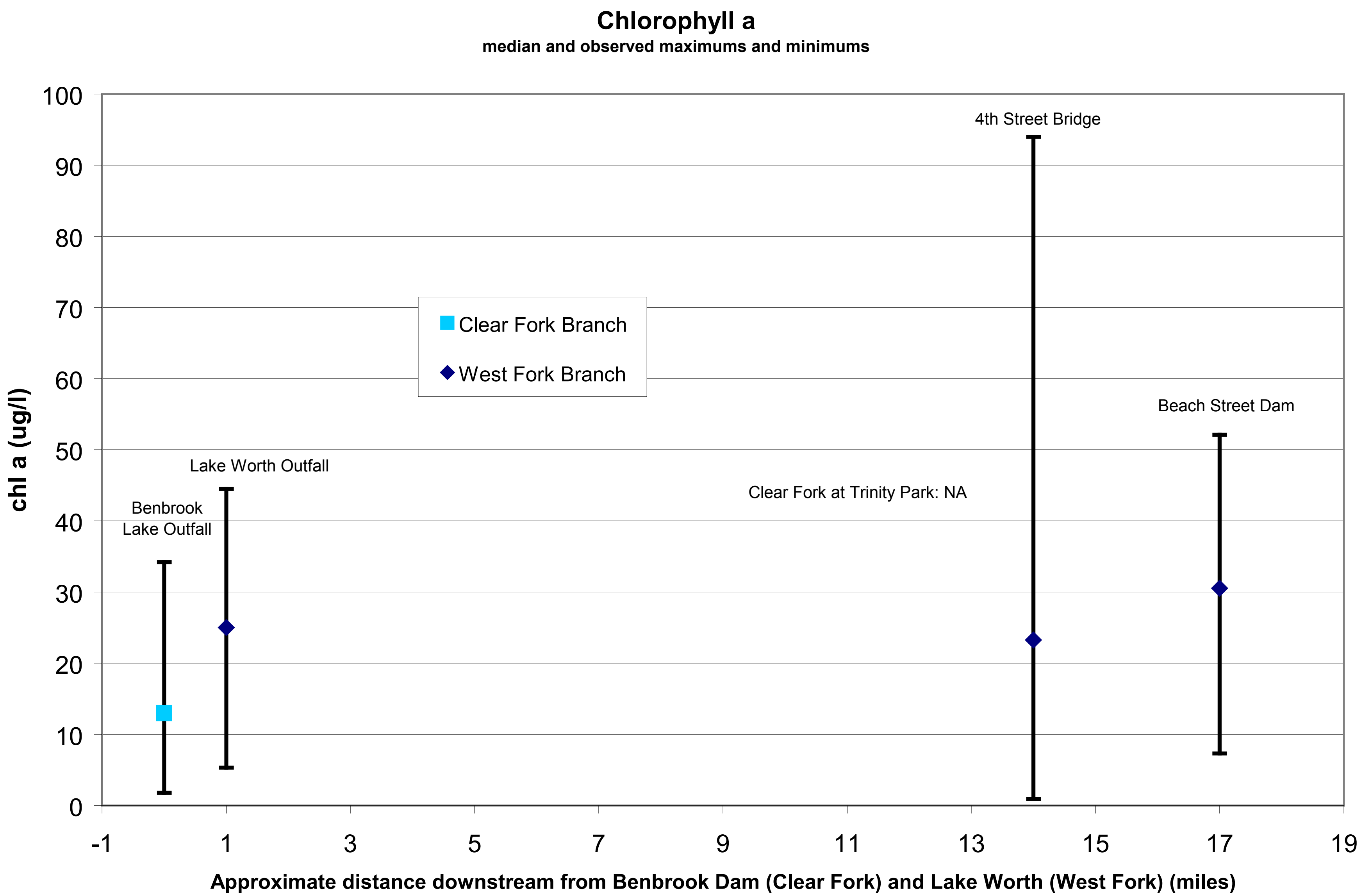
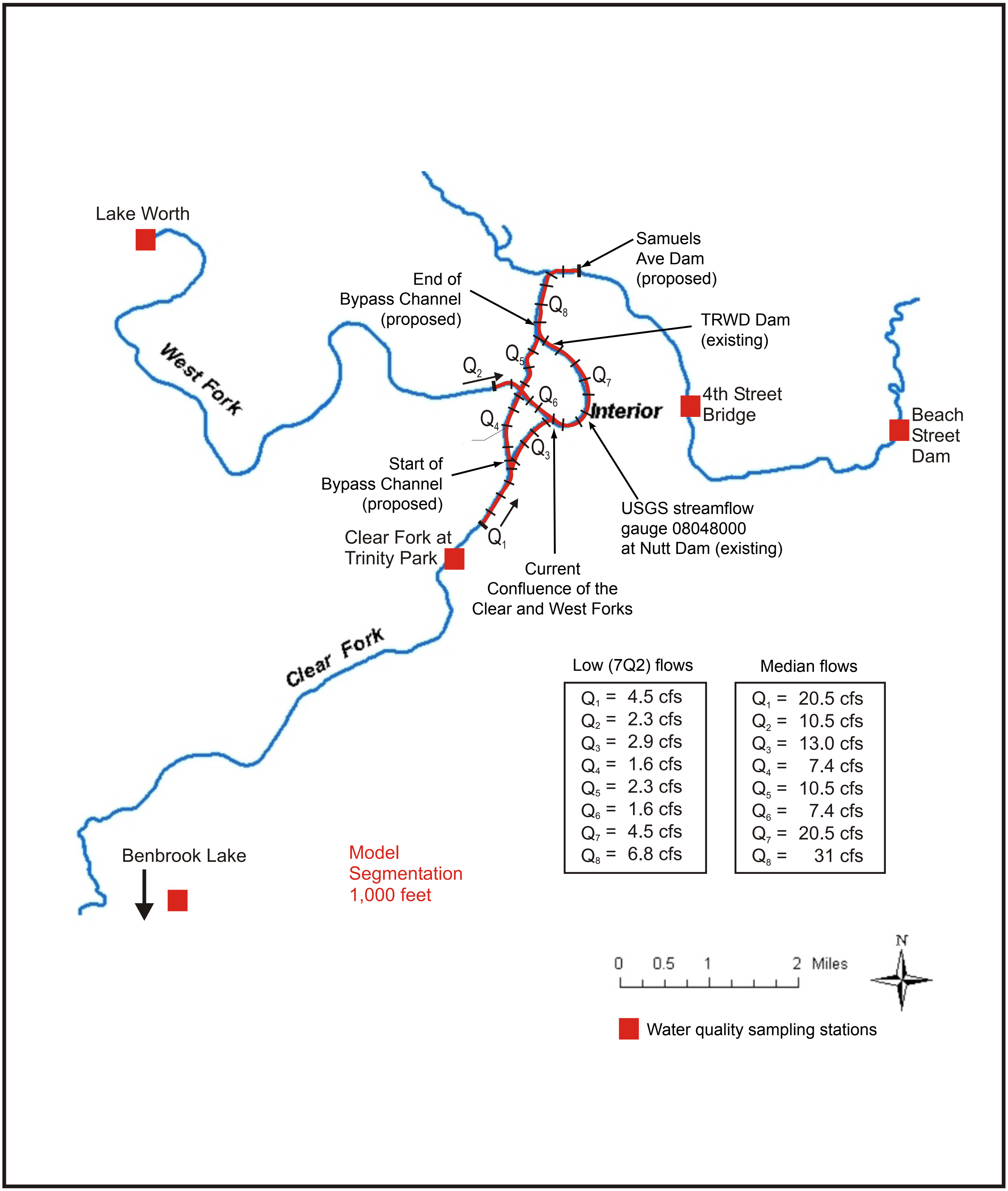


Figure 5 – Historical chlorophyll a for the Clear and West Forks of the Trinity River (StateStream Segments 0806 and 0829)



Low (7Q2) flows

Q_1 =	4.5 cfs
Q_2 =	2.3 cfs
Q_3 =	2.9 cfs
Q_4 =	1.6 cfs
Q_5 =	2.3 cfs
Q_6 =	1.6 cfs
Q_7 =	4.5 cfs
Q_8 =	6.8 cfs

Median flows

Q_1 =	20.5 cfs
Q_2 =	10.5 cfs
Q_3 =	13.0 cfs
Q_4 =	7.4 cfs
Q_5 =	10.5 cfs
Q_6 =	7.4 cfs
Q_7 =	20.5 cfs
Q_8 =	31 cfs

Figure 6 – Schematic of the Trinity River/Central City WASP model including major components of the existing and proposed systems

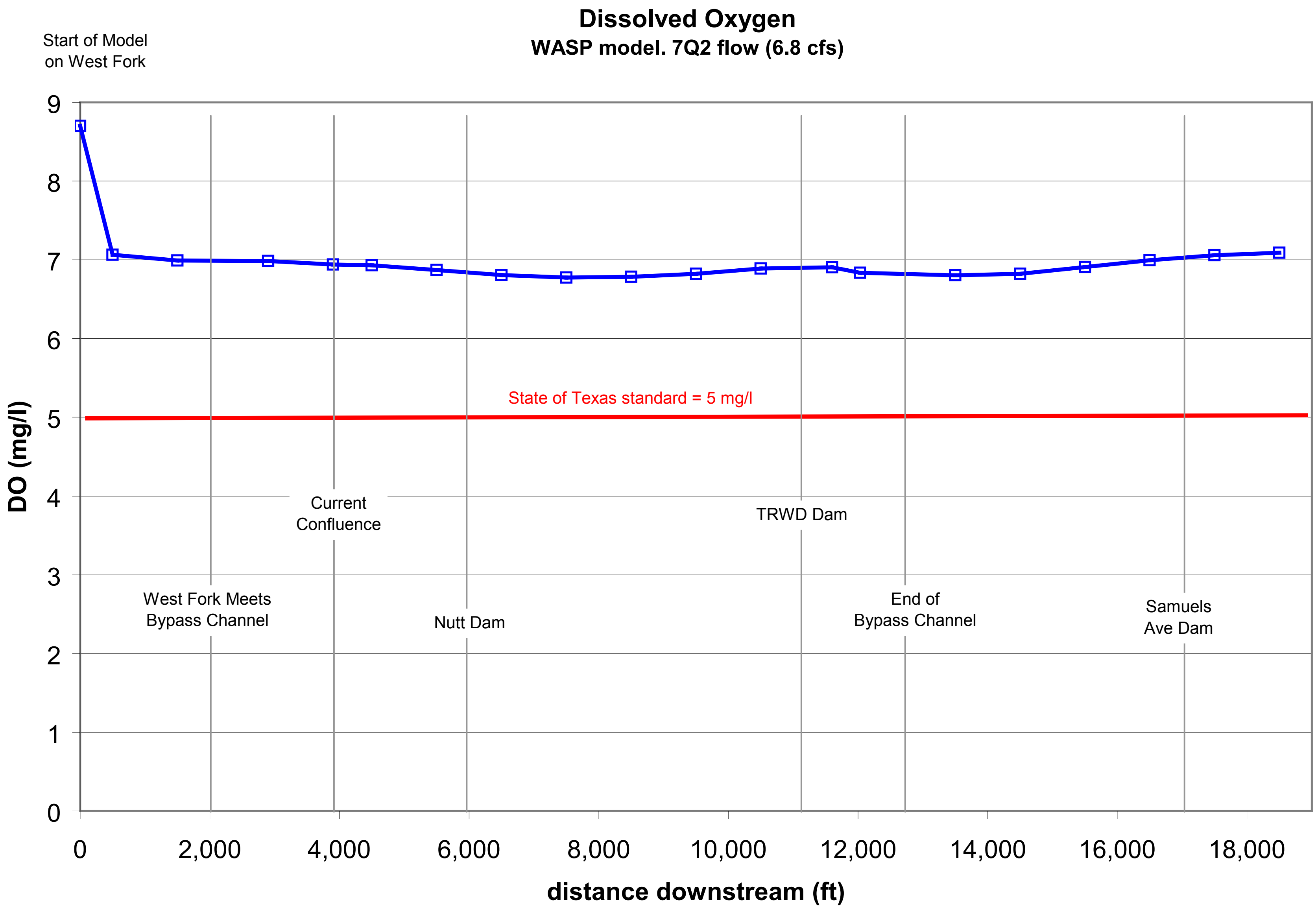


Figure 7 - Results of WASP analysis for low flow conditions for dissolved oxygen for the proposed project

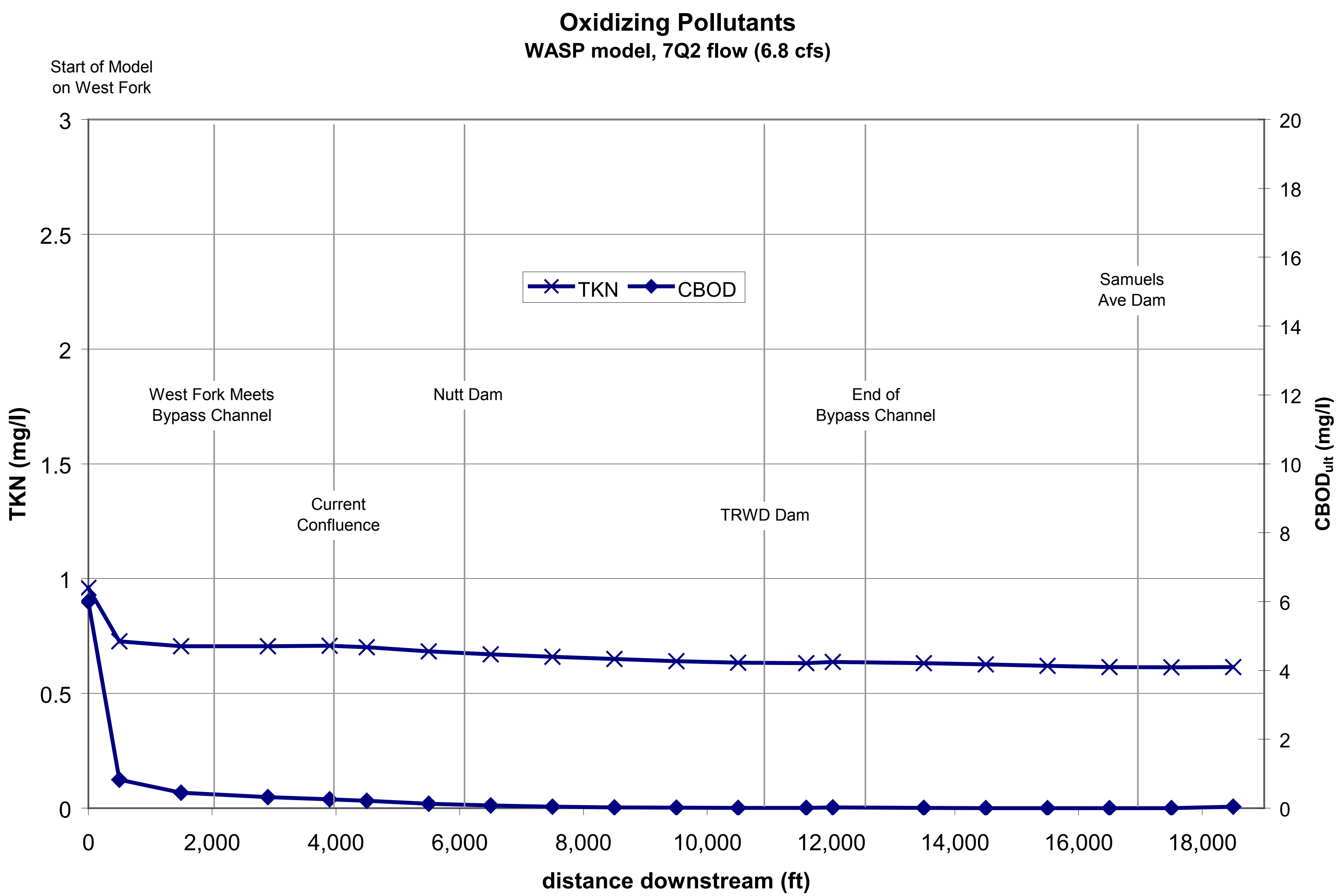


Figure 8 - Results of WASP analysis for low flow conditions for oxidizing pollutants for the proposed project

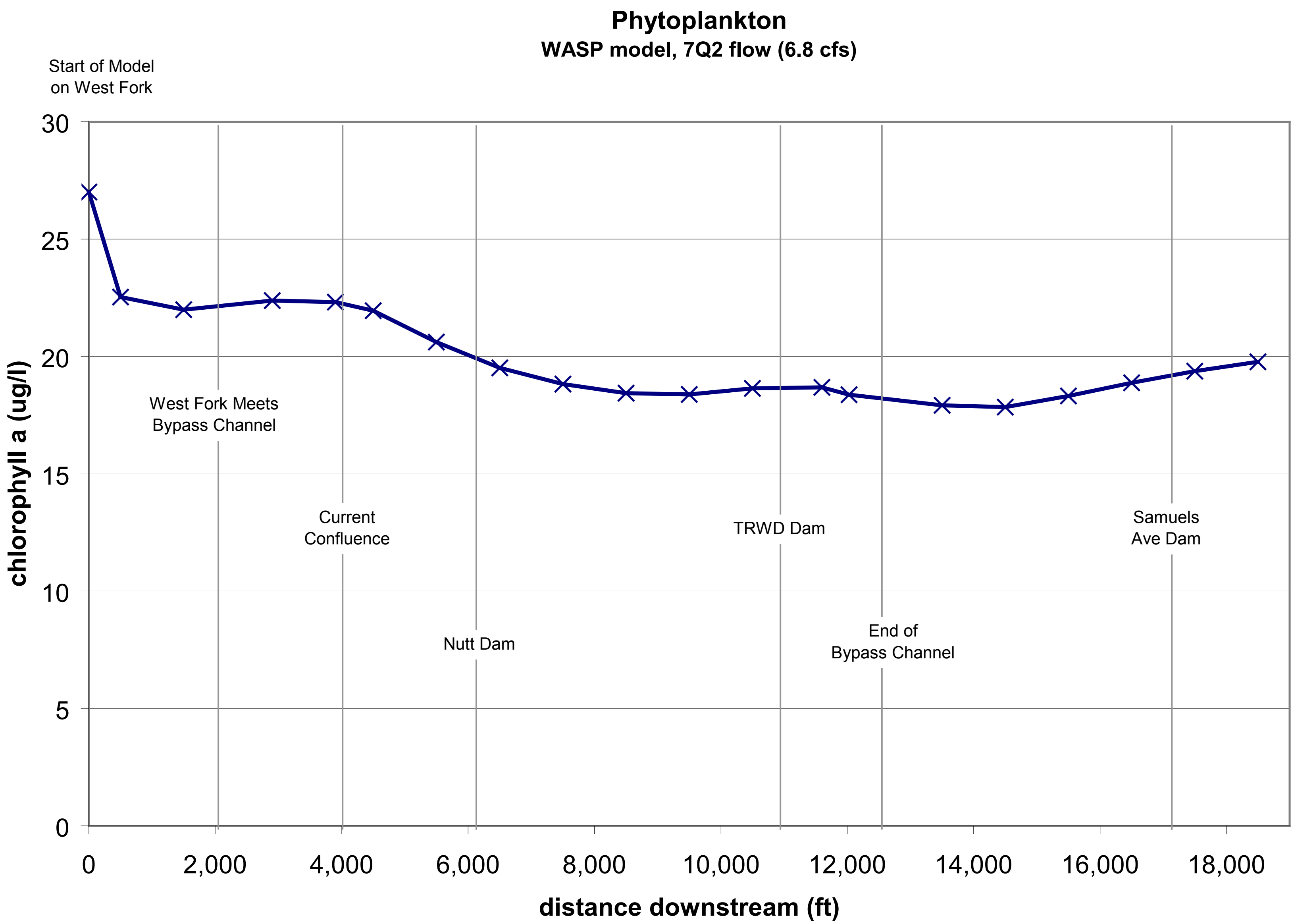


Figure 9- Results of WASP analysis for low flow conditions for chlorophyll *a* for the proposed project

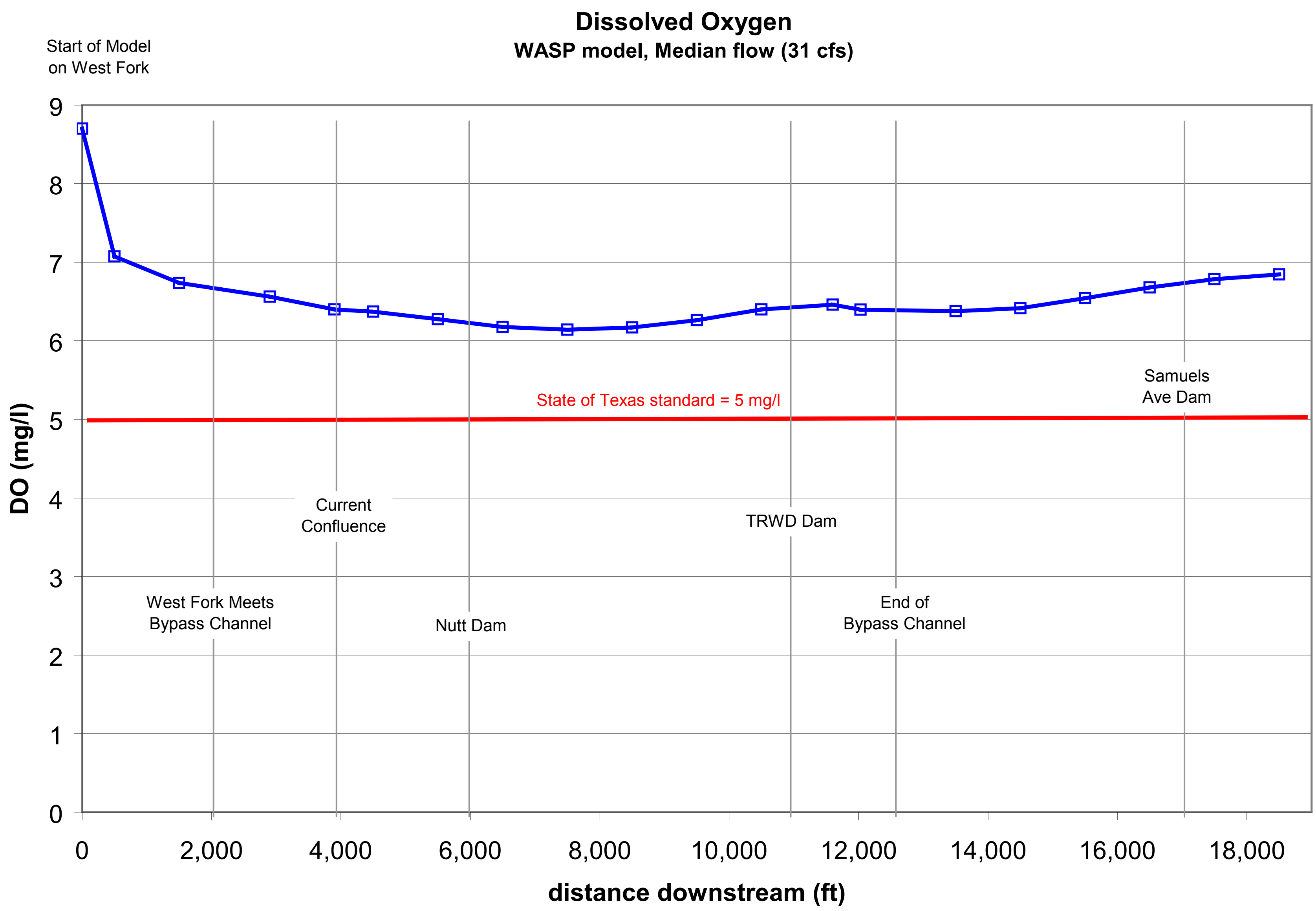


Figure 10 - Results of WASP analysis for median flow conditions for dissolved oxygen for the proposed project

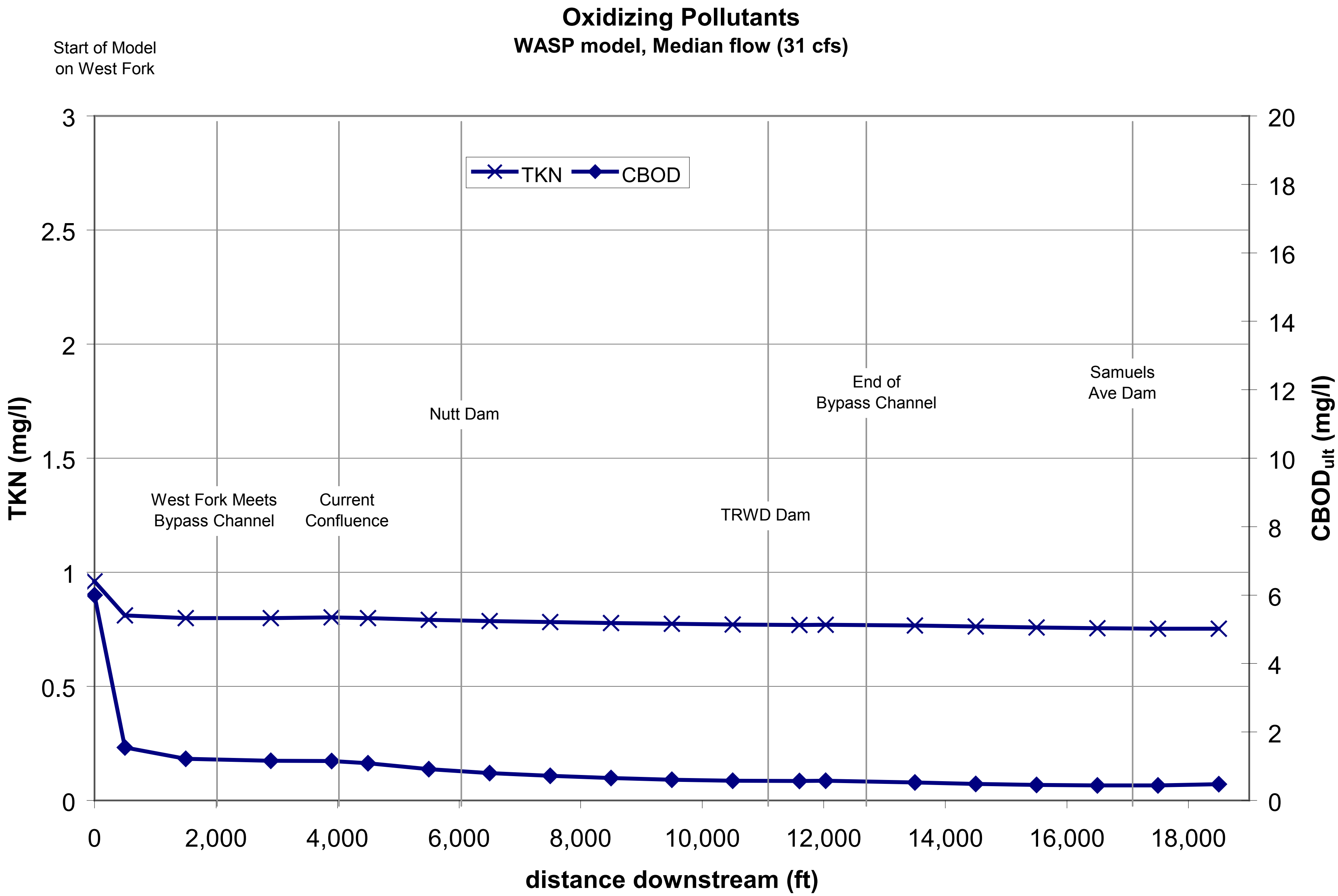


Figure 11 - Results of WASP analysis for median flow conditions for oxidizing pollutants for the proposed project

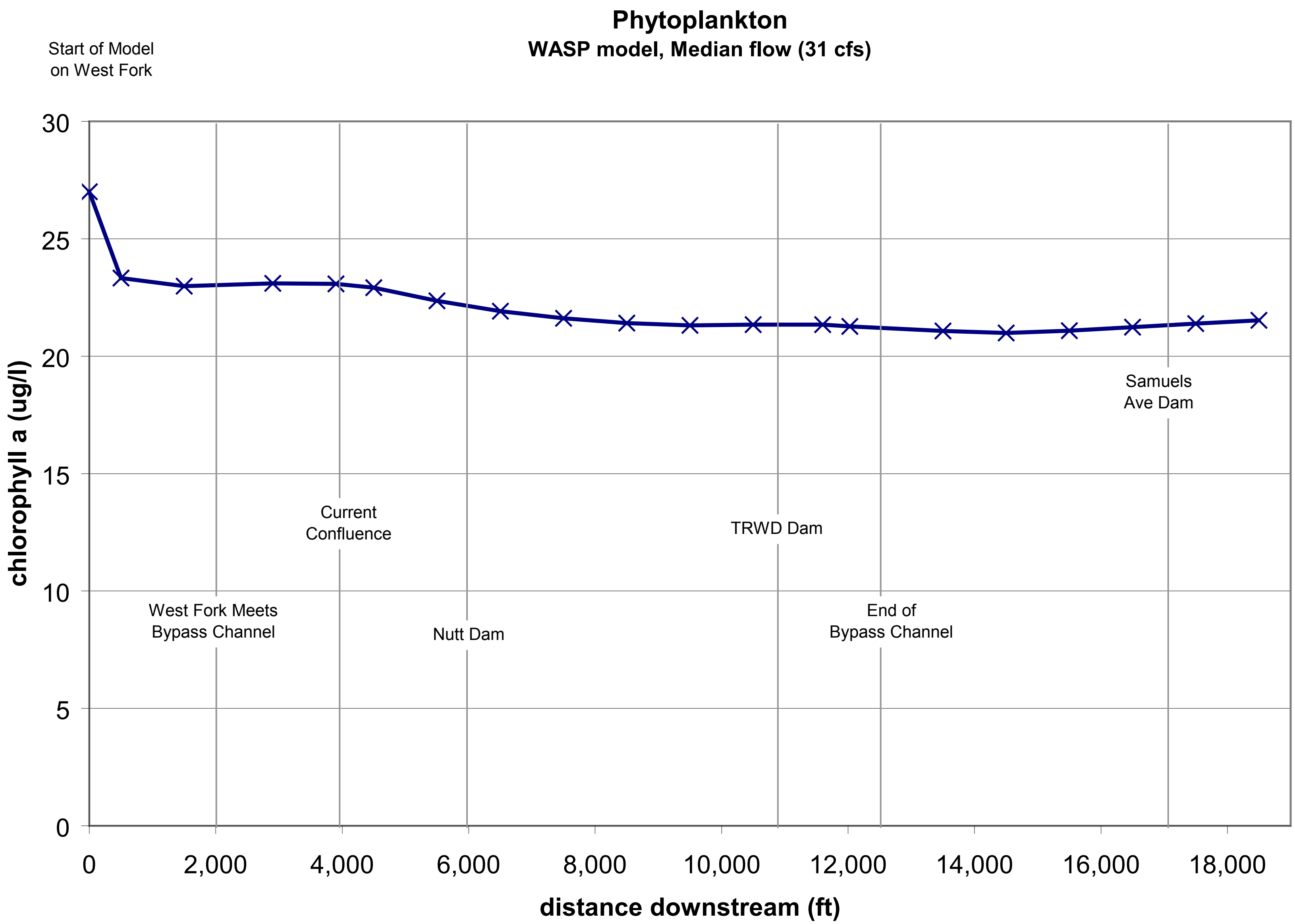


Figure 12 - Results of WASP analysis for median flow conditions for chlorophyll *a* for the proposed project

CDM

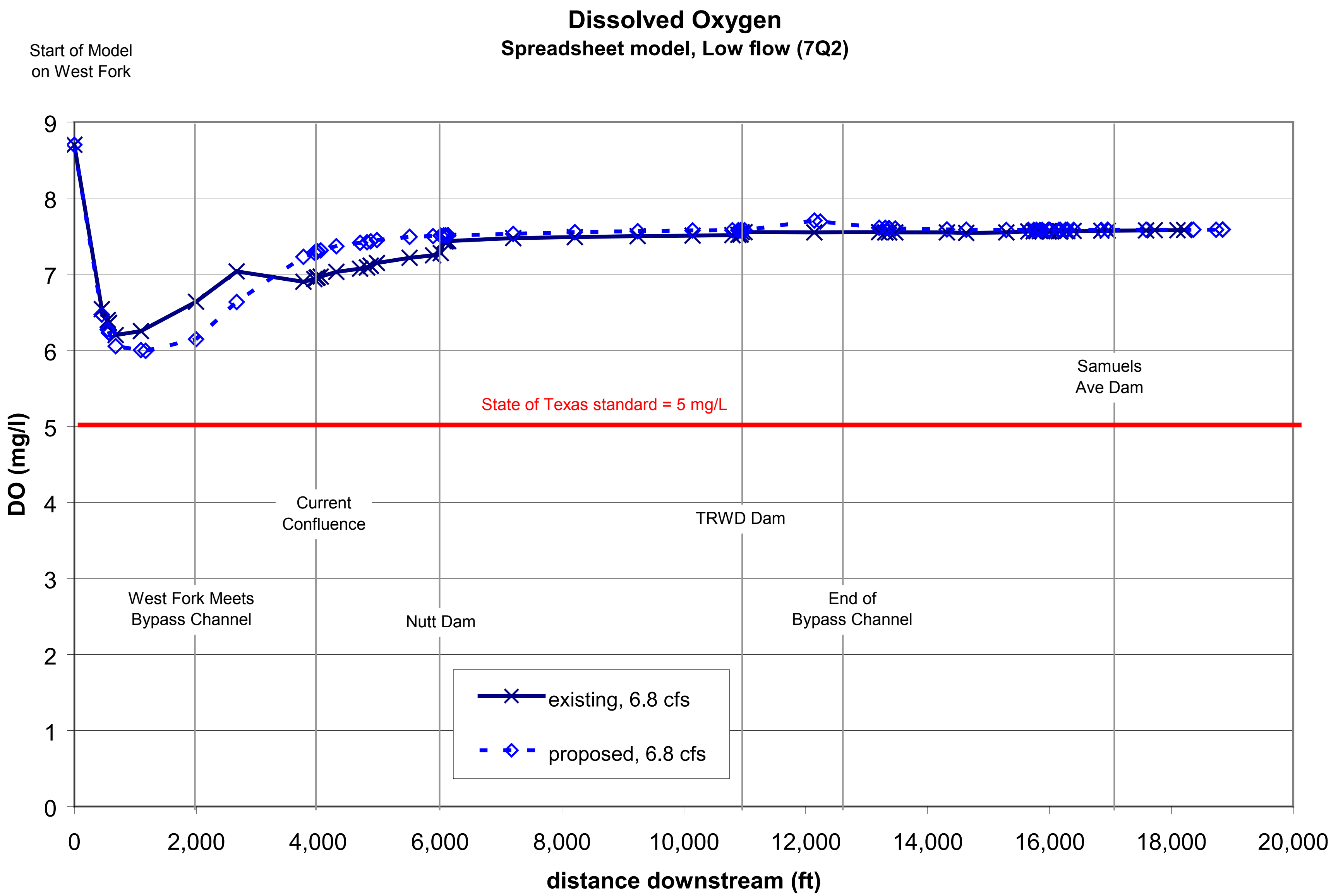


Figure 13 – Comparison of modeled dissolved oxygen concentrations between existing and proposed conditions for low flow

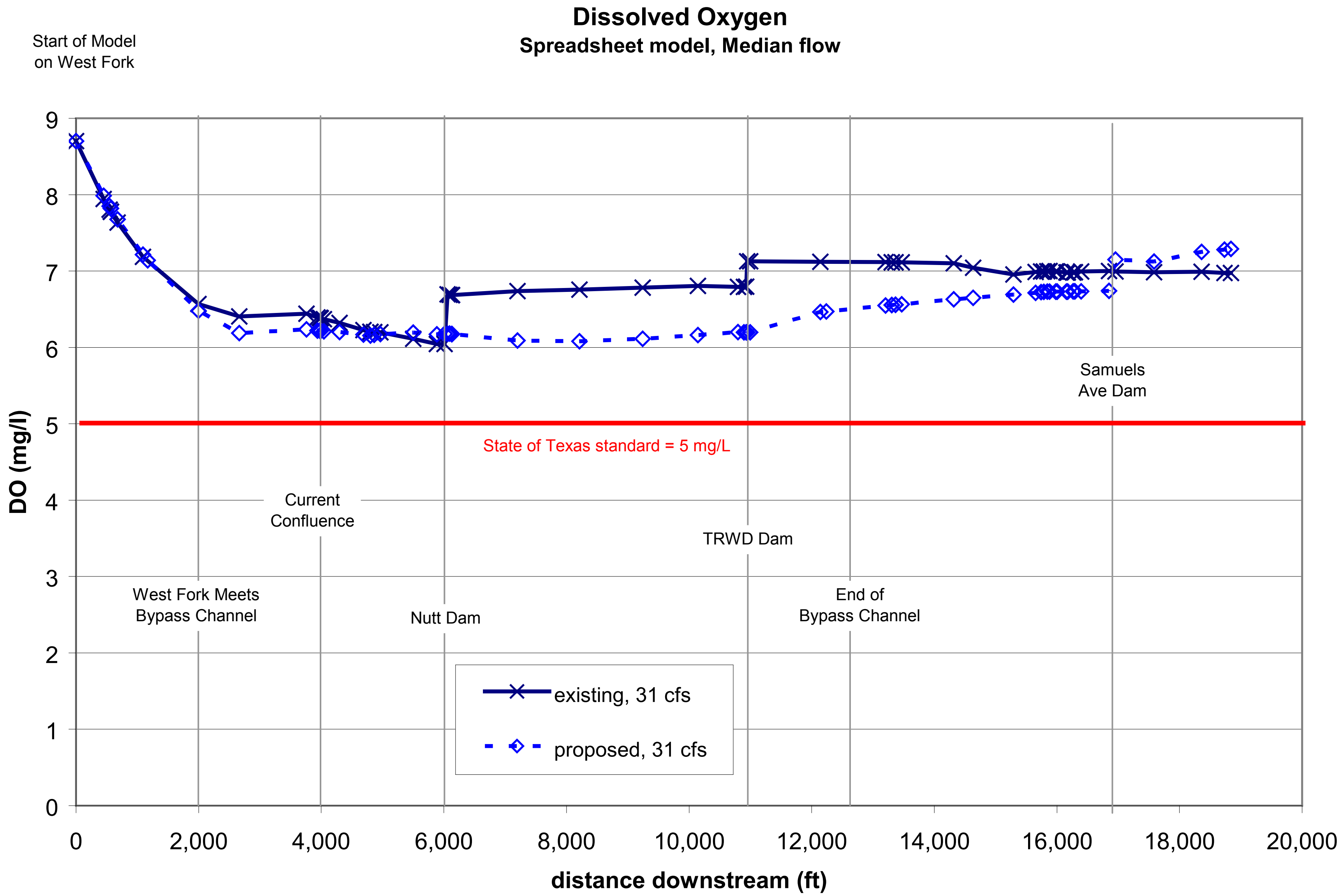


Figure 14 – Comparison of modeled dissolved oxygen concentrations between existing and proposed conditions for median flow