TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

AGENDA ITEM REQUEST

AGENDA REQUESTED: April 2, 2008

DATE OF REQUEST: March 14, 2008

NAME & NUMBER OF PERSON TO CONTACT REGARDING CHANGES TO THIS REQUEST, IF NEEDED: Suzanne Vargas, 239-4619.

CAPTION: Docket No. 2008-0220-TML. Consideration for approval to publish and solicit public comment on one draft TMDL for dissolved oxygen in Upper Oyster Creek (Segment 1245), of the Brazos River Basin, in Fort Bend County.
(Faith Hambleton, Marc Friberg)

_____

Chief Engineer

Texas Commission on Environmental Quality

INTEROFFICE MEMORANDUM

To: Commissioners Date: March 14, 2008

Thru: LaDonna Castañuela, Chief Clerk

Glenn Shankle, Executive Director

From: David C. Schanbacher, P.E., Chief Engineer
Chief Engineer's Office

Subject: Release of One Draft Total Maximum Daily Load for Dissolved Oxygen in Upper Oyster Creek for Public Comment

Issue Consideration for approval to publish and solicit public comment on one draft TMDL for dissolved oxygen in Upper Oyster Creek (Segment 1245) of the Brazos River Basin, in Fort Bend County.

Background and Current Practice One draft TMDL has been prepared as required by Section 303(d) of the Clean Water Act. TMDLs must be submitted to U.S. EPA for approval as certified updates to the State of Texas Water Quality Management Plan (WQMP). Prior to submission of TMDLs to EPA, TCEQ staff request approval from the commission to release the draft TMDLs for a formal public review and comment period. After the public comment period, TCEQ staff make appropriate changes to the draft TMDLs and document public comments for the record. The next step is to request that the commission adopt and certify the final TMDLs as an update to the State of Texas WQMP. The commission approved TMDLs are then forwarded to U.S. EPA for their final approval or disapproval within 60 days.

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Attachments

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Upper Oyster Creek (Segment 1245) TMDL for Dissolved Oxygen
Summary Outline – February 7, 2008

I. Introduction

- The goal of this project is to determine the allowable loadings for oxygen-demanding substances (carbonaceous biochemical oxygen demand (CBOD) and ammonia nitrogen (NH_3-N)) that will enable Upper Oyster Creek to meet its designated intermediate aquatic life use.

II. Background Information

- Upper Oyster Creek (Figure 1) is a freshwater stream located in the Brazos River Basin, southwest of Houston, Texas, in northern Fort Bend County. It is approximately 54 miles long and has a watershed area of 107 square miles.

Figure 1. Upper Oyster Creek Watershed

- The segment called "Upper Oyster Creek" actually includes portions of several water bodies, and has been significantly modified from natural conditions. It begins at the Gulf Coast Water Authority (GCWA) Shannon Pump Station on the Brazos River and continues through Jones Creek to its confluence with Oyster Creek, through the City of Sugar Land to its confluence with Flat Bank Creek, through Flat Bank Creek to its confluence with the diversion canal, through the diversion canal to its confluence with Steep Bank Creek, and finally through Steep Bank Creek to its confluence with the Brazos River.

- Three small dams on Upper Oyster Creek are located on the watercourse around the City of Sugar Land. The dams form impoundments to maintain nearly constant water levels for industrial and recreational uses.

- There are two distinct hydrologic reaches within the Upper Oyster Creek segment. The upper reach extends from the GCWA Shannon Pump Station on the Brazos River to Dam #3 within the City of Sugar Land. The lower reach begins at Dam #3 and continues downstream to its confluence with the Brazos River. TMDL allocations have been calculated for each of these two reaches.

- Fort Bend County is rapidly urbanizing. This is particularly evident in the lower portion of the watershed, which includes the cities of Stafford, Missouri City, and Sugar Land.

III. Problem Definition

- Upper Oyster Creek was first placed on the State of Texas 303(d) List in 1996 due to depressed dissolved oxygen levels causing nonsupport of the intermediate aquatic life use.

- A TMDL project was initiated to quantify appropriate reductions of oxygen-demanding substances necessary to comply with established water quality standards.

IV. Endpoint Identification

- The primary endpoint for this TMDL will be based on the intermediate aquatic life use criteria: 24-hr average dissolved oxygen concentration $\geq$ 4.0 mg/l; 24-hr absolute minimum dissolved oxygen concentration $\geq$ 3.0 mg/l.

- Note that more stringent criteria are in place to protect fish spawning during any of the first 6 months of the year when average water temperature is between 63 and 73 °F: 24-hr average dissolved oxygen concentration $\geq$ 5.0 mg/l; 24-hr absolute minimum dissolved oxygen concentration $\geq$ 4.0 mg/l.

V. Source Analysis

- Oxygen-demanding pollutants may come from several sources, both point and nonpoint. The pollutants considered of greatest concern were CBOD and NH_3-N.

- Potential point source dischargers in the Upper Oyster Creek watershed include 17 facilities permitted to discharge wastewater (or with pending discharge permits).

- Possible nonpoint pollution sources in the Upper Oyster Creek watershed include Brazos River water pumped in at the Shannon Pump Station and rainfall runoff from non-permitted areas. A strong linkage of rainfall-runoff derived pollution to impairment of the intermediate aquatic life use of Segment 1245 was not established and this TMDL, therefore, does not address traditional nonpoint source pollution or permitted municipal storm water (which is considered a point source discharge).

VI. Linkage

- A series of 24-hr dissolved oxygen surveys were conducted in 2003, 2004, and 2005. These surveys confirmed that Upper Oyster Creek is not supporting its intermediate aquatic life use.

- Many of the dissolved oxygen exceedances occurred under flow conditions that approached steady state conditions as opposed to dynamic flow conditions under the influence of rainfall runoff. Linkage analysis, therefore, emphasized regulated point source contributions.

- Linkage of sources to the receiving waters in Segment 1245 was accomplished using a steady state water quality model called QUAL2K.

- Observational data for validation of the model were available from intensive surveys conducted in the Upper Oyster Creek system in May and August 2004. The intensive surveys were performed at a total of 21 stream stations (Upper Oyster Creek and tributaries) and at all 9 permitted discharges in the segment that were active during the summer of 2004.

- Model results indicated the need for reductions of CBOD and NH_3-N from permitted facilities in Upper Oyster Creek. On the other hand, the model showed that the imposition of point source phosphorus limits on permitted facilities would not lead to an improvement in dissolved oxygen concentrations.

VII. Allocations

- Load allocations were calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where

WLA = wasteload allocation (point source contributions);
LA = load allocation (nonpoint source contributions); and
MOS = margin of safety.

- The TMDL allocation process emphasized regulated point source contributions from wastewater treatment facilities (WWTFs). Therefore, WLA was defined as

contributions from WWTFs. The LA was defined as critical low-flow background contributions from the watershed, and for the upper reach, any contributions from the pumped Brazos River water.

VIII. Margin of Safety

- This TMDL uses an implicit margin of safety, based on conservative model assumptions that include evaluation under full permitted limits during critical low flow conditions, which is an extremely unlikely combination of circumstances, and conservative assumptions regarding some model input parameters.

IX. TMDL

$$TMDL = \sum WLA + \sum LA + MOS \text{ (implicit)}$$

- TMDLs were calculated for CBOD and NH_3-N for both the Upper Reach and Lower Reach. A seasonal analysis was performed. The following tables summarize the TMDL allocations. The "Allowable Loading" is the TMDL.

Table 1. TMDL summary for Lower Reach NH_3-N, critical low-flow condition, and the March – October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	253.27	186.26	26
Load Allocation	0.04	0.04	0
Total Loading	253.31	186.30	26

Table 2. TMDL Summary for Lower Reach $CBOD_5$, critical low-flow condition, and the March – October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	931.3	482.7	48
Load Allocation	1.0	1.0	0
Total Loading	932.3	483.7	48

Table 3. TMDL summary for Lower Reach NH_3-N, critical low-flow condition, and the November – February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	268.41	268.41	0
Load Allocation	0.04	0.04	0
Total Loading	268.45	268.45	0

Table 4. TMDL Summary for Lower Reach $CBOD_5$, critical low-flow condition, and the November – February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	931.3	931.3	0
Load Allocation	1.0	1.0	0
Total Loading	932.3	932.3	0

Table 5. TMDL summary for Upper Reach NH_3-N, critical low-flow condition, and the March – October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	26.86	23.60	12
Load Allocation	4.17	4.17	0
Total Loading	31.03	27.77	11

Table 6. TMDL summary for Upper Reach $CBOD_5$, critical low-flow condition, and the March – October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	114.2	114.2	0
Load Allocation	108.3	108.3	0
Total Loading	222.5	222.5	0

Table 7. TMDL summary for Upper Reach NH_3-N, critical low-flow condition, and the November – February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	26.86	26.86	0
Load Allocation	4.17	4.17	0
Total Loading	31.03	31.03	0

Table 8. TMDL summary for Upper Reach $CBOD_5$, critical low-flow condition, and the November – February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	114.2	114.2	0
Load Allocation	108.3	108.3	0
Total Loading	222.5	222.5	0

X. Implementation Strategies

- The TCEQ works with stakeholders to develop the strategies summarized in the TMDL Implementation Plan. Implementation Plans may use an adaptive management approach that achieves initial loading allocations from a subset of the source categories. Adaptive management allows for development or refinement of methods to achieve the environmental goal of the plan.

- Periodic and repeated evaluations of the effectiveness of implementation methods assure that progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. This adaptive approach provides reasonable assurance that the necessary activities to reduce the pollutants will be implemented.

For Public Comment, April 2008

One Total Maximum Daily Load for Dissolved Oxygen in Upper Oyster Creek

Segment 1245

Prepared by the:
Chief Engineer's Office, Water Programs, TMDL Section
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Distributed by the
Total Maximum Daily Load Section
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<www.tceq.state.tx.us/implementation/water/tmdl/>

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the U.S. Environmental Protection Agency.

This TMDL report is based in large part on the report titled
"Technical Support Document:
Upper Oyster Creek (Segment 1245) Dissolved Oxygen TMDL"

prepared by

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One Total Maximum Daily Load for Dissolved Oxygen in Upper Oyster Creek

Executive Summary

This document describes the total maximum daily load for dissolved oxygen in Upper Oyster Creek (Segment 1245). Monitored concentrations of dissolved oxygen are lower than the criteria used to evaluate attainment of the segment's designated intermediate aquatic life use. This impairment was first identified in the *1996 Texas Water Quality Inventory and 303(d) List*. Upper Oyster Creek extends for approximately 54 miles in rapidly urbanizing Fort Bend County and has a watershed area of approximately 107 square miles (27,600 hectares). It is located in the Brazos River Basin southwest of Houston.

Assessment sampling conducted during the project confirmed that Upper Oyster Creek is not meeting its dissolved oxygen criteria. Depressed dissolved oxygen concentrations extend through much of the length of the segment. Pollutant discharges to Upper Oyster Creek and its tributaries originate from both point and nonpoint sources. Sources include municipal wastewater treatment facilities (WWTFs), regulated and unregulated nonpoint sources, and water pumped into the segment from the Brazos River.

Upper Oyster Creek can be divided into two hydrologically distinct sections, which are referred to as the Lower Reach and the Upper Reach. Pollutant load allocations were developed for each reach for two oxygen-demanding substances—carbonaceous biochemical oxygen demand (CBOD) and ammonia. Separate steady-state water quality models of both reaches were validated and applied to determine the necessary load reductions and allowable loadings for point sources. Because depressed dissolved oxygen could not be substantively associated with nonpoint source loadings of CBOD and ammonia, this study addresses critical low-flow conditions and point source loadings, but does not address nonpoint source loadings.

Two seasonal conditions (November–February and March–October) were determined for allowable loading in the Lower and Upper Reaches. For the critical low-flow condition in the Lower Reach, a 48 percent reduction of CBOD loading and a 26 percent reduction in ammonia loading were determined for the March–October seasonal condition. No reductions in CBOD and ammonia were required for the November–February condition. For the critical low-flow condition in the Upper Reach, no reduction of CBOD loading and an 11 percent reduction in ammonia loading were determined for the March–October seasonal condition. No reductions in CBOD and ammonia were required for the November–February condition.

The same steady-state model was applied to evaluate the effectiveness of adding phosphorus controls on WWTFs in reducing aspects of depressed dissolved oxygen in the Lower Reach. The model indicated almost no improvement in dissolved oxygen

concentrations in the Lower Reach from phosphorus controls on WWTFs. This TMDL, therefore, does not include recommendations for phosphorus reductions.

Introduction

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

In simple terms, a TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. In other words, TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. TMDLs must also estimate how much the pollutant load must be reduced from current levels in order to achieve water quality standards.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies. This TMDL addresses impairments to the intermediate aquatic life use due to low dissolved oxygen levels in Upper Oyster Creek (Segment 1245). An earlier TMDL for bacteria for this segment was adopted by the TCEQ in August 2007, and was approved by the U.S. Environmental Protection Agency (EPA) in September 2007.

Section 303(d) of the Clean Water Act and the implementing regulations of the EPA in Title 40 of the Code of Federal Regulations, Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. The EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA 1991). This TMDL document has been prepared in accordance with those regulations and guidelines.

The TCEQ must consider certain elements in developing a TMDL; they are described in the following sections:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Analysis
- Seasonal Variation
- Margin of Safety

- Pollutant Load Allocation
- Public Participation
- Implementation and Reasonable Assurance

The commission adopted this document on Month, Day, Year. Upon EPA approval, this TMDL will become an update to the state's Water Quality Management Plan.

Problem Definition

The TCEQ first identified the impairment to the intermediate aquatic life use for Upper Oyster Creek (Segment 1245) in the *1996 Texas Water Quality Inventory and 303(d) List* (TCEQ 1996). The standards for water quality are defined in the *Texas Surface Water Quality Standards* (TCEQ 2000). The specific uses assigned to Upper Oyster Creek are contact recreation, intermediate aquatic life use and domestic water supply. The TCEQ has assessed dissolved oxygen concentrations as being less than optimal for attainment of Segment 1245's intermediate aquatic life use. The *2004 Texas Water Quality Inventory and 303(d) List* (TCEQ 2004a) considered six separate assessment units for the segment and reported that each assessment unit contained depressed dissolved oxygen concentrations. The 2004 inventory and list also included Segment 1245 under category 5c, which indicated that additional data would be collected before a TMDL was scheduled. Those additional data were collected in years 2003–2005.

Dissolved Oxygen Criteria

Dissolved oxygen criteria for Upper Oyster Creek consist of 24-hour average and absolute minimum concentrations. The criteria for protection of intermediate aquatic life use are:

- 24-hour average dissolved oxygen concentration $\geq$ 4.0 mg/L
- 24-hour absolute minimum dissolved oxygen concentration $\geq$ 3.0 mg/L

and to protect fish spawning during any of the first 6 months of the year when average water temperature is between 63 and 73 °F (17.2 and 22.8 °C):

- 24-hour average dissolved oxygen concentration $\geq$ 5.0 mg/L
- 24-hour absolute minimum dissolved oxygen concentration $\geq$ 4.0 mg/L

The TCEQ considers that a water body is *fully supporting* if 10 percent or less of the sample sets are in exceedance and *not supporting* if greater than 10 percent of the sample sets are in exceedance. The TCEQ uses a binomial method to specify the number of exceedances required to determine nonsupport of the aquatic life use.

Additional Assessment Data Findings

To address the need for additional assessment data, a series of 24-hour dissolved oxygen surveys were conducted in the years of 2003, 2004, and 2005. The data collection activities occurred under the following constraints:

- No more than two thirds of the events should occur in any year.

- The events must be spaced over an Index Period representing warm-weather seasons (March 15–October 15) with annually between one half to two thirds of the measurements occurring during the Critical Period (July 1–September 30).
- A period of at least one month (or four weeks) must separate sequential 24-hour sampling events.

All data used in the assessment were collected under quality assurance project plans that ensure the data are of a known and appropriate quality (TIAER 2002; TIAER 2004; TIAER 2005).

From previous assessments, the TCEQ has divided Segment 1245 into six assessment units (Figure 1).[a] For the present dissolved oxygen assessment, these same six assessment units were used:

- Assessment unit 1: From lower end of segment to Dam #3, just upstream of Lexington Blvd.
- Assessment unit 2: From Dam #3, just upstream of Lexington Blvd. to the Brooks Lake outfall
- Assessment unit 3: From the Brooks Lake outfall to Hwy 90A
- Assessment unit 4: From Hwy 90A to Dam #1, located 1.5 miles upstream of Harmon St.
- Assessment unit 5: From Dam #1 to Oyster Creek/Jones Creek confluence
- Assessment unit 6: From Oyster Creek/Jones Creek confluence to upper end of segment

The assessment was performed using TCEQ specified methodology (TCEQ 2004b). In general, the assessment found that the Upper Oyster Creek system was *not supporting* of the intermediate aquatic life use; however, there were some areas of exception (Hauck and Bing 2007). A summary of assessment findings regarding support of the intermediate aquatic life use is as follows:

- Assessment unit 1: *not supporting*
- Assessment unit 2: *fully supporting*
- Assessment unit 3: *not supporting*
- Assessment unit 4: *not supporting*
- Assessment unit 5: *fully supporting*
- Assessment unit 6: *not supporting*

Watershed Overview

Upper Oyster Creek is located in the Brazos River Basin, southwest of Houston, Texas, in northern Fort Bend County. It is identified as Segment 1245 in the *Texas Surface Water Quality Standards* (TCEQ 2000). It has been subjected to significant hydrologic

[a] The 2006 Section 305(b) assessment by TCEQ used only three assessment units. Assessment unit 1 remained the same; new assessment unit 2 combined the old assessment units 2 – 4; and new assessment unit 3 combined assessment units 5 and 6.

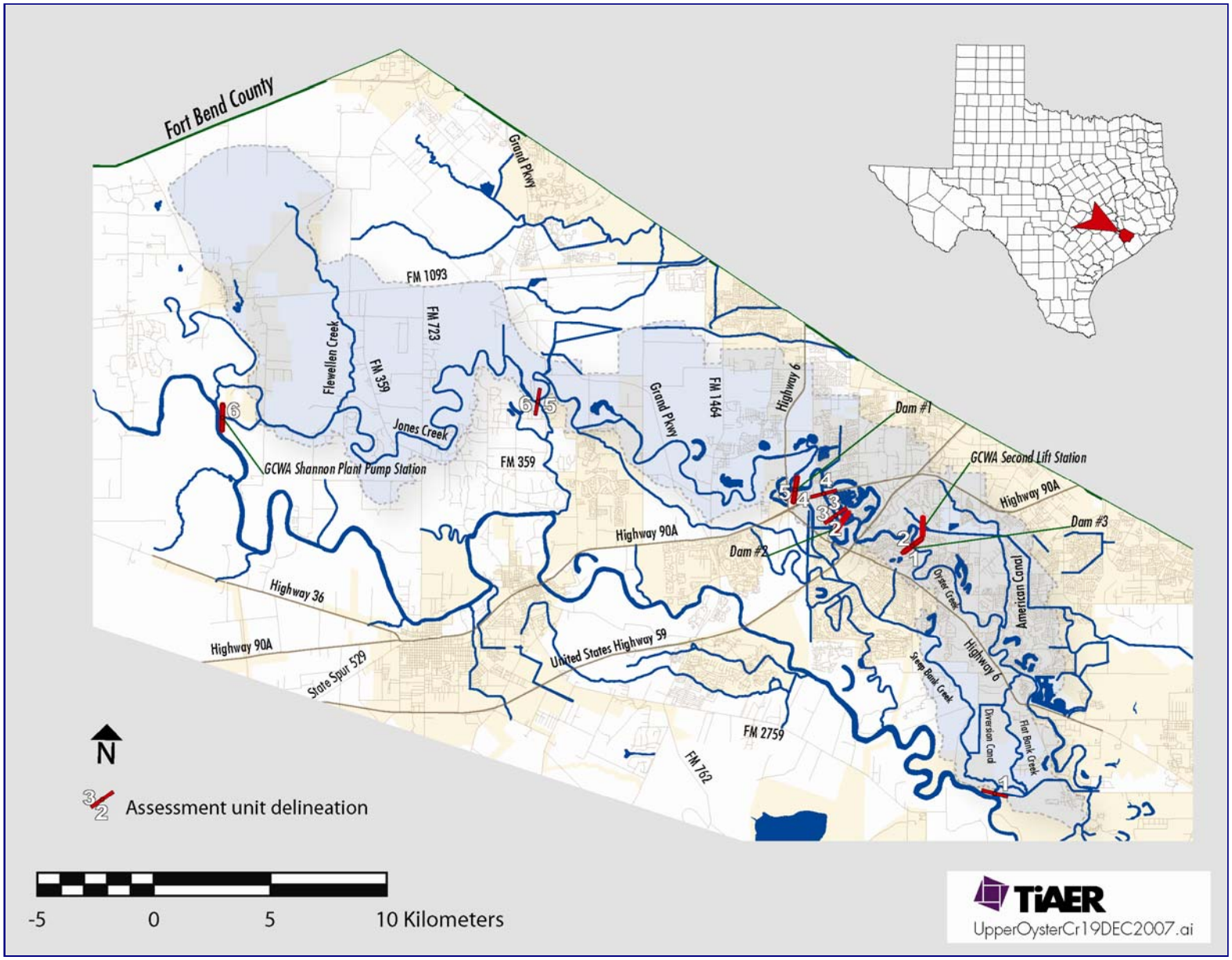


Figure 1. Upper Oyster Creek watershed

modification. The segment begins at the Gulf Coast Water Authority (GCWA) Shannon Pump Station on the Brazos River and continues through Jones Creek to its confluence with Oyster Creek, through Oyster Creek to its confluence with Flat Bank Creek, through Flat Bank Creek to its confluence with the diversion canal, through the diversion canal to its confluence with Steep Bank Creek, and finally through Steep Bank Creek to its confluence with the Brazos River (Figure 1). Segment 1245 extends approximately 54 miles, and its watershed contains four incorporated areas: Fulshear, Sugar Land, Stafford, and Missouri City. The Upper Oyster Creek watershed covers approximately 107 square miles (27,600 ha), about 12.5 percent of the area of Fort Bend County.

The Upper Oyster Creek watershed lies within a climatic region classified as subtropical humid, which is defined as having hot summers and dry winters. Between 1970 and 2000, the average annual rainfall was 49.3 inches, as measured at Sugar Land Regional Airport (NOAA 2004). During this same period, rainfall events of 0.1, 0.5, and 1 inch of rain were observed on average 64, 31, and 16 days per year, respectively. The Upper Oyster Creek watershed is within the upper portion of the Gulf Coast Prairies and Marshes ecoregion, an area characterized as containing nearly level, un-dissected plains with native vegetation types composed of tall grass prairie and post oak savanna. The elevation of the area is approximately 25 meters above mean sea level.

Hydrology

Three small dams on Upper Oyster Creek are located in the area around the City of Sugar Land (Figure 1). The dams form impoundments to maintain nearly constant water levels for industrial and recreational uses and off-channel lakes that create “lakefront” property with commensurate aesthetic and monetary value. There are two distinct hydrologic reaches within the Upper Oyster Creek segment. The Upper Reach extends from the GCWA Shannon Pump Station on the Brazos River to Dam #3 within the City of Sugar Land. The Lower Reach begins at Dam #3 and continues downstream through Steep Bank Creek to its confluence with the Brazos River. The GCWA uses the reach above Dam #3 as a section of its Canal System A, which supplies water for irrigation, industrial, and public drinking supply to areas southeast of the watershed in addition to uses in the vicinity of the City of Sugar Land. Dam #3 retains water for Alkire, Eldridge, and Horseshoe Lakes, and retains water for the GCWA Second Lift Station where water is pumped into the American Canal for transport to the Texas City area.

The hydrology of the reach below Dam #3 is highly influenced by the presence of the dam and the Second Lift Station. Minor amounts of seepage do occur through Dam #3, and there is uncontrolled, excess rainfall runoff over the dam into the Lower Reach. The Second Lift Station, however, operates under most wet-weather conditions to capture portions of the rainfall runoff, which reduces the amount released below Dam #3. This reach contains no retention structures and is characterized by reduced flow composed of small amounts of seepage from Dam #3, contributions from municipal dischargers, natural contributions from the drainage area below Dam #3, and excess rainfall runoff from the upper reach above Dam #3. The reach below Dam #3 is also hydrologically modified, though not for conveyance of water supplies and impoundment of water, but rather for flood prevention.

Monthly pumping records from the Shannon Pump Station and the Second Lift Station for the 12-year period of 1993–2004 were obtained from the GCWA. Monthly averages of these records indicated a strong seasonal trend with minimum average pumping occurring in February (approximately 0.4 cubic meters per second [cms or m^3/s]) at the Shannon Pump Station, maximum pumping in July (approximately 4.5 cms), and a monotonic increase from February to July and decrease from July to February. Historical flow data from the U.S. Geological Survey (USGS) station 08112500 located near the Shannon Pump Station indicated similar characteristics and patterns of pumped flow for a period from 1931 to 1973.

In addition to the seasonal pumping of Brazos River water into the upper reach via the Shannon Pump Station, there is also pumping related to precipitation and rainfall-runoff. When rainfall-runoff is occurring into the Upper Reach, the storage capacity of the system allows pumping at the Shannon Pump Station to be curtailed and the necessary water needed at the Second Lift Station to be supplied by rainfall-runoff.

Land Use

The dominant land use category in the watershed is pasture, which accounts for 56.1 percent of the total area. The urban areas (urban mixed and residential) occupy 24 percent of land cover within the watershed. Other land uses include rangeland at 9.5 percent, forest at 7.2 percent, and water at 3.2 percent (see Figure 2).

Population Density

The population of the Upper Oyster Creek watershed in 2000 was estimated to be 96,273 (31,573 households) with an overall average population density of 877 persons per square mile (U.S. Census Bureau 2000). The population of Fort Bend County is estimated by the U.S. Census Bureau to have increased approximately 6 percent per year since the 2000 census, so the recent (2005) population may exceed 125,000.

Fort Bend County is expected to increase in population by approximately 78 percent from 2000 to 2020, according to the Texas Water Development Board (TWDB; TWDB 2006). As a result, the county expects significant increases in water demand for municipal purposes (65 percent increase). Smaller increases are expected for manufacturing (17 percent), mining (8 percent), and steam electric (10 percent) uses. Table 1 provides TWDB population growth estimates for selected cities within Fort Bend County from 2000 to 2020.

The population estimates for Sugar Land are held constant after the year 2010 because the city is expected to be completely built-out by this date. Conversations with TWDB staff confirmed that previous TWDB estimates were in error because they did not account for the built-out issue. However, TWDB estimates may not account for future annexations that could occur. Annexations were used to drive population growth in the 1990s. The 2000 census figures indicate a 158 percent increase in the population of Sugar Land since 1990.

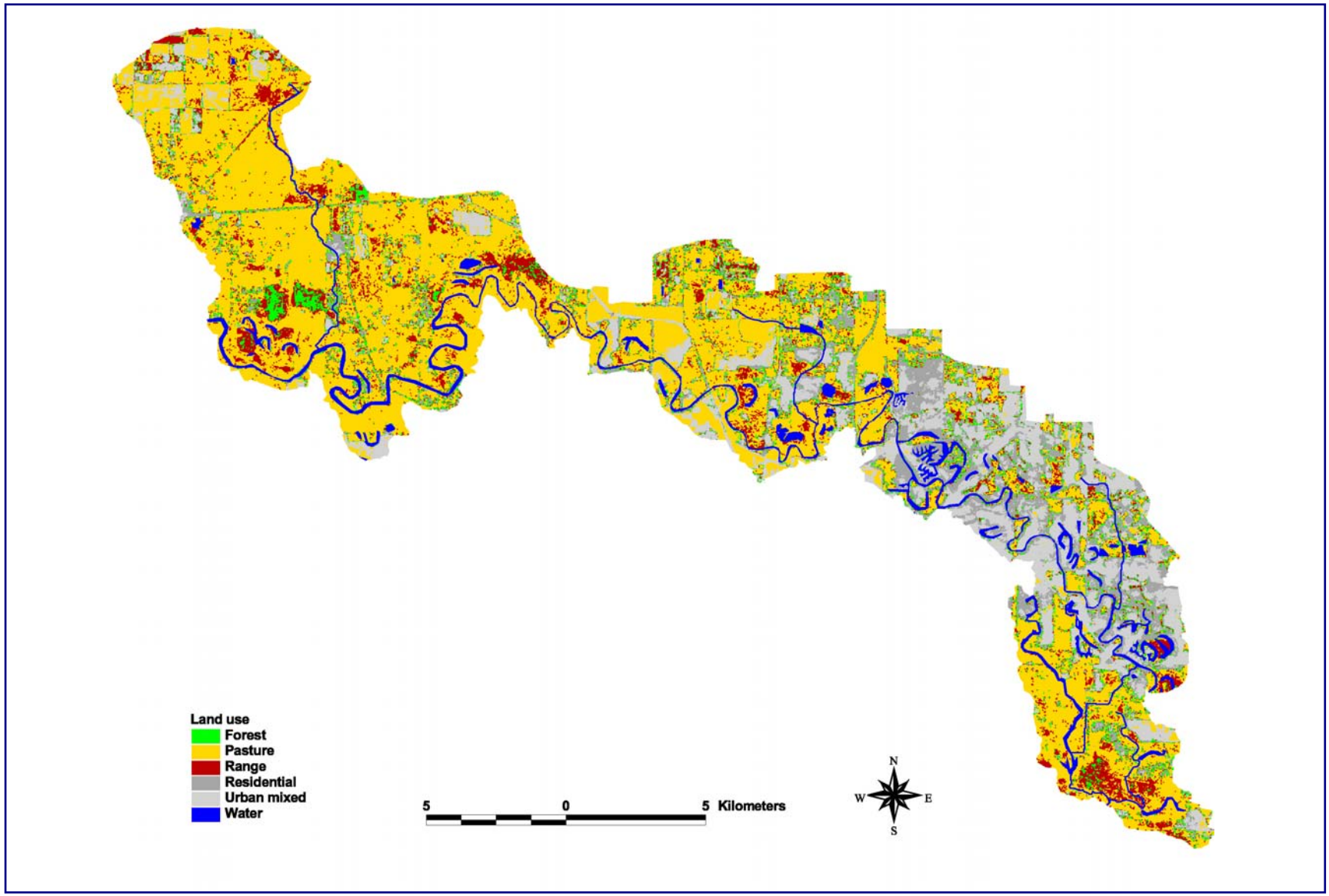


Figure 2. Land use/land cover for the Upper Oyster Creek watershed
(Source: Baylor 1997)

Table 1. Fort Bend County population and projected increases by city, 2000 to 2020

City	2000 Census Population	2010 Population	2020 Population	Growth Rate (2000-2020)
Fulshear	716	883	1,056	47%
Missouri City	47,419	76,768	96,601	104%
Stafford	15,371	23,026	30,959	101%
Sugar Land	63,328	72,500	72,500	14%

Source: TWDB (2006)

Sewage Disposal

The method of sewage disposal for housing units in the Upper Oyster Creek watershed was estimated from the 1990 federal census at the block group level because these data were not collected in the 2000 census (U.S. Census Bureau 1990). Because of rapid urbanization in the watershed, estimates based on those data may no longer be accurate. At that time, approximately 7 percent of households (about 1,400 units) were not connected to a sanitary sewer system (the majority of those utilized septic tanks for sanitary waste disposal), while 93 percent were connected to a sanitary sewer system.

The more rural western half of the watershed was primarily served by septic tanks. However, the highest density of septic tanks was in two areas:

- the Fifth Street area, bounded roughly by Cartwright Road on the south, American Canal on the north and east, and farm-to-market (FM) Road 1092 on the west, and
- the Four Corners area northwest of Sugar Land, bounded by SH 6 on the east, Old Richmond Road on the west, Voss Road on the south, and Boss-Gaston Road on the north.

The density of septic tanks in these two areas ranged from approximately 0.2 to 0.3 per acre.

Aquatic Vegetation

Upper Oyster Creek in many places has a high abundance of aquatic vegetation that includes submersed and emersed macrophytes, periphytic algae (referred to as periphyton and bottom algae herein), and suspended algae (or phytoplankton). This vegetation likely plays various roles in the dissolved oxygen concentrations observed in Upper Oyster Creek and its tributaries. In some important aspects, the aquatic plant communities are markedly different between the Lower and Upper Reaches. Much of the Lower Reach is dominated by submersed macrophytes, such as pondweed and coontail, whereas other portions show a greater dominance of periphyton (Figure 3). In the Upper Reach, emergent macrophytes, most notably alligator weed, are often dense along the bank and at times extend several feet out into the stream (Figure 4). Water hyacinth becomes more common toward the impoundment region of each of the three dams. During the

maximum growing season of April to October or November, macrophytes are sufficiently abundant that the GCWA must employ periodic herbicide spraying to maintain sufficient hydraulic capacity in Upper Reach for proper water conveyance.

a) Lower reach in an area dominated by macrophytes

b) Lower Reach in an area dominated by bottom algae

Figure 3. Photographs of Lower Reach of Upper Oyster Creek showing aquatic vegetation

Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The standards for water quality are defined in the *Texas Surface Water Quality Standards* (TCEQ 2000), which includes the 24-hour average and 24-hour minimum dissolved oxygen criteria to protect the designated intermediate aquatic life use for Upper Oyster Creek. The watershed of Segment 1245 also includes several tributaries to Upper Oyster

Creek that receive effluent from WWTFs. Each of these tributaries, in addition to Upper Oyster Creek, has been assigned an aquatic life use by the TCEQ and protective dissolved oxygen criterion under general conditions and spawning conditions (Table 2). These tributaries include Stafford Run, Steep Bank Creek, and Remnant of Flat Bank Creek in the Lower Reach and Flewellen Creek and Red Gully in the Upper Reach (Figure 5).

Figure 4. Photograph of alligator weed on Jones Creek, July 2004

Table 2. Aquatic life use and dissolved oxygen criteria for Upper Oyster Creek and tributaries

Stream Name	Designated Aquatic Life Use	General 24-hour Average DO Criterion (mg/L)	General 24-hour Minimum DO Criterion (mg/L)	Spawning-Season 24-hour Average DO Criterion (mg/L)	Spawning-Season 24-hour Minimum DO Criterion (mg/L)
Upper Oyster Creek	Intermediate	4	3	5	4
Stafford Run	No Significant	2	2	2	2
Steep Bank Cr.	Limited	3	2	4	3
Remnant Flat Bank Cr.	Intermediate	4	3	5	4
Flewellen Cr.	No Significant	2	2	2	2
Red Gully	Intermediate	4	3	5	4

Source Analysis

Pollutants may come from several sources, both point and nonpoint. Point source pollutants come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES). Storm water

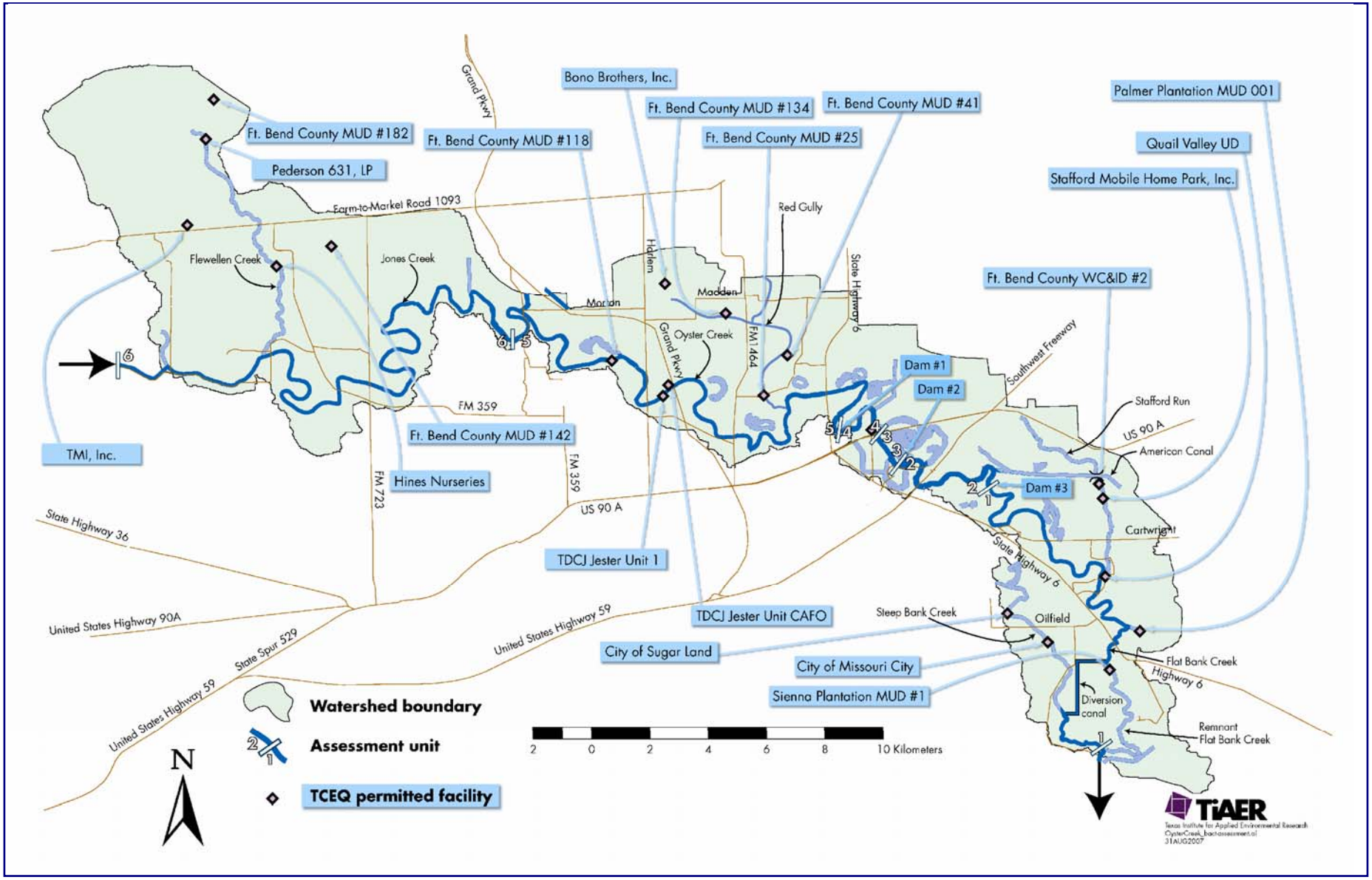


Figure 5. Upper Oyster Creek with tributaries and locations of permitted facilities

discharges from industries, construction, and the separate storm sewer systems of cities are considered point sources of pollution. Nonpoint source pollution originates from multiple locations, usually carried to surface waters by rainfall runoff, and is not regulated by permit under the TPDES.

Since dissolved oxygen is not a pollutant, the pollutants of concern are those which exert a demand upon instream dissolved oxygen. The pollutants considered of greatest concern were carbonaceous biochemical oxygen demand (CBOD) and ammonia nitrogen (NH_3-N). Both CBOD and NH_3-N exert a demand on oxygen as they undergo biological and chemical processes in Upper Oyster Creek and its tributaries. Also of consideration is the total amount of nutrients (nitrogen and phosphorus) with phosphorus being of greater focus. Excessive amounts of these nutrients in receiving waters present the potential of causing undesirable amounts of aquatic vegetation and impacts on 24-hour minimum dissolved oxygen concentrations.

The source analysis for this dissolved oxygen TMDL focused on point sources of CBOD and NH_3-N. To a lesser extent, nutrient contributions were considered from point sources.

Permitted Point Source Discharges

Under TPDES, 17 facilities within Segment 1245 hold permits to discharge wastewater or have pending discharge permits as of June 2007 (Table 3, Figure 5). Two additional facilities hold permits without provisions that allow discharge of wastewater—the Texas Department of Criminal Justice (TDCJ) holds a permit for a confined animal feeding operation (CAFO) with land application of solid and liquid waste and Bono Brothers, Inc. holds a permit for beneficial land application of sewage sludge and domestic septage. For completeness, these two facilities are also included in Table 3. Finally, Hines Nurseries, in addition to holding a permit for internal discharge of a small amount of treated human waste, also holds a permit to discharge storm/irrigation waters. All entities holding active TPDES discharge permits are domestic wastewater (sewage) treatment facilities. From approximately 2000 to mid-2004, the reported average daily domestic wastewater discharge to Upper Oyster Creek was 11.9 MGD, which is well below the permitted daily flow of 31.9 MGD. Increasing discharge limits for some municipal permittees within the segment and adding new discharge permits in recent years indicate a steadily increasing wastewater input of CBOD and NH3-N loadings into the segment commensurate with the rapid urbanization of the watershed.

The City of Sugar Land and Fort Bend County WCID #2 permits allow the largest discharge of the wastewater facilities at over 5 MGD each. The other wastewater facilities with permitted wastewater discharges of greater than 1 MGD are Quail Valley Utility District, Missouri City, and Fort Bend County MUDs #s 25, 118, and 142. As indicated in Table 3, several facilities are designed such that effluent enters a polishing pond prior to final discharge. Based on the TCEQ evaluations of the facilities with polishing ponds, the final effluent from each facility was considered to be at background levels of 5-day CBOD ($CBOD_5$; 1.3 mg/L) and NH_3-N (0.050 mg/L) (personal communications with Mr. Mark Rudolph, P.E., TCEQ, June 2007).

Table 3. Permitted facilities, existing permit limits, and related information for Upper Oyster Creek watershed

TPDES Permit No.	Facility	Monthly Average Discharge 1999-2004 (MGD)	Final Permitted Discharge (MGD)	5-Day CBOD (mg/L)	Total Suspended Solids (mg/L)	Ammonia-N (mg/L)	Dissolved Oxygen (mg/L)	Polishing Pond (Yes Or No)
WQ0013873-001	City of Missouri City	0.69	3.0	10.0	15.0	3.0	5.0	No
WQ0012833-002	City of Sugar Land	4.61	10.0	10.0	15.0	3.0	5.0	No
WQ0012003-001	Fort Bend County MUD # 25	0.42	1.6	5.0	5.0	1.0	5.0	No
WQ0012475-001	Fort Bend County MUD # 41	0.25	0.86	10.0	15.0	3.0	5.0	No
WQ0013951-001	Fort Bend County MUD # 118	0.064	1.2	5.0	12.0	1.5	5.0	No
WQ0014715-001	Fort Bend County MUD # 134	—[5]	0.30	7.0	15.0	2.0	4.0	Yes
WQ0014408-001	Fort Bend County MUD # 142	—[5]	1.2	5.0	5.0	2.0	6.0	Yes
WQ0014692-001	Fort Bend County MUD # 182	—[5]	0.8	7.0	15.0	1.0	5.0	Yes
WQ0010086-001	Fort Bend County WCID #2	3.52	6.0	10.0	15.0	2.0	6.0	No
WQ003015-000	Hines Nurseries Inc.[2]	[5]	0.0035	30.0	90.0	—	—	No
WQ0012937-001	Palmer Plantation MUD 001	0.29	0.60	10.0	15.0	3.0	5.0	No
WQ0014758-001	Pederson 631, LP	—[5]	0.60	10.0	15.0	2.0	6.0	Yes
WQ0011046-001	Quail Valley UD	1.77	4.0	10.0	15.0	4.0/3.0[4]	6.0/5.0[4]	No

TPDES Permit No.	Facility	Monthly Average Discharge 1999-2004 (MGD)	Final Permitted Discharge (MGD)	5-Day CBOD (mg/L)	Total Suspended Solids (mg/L)	Ammonia-N (mg/L)	Dissolved Oxygen (mg/L)	Polishing Pond (Yes Or No)
WQ0014100-001	Sienna Plantation MUD # 1	—[5]	0.902	10.0	15.0	2.0	6.0	No
WQ0014064-001	Stafford Mobile Home Park, Inc.	—[5]	0.10	10.0	15.0	3.0	5.0	No
WQ0011475-001	TDCJ Jester Unit # 1–WWTF	0.27	0.315	10.0	15.0	3.0	5.0	No
WQ0014745-001	TMI, Inc.	—[5]	0.50	10.0	15.0	3.0	6.0	Yes
TXL005010	Bono Brothers, Inc. [1]	NA	NA	—	—	—	—	NA
TXG920522[3]	TDCJ Jester (Swine CAFO) [1]	NA	NA	—	—	—	—	NA
Total		**11.884**	**31.9805**					

Notes:

NA = Not applicable; MGD = million gallons per day

[1] Permit does not contain a discharge provision

[2] Discharge outfall is internal to the facility and no wastewater is discharged to a receiving stream. Permit also includes storm water discharge not to exceed 1.0 MGD

[3] Concentrated Animal Feeding Operation (CAFO) general permit number

[4] Quail Valley UD operates under seasonal permit limits. First number is the limit for Dec-Feb; the second number is for Mar-Nov.

[5] No monitored discharge information available for this permitted facility when the modeling was performed

In 2001, TIAER staff reviewed the TPDES permit files to identify enforcement actions or other persistent problems with permitted discharge facilities within Segment 1245. This review was updated in 2005 by reviewing the discharge monitoring reports (DMR) from the Permit Compliance System (PCS) downloaded from the USEPA Envirofacts Data Warehouse (USEPA 2005). No enforcement actions were uncovered in the screening; however, some self-reporting, operation, and administration violations were noted in the files. The TDCJ facility has had some minor violations regarding uncertified personnel, operational requirements, and final effluent limitations. However, these violations surfaced during an annual inspection and were completely resolved within the required time frame. The TDCJ facility underwent a $4.5 million expansion during 2001-2002. Imperial Sugar Corporation resolved a recurring violation on the annual certification of accuracy for pumping capacity used to measure flow, which was observed on biannual inspections in 1996 and 1998. However, this facility has ceased operation since late 2003. A violation of the fecal coliform bacteria daily maximum, 7-day average, and daily average criteria by Missouri City occurred in August 2000. The problem was resolved immediately. No other fecal coliform effluent quality violations were reported since that time.

Because efforts to improve water quality problems have a long history in Upper Oyster Creek, a number of significant changes and improvements have occurred, which likely improved water quality. Kolbe (1992) reports:

- Prior to 1975 the City of Sugar Land operated three WWTF facilities that discharged into the Upper Reach; but, beginning in 1975, these facilities were closed and the sewage was piped to the Brazos River Authority's (BRA) Sugar Land Regional WWTP, which does not discharge in Segment 1245. (Note: Since 1991 the City of Sugar Land has operated a WWTF that discharges into Steep Bank Creek in the Lower Reach.)
- The Hines Horticulture direct discharge was removed in 1990 and reduced to storm water overflow releases and a very small internal domestic wastewater discharge that does not go to receiving waters.
- Wastewater treatment at the TDCJ unit has been improved since the late 1980s. Feedlot runoff has been controlled through coverage under a general permit since roughly that same time.

In addition, changes have been made to mitigate the effects of the previously permitted discharges from the Imperial Sugar facility. After June 1996, Imperial Sugar's major discharges were delivered to the BRA regional WWTF for treatment and subsequent discharge outside the watershed. Kolbe (1992) states that from 1987 through 1990, Imperial Sugar discharged an average of 17 to 21 MGD of wastewater at elevated temperature, which was allowed in their permits. In 2003, the facility ceased any discharge to Upper Oyster Creek.

Other Sources

Other sources are known to contribute loadings of oxygen demanding pollutants into Segment 1245, both directly and via its tributaries. The Brazos River water pumped at the GCWA Shannon Lift Station into Segment 1245 represents one of these sources. Traditional nonpoint pollution originating in the Upper Oyster Creek watershed from rainfall runoff represents the other source. A strong linkage of rainfall-runoff derived pollution to impairment of the intermediate aquatic life use of Segment 1245 was not established and this TMDL, therefore, does not address traditional nonpoint source pollution.

Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques.

Dissolved oxygen is not itself a pollutant. To support aquatic life use dissolved oxygen criteria, unlike most other criteria, are established to protect against depressed concentrations rather than elevated concentrations. Within this TMDL, the constituents or pollutants of concern are those which exert a demand upon instream dissolved oxygen. Regarding depressed dissolved oxygen in Segment 1245, the constituents considered of greatest concern were carbonaceous biochemical oxygen demand, which is typically measured as $CBOD_5$, and NH_3-N. Both $CBOD_5$ and NH_3-N exert a demand on oxygen as they undergo biological and chemical processes. Also of secondary consideration is the total amount of nutrients (nitrogen and phosphorus) with phosphorus given greater consideration in freshwater systems. Excessive amounts of these nutrients in receiving waters can cause undesirable amounts of aquatic vegetation, which can impact 24-hour minimum dissolved oxygen concentrations (through photosynthesis and respiration).

Background Factors

An objective of the linkage analysis is to determine the simplest mathematical model and expressions that represent the conditions and sources under which dissolved oxygen exceedances occur and that can be applied to perform the TMDL allocation. Pertinent factors considered in the linkage analysis process and presented in more detail in Hauck and Du (2007) include:

- Two distinct hydrologic reaches exist within Upper Oyster Creek. The Lower Reach begins at Dam #3 and continues downstream through Steep Bank Creek to its confluence with the Brazos River. The Upper Reach extends downstream from the GCWA Shannon Pump Station on the Brazos River to Dam #3 within the City of Sugar Land.
- In the Lower Reach, the dissolved oxygen exceedances during the assessment monitoring conducted in year 2003–2005 were usually associated with the 24-hour absolute minimum dissolved oxygen criterion, though for a couple of 24-hour data events the exceedance involved both the minimum dissolved oxygen

criterion and the 24-hour average dissolved oxygen criterion. For the 2 stations used in assessing the Lower Reach and a total of 32 assessment events, 15 dissolved oxygen exceedances were observed. Thirteen exceedances involved solely the minimum criterion and two exceedances included both the minimum and average criteria.

- In contrast to the Lower Reach, the dissolved oxygen exceedances in the Upper Reach during the same assessment-monitoring period occurred with both the average criterion and the absolute minimum criterion for a 24-hour data event. For the 6 stations used during assessing the Upper Reach and a total of 95 assessment events, 24 exceedances were observed. Four exceedances involved only the 24-hour average dissolved oxygen concentration, 4 exceedances involved only the absolute minimum criterion, and 16 exceedances involved both the average and minimum criteria.
- In both reaches, the temporal dissolved oxygen concentration pattern for the vast majority of 24-hour events exhibited lowest concentrations about the time of sunrise and maximum concentrations in mid to late afternoon. The dissolved oxygen pattern exhibited is indicative of a system where aquatic plants (macrophytes, benthic algae, and phytoplankton) are in sufficient abundance to exert a cyclic pattern on dissolved oxygen concentrations. This cyclic pattern of the dissolved oxygen results from dominance of photosynthetic activity and dissolved oxygen production during daylight hours and a dominance of respiration and dissolved oxygen utilization in the absence of sunlight.
- The occurrences of dissolved oxygen exceedances in the Lower Reach are predominately associated with low and base flow conditions and the occurrence of abundant aquatic vegetation.
- For the Upper Reach dissolved oxygen exceedances are associated with increased water temperatures that prevail from approximately May through September. Available data indicate that dissolved oxygen exceedances occur under non-runoff influenced conditions but also in association with runoff conditions. Despite a relative abundance of data, what cannot be deciphered are the factors that are causing the dissolved oxygen exceedances, since elevated water column concentrations of oxygen demanding substances (i.e., NH_3-N and CBOD) and sediment oxygen demand (SOD) rates do not seem to be associated with the exceedances. A complex hydrology of Brazos River water pumping into the system and curtailment of that pumping at times also seems potentially to influence the occurrence of some exceedances, but again the data are not entirely clear regarding the importance of this factor. Some maintenance dredging, periodic herbicide treatment to control aquatic vegetation, hydraulic changes with lower stream velocities and commensurate reductions in anticipated reaeration rates in the lake-like or impoundment area all add to the complexities of this system and all of these have some role of unknown extent in the observed exceedances.

Linkage Tool Selection

Based on factors above, linkage of sources to the receiving waters in Segment 1245 was accomplished using a steady state water quality model called QUAL2K. QUALTX is the standard steady-state dissolved oxygen model employed by TCEQ for waste load allocations and other applications where steady-state hydraulic conditions may be assumed and 24-hour average dissolved oxygen is the primary state variable of concern. However, 24-hour minimum dissolved oxygen requires evaluation for this TMDL, especially in the Lower Reach. QUAL2K has similar capabilities to those of QUALTX with the added dimension of simulating diel variations in water quality. QUAL2K is supported by EPA's Watershed and Water Quality Modeling Support Center and will likely be supported in subsequent versions of EPA's Better Assessment Science Integrating Point & Nonpoint Sources (BASINS).

QUAL2K is a relatively recent model that was developed to provide a modernized version of QUAL2E, a long-standing EPA supported model that cannot be operated under the now common XP Operating System. In Chapra et al. (2006), the model is described as follows. QUAL2K provides for the prediction of water quality in river and stream systems by representing the channel in a one dimensional, longitudinal manner with the assumption of vertical and lateral complete mixing. The model allows branching tributaries, provides non-uniform, steady flow hydraulics, and water quality variables are simulated on a diel time scale. An Excel workbook serves as the interface for QUAL2K. Model execution, input and output are all implemented from within Excel. Visual Basic for Applications (VBA) serves as Excel's macro language for implementing all interface functions, and numerical calculations are implemented in FORTRAN 90. The most recent version of QUAL2K available when this TMDL was developed (the version used in the TMDL allocation process) was Version 2.04.

Model selection for the Lower Reach was based on the prevalence of exceedances associated with the 24-hour minimum dissolved oxygen criterion and the occurrence of these exceedances under low and base flow conditions. The dominance of exceedances of the absolute minimum dissolved oxygen criterion in the Lower Reach necessitated choice of a model, such as QUAL2K, that allowed the simulation of diel fluctuations in dissolved oxygen.

Model choice for the Upper Reach TMDL was determined to some extent by data availability. The complexities of the hydrology and water quality in the Upper Reach indicated the potential need to apply a dynamic water quality model, but the poorly understood causes of dissolved oxygen exceedances in the Upper Reach indicated the need for a more comprehensive understanding of the causes of the exceedances before applying such a data intensive model. To remain consistent with the model selected for the Lower Reach, QUAL2K was applied to the Upper Reach using available data to validate the model. As understanding of the system is increased, and if needed for adaptive management of the implementation plan, a dynamic water quality model of the Upper Reach might be developed.

Validation of QUAL2K Models of Lower and Upper Reaches

Separate QUAL2K models were developed for the Lower and Upper Reaches, and each model represented the hydraulic, physical, biological, and chemical characteristics of each reach, its major tributaries and the WWTFs discharging into the reach (Figures 6 and 7). The model validation step establishes model reliability, acceptability, and robustness for use in developing the TMDL allocation. The QUAL2K models of each reach were developed using separate calibration and verification steps, which collectively are referred to as validation and which can be defined as follows:

- Calibration—the first stage testing and tuning of a model to a set of observational data, such that the tuning results in a consistent and rational set of theoretically defensible input parameters.
- Verification—Subsequent testing of a calibrated model to additional observational data to further examine model validity, preferably under different external conditions from those used during calibration (Thomann and Mueller 1987).

Hence, calibration was performed as a systematic procedure of selecting model input parameters that resulted in model predictions that best match the observational data. In addition, the adjustments of input parameters were restricted to be within literature-suggested ranges from such sources as TNRCC (1995) and Bowie et al. (1985). For any input parameters without direct measurement within the project area and literature values, professional judgment was utilized.

Within the separate verification step, the input parameters defining such things as kinetic rates were kept at the values used in the calibration step and separate sets of observational data were used for comparison purposes.

Observational data for validation of QUAL2K were available from intensive data collection efforts (intensive surveys) conducted in the Upper Oyster Creek system in May and August 2004. In recognition of the hydrologic separation provided by Dam #3, the surveys had been conducted separately for the Lower and Upper Reaches. The two intensive dissolved oxygen surveys were performed at a total of 21 stream stations (Upper Oyster Creek and tributaries) and at all 9 permitted discharges in Segment 1245 that were active during the summer of 2004. These surveys occurred during relatively steady-flow conditions with minimal interference from rainfall runoff and under two different conditions of temperature and streamflow. For the Lower Reach, the two surveys were conducted May 5–9, 2004, and August 9–10, 2004. The two surveys for the Upper Reach were conducted May 25–28, 2004, and August 16–19, 2004.
Each intensive survey included:

- 24-hour measurements of dissolved oxygen, temperature, specific conductance, and pH
- Ambient water quality grab samples collected at 6-hour intervals for compositing
- Flow determination from velocity measurement for stream stations

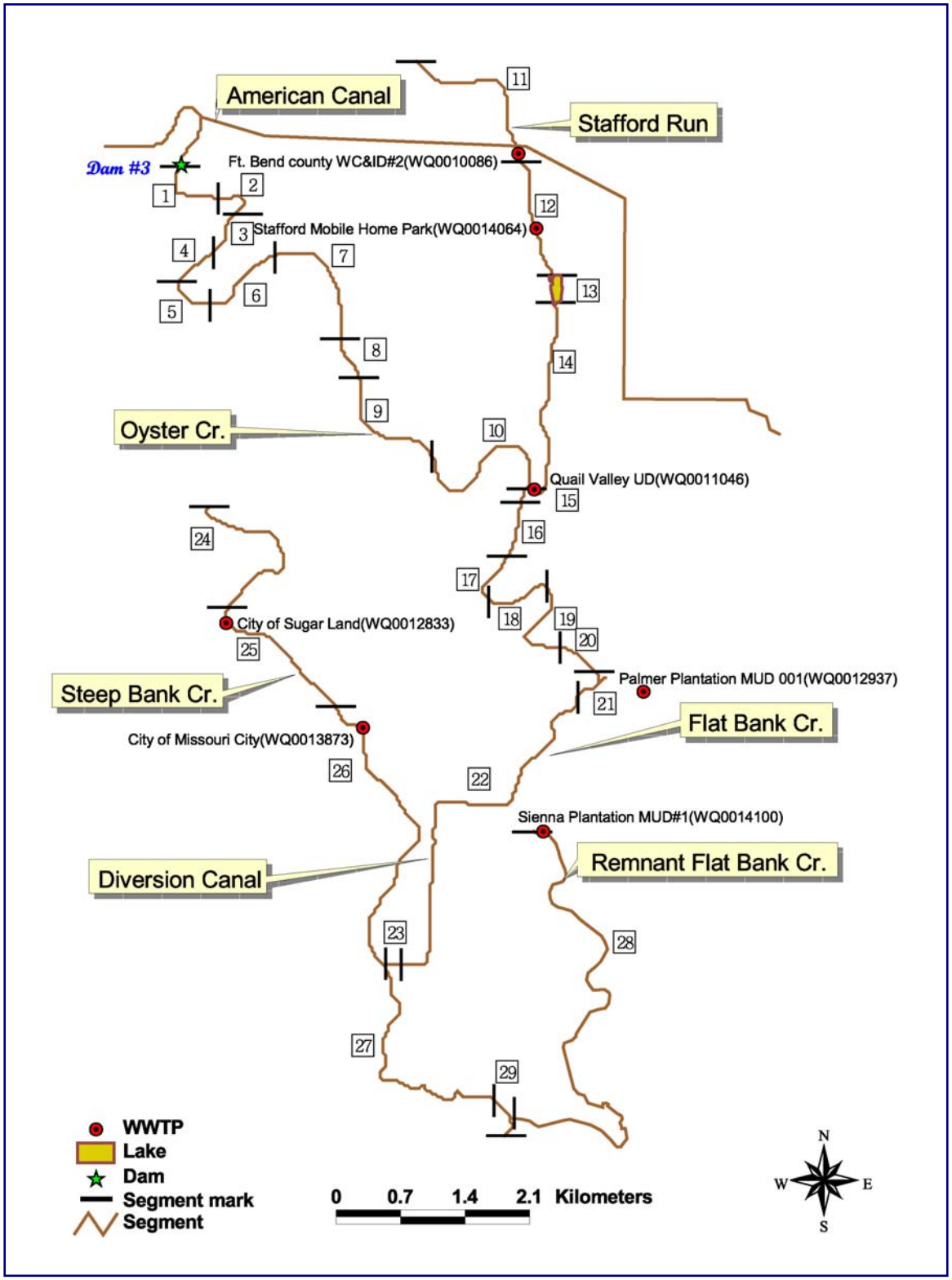


Figure 6. QUAL2K segmentation of Lower Reach, Upper Oyster Creek

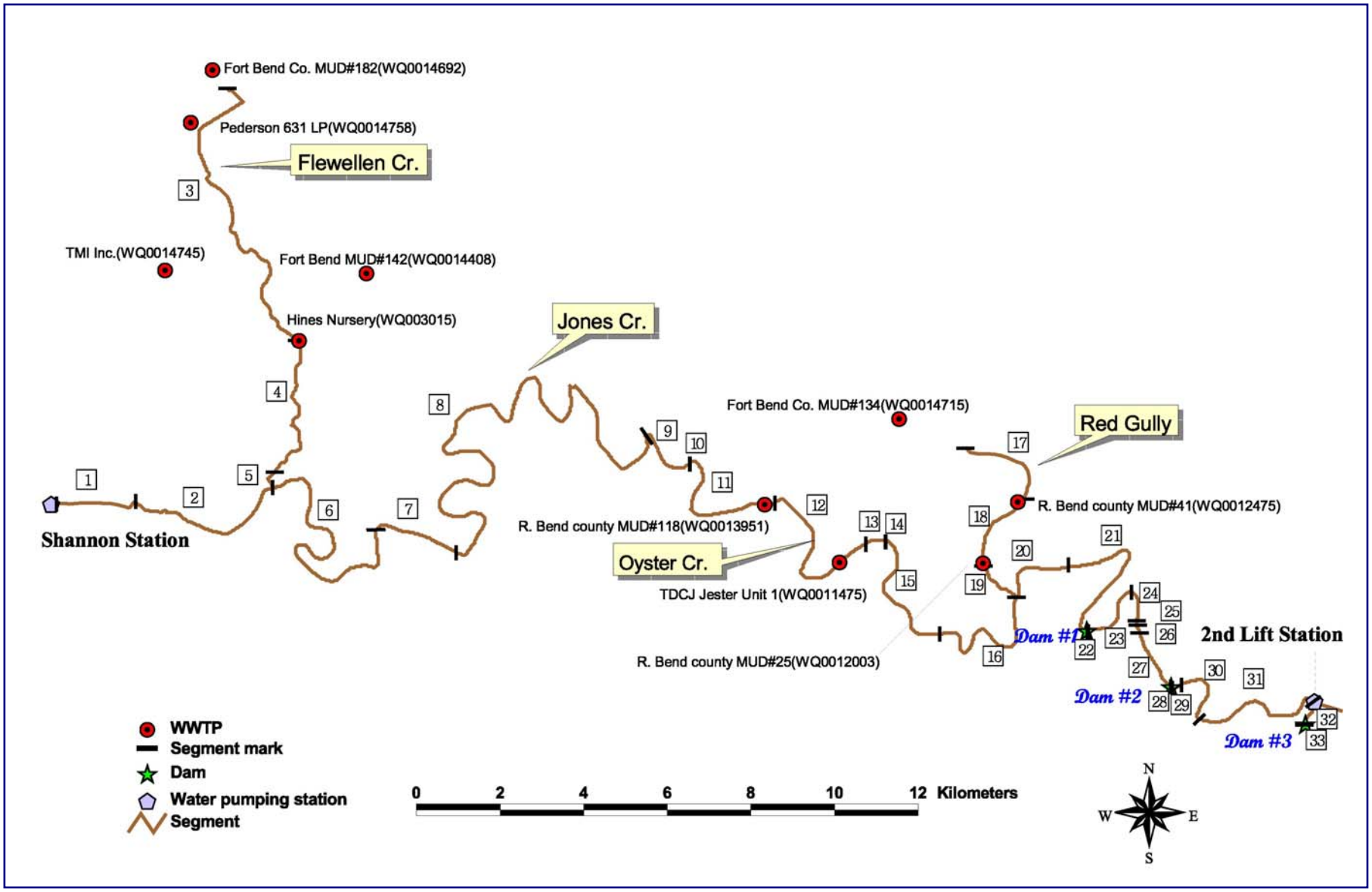


Figure 7. QUAL2K segmentation of Upper Reach, Upper Oyster Creek

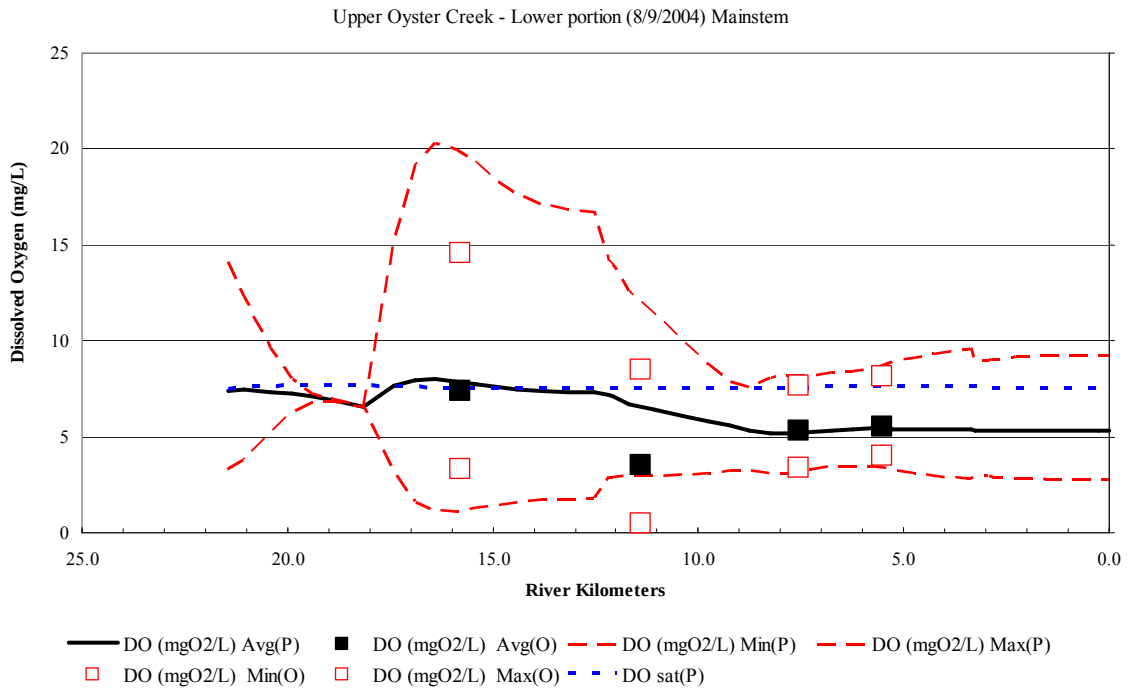
- Flow determination from wastewater treatment facilities using on-site instrumentation and at two stream stations using Gulf Coast Water Authority (GCWA) records
- Time-of-travel studies
- Suspended algae productivity measurements
- SOD measurements (occurred August-September 2004 and May-July 2005)

The QUAL2K models of the Lower and Upper Reaches were successfully validated to the intensive survey data. The dissolved oxygen predicted results from QUAL2K for the main stem of Segment 1245 and the monitoring data used for comparison are provided for the calibration and verification steps in Figure 8 for the Lower Reach and Figure 9 for the Upper Reach. It should be noted that the particularly low DO concentrations at kilometer 11.3 (Figure 8a) during the August 9-10, 2004, calibration survey could not be replicated by the model. They did not appear to be caused by measured water-quality constituents, and potentially could be attributable to both morning cloud cover on August 10 and residual effects from the late June and early July high-flow event on the Brazos River that backed water into the Lower Reach.

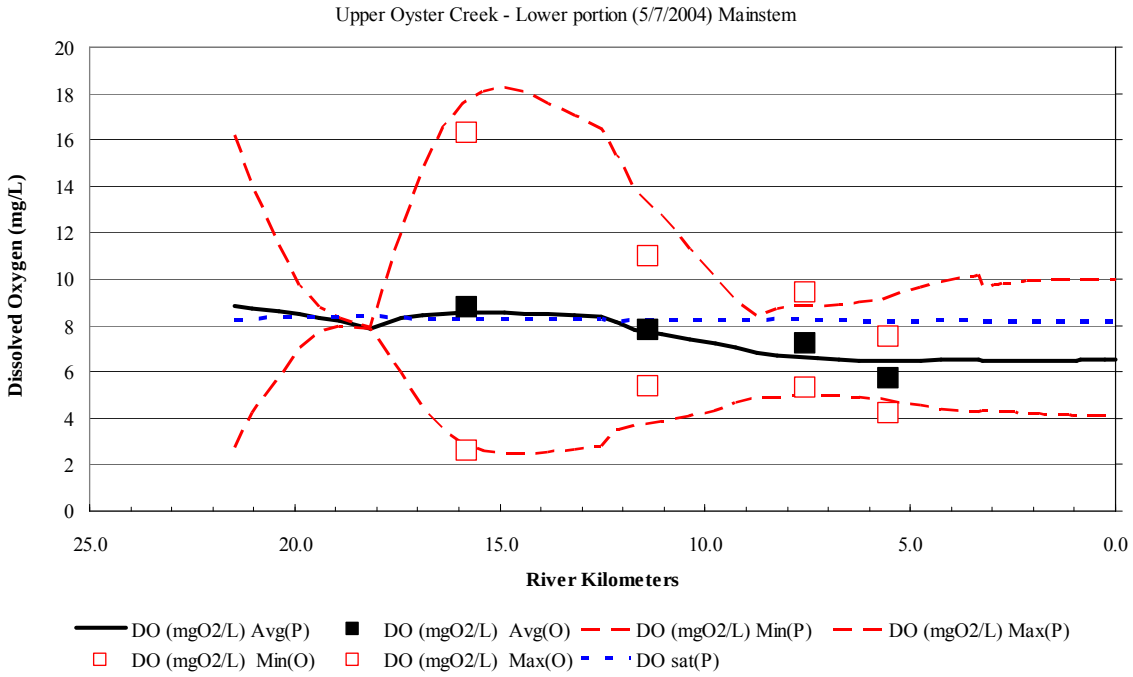
The model of each reach exhibited low sensitivity to changes in existing point source loadings of CBOD and NH_3-N and instream decay rates for CBOD and NH_3-N. This low sensitivity is the result of low instream and WWTF discharge concentrations of these constituents in both the model and observational data. In both reaches the prescribed CBOD decay rate of 0.1 d^{-1} and NH_3-N decay rate of 0.3 d^{-1} are the default values assigned by TCEQ staff when modeling dissolved oxygen in a stream system that is insensitive to these decay rates because instream concentrations of CBOD and NH_3-N are low. Likely, because of the relatively small loadings of CBOD and NH_3-N from WWTFs and commensurate low instream concentrations presently in both the Lower and Upper Reaches, the models showed highest sensitivity to reaeration and SOD rates.

Point Source Phosphorus Discharge Linkage Analysis

The large diel dissolved oxygen range in the Lower Reach, and the dominance of exceedances related to the 24-hour minimum criterion rather than to the 24-hour average criterion, indicated an abundance of aquatic vegetation and a possible linkage of this abundance to nutrient sources. To investigate the potential linkage of phosphorus in WWTF effluents to receiving water dissolved oxygen, various permit limits on total phosphorus (total-P) were considered in the model for the WWTFs in the Lower Reach. This considered the effectiveness of nutrient reduction to inhibit aquatic vegetation and to both reduce diel dissolved oxygen fluctuations and increase minimum dissolved oxygen levels. Permit limits of 1.0 mg/L and 0.5 mg/L total-P were evaluated and an extreme limit of 0.2 mg/L was considered. Based on the intensive survey data for the WWTFs, 94 percent of the total-P was considered to be in the soluble form as orthophosphate phosphorus (PO_4-P) and the remainder as organic-P. Even results with permit limits of 0.2 mg/L total-P indicated unresponsiveness of the minimum dissolved oxygen to phosphorus control on WWTFs, though phytoplankton levels were reduced slightly (Figure 10).

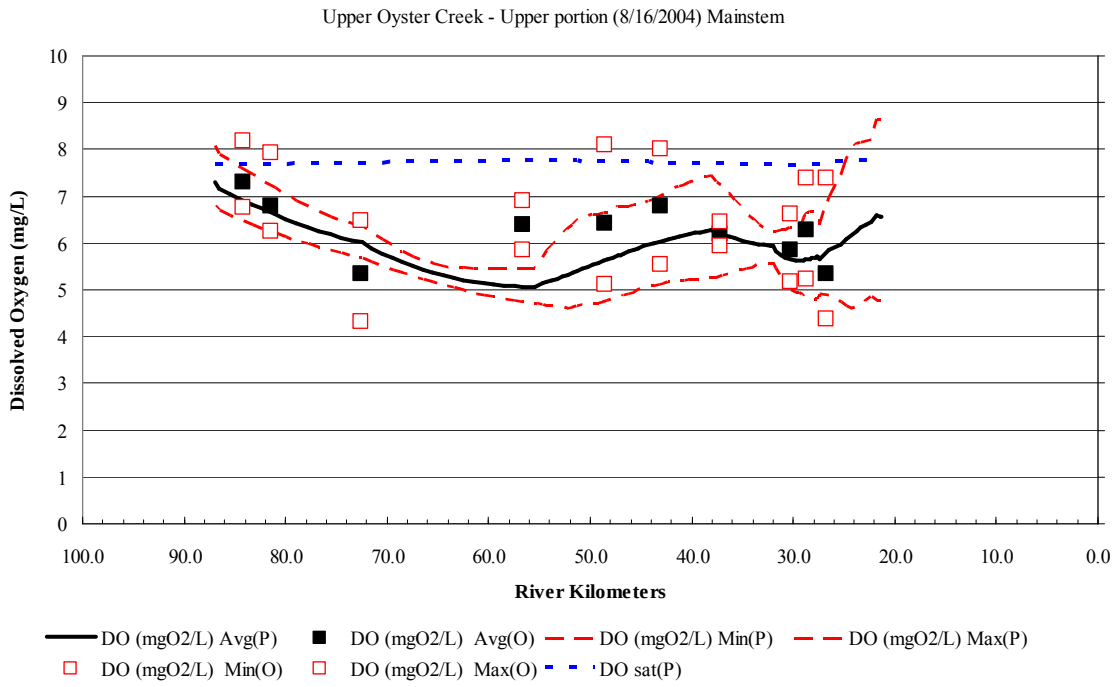


a) August 2004 calibration survey

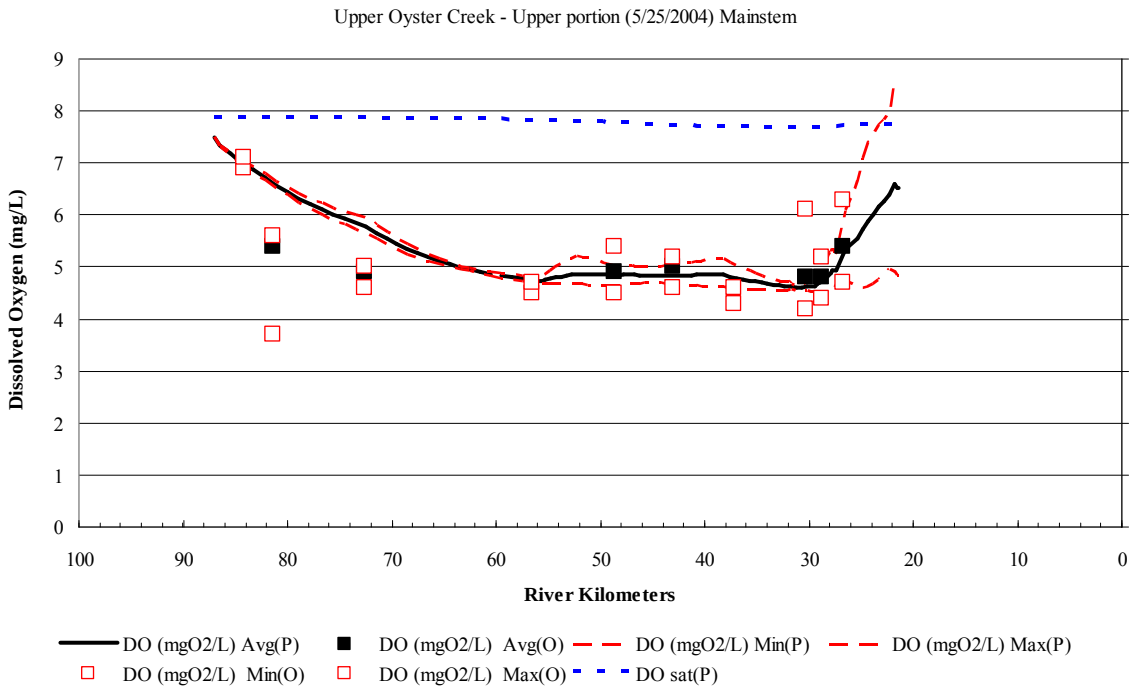


b) May 2004 verification survey

Figure 8. Observed (O) vs. predicted (P) dissolved oxygen in the main stem of the Lower Reach



a) August 2004 calibration survey



b) May 2004 verification survey

Figure 9. Observed (O) vs. predicted (P) dissolved oxygen in the main stem of the Upper Reach

Because of the small amount of headwater flows in the Lower Reach, as compared to the dominance of WWTFs discharges, even under the most extreme limit of 0.2 mg/L total-P, instream concentrations of readily bioavailable PO_4-P in much of the system were predicted to remain at about 0.1 mg/L. A concentration of 0.1 mg/L is generally more than ample to support abundant aquatic vegetation, as compared to PO_4-P concentrations of about 3.0 mg/L without P removal imposed on WWTFs (Figure 10).

Even if QUAL2K had predicted positive responsiveness showing reductions in phytoplankton and periphyton, this response would have had to be evaluated against the fact that much of the observed vegetation in the system are submersed rooted macrophytes. These macrophytes are capable of obtaining nutrients through roots and are therefore unlikely to be responsive to reductions in phosphorus concentrations in the water column (e.g., USDA-NRCS 1999). The lack of responsiveness in predicted minimum dissolved oxygen in the model simulations in relation to P reduction scenarios indicates that the imposition of P limits on WWTFs has limited-to-no potential of substantively improving 24-hour minimum dissolved oxygen concentrations in the Lower Reach. The prevalence of rooted macrophytes throughout much of Stafford Run and Upper Oyster Creek supports this conclusion.

In the Upper Reach, a phosphorus discharge linkage was not performed for two reasons. First, the aquatic vegetation in the Upper Reach is strongly dominated by macrophytes, and it is very unlikely that their abundance will be responsive to reductions in water column phosphorus. Second, and more importantly, the exceedances of the absolute minimum dissolved oxygen criterion without contemporaneous exceedances of the 24-hour average criterion occurred in only 4 of 24 exceedances monitored during the assessment period in the years 2003-2005, indicating only limited concerns with minimum dissolved oxygen concentrations in the Upper Reach.

Seasonal Variation

The Upper Reach of Segment 1245 has a long history of depressed dissolved oxygen concentrations and at times associated fish kills dating back to the late 1960s, and these depressed dissolved oxygen conditions occurred at virtually any time of the year (Kolbe 1992). Beginning in the mid-1970s, a number of improvements in treatment and relocation or discontinuation of wastewater discharges has substantially changed the volume and content of discharges into the Upper Reach (as summarized in this document under the Watershed Overview section). Because of these substantial changes in operation of WWTFs, historical instream dissolved oxygen data prior to the late 1990s are not indicative of present conditions. Further, the emphasis of most monitoring efforts has traditionally been directed toward the Upper Reach with more limited monitoring activities below Dam #3. Consequentially, seasonal variation is best discussed in terms of the assessment survey data collected within the Index Period (15 March–15 October) of years 2003, 2004, and 2005, and for the Upper Reach more limited surveys conducted during the winter in years 2003 and 2004.

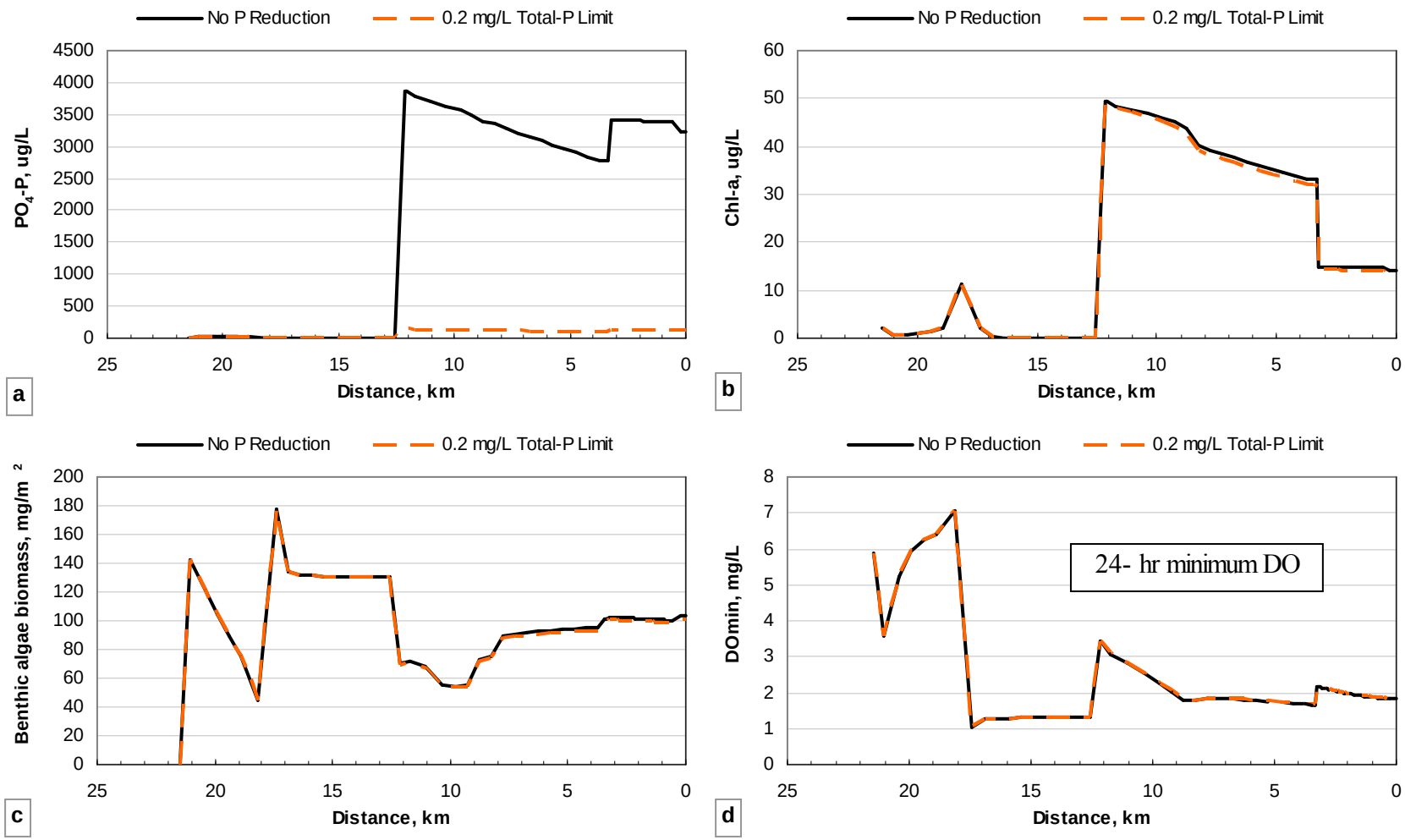


Figure 10. QUAL2K predictions for Lower Reach with and without WWTFs Total-P limits during critical summer conditions.

Main stem predictions of:

a) PO4-P
b) chlorophyll-α
c) benthic algae biomass
d) dissolved oxygen

The assessment survey data indicated that within the Upper Reach of Segment 1245, depressed dissolved oxygen concentrations were most likely to occur during the late spring and through the summer when water temperatures are high, resulting in critical conditions for dissolved oxygen.

For the Lower Reach under the assessment survey conditions, the 24-hour minimum dissolved oxygen concentrations were found to be depressed much more often than the 24-hour average concentrations.Depressed minimum dissolved oxygen concentrations were observed during every month except March (and October for which there are no data) within the Index Period, which leads to speculation that these depressed concentrations prevail whenever water temperatures, streamflow, and sunlight are adequate to support an abundant aquatic plant community in the Lower Reach. It is reasonable to presume that depressed minimum dissolved oxygen concentration are not as prevalent in the late fall, winter and early spring, but inadequate data exist to support this presumption.

Margin of Safety

The margin of safety (MOS) should account for uncertainty in the analysis used to develop the TMDL and thus provide a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (USEPA 1991), the MOS can be incorporated into the TMDL using two methods:

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The margin of safety is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

An implicit MOS based on conservative model assumptions is used in this TMDL. First, the evaluation was performed under full permitted limits during critical low-flow conditions, which is an extremely unlikely combination of circumstances. Second, conservative assumptions were made regarding some model input parameters, such as specification of the chlorophyll-α flux term for the Lower Reach and the settling velocities in the Upper Reach at values from the calibration and verification cases that gave lower dissolved oxygen concentrations.

Pollutant Load Allocation

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding the water quality standard. The load allocations for this TMDL are calculated using the following equation:

$$TMDL = \Sigma\ WLA + \Sigma\ LA + MOS$$

Where:

WLA = wasteload allocation (point source contributions)
LA = load allocation (nonpoint source contributions)
MOS = margin of safety

Typically, several possible allocation strategies would achieve the TMDL endpoint and water quality standards. Available control options depend on the number, location, and character of pollutant sources.

For dissolved oxygen exceedances, the pollutants most closely related to the impairment are $CBOD_5$ and NH_3-N. When the minimum 24-hour dissolved oxygen criterion is also being exceeded because of diel dissolved oxygen fluctuations, as is the situation for the Lower Reach, nutrient removal must also be evaluated as a means to control aquatic vegetation and to improve minimum dissolved oxygen concentrations. However as previously presented under the Linkage Analysis section, reasonable phosphorus controls on WWTF discharges could not be linked through QUAL2K to depressed concentrations of 24-hour minimum dissolved oxygen in the Lower Reach. Consequentially, phosphorus is not an allocated pollutant of this TMDL.

Especially in the Lower Reach and to a lesser extent in the Upper Reach many of the dissolved oxygen exceedances appeared to occur under flow conditions that approached steady state conditions as opposed to dynamic flow conditions under the influence of rainfall runoff. The TMDL allocation process, therefore, emphasized regulated point source contributions from WWTFs. For the Upper Reach, contributions from the Brazos River water pumped into the system were also included.

For the TMDL allocation process as defined in the equation above, WLA and LA included various sources of $CBOD_5$ and NH_3-N. WLA was defined as contributions from WWTFs. Individual WLAs are outlined in Appendices B and D. LA was defined as critical low-flow background contributions from the watershed, and for the Upper Reach, any contributions from the pumped Brazos River water.

Because this TMDL allocation is for the critical low-flow condition, the allocations are not intended to characterize allowable loadings for regulated and unregulated storm water sources. Regulated storm water discharges will be included in the upcoming Phase II permits. This TMDL presumes that implementation of best management practices identified in each of these permits will not cause or contribute to violation of water quality standards during the critical low-flow period. Therefore, the WLA for these permittees during the critical low-flow period is the WLA identified in this document. Monitoring of these discharges and evaluation of BMP effectiveness over time will determine if this presumption is correct or needs to be modified.

To determine maximum allowable loadings from WWTFs in both the Lower and Upper Reaches, the validated QUAL2K models of each reach were applied. For this task of the pollutant load allocation, the model application was identical to a waste load evaluation

process wherein the maximum allowable loading of oxygen demanding pollutants from WWTFs was determined under the critical combination of water temperature and steady-state, low flow.

For both the Lower and Upper Reaches, QUAL2K was applied using the existing segmentation and kinetic rates developed during the model validation process. Applications of QUAL2K were made for low-flow conditions when minimum dissolved oxygen concentrations could occur in both reaches.

Defining Allocation Critical Flow

The Lower Reach headwater flows were defined as the values used by TCEQ staff in previous assessments of Upper Oyster Creek, which are based on the 7-day 2-year low-flow (7Q2). Since the 7Q2 for the headwater of the Lower Reach is 0.0 cms, the default minimum low-flow specification for a classified segment of 0.0028 cms (0.1 cfs) was applied. The 7Q2 flow defines the critical low flow at and above which the dissolved oxygen criteria are applicable.

For unclassified streams, the critical low-flow specification was based on Table 5 of *Texas Surface Water Quality Standards* (TCEQ 2000), which provides for determination of critical low-flow based on designated aquatic life use and average stream bedslope. Therefore, values in this table and tributary bedslope were used to determine the critical low-flow for the tributaries to Segment 1245 that are represented in QUAL2K for the Lower and Upper Reaches.

Critical low-flow determination for the area of the headwater to the Upper Reach was complicated by:

- the pumping of Brazos River water at the Shannon Pump Station,
- the procedure to meet demands at the Second Lift Station when possible from rainfall-runoff and to curtail pumping at the Shannon Pump Station during runoff conditions, and
- absence of gauged daily streamflow records at any location in the Upper Reach.

This lack of historical streamflow records was also encountered in developing the adopted bacteria TMDL for Upper Oyster Creek (TCEQ 2007) and addressed by applying the Soil & Water Assessment Tool (SWAT; Arnold et al. 1998) to predict daily streamflow at several locations within both the Upper Reach and Lower Reach for the 12-year period of 1993–2004. The calibration and application of SWAT to Upper Oyster Creek is provided in Section 4–Bacteria Allocation Tool Development of the bacteria TMDL technical support document (Hauck and Bing 2006).

The hydrologic predictions from application of SWAT to Upper Oyster Creek watershed were evaluated to determine the critical low flows in the Upper Reach. To determine the 7Q2 flow, the predicted daily flow data from SWAT for the period 1993–2004 were used as input 7Q2HM, which is a TCEQ program developed to compute 7Q2 and harmonic means flows. SWAT results for the following two locations were used:

- a location just below the Shannon Lift Station and
- a location immediately above the Second Lift Station.

The results from 7Q2HM indicated that the 7Q2 for any given year typically occurred during the fall, winter, and early spring (October–March), which did not coincide with the occurrence of maximum water temperatures in the system (June–September). The 7Q2 value just below the Shannon Lift Station was 0.009 cms and above the Second Lift Station was 0.117 cms. Because the critical low flow did not occur at the same time as critical high water temperatures (i.e., during the summer), a seasonal analysis was necessary for the QUAL2K application to the Upper Reach to determine the combination of low flow and temperature that caused the lowest dissolved oxygen.

For the determination of low flows in the seasonal analysis, the 10th percentile flow (i.e., the flow that is exceeded 90 percent of the time) was determined on a monthly basis using the 1993–2004 SWAT daily predictions. Critical low flow was determined for each month of the year as the greater of the 10th percentile flow for that month and the 7Q2 (Table 4). Because the computations indicated differences in the monthly critical low flows between the headwater (just below the Shannon Pump Station) and the outlet (near the Second Lift Station), QUAL2K was operated using the "diffuse source" option to provide the necessary water balance, which considered pumped flows, tributary headwater flows, and the average WWTF discharges used in the SWAT model.

Defining Allocation Critical Water Temperature

To perform the seasonal analysis, monthly water temperatures also needed to be considered. All available historical water temperature data for Segment 1245 from 1988 - 2006 were obtained from the TCEQ water quality database. For station 12083 in the immediate vicinity of the formerly operating Imperial Sugar facility, temperature data prior to 1996 were excluded from subsequent analyses. Prior to 1996, Imperial Sugar discharged heated effluent into Oyster Creek, which would have improperly biased data in the vicinity of this discharge. The seasonal analysis of temperature followed TCEQ guidance, which requires that a single, reasonable value be computed to represent the temperature for the three months with highest temperatures and that a reasonable high temperature be determined for each of the remaining nine months. The resulting critical water temperatures, which are defined as the monthly 90th percentile temperatures (i.e., the temperature that is exceeded 10 percent of the time for the month being evaluated) except for the three hottest months, are provided with footnote explanations in Table 5.

One further refinement was made to the temperature analysis, and that refinement was to the summer water temperatures (June–September) used for the Lower Reach. The process of data exploration for determining appropriate monthly temperatures showed that during the summer months, the Lower Reach experienced lower temperatures below the confluence of Oyster Creek and Stafford Run than temperatures experienced in the Upper Reach. Data comparisons indicated on average a 1.1º C lower temperature in the Lower Reach than in the Upper Reach during these three hottest months of June, July,

Table 4. Monthly headwater and diffuse sources flows information for Upper Reach

All flows in units of cubic meters/second (cms)

Location	Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Headwater	10th percentile flow	0.014	0.026	0.016	0.146	0.392	1.247	2.463	2.546	0.072	0.016	0.011	0.012
	Critical low flow [maximum of 7Q2 (0.009 cms) and 10th percentile flow]	0.014	0.026	0.016	0.146	0.392	1.247	2.463	2.546	0.072	0.016	0.011	0.012
2nd Lift Station [a]	10th percentile flow	0.019	0.010	0.004	0.666	1.045	2.109	2.601	2.420	0.999	0.050	0.032	0.021
	Critical low flow [maximum of 7Q2 (0.117 cms) and 10th percentile flow]	0.117	0.117	0.117	0.666	1.045	2.109	2.601	2.422	0.999	0.117	0.117	0.117
Diffuse Sources [b]	Computed by water balance [c]	-0.026	-0.037	-0.028	0.390	0.524	0.739	0.014	-0.246	0.807	-0.020	-0.016	-0.018

Notes:

a The 2nd Lift Station withdrawal location is used to define the most downstream location for critical flow determination, though physically the most downstream location is at Dam #3.

b Negative diffuse sources flow is an abstraction or withdrawal.

c Water balance considered flow at the 2nd Lift Station less headwater flow at Shannon Pump Station less headwater flows from Flewellen Creed and Red Gully less average WWTF discharges used in SWAT.

Table 5. Monthly water temperature information for Upper Reach

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average (°C) [a]	12.5	15.3	19.9	23.0	26.8	29.5	29.7	30.0	28.9	24.3	19.7	14.2
Standard Deviation (°C)	3.4	2.7	2.1	2.2	2.6	1.6	2.0	1.7	1.9	2.4	2.8	4.3
Sample Size (n)	41	62	37	40	102	66	71	131	30	32	51	42
90th percentile (°C) [b]	16.9	18.8	22.6	25.9	30.2	31.6	32.3	32.2	31.4	27.4	23.3	19.8
3 hottest months temperature (°C)						31.5 [c]						

Notes:

[a] Water temperature data are for Segment 1245 for years 1988-2006 obtained from the TCEQ web site <www.tceq.state.tx.us/compliance/monitoring/crp/data/samplequery.html>.

[b] 90th percentile estimated using Avg + STD x t-value assuming a normal or t-distribution using a one-tailed test

[c] Calculated using Avg of months 6, 7 and 8 + Avg of their STD values, and the 3 hottest months (6, 7, 8) are selected by the 90th percentile temperature.

and August. Therefore for the Lower Reach, the critical water temperature for the three hottest months was calculated to be 30.4º C (1.1º C lower than 31.5º C from Table 5).

Inadequate data existed to determine the existence of differences in water temperature between the Lower and Upper Reaches for periods other than the summer months, hence, the monthly water temperatures for September–May in Table 5 were considered appropriate for both reaches.

Defining WLA and LA Inputs

The municipal WWTFs were represented in the input data to QUAL2K at full permitted discharge and initially at existing permit limits for NH_3-N, $CBOD_5$, and dissolved oxygen (Table 3). TCEQ's default multiplier of 2.3 was employed to convert $CBOD_5$ to ultimate CBOD as needed for input to QUAL2K. Total-P in effluent was assumed to be 5 mg/L for all facilities, which was considered a somewhat conservative number since the highest total-P concentration measured during the intensive surveys for model validation was 4.3 mg/L and most facilities were discharging between about 3.5 and 4.0 mg/L of total-P. Based on the intensive survey data for the WWTFs, 94 percent of the total-P was considered to be in the soluble form as PO_4-P and the remainder as organic-P. Organic-N and nitrite + nitrate nitrogen (NO_2+NO_3-N) effluent concentrations were based on TCEQ guidance for estimating these constituents based on permitted values of BOD_5 and NH_3-N. Several recent and pending facilities in the Upper Reach have polishing ponds, which have been evaluated by TCEQ staff to produce effluent from the ponds that is at background levels of CBOD and NH_3-N with dissolved oxygen at approximately 5 mg/L (personal communications with Mr. Mark Rudolph, TCEQ, June 2007). The facilities with polishing ponds are indicated as such in the last column of Table 3. For modeling purposes, the effluent from facilities with polishing ponds was assigned background concentrations for ultimate CBOD and NH_3-N, organic-N of 1 mg/L, and a chlorophyll-α concentration of 79.2 µg/L (the average of the chlorophyll-α concentration measured at the outfall from the holding pond of Quail Valley UD WWTF during the two model support surveys). To be conservative and in lieu of any information, NO_2+NO_3-N and PO_4-P were left at high concentrations assuming no nutrient removal by the ponds.

When existing WWTFs permit limits resulted in exceedances of dissolved oxygen criteria, reductions were made in NH_3-N and $CBOD_5$ limits using the TCEQ domestic effluent set hierarchy as guidance until the dissolved oxygen criteria were met. Dissolved oxygen limits were also increased, if necessary, applying the same hierarchical guidance.

The input data to QUAL2K to define LA contributions were defined as the headwater, tributary, and diffuse source flows, as previously discussed in the section titled "Defining Allocation Critical Flow." The model input concentrations for LA contributions where defined at background concentrations, which included $CBOD_5$ at 1.3 mg/L and NH_3-N at 0.050 mg/L.

Applications of QUAL2K

The validated QUAL2K models of the Lower and Upper Reaches were applied to determine allowable loadings from municipal WWTFs. For initial assessment, each WWTF was evaluated within QUAL2K at its full permit limits. Subsequent applications were made with more stringent permit limits if applicable dissolved oxygen criteria were not met, and the permit limits were adjusted until the criteria were not exceeded.

The initial focus was on 24-hour average dissolved oxygen criterion in both reaches and their tributaries. For the Upper Reach, as established in this report, the average dissolved oxygen criterion was important to the majority of exceedances in the assessment survey data sets. In the Lower Reach, the dissolved oxygen exceedances were usually associated with the minimum dissolved oxygen criterion and rarely associated with both the minimum and average dissolved oxygen criterion. However, the decision was made to focus on the average dissolved oxygen criterion for the Lower Reach based on the following reasons:

- Of the two assessment survey stations in the Lower Reach, data for the uppermost station had twice as many exceedances as the lowermost station, yet the uppermost station is upstream of any WWTFs, indicating dissolved oxygen exceedances occur in both the effluent impacted and non-effluent impacted portions of the Lower Reach. Thus, there are indications that the exceedance of the minimum dissolved oxygen criterion in the main stem of the Lower Reach is associated with hydrologic modification due to the presence of Dam #3 and the abundance of submersed macrophytes and not as a result of any readily controllable pollutants.
- Implications of full WWTF permit limits (especially discharge, NH_3-N, and BOD_5) on average dissolved oxygen concentrations in the Lower Reach were not evaluated through the assessment data obtained in years 2003 through 2005, because the facilities were operating well below their permit limits based on measurements taken during the model validation surveys and Discharge Monitoring Reports. The evaluation of the response of instream 24-hour average dissolved oxygen concentrations to full permits limits of WWTFs was performed under the modeling discussed herein.

Load Reduction and WLA for Lower Reach

The initial applications of QUAL2K to the Lower Reach were performed for the critical conditions of summer (June–August) temperatures (30.4° C) and low flow to determine maximum allowable loadings. The second set of model applications were performed under existing permit limits for WWTFs. The purpose was to determine maximum allowable daily loadings in order to evaluate average dissolved oxygen for conditions that are protective of the spawning season, which for Segment 1245 occurred in March. The dissolved oxygen criterion was 1 mg/L higher to protect spawning except in Stafford Run, which has a no significant aquatic life use designation (Table 2). The 90th percentile water temperature for March was 22.6° C (Table 5). The third model application was made to investigate potential benefits of seasonal permit limits to be effective from

November through February that accounted for the fact that fall and winter water temperatures are cooler than summer temperatures so that kinetic rates are reduced and dissolved oxygen saturation concentrations are increased. As an existing example, the Quail Valley Utility District WWTF presently operates under seasonal permits (Table 3). QUAL2K was applied with the existing permit limits for WWTFs and 90th percentile November water temperature (23.3° C; Table 5). The minimum 24-hour average dissolved oxygen predicted for the main stem, Stafford Run, Steep Bank Creek, and Remnant of Flat Bank Creek under the existing WWTF permit limits condition are provided in Table 6 for the three different model applications.

For the critical high temperature and low flow conditions of June-August, existing allowable loadings resulted in exceedances of the 24-hour dissolved oxygen criteria in Upper Oyster Creek (main stem) and Steep Bank Creek, and acceptable dissolved oxygen concentrations in Stafford Run and Remnant of Flat Bank Creek (Table 6). Model predicted dissolved oxygen under existing WWTF permit conditions and the allowable WWTF loading conditions that reduced loadings sufficiently to meet dissolved oxygen criterion are provided in Appendix A, Figure A-1. The maximum allowable loadings from WWTFs that did not result in exceedances of the average dissolved oxygen criterion and associated percent reduction in loadings are provided in Table 7. It should be further noted that under this model scenario all WWTFs had a dissolved oxygen limit of 6.0 mg/L, representing an increase from 5.0 mg/L for some facilities (see present dissolved oxygen permit limits in Table 3).

Table 6. Simulated minimum 24-hour average DO concentrations (mg/L) under the existing permits limits in the Lower Reach

(Red font indicates exceedance of criterion)

Location	Mar	Jun-Aug	Nov
Main stem	**4.3**	**2.9**	4.0
Stafford Run	3.7	2.1	3.4
Steep Bank Creek	4.7	**2.9**	4.6
Remnant of Flat Bank Cr.	6.4	4.9	6.3

For the spawning season (March) conditions, the existing permit loadings resulted in exceedances of the dissolved oxygen criterion, though the exceedances were less than for the June-August condition and were restricted to the main stem (Table 6). The predicted average dissolved oxygen for the main stem, Stafford Run, Steep Bank Creek, and Remnant of Flat Bank Creek under the existing WWTF permit limits conditions and under the allowable WWTF loading conditions that reduced loadings sufficiently to meet the average dissolved oxygen criterion are provided in Appendix A, Figure A-2. The maximum allowable loadings that did not result in exceedances of the average dissolved oxygen criterion and the necessary percent reductions in exiting loadings to achieve the allowable loadings are provided in Table 7. It should be noted that under this model

scenario all WWTFs had a dissolved oxygen limit of 6.0 mg/L, representing an increase from 5.0 mg/L for some facilities.

Under the third model application for November conditions, the average dissolved oxygen criterion was met without the need for any load reductions and with dissolved oxygen limits as specified in existing permits (Table 6 and Appendix A, Figure A-3). Since 90th percentile temperatures were lower in the months from December through February than November (Table 5), the dissolved oxygen criterion will also be met for these months. The water temperature for March was also lower than that of November; however, the higher dissolved oxygen criterion to protect spawning was effective for that month. As presented in Table 6, this higher spawning criterion could not be met under existing permit limits.

Table 7. Existing, maximum allowable loadings, and percent reductions for WLA in Lower Reach

Condition	Discharge (cms)	$CBOD_5$ (kg/d)	Ammonia N (kg/d)
Existing Permit Loadings	1.078	931.3	253.27 [b]
Allowable Loadings (June - August Condition) [a]	1.078	482.7	186.26
Percent Reductions (June-August Condition)	0 %	48 %	26 %
Allowable Loadings (Spawning Season, March) [a]	1.078	662.1	186.26
Percent Reductions (Spawning Season, March)	0 %	29 %	26 %
Allowable Loadings (November Condition)	1.078	931.3	268.41 [b]
Percent Reductions (November Condition)	0 %	0 %	0 %

[a] The allowable loading condition also assumes that the DO permit limit for WWTFs is 6.0 mg/L whereas several facilities have an existing limit of 5.0 mg/L.

[b] The existing Quail Valley UD permit has seasonal limits allowing more ammonia to be discharged in the winter, which was made applicable for the November condition (see Table 3).

Based on these applications of QUAL2K and restricting seasonal limits to two subdivisions of the year, the following maximum allowable loadings for WLA contributions result in the pertinent average dissolved oxygen criteria being meet for the Lower Reach of Upper Oyster Creek and its major tributaries:

- November–February:
  Permit loadings for November conditions (from Table 7)
- March–October:
  Permit loadings for June-August conditions (from Table 7).

Because the June–August allowable permit loadings are less than those required to protect spawning in March, the summer loadings will more than suffice to maintain dissolved oxygen concentrations during the spawning season. The maximum allowable

loadings by individual WWTF are provided in Appendix B for the two seasonal conditions of March–October and November–February.

At this time, the individual permittees have been made aware of the individual WLAs identified in Appendices B and D. It is the TCEQ's intention to implement these individual WLAs through the permitting process as either monitoring requirements or effluent limitations. However, there may be a more economical or technically feasible means of achieving the goal of improved dissolved oxygen and circumstances may warrant changes in individual WLAs after this TMDL is adopted. Therefore, these individual WLAs are non-binding until implemented via a separate TPDES permitting action which may involve a Water Quality Management Plan Update. Regardless, all permitting actions will demonstrate compliance with the TMDL.

The Commission understands that this TMDL is, by definition, the total of the sum of the wasteload allocation, the sum of the load allocation, and the margin of safety. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the actual TMDL and will be accommodated through the WQMP update process. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Load Reduction and WLA for Upper Reach

Since a seasonal analysis was required for the Upper Reach, QUAL2K was operated under conditions of existing permit loading for water temperature and headwater, diffuse sources and tributary flow conditions for January, February, March, April, May, three hottest months (June–August), September, October, November, and December. The headwater and diffuse source flows for June were used in the simulation of the three hottest months, since these were the lowest monthly flows for June–August. The dissolved oxygen results for March were evaluated against the 24-hour average dissolved oxygen criterion to protect spawning whereas results for all other months were evaluated against the general dissolved oxygen criterion. The minimum 24-hour average dissolved oxygen predicted for the main stem, Flewellen Creek, and Red Gully are provided in Table 8 for each condition. These model predictions indicated that potential exceedances of the 24-hour average dissolved oxygen criterion occurred during the March, September, October, and November scenarios.

For the March spawning scenario, the dissolved oxygen exceedance occurred in the very upper portion of Jones Creek above the confluence with Flewellen Creek (which is at location 81.65 km) and above the influences of any WWTF discharges (Appendix C, Figure C-1). This dissolved oxygen exceedance was attributable to the small amount of inflow entering the headwater and the relatively high SOD throughout the main stem. The March dissolved oxygen exceedance was considered to be the result of conditions that could not be remedied by reductions in loadings from WWTFs. Similarly, though plots are not shown, the dissolved oxygen exceedance for the October and November scenarios occurred in the same location as the March scenario—very upper portion of Jones Creek above the confluence with Flewellen Creek.

Table 8. Simulated minimum 24-hour average DO concentrations (mg/L) under the existing permits limits in the Upper Reach

(Red font indicates exceedance of criterion)

Location	Jan	Feb	Mar	Apr	May	Jun-Aug	Sep	Oct	Nov	Dec
Main stem	6.4	6.3	**4.5**	4.9	4.7	4.6	4.0	**3.5**	**3.8**	5.3
Flewellen Cr.	7.3	7.1	6.7	6.0	6.6	6.4	5.4	6.0	6.2	6.9
Red Gully	6.8	6.4	5.7	5.1	4.6	4.2	**3.9**	4.7	5.4	6.2

For the September scenario, predicted average dissolved oxygen was slightly below the criterion in Red Gully and barely meeting the criterion in Oyster Creek near the confluence with Red Gully (Appendix C, Figure C-2). Reductions in allowable loading of NH_3-N from one of the facilities discharging into Red Gully were sufficient to provide predicted dissolved oxygen that met the dissolved oxygen criterion in Red Gully under September conditions. The June-August scenario, representing the critical summer conditions of temperature (Table 5) and the June headwater flow (Table 4), which was the lowest flow for the three months of June, July, and August, was not indicated to result in any dissolved oxygen exceedances (Appendix C, Figure C-3).

Based on these applications of QUAL2K to the Upper Reach and restricting seasonal limits to two subdivisions of the year as defined for the Lower Reach, the following maximum allowable loadings for WLA contributions resulted in the pertinent average dissolved oxygen criteria being meet for the Upper Reach of Upper Oyster Creek and its major tributaries:

- November–February:
  existing permit loadings (from Table 9)
- March–October:
  Permit loadings for September (from Table 9).

The maximum allowable loadings by individual WWTF are provided in Appendix D for the two seasonal conditions of November–February and March–October.

At this time, the individual permittees have been made aware of the individual WLAs identified in Appendices B and D. It is the TCEQ's intention to implement these individual WLAs through the permitting process as either monitoring requirements or effluent limitations. However, there may be a more economical or technically feasible means of achieving the goal of improved dissolved oxygen and circumstances may warrant changes in individual WLAs after this TMDL is adopted. Therefore, these individual WLAs are non-binding until implemented via a separate TPDES permitting action which may involve a Water Quality Management Plan Update. Regardless, all permitting actions will demonstrate compliance with the TMDL.

The Commission understands that this TMDL is, by definition, the total of the sum of the wasteload allocation, the sum of the load allocation, and the margin of safety. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the actual TMDL and will be accommodated through the WQMP update process. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Table 9. Existing, maximum allowable loadings, and percent reductions for WLA in Upper Reach

Condition	Discharge (cms)	$CBOD_5$ (kg/d)	NH_3-N (kg/d)
Existing Permit Loading	0.323	114.2	26.86
Allowable Loading (September Condition)	0.323	114.2	23.60
Percent Reduction (September Condition)	0%	0%	12%
Allowable Loading (June-August Condition)	0.323	114.2	26.86
Percent Reduction (June-August Condition)	0%	0%	0%
Allowable Loading (Spawning Season, March)	0.323	114.2	26.86
Percent Reduction (Spawning Season, March)	0%	0%	0%

LA for Lower and Upper Reaches

LA was defined as the allowable loading from critical low-flow background contributions within the watershed. For the Upper Reach critical low-flow, background contributions also included any contributions from the pumped Brazos River water at the Shannon Pump Station. To determine the loadings from background contributions, a flow and associated constituent concentration must be known. Relevant pollutants for this dissolved oxygen TMDL, as previously discussed, are the oxygen demanding constituents of $CBOD_5$ and NH_3-N. The critical low flows were considered the same for all modeled conditions in the Lower Reach. For the Upper Reach, the headwater and diffuse source critical low flows varied by month (Table 4). Much of this variability is attributable to the seasonality of the pumped Brazos River water. Because September conditions resulted in the lowest dissolved oxygen concentrations considered correctable by pollution control measures within the watershed, the critical low flows for September were used in determination of LA for the Upper Reach. For the Lower and Upper Reaches, LA was calculated from the critical low flows and background $CBOD_5$ and NH_3-N concentrations specified as input to QUAL2K (Table 10).

Table 10. Estimated background NH_3-N and $CBOD_5$ daily loadings (LA) and critical low flow for Lower and Upper Reaches

Description	
Lower Reach:	
Critical Low Flow (cms) *	0.0085
Background NH_3-N Load (kg/d)	0.04
Background $CBOD_5$ Load (kg/d)	1.0
Upper Reach:	
Critical Low Flow (cms) *	0.9640
Background NH_3-N Load (kg/d)	4.17
Background $CBOD_5$ Load (kg/d)	108.3

* Critical low flow includes all model specified headwater and diffuse sources inputs.

TMDL Allocation Summary for Lower and Upper Reaches

The TMDL allocations for the Lower and Upper Reaches of Upper Oyster Creek (Segment 1245) were developed for the critical low-flow condition considering seasonal permit limits for WWTFs for the two periods of March–October and November–February. The March–October period represents a period of higher water temperatures and includes the March spawning season, and the November–February period represents a period of cooler water temperatures.

For the Lower Reach, the TMDL allocations for NH_3-N and $CBOD_5$ for the March–October period are provided in Tables 11 and 12. Tables 13 and 14 are for the November–February period. Correspondingly, for the Upper Reach, the TMDL allocations for NH_3-N and $CBOD_5$ for the March–October period are provided in Tables 15 and 16 and in Tables 17 and 18 for the November–February period.

Because this TMDL allocation is for the critical low-flow condition, the allocations are not intended to characterize allowable loadings for regulated and unregulated storm water sources. Regulated storm water discharges will be included in the upcoming Phase II permits. This TMDL presumes that implementation of best management practices identified in each of these permits will not cause or contribute to violation of water quality standards during the critical low-flow period. Therefore, the WLA for these permittees during the critical low-flow period is the WLA identified in this document. Monitoring of these discharges and evaluation of BMP effectiveness over time will determine if this presumption is correct or needs to be modified.

Table 11. TMDL summary for Lower Reach NH_3-N, critical low-flow condition, and the March–October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation [a]	253.27	186.26	26
Load Allocation	0.04	0.04	0
Total Loading	253.31	186.30	26

[a] Waste Load Allocation existing loading includes the present summer seasonal permit limit for NH_3-N at Quail Valley Utility District (WQ0011046)

Table 12. TMDL Summary for Lower Reach $CBOD_5$, critical low-flow condition, and the March–October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	931.3	482.7	48
Load Allocation	1.0	1.0	0
Total Loading	932.3	483.7	48

Table 13. TMDL summary for Lower Reach NH_3-N, critical low-flow condition, and the November–February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation [a]	268.41	268.41	0
Load Allocation	0.04	0.04	0
Total Loading	268.45	268.45	0

[a] Waste Load Allocation existing and allowable loading includes the present winter seasonal permit limit for NH_3-N at Quail Valley Utility District (WQ0011046)

Table 14. TMDL Summary for Lower Reach $CBOD_5$, critical low-flow condition, and the November–February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	931.3	931.3	0
Load Allocation	1.0	1.0	0
Total Loading	932.3	932.3	0

Table 15. TMDL summary for Upper Reach NH_3-N, critical low-flow condition, and the March–October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	26.86	23.60	12
Load Allocation	4.17	4.17	0
Total Loading	31.03	27.77	11

Table 16. TMDL summary for Upper Reach $CBOD_5$, critical low-flow condition, and the March–October period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	114.2	114.2	0
Load Allocation	108.3	108.3	0
Total Loading	222.5	222.5	0

Table 17. TMDL summary for Upper Reach NH_3-N, critical low-flow condition, and the November–February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	26.86	26.86	0
Load Allocation	4.17	4.17	0
Total Loading	31.03	31.03	0

Table 18. TMDL summary for Upper Reach $CBOD_5$, critical low-flow condition, and the November–February period

Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	114.2	114.2	0
Load Allocation	108.3	108.3	0
Total Loading	222.5	222.5	0

Allowance for Future Growth

The TMDL allocations for the Lower and Upper Reaches do not preclude nor prevent consideration of expansions to WWTFs and addition of new WWTFs. Any expansions and additional facilities need to be evaluated on a permit-by-permit basis. This evaluation will be conducted through the appropriate QUAL2K model or an updated replacement model. Additional allowable loadings, if any, under new permits and amendments for permit expansions will be determined subject to the outcome of the modeling and predicted dissolved oxygen concentrations using information specific to each WWTF as well as the QUAL2K analysis that supports this TMDL. Further, the TMDL allocations are not intended to restrict or limit the GCWA pumping of Brazos River water into the Upper Reach at the Shannon Pump Station and associated loadings of NH_3-N and $CBOD_5$. Based on QUAL2K seasonal-analysis results for the Upper Reach (Table 8), a comparison can be made of model predicted minimum 24-hour average dissolved oxygen concentrations for June–August to the minimum dissolved oxygen concentrations for September for which both sets of predictions were made with comparable model inputs except for headwater inflow. This comparison indicates that higher dissolved oxygen concentrations occur under the higher pumping rates experienced in the June–August scenario than the lower rates in September. These QUAL2K results indicate that any future increases to the critical headwater pumped flows from the Brazos River as a result of increased water demands on the GCWA system should improve dissolved oxygen conditions in the Jones Creek/Oyster Creek portion of the Upper Reach.

Public Participation

The TCEQ maintains an inclusive public participation process. From the inception of the investigation, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

An official steering committee of stakeholders was established for the Upper Oyster Creek TMDL project in 2002. The first steering committee meeting was held in June 2003, and one or two meetings have been held each year since that time, always within the watershed. The steering committee members represent a broad array of interests in the watershed, such as local industries (including wastewater treatment facilities), landowners, environmental groups, and local and regional government groups. The

stakeholder committee has had very little turnover over the life of the project. Their knowledge of the watershed and consistency in attending meetings and providing input have been—and will continue to be—a valuable resource for restoring the beneficial uses of Upper Oyster Creek. To ensure that absent members and the public were informed of past meetings and pertinent material, a project web page was established to provide meeting summaries, ground rules, and a list of steering committee members at <www.tceq.state.tx.us/implementation/water/tmdl/25-oystercreek_group.html>

Implementation and Reasonable Assurances

The TMDL development process involves the preparation of two documents:

1) **a TMDL**, which determines the maximum amount of pollutant a water body can receive in a single day and still meet applicable water quality standards, and
2) **an implementation plan (I-Plan)**, which is a detailed description and schedule of the regulatory and voluntary management measures necessary to achieve the pollutant reductions identified in the TMDL.

The TCEQ is committed to developing I-Plans for all TMDLs adopted by the commission and to ensuring the plans are implemented. I-Plans are critical to ensure water quality standards are restored and maintained. They are not subject to EPA approval.

The TCEQ works with stakeholders to develop the strategies summarized in the I-Plan. I-Plans may use an adaptive management approach that achieves initial loading allocations from a subset of the source categories. Adaptive management allows for development or refinement of methods to achieve the environmental goal of the plan.

Periodic and repeated evaluations of the effectiveness of implementation methods assure that progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. This adaptive approach provides reasonable assurance that the necessary regulatory and voluntary activities to achieve the pollutant reductions will be implemented.

The complexity of Segment 1245 necessitates additional investigations to continue progress toward understanding dissolved oxygen and protecting the designated aquatic life use of both the Lower and Upper Reaches. Within the Lower Reach, the 24-hour minimum dissolved oxygen issue was not addressed by the TMDL, because the cause of the exceedances was not indicated to be responsive to controllable pollutants, such as nutrients from WWTFs. Because hydrologic modifications may be a factor in the Lower Reach regarding minimum dissolved oxygen, it may be advisable to consider whether the existing aquatic life use is appropriate. For the Upper Reach additional monitoring studies are also recommended during the implementation process to obtain a better understanding of the conditions resulting in the dissolved oxygen exceedances.

Implementation Processes to Address the TMDL

Together, the TMDL and I-Plan direct the correction of unacceptable water quality conditions that exist in an impaired surface water. A TMDL identifies a total loading from the combination of point sources and nonpoint sources that allows attainment of the water quality standard.

The I-Plan specifically identifies required or voluntary implementation actions that will be taken to achieve the pollutant loading goals of the TMDL. Regulatory actions identified in the I-Plan could include:

- adjustment of an effluent limitation in a wastewater permit,
- a schedule for the elimination of a certain pollutant source,
- identification of any nonpoint source discharge that would be regulated as a point source,
- a limitation or prohibition for authorizing a point source under a general permit, or
- a required modification to a storm water management program (SWMP) and pollution prevention plan (PPP).

Strategies to optimize compliance and oversight are identified in an I-Plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to an impairment.

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Appendix A: QUAL2K Predictions for Lower Reach

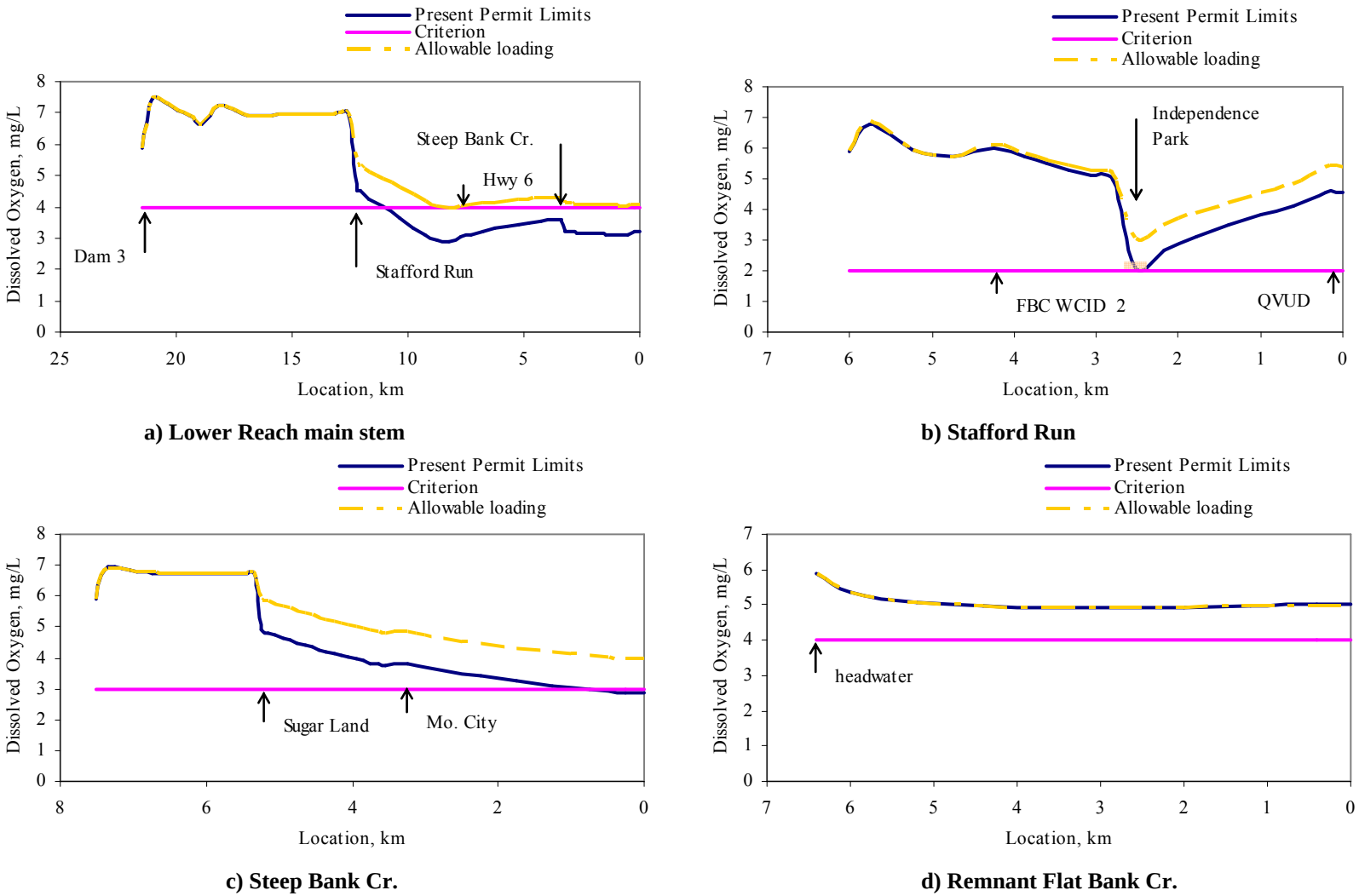


Figure A-1. QUAL2K average dissolved oxygen predictions for Lower Reach during critical summer conditions

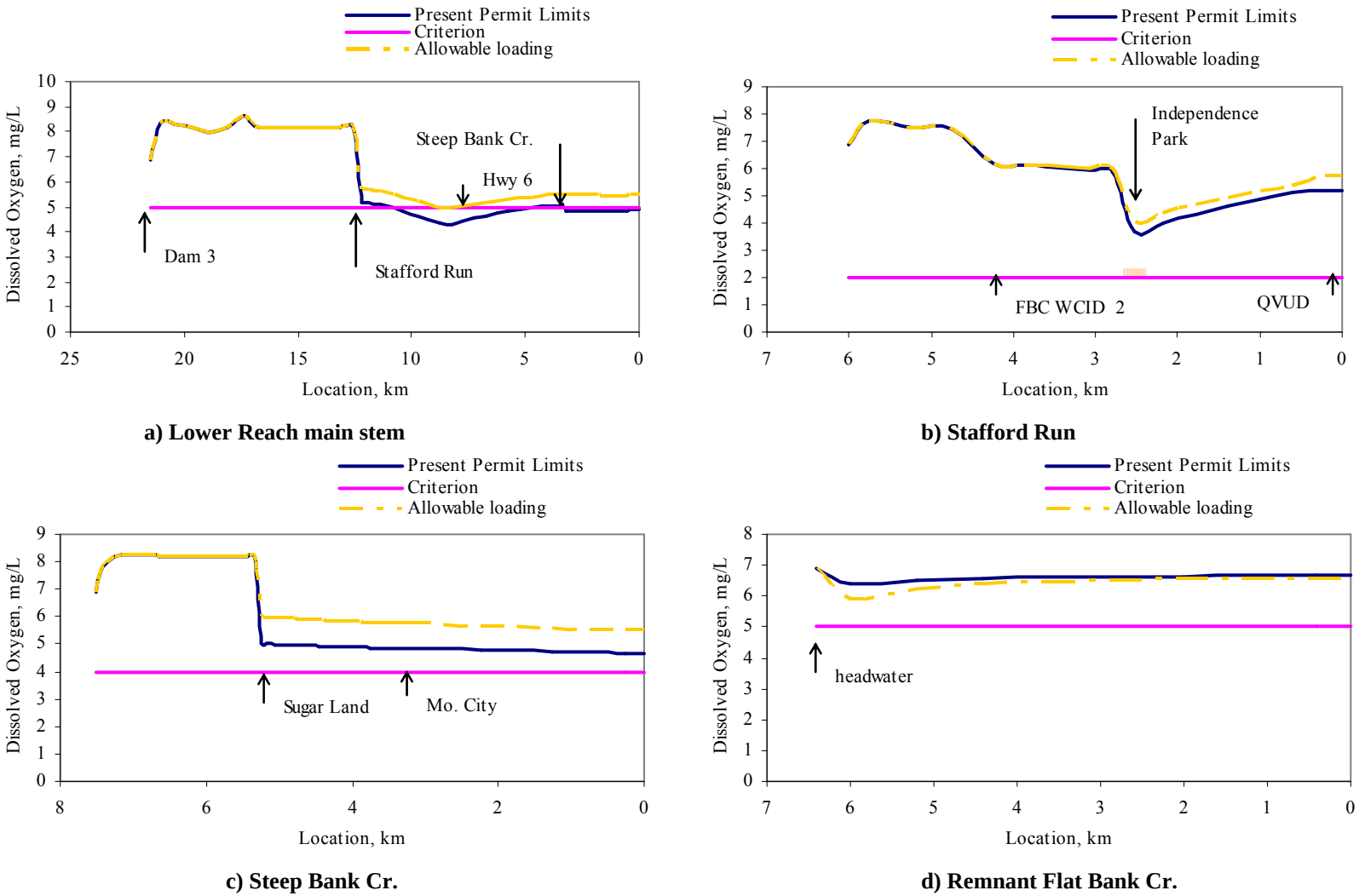


Figure A-2. QUAL2K average dissolved oxygen predictions for Lower Reach during spawning conditions (March)

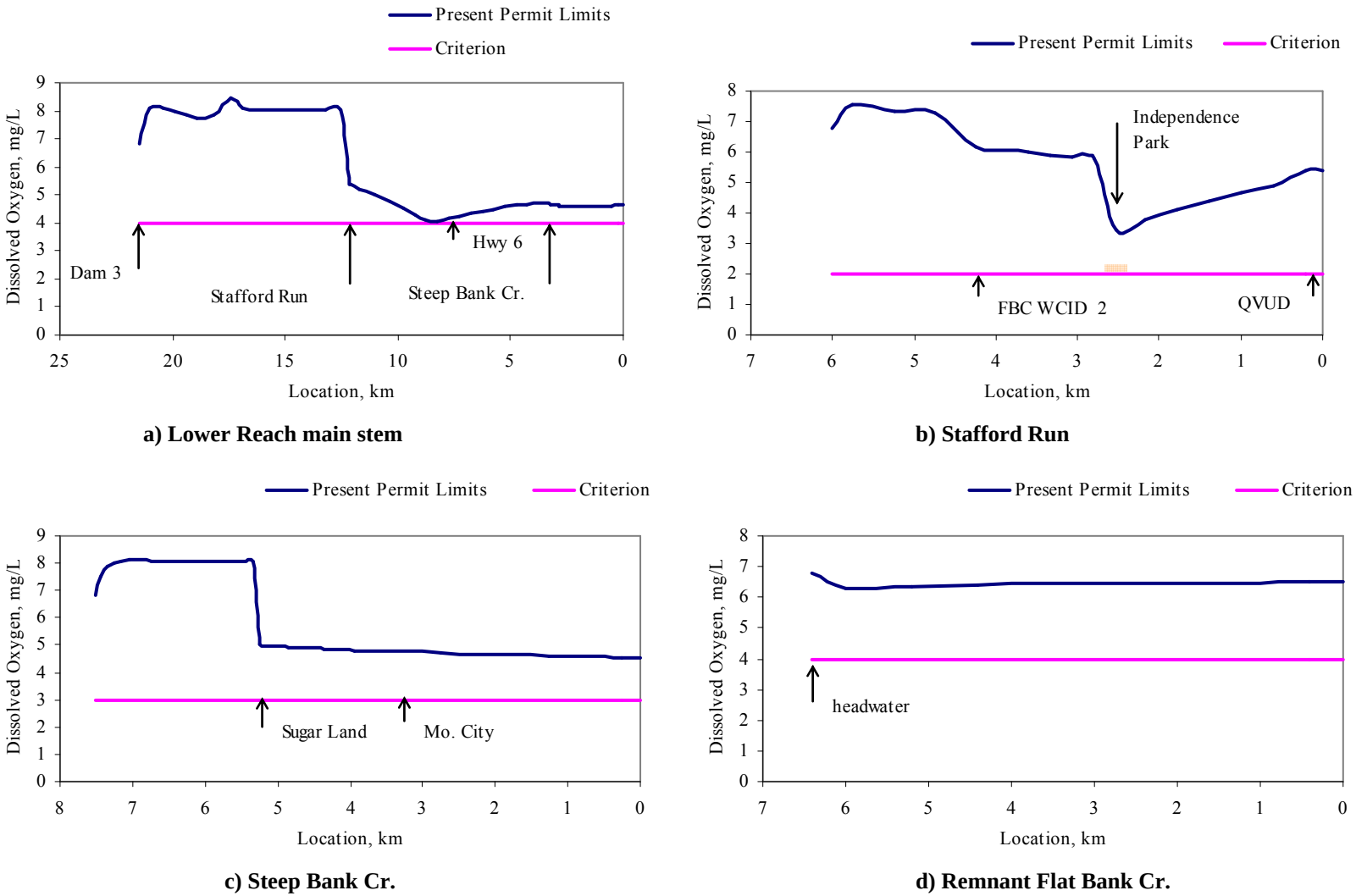


Figure A-3. QUAL2K average dissolved oxygen predictions for Lower Reach during winter conditions (Nov-Feb)

Appendix B: Lower Reach WLA by Individual WWTF

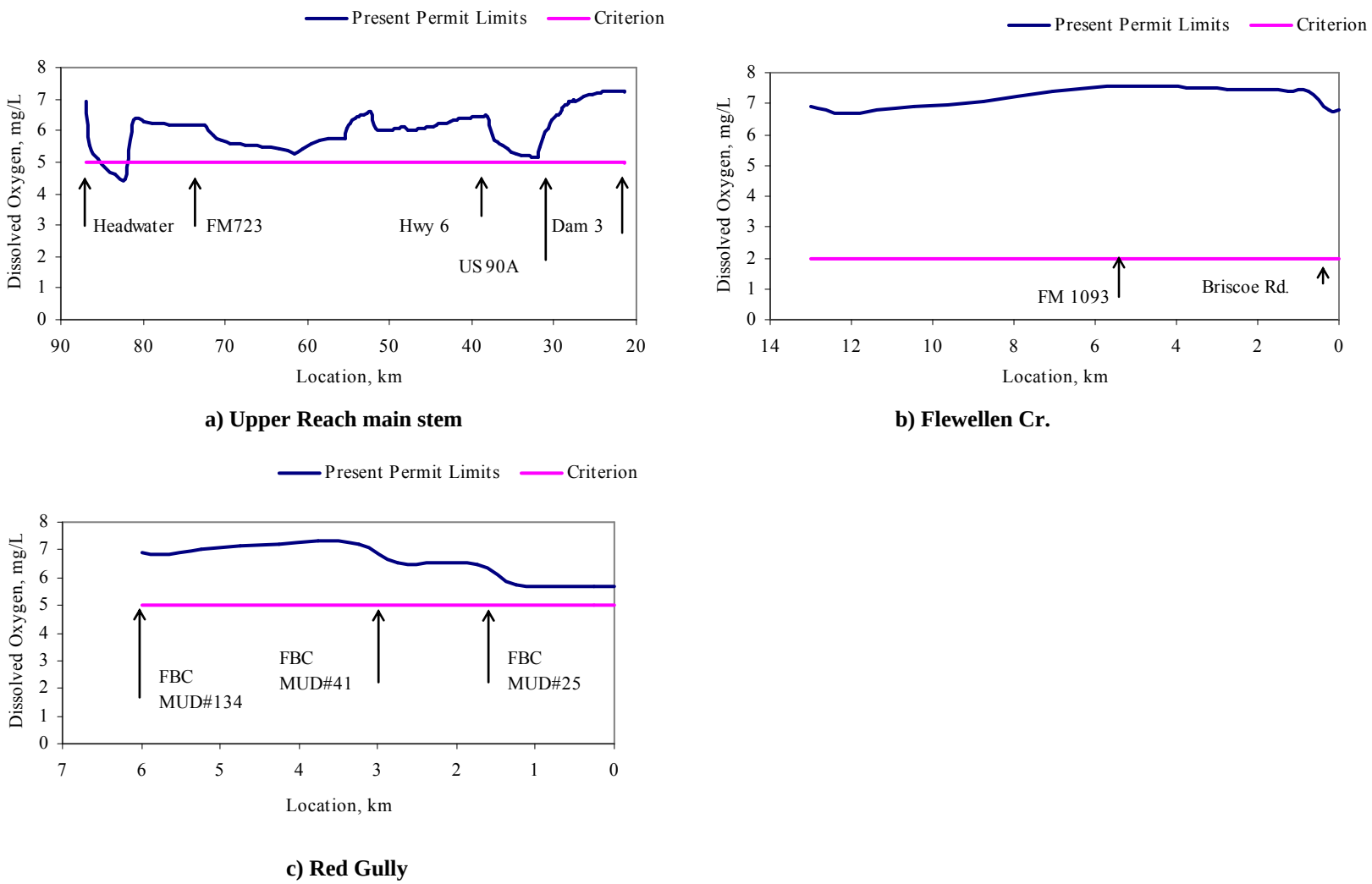
Table B-1. WLA for Lower Reach, March - October Conditions by Individual WWTF

Facility	Final Permitted Discharge (MGD)	Allowable $CBOD_5$ Loading (kg/d)	Allowable NH_3-N Loading (kg/d)
City of Missouri City	3.0	56.78	22.71
City of Sugar Land	10.0	189.27	75.71
Fort Bend County WCID #2	6.0	113.56	45.43
Palmer Plantation MUD 001	0.60	11.36	4.54
Quail Valley UD	4.0	75.71	30.28
Sienna Plantation MUD #1	0.902	34.14	6.83
Stafford Mobile Home Park, Inc.	0.1	1.89	0.76
Total	**24.602**	**482.71**	**186.26**

Table B-2. WLA for Lower Reach, November - February Conditions by Individual WWTF

Facility	Final Permitted Discharge (MGD)	Allowable $CBOD_5$ Loading (kg/d)	Allowable NH_3-N Loading (kg/d)
City of Missouri City	3.0	113.56	34.07
City of Sugar Land	10.0	378.54	113.56
Fort Bend County WCID #2	6.0	227.13	45.43
Palmer Plantation MUD 001	0.60	22.71	6.81
Quail Valley UD	4.0	151.42	60.57
Sienna Plantation MUD #1	0.902	34.14	6.83
Stafford Mobile Home Park, Inc.	0.1	3.79	1.14
Total	**24.602**	**931.29**	**268.41**

Appendix C: QUAL2K Predictions for Upper Reach

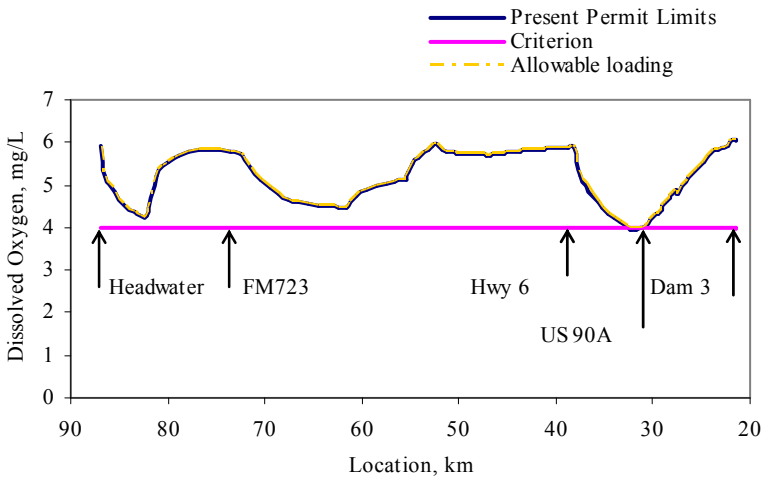


a) Upper Reach main stem

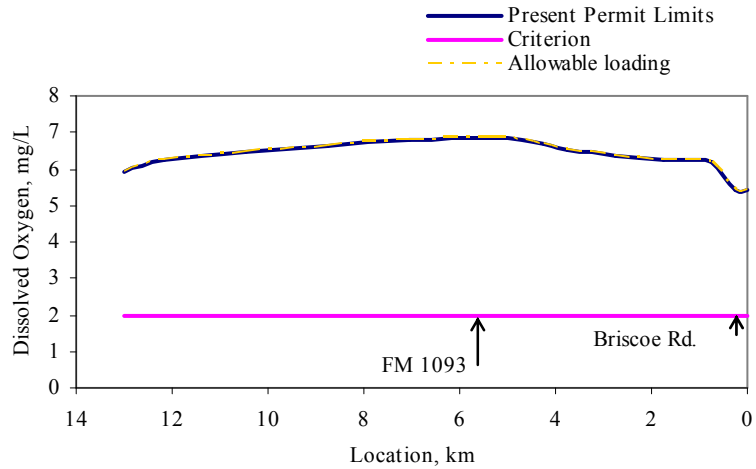
b) Flewellen Cr.

c) Red Gully

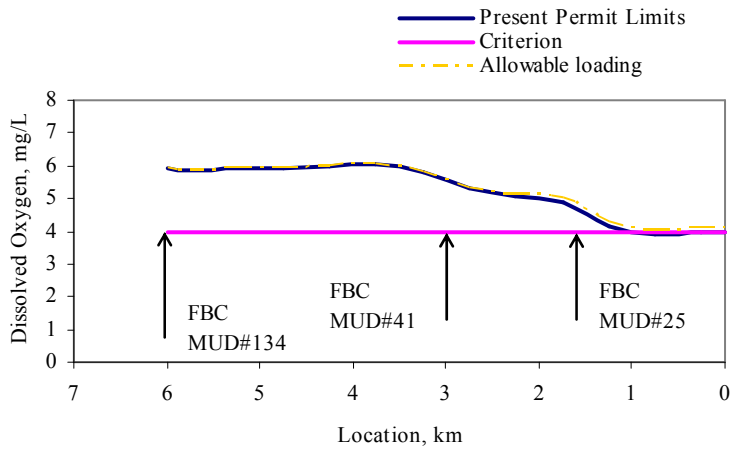
Figure C-1. QUAL2K average dissolved oxygen predictions for Upper Reach during spawning conditions (March)



a) Upper Reach main stem

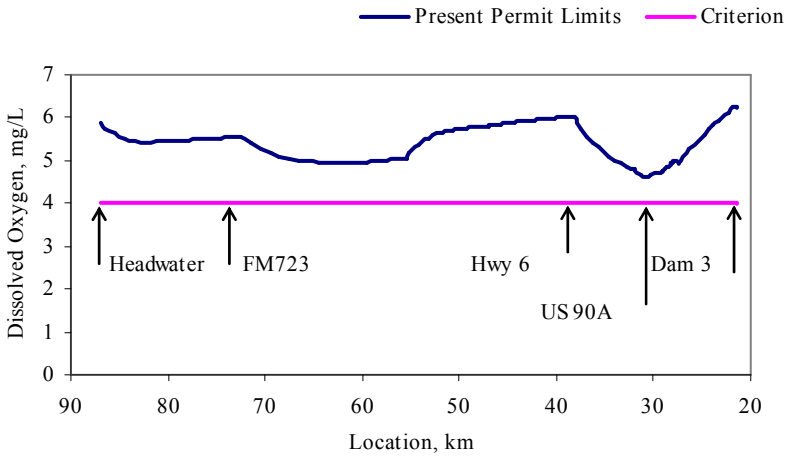


b) Flewellen Cr.

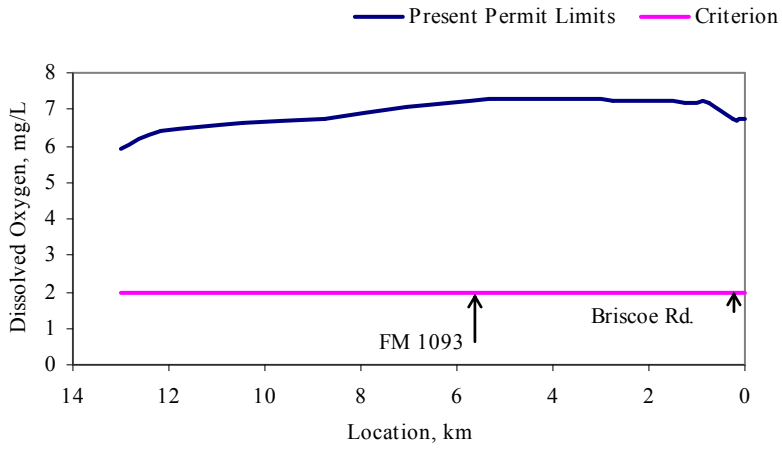


c) Red Gully

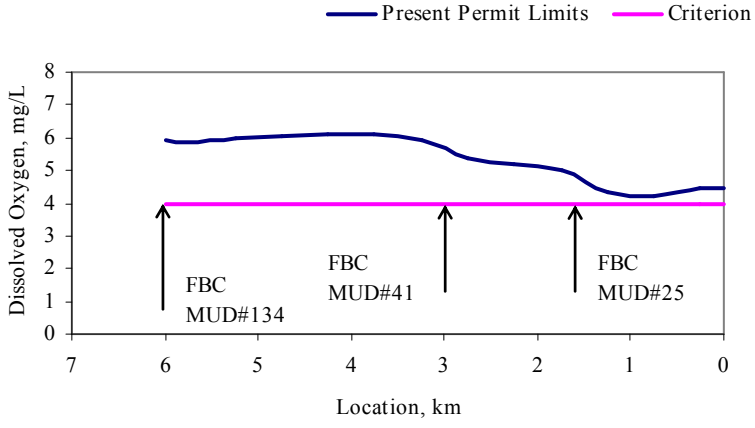
Figure C-2. QUAL2K average dissolved oxygen predictions for Upper Reach during September conditions



a) Upper Reach main stem



b) Flewellen Cr.



c) Red Gully

Figure C-3.QUAL2K average dissolved oxygen predictions for Upper Reach during June-August low flow and high temperature conditions

Appendix D: Upper Reach WLA by Individual WWTF

Table D-1. WLA for Upper Reach, March - October Conditions by Individual WWTF

Facility	Final Permitted Discharge (MGD)	Allowable $CBOD_5$ Loading (kg/d)	Allowable NH_3-N Loading (kg/d)
Fort Bend County MUD #25	1.6	30.28	6.06
Fort Bend County MUD #41	0.86	32.55	6.51
Fort Bend County MUD #118	1.2	22.71	6.81
Fort Bend County MUD #134 *	0.3	1.48	0.06
Fort Bend County MUD #142 *	1.2	5.91	0.23
Fort Bend County MUD #182 *	0.8	3.94	0.15
Pederson 631, LP *	0.6	2.95	0.11
TDCJ Jester Unit #1	0.315	11.92	3.58
TMI, Inc. *	0.5	2.46	0.09
Total	**7.375**	**114.20**	**23.60**

* Facility includes a polishing pond system. The WLA for each facility with a polishing pond system was based on analyses by TCEQ. The permit discharge limits into the polishing pond system for each of these facilities is provided in Table 3. The WLAs in this table represent the loadings leaving the polishing pond system.

Table D-2. WLA for Upper Reach, November - February Conditions by Individual WWTF

Facility	Final Permitted Discharge (MGD)	Allowable $CBOD_5$ Loading (kg/d)	Allowable NH_3-N Loading (kg/d)
Fort Bend County MUD #25	1.6	30.28	6.06
Fort Bend County MUD #41	0.86	32.55	9.77
Fort Bend County MUD #118	1.2	22.71	6.81
Fort Bend County MUD #134 *	0.3	1.48	0.06
Fort Bend County MUD #142 *	1.2	5.91	0.23
Fort Bend County MUD #182 *	0.8	3.94	0.15
Pederson 631, LP *	0.6	2.95	0.11
TDCJ Jester Unit #1	0.315	11.92	3.58
TMI, Inc. *	0.5	2.46	0.09
Total	**7.375**	**114.20**	**26.86**

* Facility includes a polishing pond system. The WLA for each facility with a polishing pond system was based on analyses by TCEQ. The permit discharge limits into the polishing pond system for each of these facilities is provided in Table 3. The WLAs in this table represent the loadings leaving the polishing pond system.