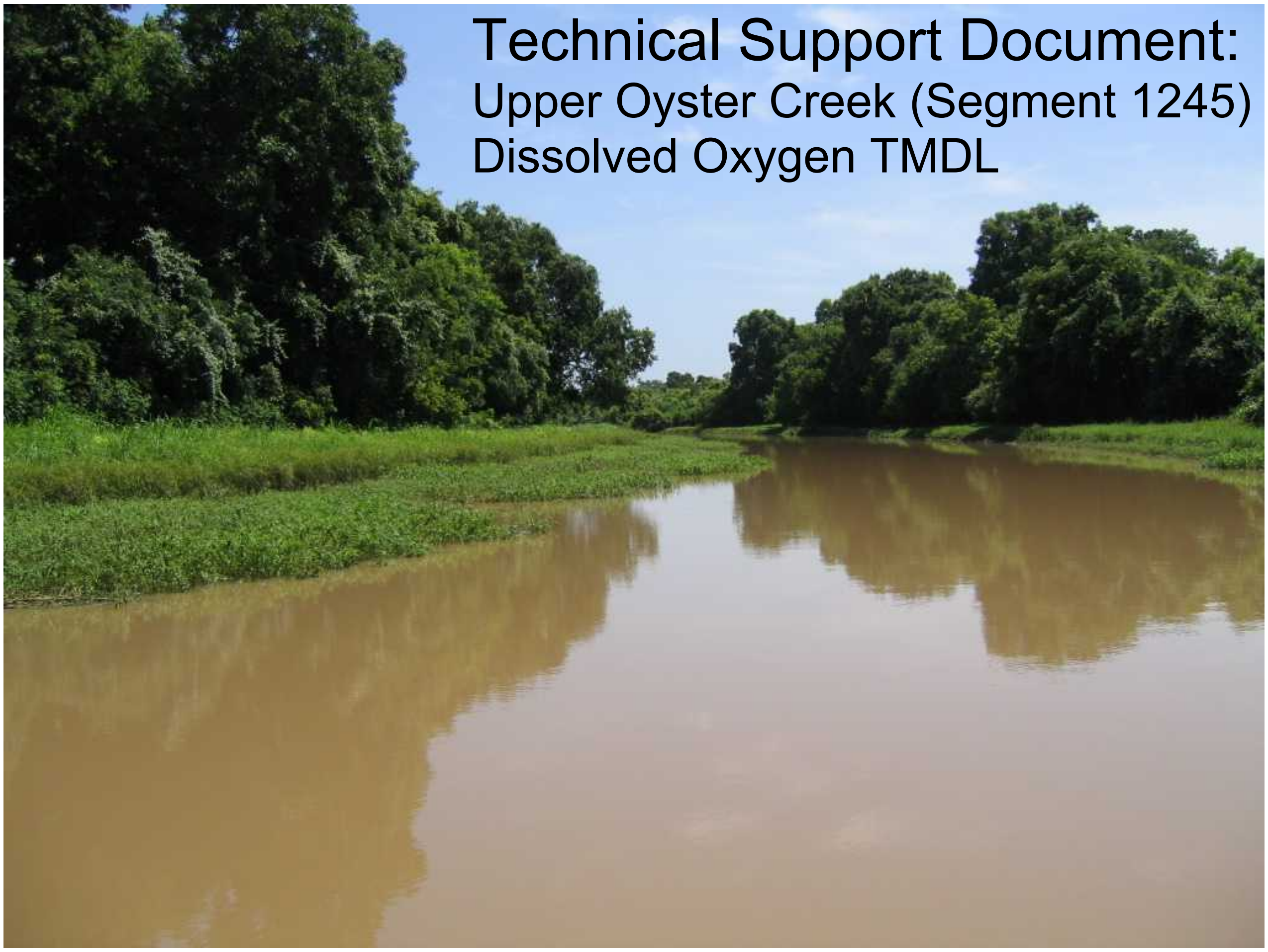

Technical Support Document:
Upper Oyster Creek (Segment 1245)
Dissolved Oxygen TMDL

Prepared by:

Larry M. Hauck

Bing Du

Texas Institute for Applied Environmental Research (TIAER)
Tarleton State University

Stephenville, Texas

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Prepared for:

Texas Commission on Environmental Quality
TMDL Team

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ACRONYMS AND ABBREVIATIONS

Ac-ft	Acre-feet
ac-ft/m	Acre-feet per month
BMP	Best management practice
BRA	Brazos River Authority
CAFO	Confined animal feeding operation
CBOD	Carbonaceous biochemical oxygen demand
CFR	Code of Federal Regulations
Chla	Chlorophyll-α
cms	Cubic meters per second
CWA	Clean Water Act
DO	Dissolved Oxygen
FM	Farm to market road
GCWA	Gulf Coast Water Authority
hr	Hour
ID	Identification or identifier
ISS	Inorganic suspended solids
LA	Load allocation
MGD	Million gallons per day
mg/L	Milligrams per liter
MOS	Margin of safety
MUD	Municipal utility district
NO_2+NO_3-N	Nitrite – Nitrate Nitrogen
NH_3-N	Ammonia Nitrogen
PO_4-P	Ortho-Phosphate Phosphorus
SH	State highway
SOD	Sediment oxygen demand
SWMP	Stormwater management program
TCEQ	Texas Commission on Environmental Quality
TDCJ	Texas Department of Criminal Justice
TKN	Total Kjeldahl nitrogen
TMDL	Total maximum daily load
TPDES	Texas Pollution Discharge Elimination System
Total-P	Total phosphorus
TSS	Total suspended solids
TWDB	Texas Water Development Board
µg/L	Micrograms per litter
WLA	Waste load allocation
WWTF	Wastewater treatment facility

SECTION 1

INTRODUCTION

1.1 Report Scope

Section 303(d) of the Clean Water Act (CWA) and U.S. Environmental Protection Agency (USEPA) Water Quality Planning and Management Regulations (40 Code of Federal Regulations [CFR] Part 130) require States to develop total maximum daily loads (TMDL) for water bodies not meeting designated uses where water quality-based controls are in place. TMDLs establish the allowable loadings of pollutants or other quantifiable parameters for a water body based on the relationship between pollution sources and in-stream water quality conditions, so States can implement water quality-based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of its water resources (EPA, 1991).

Texas Commission on Environmental Quality (TCEQ) is leading an effort to assess the water quality of classified Segment 1245 of Oyster Creek, known as “Upper Oyster Creek.” Segment 1245 was placed on the State of Texas 2002 303(d) list as not supporting its aquatic life use due to low dissolved oxygen concentrations. Segment 1245 is located within the Brazos River Basin, southwest of Houston, Texas in northern Fort Bend County (Figure 1-1 and 1-2). 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 1-2). Segment 1245 extends approximately 54 miles, and its watershed contains four incorporated areas: Fulshear, Sugar Land, Stafford, and Missouri City.

1.2 Water Quality Standards

Water quality standards (WQS) consist of designated beneficial uses, water quality criteria to protect the uses, and antidegradation policies. These standards serve dual purposes of establishing water quality goals for the nation’s water bodies and providing the regulatory basis for establishing certain treatment controls and strategies. The State of Texas WQSs applies to Upper Oyster Creek as described in the Texas Surface Water Quality Standards (TNRCC, 2000). Designated uses of Segment 1245 are intermediate aquatic life use, contact recreation, and public water supply. This report addresses only the intermediate aquatic life use.

Water quality criteria list specific constituent levels to be maintained to ensure that designated uses are met. To protect aquatic life use, water quality criteria are based on concentrations of minimum and average dissolved oxygen concentrations over a 24-hour period. Dissolved oxygen is an easy-to-measure characteristic of water that correlates with the occurrence and diversity of aquatic life in a water body. Of itself dissolved oxygen is not considered a pollutant; however, its concentration can be depleted in waters due to the presence of organic matter and ammonia, which undergo bacterial oxidation processes, and excessive amounts of aquatic vegetation.

DO criteria consist of 24-hr average and absolute minimum concentrations. In previous studies it was determined that Upper Oyster Creek's attainable aquatic-life use was intermediate (TWC, 1991a), and the intermediate aquatic life use is applicable per the present State of Texas Surface Water Quality Standards (TNRCC, 2000). The criteria for protection of intermediate aquatic life use are:

- 24-hr average DO concentration $\geq$ 4.0 mg/L
- 24-hr absolute minimum DO 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-hr average DO concentration $\geq$ 5.0 mg/L
- 24-hr absolute minimum DO concentration $\geq$ 4.0 mg/L

1.3 Report Purpose and Organization

The TCEQ contracted with the Texas Institute for Applied Environmental Research (TIAER) to conduct the appropriate studies to (1) acquire data and information necessary to identify pollutant sources and support modeling and assessment activities; (2) perform the assessment activities necessary to allocate the loadings of the constituent of concern; and (3) assist TCEQ in preparing a TMDL. The purpose of this report is to provide technical documentation for the dissolved oxygen TMDL of Upper Oyster Creek (Segment 1245). The report contains information on historical data; watershed properties; dissolved oxygen assessment monitoring to confirm the State of Texas 2002 Section 303(d) listing of impairment due to low dissolved oxygen concentrations; verification and application of a dissolved oxygen model; and development of the TMDL load allocation. TIAER was the technical lead entity for all studies and work provided in this report.

Because of the extensive number of tables and graphics that are part of this report, tables and figures are provided at the end of each section in order to facilitate continuity of the text portion of the report. It is recognized that this arrangement to provide continuity of text does make access to tables and figures more difficult, and the authors apologize for that inconvenience. At the end of each section tables are provided first followed by figures.

SECTION 1

FIGURES

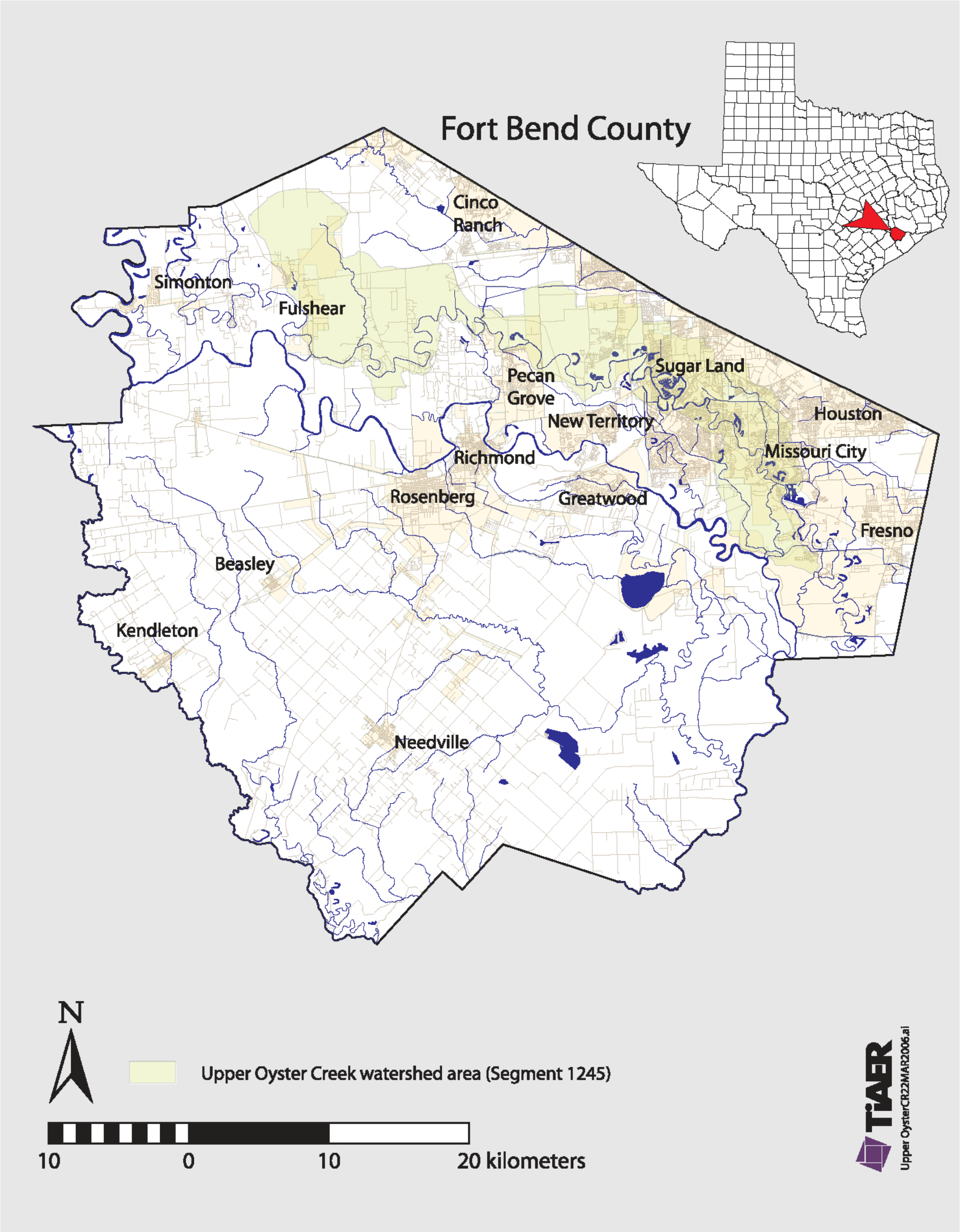

Figure 1-1 **Location of Segment 1245 (Upper Oyster Creek), Fort Bend County, Texas**

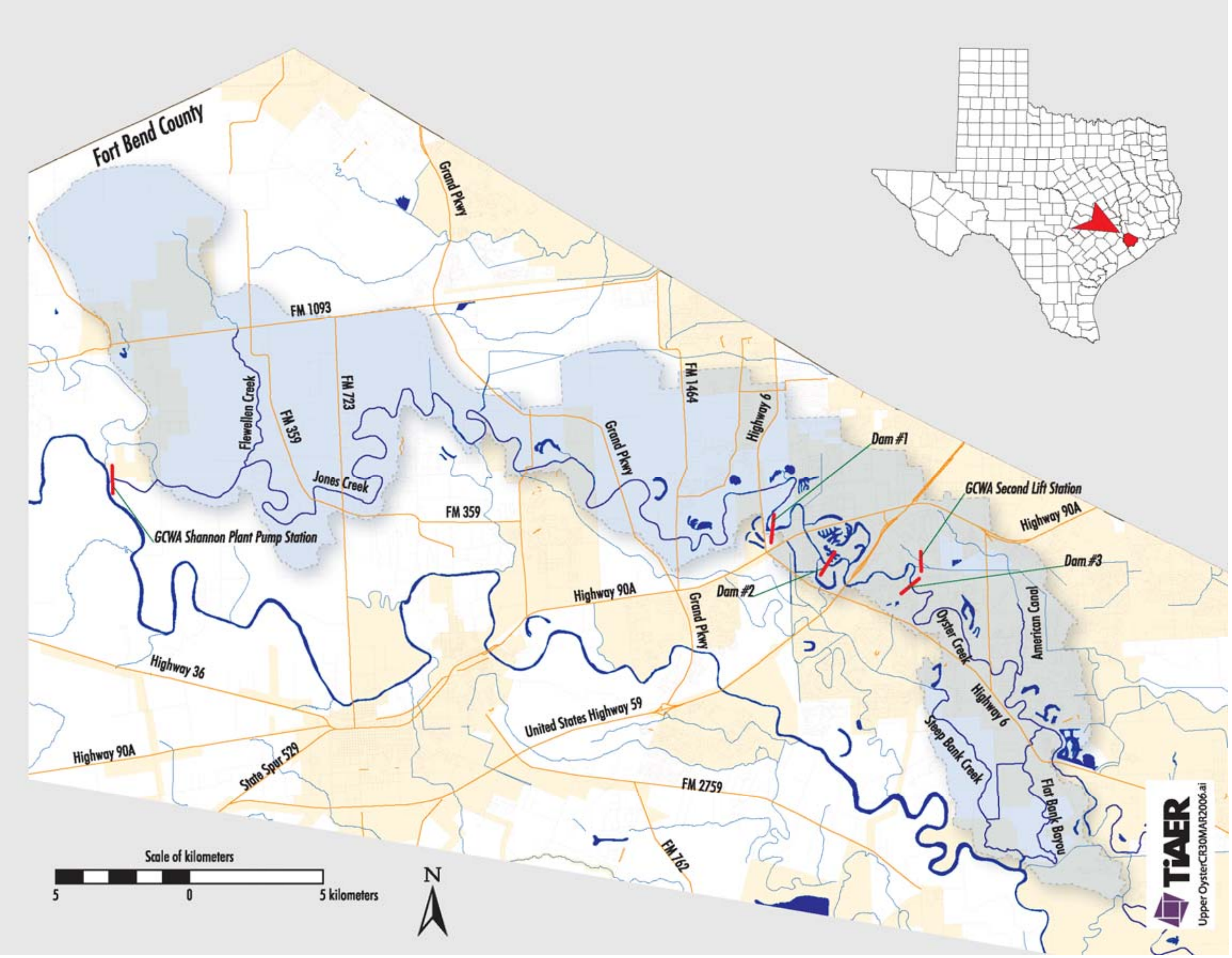

Figure 1-2 **Relevant geographical references in Upper Oyster Creek**

SECTION 2

WATERSHED PROPERTIES AND HYDROLOGY

2.1 Environmental Features

The Upper Oyster Creek watershed lies within a climatic region classified as subtropical humid, which is defined as having hot summers and dry winters. An average annual rainfall of 49.3 inches was measured at Sugar Land airport between 1970 and 2000 (NOAA, 2004). Over 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, undissected 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.

2.2 Land Use

The Upper Oyster Creek watershed covers approximately 107 square miles, approximately 12.5 %, of the area of Fort Bend County. Based on 1996-97 Landsat Thematic Mapper imagery identification performed by Baylor University much of the watershed is in pasture lands, though the residential and urban land uses comprised 24 % at that time (Table 2-1 and Figure 2-1; Baylor University 1997). Undoubtedly because of rapid population growth, an even greater percentage of the watershed is in residential and urban land use in 2007 than roughly 10 years ago.

2.3 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, 2000a). The population of Fort Bend County is estimated by the U.S. Census Bureau to have increased approximately 6 % per year since the 2000 census, so the current (2005) population may exceed 125,000.

Fort Bend County is expected to increase in population by approximately 78 % 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 % increase). Smaller increases are expected for manufacturing (17 %), mining (8 %), and steam electric (10 %) uses. Table 2-2 sets out 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 made in error and 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 % increase in the population of Sugar Land since 1990.

2.4 Sewered and Non-Sewered Areas

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 % 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 % 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.

2.5 Permitted Wastewater Discharges

Under the Texas Pollution Discharge Elimination System (TPDES), 17 facilities within Segment 1245 hold permits to discharge wastewater or have pending discharge permits as of June 2007 (Table 2-3, Figure 2-2). 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 2-3. 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. A number of facilities have become operational since 2004 and no monitored discharge information is provided for these facilities. Increasing discharge limits for some municipal permittees within the segment and adding new discharge permits in recent years indicate a steadily increasing wastewater loading 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 2-3, several facilities are designed such that effluent enters a polishing pond prior to final discharge. Based on TCEQ evaluations of the facilities with polishing ponds, the final effluent from each facility will be at background levels of five-day carbonaceous biochemical oxygen demand (1.3 mg/L) and ammonia nitrogen (0.050 mg/L).

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 (EPA, 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, though this facility has ceased operation and discharge since late in 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, and subsequent fecal readings indicated no long-term concerns. 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 wastewater treatment facilities (WWTFs) 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.

2.6 Watershed Hydrology

An important factor in assessing water quality of a water body such as Segment 1245 is the hydrology of the system. There are two distinct hydrologic reaches within the Upper Oyster Creek segment. 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 from the GCWA Shannon Pump Station on the Brazos River to Dam #3 within the City of Sugar Land.

2.6.1 Hydrology of Lower Reach

Hydrology of the reach below Dam #3 (the Lower Reach) is highly impacted by the presence of Dam #3 and the Second Lift Station. Very small amounts of seepage do occur through Dam #3, and there is partially controlled release of 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 releases from Dam #3. This reach, therefore, contains no retention structures, and is characterized by reduced flow composed of minor 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 via release from Dam #3. The reach below Dam #3, however, is also hydrologically modified, though not for conveyance of water supplies and impoundment of water, but rather for flood prevention. These modifications result in Oyster Creek being diverted into Flat Bank Creek and then into Steep Bank Creek via a diversion channel. These confluences and connections are not a result of natural stream conveyance and hydrologic conveyance patterns, but as stated previously, serve the utility of flood flow conveyance.

Another aspect of the hydrology of the Lower Reach that has water quality implications is the result of backwater influences from the Brazos River. During more elevated water stages on the Brazos River, its waters will effectively move into the Lower Reach and the degree of backwater into the reach is directly related to the height of the stage on the Brazos River. The occurrence of these events is not as rare as might be anticipated as indicated in Figure 2-3, which shows the water level duration curve for the Brazos River at Richmond, TX (USGS gage 08114000) for a recent 20-year period of record. TIAER staff has documented three such backwater occurrences with our relatively infrequent visits to the watershed. Two of these recent events provide points of reference for interpretation of Figure 2-3. On May 10, 2007 when the Brazos River at Richmond was at an elevation of approximately 34 ft (10.4 m), backwater, atypically turbid water, and very sluggish flow conditions were observed by TIAER staff beginning somewhat upstream of the point were Oyster Creek enters into Flat Bank Creek and increasing in the downstream direction from that point. On July 12, 2007 when the Brazos River at Richmond was at an elevation of approximately 43 ft (13 m), very extensive backwater conditions and very turbid water were observed through much of the Lower Reach and portions of Stafford Run. In the two photographs of Figure 2-4, the observed backwater conditions on July 12th are contrasted with normal conditions in Oyster Creek at Dulles Avenue, which is approximately 2.5 miles downstream of Dam #3 and 11 miles upstream of the mouth of Segment 1245 with the Brazos River. All these events have the potential to bring turbid water from the Brazos River into portions of the Lower Reach, and the larger events in both water level and duration can result in saturated bank conditions that result in appreciable bank sloughing and decimation of the periphytic and macrophytic communities through the system, as was observed by TIAER staff in the aftermath of the June/July 2004 backwater event.

2.6.2 Hydrology of Upper Reach

Hydrology of the Upper Reach above Dam #3 is highly variable and has been modified by seasonal pumping of water into the segment from 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. Canal System A is operated by the GCWA in tandem with Canal System B, located south of the Upper Oyster Creek watershed. To serve as a conveyance for the pumped water, Jones Creek and the portion of Oyster Creek above Dam #3 have been dredged to provide adequate capacity. The hydrologic modifications also include a diversion structure that allows the water pumped from the Brazos River into Jones Creek to be diverted into Oyster Creek, and the presence of three small dams or retention structures operated by the GCWA.

The discussion of these small dams and their operation is taken from Kolbe (1992) and personal observations by TIAER staff. Each retention structure is constructed of concrete with slots for horizontally placed wooden boards, which may be added or removed to control water level. 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. Dam #2 stores water for industrial use and forms Brooks and Cleveland Lakes. Dam #3 retains water for Alkire, Eldridge, and Horseshoe Lakes, and also serves to retain water for the GCWA Second Lift Station where water is pumped into the American Canal for transport to the Texas City area. The portion of the creek in the vicinity of these dams is appreciably wider than the more upstream portions of the Upper Reach, and within this report the portion of the creek around the dams will be referred to interchangeably as the impoundment region or lake-like region.

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 (Figure 2-5). 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 a hydrologic component to the pumping that is 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.

A lack of recent historical streamflow records prevented ready analysis of the relationship of pumped Brazos River water to direct runoff into the Upper Reach. This lack of hydrologic 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 daily hydrologic predictions from SWAT provide a means to investigate the relationship of pumped Brazos River water to direct surface runoff into the Upper Reach.

For purposes herein, SWAT predictions of surface runoff from precipitation were separated from the model predictions of streamflow that include Brazos River water entering the system at the Shannon Pump Station and wastewater treatment plant discharges. SWAT predicted daily surface runoff for the Upper Reach and the corresponding pumping record of the Shannon Pump Station for each day were compiled into a data file. Thus, each data record consisted of the date, surface runoff predicted by SWAT for the Upper Reach on that date, and the GCWA Shannon Pump Station recorded pumping rate for that same date. These data were then ranked by daily surface runoff from highest to lowest value, and a flow duration curve was developed and the corresponding Shannon Pump Station pumping rate was plotted on the flow duration curve (Figure 2-6). Interpretation of the relationship of surface runoff and Brazos River pumping is facilitated by dividing the flow duration curve into intervals of flow regime as provided in Cleland (2003): (1) 0 – 10 % (high flows); (2) 10 – 40 % (moist conditions); (3) 40 – 60 % (mid-range flows); (4) 60 – 90 % (dry conditions; and (5) 90 – 100 % (low flows). The median surface runoff and corresponding Brazos River pumping is provided for each of these five flow regimes in Table 2-4. While Figure 2-6 indicates some exceptions, the data largely indicate that when surface runoff is in the high flow regime, pumping of Brazos River water does not occur and that under moist conditions Brazos River water pumping does occur, but not at quite as high a rate as experienced under the three lower runoff flow regimes. To provide additional information on the water balance of the Upper Reach, the average discharge from all WWTFs in the reach for the period 1999-2004 are also included in Table 2-4 and on Figure 2-6.

In the future the hydrology of the Upper Reach will likely be impacted as Sugar Land, Missouri City, Fort Bend Water Control and Improvement District (WCID) No. 2, and the western portions of the City of Houston continue with plans to reduce their total reliance on ground water for public water supply and supplement demand with surface water from the Brazos River. In a now somewhat dated project for the GCWA and TWDB, a feasibility study by Montgomery Watson America, Inc. (2000) for a regional surface water treatment plant for Brazoria, Fort Bend, and west Harris counties indicated a two-fold need to supplement groundwater with surface water. First, groundwater pumpage was causing subsidence, which can greatly increase flooding, and second, large population growth in the area may exceed reliable groundwater supplies. Discussions by TIAER staff with both GCWA in 2001 and the cities of Sugar Land and Missouri City in 2007 indicated that facilities to supply surface water from the Brazos River are being considered, though the exact timeframe, size, and location of the facilities are unknown. The current plans for Missouri City involve surface water supply that does not use the Upper Reach for conveyance. Any plans for a facility or facilities to supply surface water from the Brazos River appear to have future hydrologic implications to the Upper Reach of Upper Oyster Creek. The exact location of the water treatment plant(s) would determine how much of the reach above Dam #3 would be directly impacted. Not only could the amount of additional flow in the Upper Reach of Segment 1245 be substantial, the historical seasonal component would be modified because of the water needs of municipalities are more constant than agricultural needs, which comprise a large portion of the pumping demand.

2.7 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 DO 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 2-7). A major tributary to the Lower Reach, Stafford Run, not only has macrophytes and periphyton, but occasionally notable concentrations of phytoplankton that are thought to originate from ponds on Stafford Run in Independence Park. The limited synoptic data available for the Lower Reach indicate that the phytoplankton levels found in Stafford Run persist, albeit at decreasing concentrations, below its confluence with Oyster Creek and further downstream through the segment. The phytoplankton pattern in the Lower Reach is discussed in more detail in Section 5 – Selection and Validation of the Dissolved Oxygen Model. The backwater flooding from the Brazos River can have a pronounced effect on the macrophyte and periphyton communities, especially if the event is of sufficient duration as observed following the June through early July 2004 event. It was observed by TIAER staff that this event seriously reduced attached plant communities for several weeks following this event, and this reduction in plant densities necessitated postponement of a planned intensive monitoring survey until August 9th. The implications of the decomposition of dead aquatic vegetation on DO have not been quantified, but some additional oxygen demand must be derived from the sudden dieback during and following extended backwater events.

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 2-8). Water hyacinth becomes more common toward the impoundment region upstream of each of the three dams. The Figure 2-8 photograph also shows the typical turbid, reddish brown color of the Upper Reach when influenced by Brazos River water. 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 (Chapman, 2007). Similar to the dieback of aquatic vegetation from backwater events in the Lower Reach, the oxygen demand resulting from vegetation control practices has not been quantified, but additional demand must be exerted following herbicide treatment and plant dieback.

2.8 Other Features and Characteristics

Another important feature of the Upper Reach is the result of the abrupt change in stream cross sectional area from relatively narrow stream conveyance above State Hwy 6 and the more downstream lake-like region. Within the lake-like region stream velocities are greatly reduced from the velocities experienced in other portions of the Upper Reach. Often the decrease in stream velocities results in an observable decrease in water turbidity, sedimentation, and the potential for less reaeration due to the reduced velocities and turbulence, which are observations made not only during TIAER's studies of the system, but also by others (BRA, 1997; Kolbe, 1992; TWC, 1991a).

Finally, the heavy suspended sediment load from the Brazos River results in sediment accumulation throughout much of the Upper Reach. As an example of the sediment loading from the Brazos River into the Upper Reach and the settling that occurs in the downstream direction, total suspended sediment (TSS) data from 16 synoptic dissolved oxygen assessment surveys discussed in Section 3 were considered. These data were collected during the Index Periods (March 15 – October 15) of 2003 through 2005. A summary of the TSS data in an upstream to downstream direction with road crossings referenced to locations on Figure 1-2 is as follows:

- Jones Creek at FM 723: TSS mean concentration = 109 mg/L
- Oyster Creek at FM 1464: TSS mean concentration = 62 mg/L
- Oyster Creek at State Hwy 6: TSS mean concentration = 66 mg/L
- Oyster Creek at US Hwy 90A TSS mean concentration = 28 mg/L
- Oyster Creek at US Hwy 59 TSS mean concentration = 12 mg/L

These data indicate a decrease in TSS concentration in the Upper Reach between FM 723 and FM 1464, relatively constant concentrations from FM 1464 downstream to State Highway 6, and then decreasing concentrations downstream through the remainder of the reach, which is predominately in the lake-like portion.

The typically highly turbid Brazos River water also impacts the occurrence of phytoplankton. As turbidity reduces due to particle settling along the Upper Reach, light limitations become less pronounced. Under typical GCWA pumping patterns, turbidity begins to significantly reduce in the impoundment region (TIAER data; BRA, 1997). Further, the settling of the TSS results in the need for periodic dredging to maintain flow conveyance capacity. The GCWA was conducting dredging upstream of FM723 during the time these data were being collected (Chapman, 2007). In BRA (1997) it is reported that when the Imperial Sugar facility was still operational along the banks of Oyster Creek immediately upstream of US Highway 90A that they found it necessary to conduct maintenance dredging.

SECTION 2

TABLES

Table 2-1 Land use in Upper Oyster Creek watershed in 1996-97 (Baylor, 1997)

Land use	**Area (%)**
Forest	7.2
Pasture	56.1
Range land	9.5
Residential	10.7
Urban (Mixed)	13.3
Water	3.2

Table 2-2 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).

Table 2-3 Permitted facilities, permit limits, and related information for Upper Oyster Creek watershed

TPDES Permit No.	Facility	Permit Expiration Date	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	Dec. 1, 2008	0.69	3.0	10.0	15.0	3.0	5.0	No
WQ0012833-002	City of Sugar Land	Dec. 1, 2008	4.61	10.0	10.0	15.0	3.0	5.0	No
WQ0012003-001	Fort Bend County MUD # 25	Dec. 1, 2010	0.42	1.6	5.0	5.0	1.0	5.0	No
WQ0012475-001	Fort Bend County MUD # 41	Oct. 1, 2008	0.25	0.86	10.0	15.0	3.0	5.0	No
WQ0013951-001	Fort Bend County MUD # 118	Dec. 1, 2008	0.064	1.2	5.0	12.0	1.5	5.0	No
WQ0014715-001	Fort Bend County MUD # 134	Pending[2]	—[3]	0.30	7.0	15.0	2.0	4.0	Yes
WQ0014408-001	Fort Bend County MUD # 142	Dec. 1, 2009	—[3]	1.2	5.0	5.0	2.0	6.0	Yes
WQ0014692-001	Fort Bend County MUD # 182	Dec. 1, 2008	—[3]	0.8	7.0	15.0	1.0	5.0	Yes
WQ0010086-001	Fort Bend County WCID # 2	Dec. 1, 2009	3.52	6.0	10.0	15.0	2.0	6.0	No
WQ003015-000	Hines Nurseries Inc.[4]	Dec. 1, 2008	—	0.0035	30.0	90.0	—	—	No
WQ0012937-001	Palmer Plantation MUD 001	Dec. 1, 2008	0.29	0.60	10.0	15.0	3.0	5.0	No
WQ0014758-001	Pederson 631, LP	Pending[2]	—	0.60	10.0	15.0	2.0	6.0	Yes
WQ0011046-001	Quail Valley UD	Dec. 1, 2008	1.77	4.0	10.0	15.0	4.0/3.0[6]	6.0/5.0[6]	No
WQ0014100-001	Sienna Plantation MUD # 1	Jul. 1, 2008	—[3]	0.902	10.0	15.0	2.0	6.0	No
WQ0014064-001	Stafford Mobile Home Park, Inc.	Dec. 1, 2008	—[3]	0.10	10.0	15.0	3.0	5.0	No
WQ0011475-001	TDCJ Jester Unit # 1 – WWTF	Dec. 1, 2008	0.27	0.315	10.0	15.0	3.0	5.0	No
WQ0014745-001	TMI, Inc.	Pending[2]	—[3]	0.50	10.0	15.0	3.0	6.0	Yes
TXL005010	Bono Brothers, Inc. [1]	Feb. 10, 2010	NA	NA	—	—	—	—	NA

TPDES Permit No.	Facility	Permit Expiration Date	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)
TXG920522[5]	TDCJ Jester (Swine CAFO) [1]	Jul. 20, 2009	NA	NA	—	—	—	—	NA
Total			11.884	31.9805					

Notes: [1] Permit does not contain a discharge provision

[2] Pending permit as of June 2006

[3] No monitored discharge information available for this facility when the TMDL was developed.

[4] 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

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

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

NA = Not applicable; MGD = million gallons per day

Table 2-4 Median surface runoff for Upper Reach and corresponding Shannon Pump Station pumping rates and average combined WWTF discharges (1993-2004)

	High Flows (median = 5 %)	Moist Conditions (median = 25 %)	Mid-Range Flows (median = 50 %)	Dry Conditions (median = 75 %)	Low Flows (median = 95 %)
Surface Runoff (cms)	16.39	1.17	0.08	0.00	0.00
Pumping Rate (cms)	0.00	2.59	2.96	2.96	3.02
WWTF Discharge (cms)	0.04	0.04	0.04	0.04	0.04

SECTION 2

FIGURES

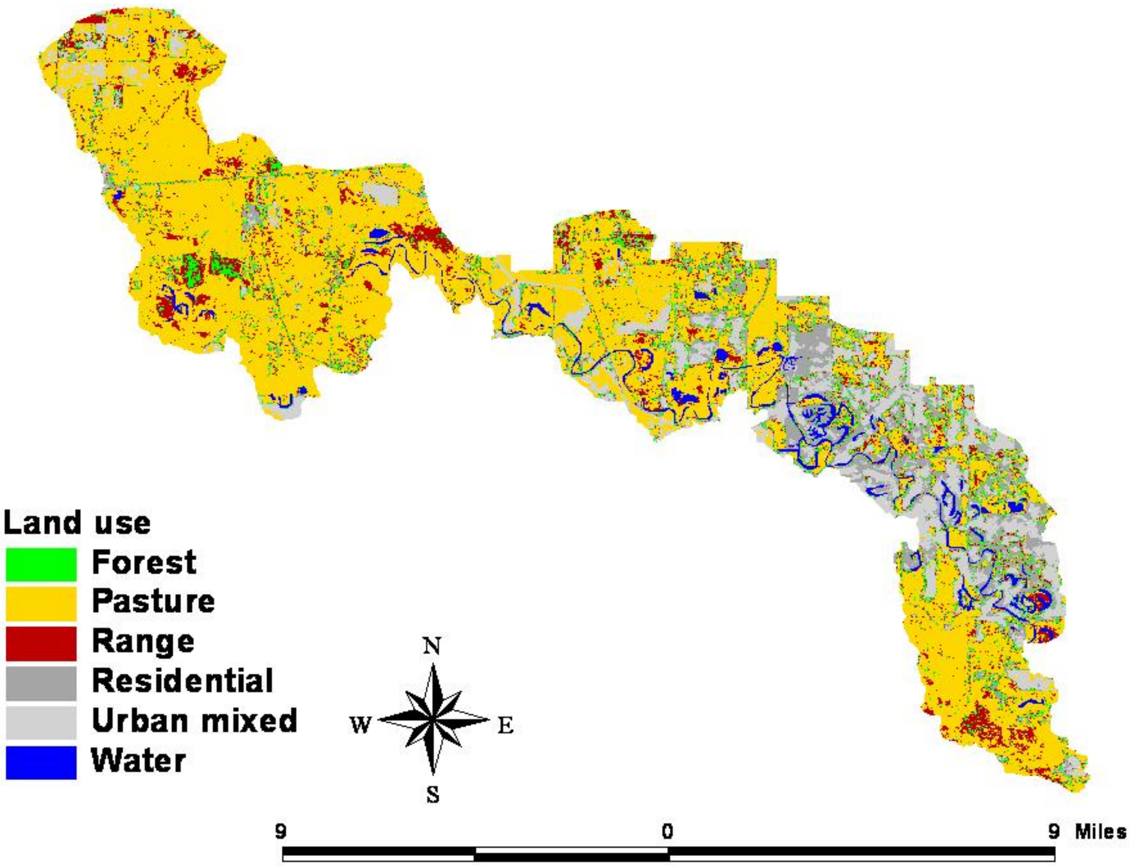

Figure 2-1 **Land use/land cover for Upper Oyster Creek watershed (Source: Baylor 1977)**

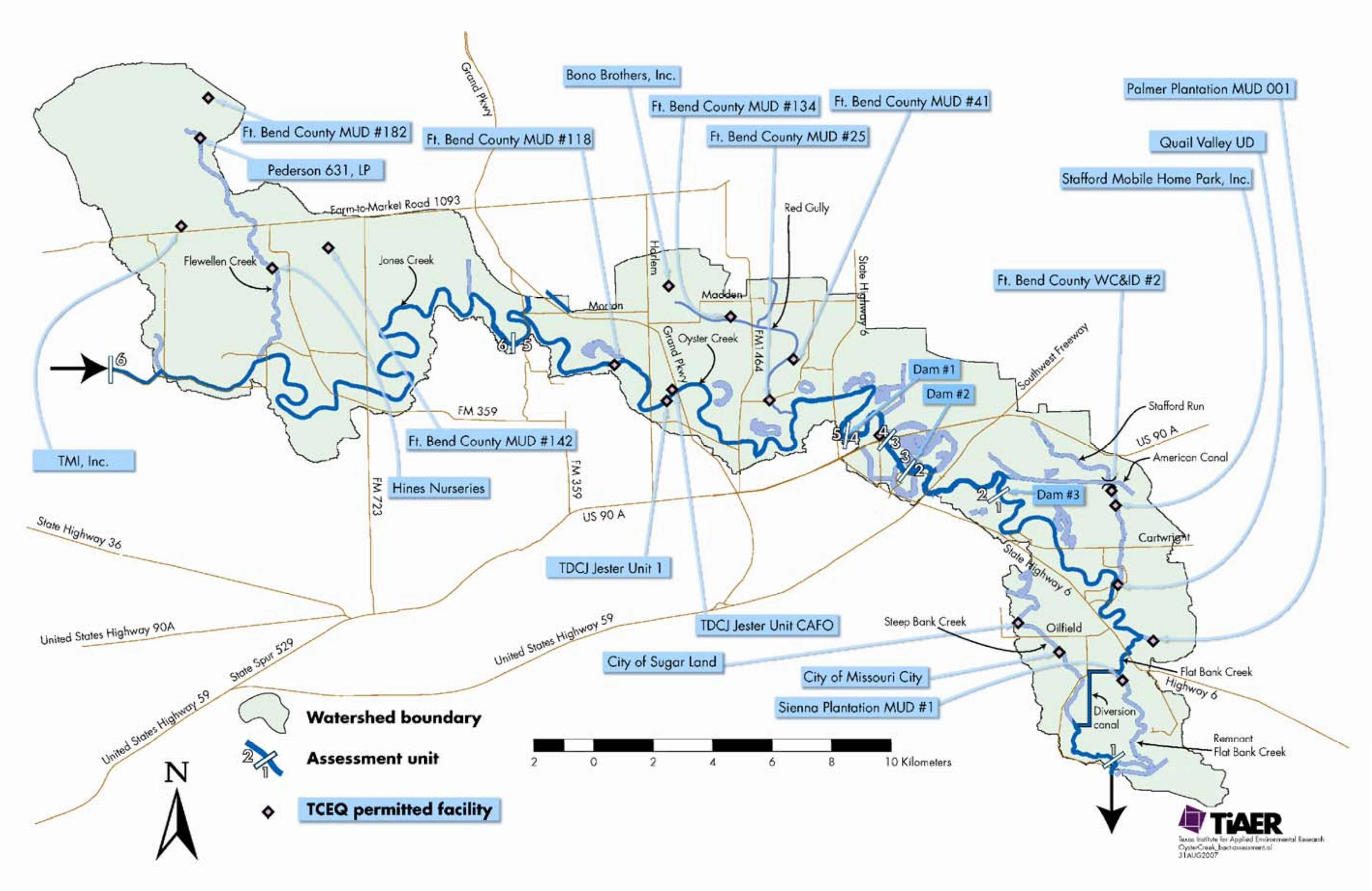

Figure 2-2 Upper Oyster Creek with locations of permitted facilities

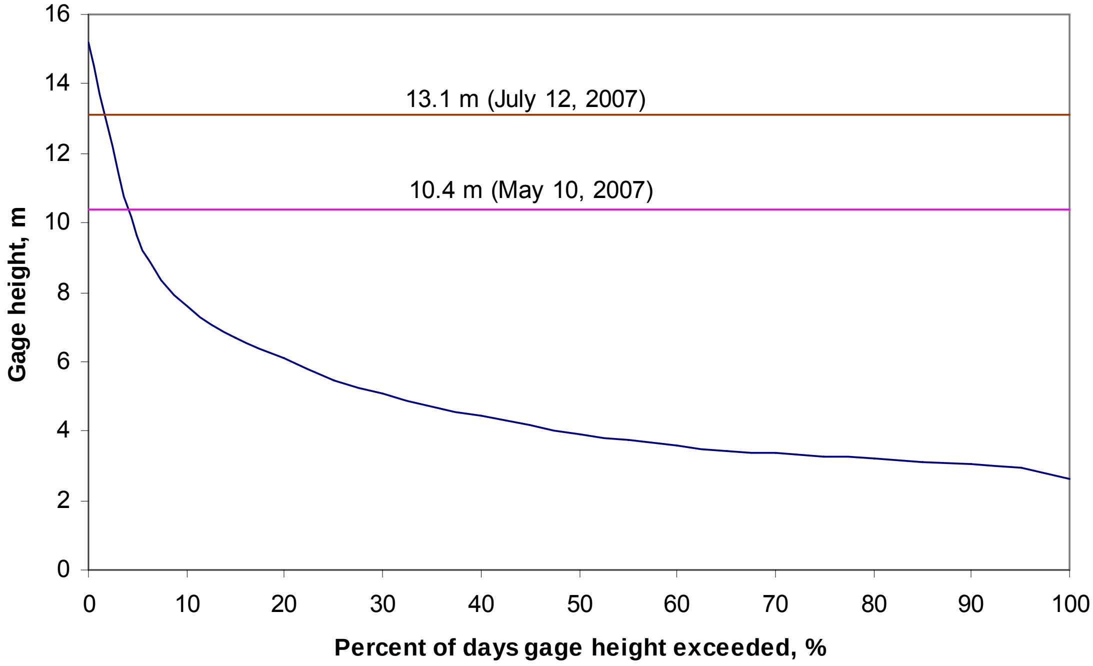

Figure 2-3 **Gage height frequency duration curve, USGS Station 08114000, Brazos River at Richmond, TX, July 24, 1977 – July 23, 2007**

Figure 2-4 **Photographs of Oyster Creek at Dulles Avenue a) normal conditions and b) during backwater event of July 2007**

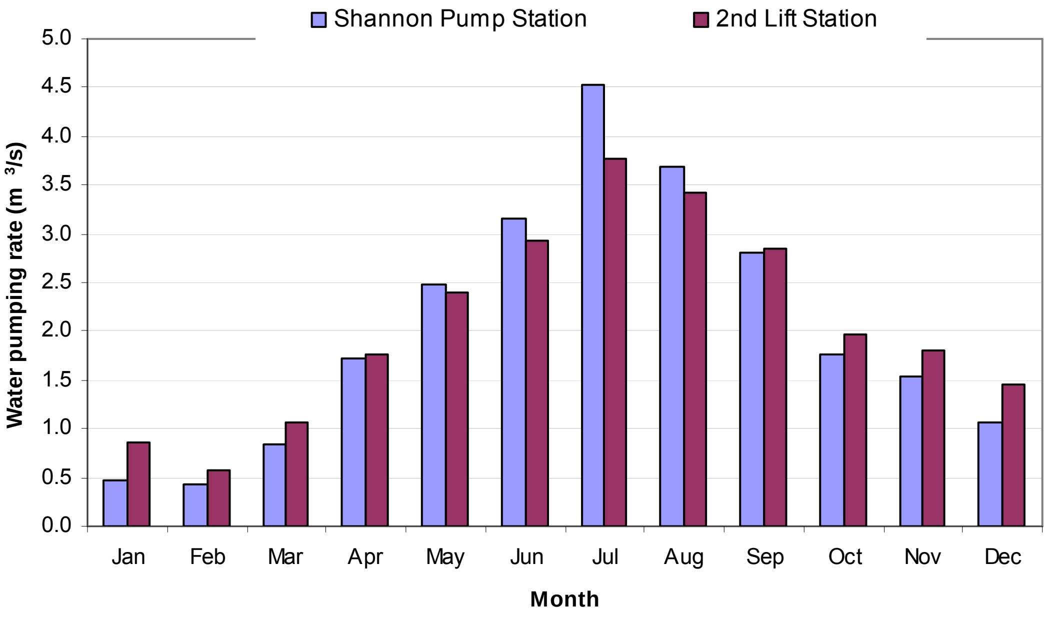

Figure 2-5 **GCWA Shannon Pump Station and 2nd lift station average-monthly pumping rates for 1993 – 2004. Source: GCWA monthly data provided to TIAER**

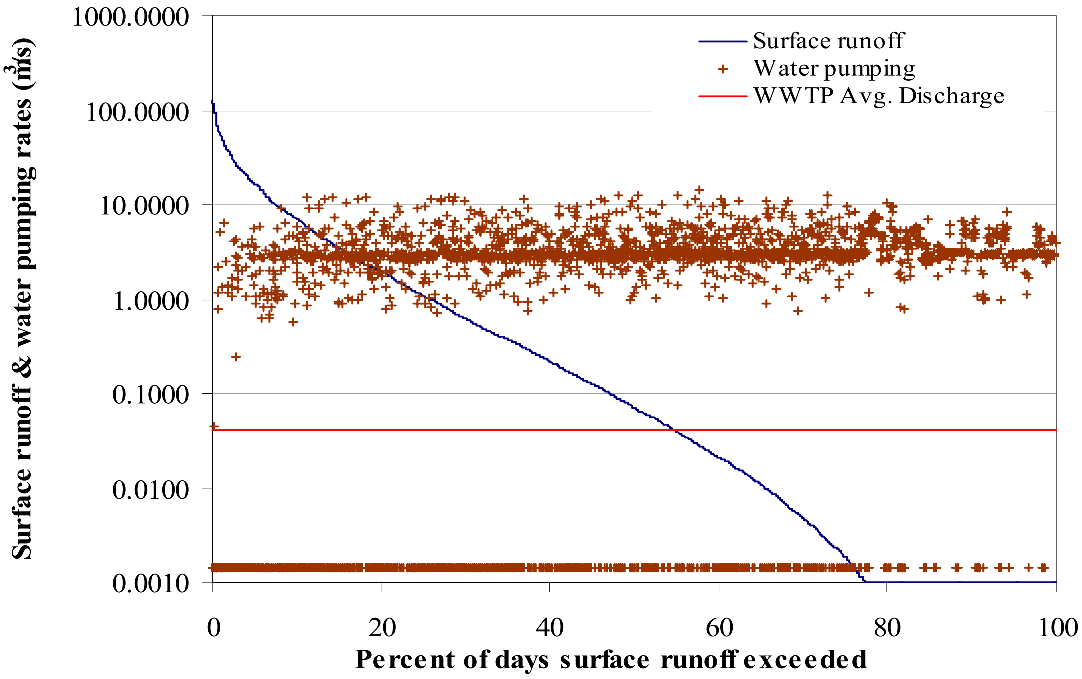

Figure 2-6 **Flow duration curve of SWAT predicted surface runoff into Upper Reach with daily pumping rates from Shannon Pump Station and average discharges of WWTFs superimposed. (Period simulated 1993-2004). [Note that the water pumping rates of 0.0014 cms (0.01 ac-ft/day) represents 0.0 cms to allow plotting on a logarithmic scale.]**

a) Lower reach in an area dominated by bottom algae

b) Lower reach in an area dominated by macrophytes

Figure 2-7 Photographs of Lower Reach of Upper Oyster Creek showing aquatic vegetation

Figure 2-8 Photograph of alligator weed on Jones Creek, July 2004

SECTION 3

ASSESSMENT OF AQUATIC LIFE USE SUPPORT

3.1 Background

The 2002 Texas 303(d) list included Segment 1245 under Category 5c ─ additional data and information will be collected before a TMDL is scheduled. To address the need for additional dissolved oxygen data, monitoring surveys were performed at eight stations along Upper Oyster Creek during the years of 2003 – 2005.

From winter 2003 through summer 2005, TIAER conducted 24-hr dissolved oxygen (DO) assessment surveys at selected stations on Upper Oyster Creek to determine whether or not present DO concentrations support the segment's aquatic life use.

This report section is based on Adams et al. (2007) wherein the original DO assessment results are provided.

3.2 Assessment Stations

From previous assessments, the Texas Commission on Environmental Quality (TCEQ) has divided Segment 1245 into six assessment units.[1] For the present DO assessment, each assessment unit was established with either one or two stations (Figure 3-1):

- Assessment unit 1: From lower end of segment to Dam #3, just upstream of Lexington Blvd. (stations 12074 and 12077)
- Assessment unit 2: From Dam #3, just upstream of Lexington Blvd. to the Brooks Lake outfall (station 12079)
- Assessment unit 3: From the Brooks Lake outfall to Hwy 90A (station 12082)
- Assessment unit 4: From Hwy 90A to Dam #1, located 1.5 miles upstream of Harmon St. (station 12083)
- Assessment unit 5: From Dam #1 to Oyster Creek/Jones Creek confluence (stations 12086 and 12087)
- Assessment unit 6: From Oyster Creek/Jones Creek confluence to upper end of segment (station 12090)

3.3 Methodology

The DO assessment for Upper Oyster Creek utilizes the methodology prescribed by the TCEQ, Office of Compliance and Enforcement, Monitoring Operations Division, Surface Water

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[1] The 2006 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.

Quality Monitoring Program in their publication *Guidance for Assessing Surface and Finished Drinking Water Quality, 2004*, August 15, 2003 (TCEQ, 2003).

All data used in the assessment were collected under a quality assurance project plan that ensures the data are of a known and appropriate quality (TIAER, 2002; TIAER, 2004; TIAER 2005). A description of the methodology and data requirements for application of the assessment is as follows.

3.3.1 Constraints on Sampling Events

A minimum of ten 24-hr measurement events within a two- to five-year period are required to assess the aquatic life use. Measurement interval for DO data should be no more than once every 15 minutes and no less than once per hour. For this assessment, data were collected at a 15-minute interval. From the data of each 24-hr event an average DO concentration and an absolute minimum DO concentration are obtained. A streamflow measurement should be obtained with each 24-hr event.

When there are less than 10 sample events, water quality data can not be assessed for impairments of aquatic life. However, with four to nine sets Tier 1 primary concerns can be ascertained.

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 about one month (or four weeks) must separate each 24-hr sampling event.

3.3.2 Assessment Criteria

Within Section 1.2 (Water Quality Standards), the supporting criteria for the segment designated intermediate aquatic life use have been previously presented. For completeness and ready access in interpreting the assessment, the criteria are repeated here. DO criteria consist of 24-hr average and absolute minimum concentrations. The criteria for protection of intermediate aquatic life use are:

- 24-hr average DO concentration $\geq$ 4.0 mg/L
- 24-hr absolute minimum DO 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-hr average DO concentration $\geq$ 5.0 mg/L
- 24-hr absolute minimum DO concentration $\geq$ 4.0 mg/L

3.3.3 Flow Conditions

Until relatively recently, in order for a sample event to be considered valid for assessment, the streamflow at the time of the 24-hr event must exceed the 7-day, 2-year low-flow (7Q2). Personal communications on February 3, 2006 with Ms. Jill Csekitz, TCEQ SWQM Team indicated the following modification to the TCEQ methodology effective with any new assessments. The sample event is excluded from assessment if the streamflow is less than the 7Q2 and if the sample event includes an exceedance of the relevant water quality criterion, which is the same as previously. However, the event is included in the assessment even if the streamflow is less than the 7Q2 as long as the event does not include an exceedance, which is the modification in methodology.

Streams located in the eastern and southern regions of Texas, including Upper Oyster Creek, have 7Q2 flow (or critical low flow) defined by the larger of the actual 7Q2 flow determined from statistical analysis of streamflow data and the value obtained from Table 5 of the Texas State Water Quality Standards (TNRCC, 2000) as based on streambed slope.

The hydrology of Upper Oyster Creek is a response to rainfall-runoff from a combination of an urban and rural land use watershed, likely shallow groundwater interactions, and several anthropogenic modifications, which include pumping, damming, and municipal wastewater treatment plant (WWTP) effluents. Assessment unit 1, itself, contains two reasonably distinct hydrologic sections. An upper portion, which is defined from immediately above the confluence with Stafford Run upstream to Dam # 3, contains as a major modification the presence of the dam, which at low flow interrupts the normal hydrologic pathway except for minimal seepage. A lower portion, which is defined from the downstream end of the stream segment to the confluence with Stafford Run, contains as the major anthropogenic modification significant WWTP effluents.

The hydrology of Upper Oyster Creek reach in assessment units 2-6 is often dominated by the GCWA's use of this reach as a conveyance channel for water pumped via the Shannon Lift Station from the Brazos River into the headwaters of Upper Oyster Creek. Limited water delivery points occur along assessment units 2-6, and most of the water is pumped out of the system at the Second Lift Station into the American Canal for an ultimate destination in the Texas City area. Minimum flows occur in this reach when pumping is not occurring and several days have elapsed since rainfall runoff. With this combination of circumstances, the streamflow may approach that of the effluents from the point source dischargers. Measurement of such reduced flows, however, is extremely difficult, if not impossible, because of the pooled and impounded nature of much of assessment units 2-6, which results in very low velocities especially at low flows. Historically the occurrence of no pumping is most common in the winter when water demands are the least, though such occurrences may happen at any time of year when repairs are required by the GCWA.

Because of the southeast Texas location of Upper Oyster Creek and the slight slopes of its streambed, the slope-based (bedslope) definition of 7Q2 flow is applicable for this DO assessment. The Fort Bend County Drainage District (District) provided elevation and stream distance information for assessment units 1 and 6 that were used to determine bed slope (Jalowy, 2004 & 2005).

The District's information for assessment unit 1 begins 3,300 feet upstream of the Brazos River and ends at Dulles Avenue just downstream of Dam 3. That entire stretch of the channel (55,100 ft) was divided by the District into three separate design gradients. Their design gradients are as follows:

- From the beginning flowline elevation to Highway 6 the slope is 0.050 %. Therefore, the change in elevation is 0.5 m/km.
- The channel slope from Highway 6 to F.M. 1092 is 0.041 %, or 0.41 m/km.
- The channel slope from F.M. 1092 to Dulles Avenue is 0.032 %, or 0.32 m/km.

The full gradient length is 55,000 ft with an elevation change of 23.65 ft, which gives an overall slope of 0.42 m/km. For a DO criterion of 4.0 mg/L, the critical low flow based on the overall bedslope is 0.5 cfs. In the upper portion of the assessment unit by station 12077, the slighter slope of 0.3 m/km allows a critical low flow of 0.8 cfs.

For assessment units 2 –5, ending streambed elevations of the surveys performed for the District in assessment units 1 and 6 were used to determine the change in elevation from Dulles Avenue near the upstream end of assessment unit 1 to the junction of Jones and Oyster Creeks very near the downstream end of assessment unit 6. Channel distance for the combined length of assessment units 2–5 was determined from information provided in the TCEQ Upper Oyster Creek waste load evaluation report (TWC, 1991b). Based on this information, an average bedslope for assessment units 2 – 5 was calculated to be 0.15 m/km. For a DO criterion of 4.0 mg/L, the bedslope adjusted critical low flow is 1.3 cfs for these assessment units.

District-provided survey information for the portion of Jones Creek that constitutes assessment unit 6 of Segment 1245 was used to calculate an average bedslope of 0.009 % or 0.09 m/km. For a DO criterion of 4.0 mg/L, the bedslope adjusted critical low flow is 3.0 cfs for assessment unit 6.

TCEQ determination of 7Q2 flow for Upper Oyster Creek based strictly on hydrologic data (personal communication, Ms. Kenda Smith, TCEQ, November 2004) and bedslope adjusted critical low flow determined from District information are found in Table 3-1. For assessment purposes the critical low flow is the larger of the 7Q2 and bedslope adjusted flows.

3.3.4 Assessment of Exceedances

Whether the water body supports the DO criteria is based on the number of exceedances that occur in the data set (with DO criteria an "exceedance" actually refers to DO concentrations that fall *below* the established criteria). If either one or both of the 24-hr average and 24-hr minimum DO concentrations for that sample event are less than the relevant criterion, the event is counted as an exceedance. Based on the number of samples in exceedance the water body is considered *fully supporting*, *partially supporting,* or *not supporting*. In addition, even if the water body is *fully supporting* a determination can be made as to whether or not there are Tier 2 *concerns* or *no concerns* about impairment of the water body.

Until recent years, TCEQ has considered that the water body is *fully supporting* if 10 % or less of the sample sets are in exceedance, *partially supporting* if greater than 10 and 25 % or less of the sample sets are in exceedance, and *not supporting* if greater than 25 % of the sample sets are in exceedance. However, TCEQ has recognized that the chance of falsely classifying a station or assessment unit as impaired (Type I error) is relatively high for the historically utilized method. Basing decisions on the simple 10 % exceedance calculation results in a 26.4 to 61.2 % chance of falsely classifying a water body as impaired. Therefore, TCEQ developed new exceedance criteria, using the binomial method, that maintain a Type I error probability below 20 % for all standards and criteria.

The three years of DO surveys resulted in a sample size of 14 to 16 for the stations in this assessment. Based on the binomial approach in TCEQ (2003), the range of sample sizes results in two groupings (14 and 15 samples, and 16 and 17 samples) that determine the number of exceedances defining level of support.

For a sample size of 14 and 15, the level of support is defined as follows:

- If there are two or less sample sets in exceedance, the water body is considered as *fully supporting*. If there are two exceedances, then there is a Tier 2 *primary concern* about the impairment of the water body. If there are one or less exceedances then there are *no concerns* about water body impairment.
- If there are three, four, or five sample sets in exceedance, the water body is considered as *partially supporting*, and
- If there were six or more sample sets in exceedance, the water body is considered *not supporting.*

For a sample size of 16 and 17, the level of support is defined as follows:

- If there are three or less sample sets in exceedance, the water body is considered as *fully supporting*. For a sample size of 16, if there are two or three exceedances, then there is a Tier 2 *primary concern* about the impairment of the water body and if there are one or less exceedances then there are *no concerns* about water body impairment. For a sample size of 17, if there are three exceedances, then there is a Tier 2 *primary concern* about the impairment of the water body and if there are two or less exceedances then there are *no concerns* about water body impairment.
- If there are four or five sample sets in exceedance, the water body is considered as *partially supporting*, and
- If there were six or more sample sets in exceedance, the water body is considered *not supporting.*

From a strict interpretation perspective, however, both the U.S. Environmental Protection Agency and TCEQ do not make a distinction between *partially supporting* and *not supporting*—both are considered as *not supporting*, and for the TCEQ year 2006 assessment, the distinction of *partially supporting* and *not supporting* will no longer exist (Roques, 2004). Therefore the intermediate distinction regarding level of support will not be used in this assessment, which results in the following for the two sample size groupings of 14 and 15, and 16 and 17:

For a sample size of 14 and 15, the level of support is defined as follows:

- If there are two or less sample sets in exceedance, the water body is considered as *fully supporting*. If there are two exceedances, then there is a Tier 2 *primary concern* about the impairment of the water body. If there are one or less exceedances then there are *no concerns* about water body impairment.
- If there are three or more sample sets in exceedance, the water body is considered as *not supporting*.

For a sample size of 16 and 17, the level of support is defined as follows:

- If there are three or less sample sets in exceedance, the water body is considered as *fully supporting*. For a sample size of 16, if there are two or three exceedances, then there is a Tier 2 *primary concern* about the impairment of the water body and if there are one or less exceedances then there are *no concerns* about water body impairment. For a sample size of 17, if there are three exceedances, then there is a Tier 2 *primary concern* about the impairment of the water body and if there are two or less exceedances then there are *no concerns* about water body impairment.
- If there are four or more sample sets in exceedance, the water body is considered as *not supporting.*

3.4 DO Assessment

3.4.1 Water Temperature and Streamflow During Events

Sampling stations, beginning date of sampling, streamflow and 24-hr average water temperature for each sampling event are listed in Table 3-2. In addition, the 24-hr average temperatures for surveys occurring during the first six months of the year are provided in Table 3-2. Therefore, Table 3-2 can also be used to determine which events should be used for DO assessment based on streamflow at or above the 7Q2 values in Table 3-1, presence or absence of required streamflow measurement for the event, and whether the temperature-based DO criteria to protect fish spawning applies for the event.

It can be seen from the distribution of dates in Table 3-2 that the minimum frequency and duration of sampling requirements are met by the data set. The events span two seasons (Spring and Summer), and include a 3-year period from May of 2003 to September of 2005. No more than two thirds of the samples are from the same year. All of the sampling dates occurred within the Index Period (March 15 – October 15) and one half or more of the sample events in each year occurred during the Critical Period (3 of 5 in year 2003, 3 of 6 in year 2004, and 3 of 5 in year 2005).

Gray shaded values in Table 3-2 are temperatures that fall within the range of 17.2 °C to 22.8 °C during the first six months of the year. Sampling events with temperatures shaded gray were evaluated against the higher DO criteria of 5.0 mg/L average 24-hr DO and 4.0 mg/L absolute minimum 24-hr DO.

All measured flows were above the 7Q2 flows or the bedslope adjusted critical low flows (Table 3-1), so all the sample sets with measured flows could be used for the DO assessment.[2] There were two dates (5/19/2003 and 8/11/2003) at station 12077 during which flow was too low to be measured. Due to lack of flow data for these dates, these sampling events cannot be used for the DO assessment. On 7/1/2004 there was backwater from a flooding event on the Brazos River that prevented flow measurements from being taken at both stations (12077 and 12074) in assessment unit 1 of Upper Oyster Creek. Starting 9/29/2004 a 24-hr DO event was conducted only at stations 12074, 12077, and 12090 to replace the event missed at 12074 and 12077 due to backwater conditions and the missing July 2003 event data from failed instrumentation at station 12090. Because pumping had stopped from both the Shannon and the Second Lift Stations prior to and during the September 2005 monitoring survey, flow was not attainable at any station in assessment units 2-6. Therefore, data from these stations were not included in this assessment.

Prior to 2005, flow could not be measured at stations 12083 and 12079, because these stations are located in reservoir-like impoundment areas between small dams where extremely low velocities do not allow accurate measurement of flow. Based on contiguous streamflow and proximity of stations 12083 and 12079 to station 12082, where flow could be measured (see Figure 3-1), it was assumed that the flow at station 12082 reasonably represented the flow at the other two stations. All streamflows at station 12082 were well above the critical low flows in Table 1. For the 2005 monitoring period, acoustic Doppler technology allowed flow measurements to be made at these low velocity stations. As shown in Table 2, only one event on 6/8/2005 at station 12083 did not yield a flow measurement. However, because a flow measurement was obtained at station 12082 during the same monitoring period, this event was included in the assessment. For all events and stations where flow was measurable, streamflows were above critical low flow, which allows all such data to be used in this assessment.

3.4.2 Assessment Results

Table 3-3 shows the 24-hr average and absolute minimum DO concentrations for all sampling dates and stations. Based on the sample size and the number of exceedances, the aquatic life use assessment is provided in the last row in Table 3-3. The DO concentrations in red font do not meet the DO criteria. The values shaded in gray are samples that are subject to the higher DO criteria based on average water temperature and time of year. It can be seen that all

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[2] Station 12077 presented a challenge regarding measurement of low streamflows, because the entire stream channel along that reach was mildly pooled, which prohibited measurement at lower flows. Beginning September 2003, station 18211(location of a small riffle) was established about 1 km downstream from station 12077 as an alternative location for streamflow measurement when flow could not be measured at station 12077. Twenty-four hr DO assessment, however, could not be moved to station 18211. Unacceptable exposure of instrumentation to vandalism at this station would occur, because its location was adjacent to a heavily trafficked walking and jogging trail.

events during the period of higher restrictions meet the higher criteria. The values that are shaded in yellow in Table 3-3 are samples that should not be used in the assessment due to absence of streamflow data.

All stations, except 12087 and 12079, were assessed as *not supporting* the intermediate aquatic life use. Station 12087 was found to be in *full support* of the intermediate aquatic life use with *no concerns* about impairment. Station 12079 was determined to be in *full support* of the intermediate aquatic life use with *primary concerns* about impairment.

Figures 3-2 ─ 3-9 graphically show the pattern of DO at each station. The blue and red lines represent the 24-hr DO average and absolute minimum limitation respectively. Values that are in exceedance of the criteria are circled. All sampling data are shown on the figures regardless of whether or not the data point was used in the DO assessment due to flow limitations.

3.5 Findings and Discussions

In general, the assessment found that the Upper Oyster Creek system is *not supporting* of the intermediate aquatic life use; however, there are some areas of exception. DO concentrations were particularly low during the second year, especially at stations 12082, 12083 and 12086 where both 24-hr average and absolute minimum DO concentrations were frequently in exceedance (Table 3-3). A summary of assessment findings regarding support of the intermediate aquatic life use is as follows:

- Assessment unit 1, lower portion, station 12074: *not supporting*
- Assessment unit 1, upper portion, station 12077: *not supporting*
- Assessment unit 1, combined stations: *not supporting*
- Assessment unit 2, station 12079: *fully supporting,* Tier 2 primary concern
- Assessment unit 3, station 12082: *not supporting*
- Assessment unit 4, station 12083: *not supporting*
- Assessment unit 5, station 12086: *not supporting*
- Assessment unit 5, station 12087: *fully supporting*, no Tier 2 primary concern
- Assessment unit 5, combined stations: *fully supporting*, Tier 2 primary concern
- Assessment unit 6, station 12090: *not supporting*

The fact that most exceedances in assessment unit 1 (both stations 12075 and 12077) are caused by DO concentrations below the minimum criterion while the average DO concentrations are acceptable (Table 3-3) indicates a system influenced by aquatic plant growth. During daylight hours a large increase in DO occurs as oxygen is released into the water by the photosynthetic process. At night, however, when photosynthesis is not occurring, respiration of the large aquatic plant population depletes much of the DO. Therefore, there are large daily swings in DO concentration resulting in high 24-hr average DOs, but low 24-hr absolute minimum DO concentrations.

Diel variations in DO concentrations are not nearly as pronounced in assessment units 2-6 as in assessment unit 1. In these other assessment units, exceedances often included both average and minimum DO concentrations from the same event.

Four supplementary DO assessment events were conducted during the winter (February 2003, December 2003, January 2004, and February 2004). No DO exceedances occurred with any of these events. Historical data from the 1980s and 1990s indicated occurrences of low DO concentrations within assessment units 2-4 during the winter when Gulf Coast Water Authority pumping was often lowest. Past winter DO excursions occurred when significantly greater amounts of point source effluents were present in the area of assessment units 2-4. While these recent winter surveys portend that present condition in Segment 1245 are not conducive to low winter DO concentrations, the data are inadequate to definitively reach that conclusion.

As indicated in Table 3-3 and Figures 3-2 ─3-9, the data from the 24-hour DO assessment surveys for the Index Period of 2003 showed pronounced differences in the number of criteria exceedances at stations 12086, 12083, and 12082 when compared to the data for the Index Period of 2004. Also, within some assessment units and during some surveys, the measured exceedances were only 0.1 to 0.2 mg/L below the criteria. Some steering committee members at their December 9, 2004 public meeting noted the small magnitudes of some exceedances and that ignoring these small exceedances would result in more assessment units supporting the segment's aquatic life use.

Regarding observation of some stakeholders that the measured exceedances for some surveys were only slightly (0.1 to 0.2 mg/L) below the criteria, review of Table 3-3 also indicates a roughly equal number of non-exceedances that are at or only slightly above the criteria. While it is both unfortunate that the measured values occasionally were very near the criteria and acknowledged that these slight differences are within the instrumentation accuracy, the roughly equal number of slight exceedances and slight non-exceedances must be presumed to offset one another in lieu of any contrary information. That is while some of the slight exceedances might actually not have been exceedances, some of the slight non-exceedances might actually have been exceedances.

SECTION 3

TABLES

Table 3-1 Seven-day, two-year low flow (7Q2) assessment showing TCEQ determined 7Q2 and bedslope adjusted critical low flow from Table 5 of TNRCC (2000). For each station the critical low flow used in the assessment is indicated by yellow shading.

Station Id	TCEQ Determined 7Q2 Flow (cfs)	Bedslope Adjusted Critical Low Flow (cfs)
12074	6.77	0.5
12077	0.1	0.8
12079	0.86	1.3
12082	0.73[a]	1.3
12083	0.86	1.3
12086	0.86	1.3
12087	0.38	1.3
12090	0.1	3.0

a. Based on Gulf Coast Water Authority information, it is estimated that 15 % of the flow at station 12083 is diverted through Brooks Lake, thus effectively bypassing station 12082, and that flow reenters Oyster Creek before station 12079.

Table 3-2 Sample stations, dates of sampling, and the flow rate at each station for the 24-hr DO assessment (NA – not applicable, NM – not measured, MD – missing data; gray shaded temperatures indicate that DO criteria to protect fish spawning pertain because of time of year and water temperature.)

Beginning Date of 24-hr Event	Stations (assessment units)															
	12090 (6)		12087 (5)		12086 (5)		12083 (4)		12082 (3)		12079 (2)		12077 (1)		12074 (1)	
	Flow	Temp	Flow	Temp	Flow	Temp	Flow	Temp	Flow	Temp	Flow	Temp	Flow	Temp	Flow	Temp
	cfs	°C	cfs	°C	cfs	°C	cfs	°C	cfs	°C	cfs	°C	cfs	°C	cfs	°C
5/19/2003	214	30.0	111	30.2	189	29.5	NM	30.7	122	30.6	NM	30.2	NM	28.1	14.7	28.9
6/16/2003	114	28.1	113	28.6	104	29.4	NM	28.7	83.0	29.2	NM	29.4	53.4	28.9	51.8	27.5
7/14/2003	MD	NA	42.1	NA	144	NA	NM	NA	87.9	NA	NM	NA	66.0	NA	162	NA
8/11/2003	85.2	NA	97.1	NA	89.8	NA	NM	NA	77.7	NA	NM	NA	NM	NA	30.0	NA
9/9/2003	114	NA	109	NA	103	NA	NM	NA	72.9	NA	NM	NA	3.2	NA	22.8	NA
3/23/2004	126	20.4	110	20.6	105	20.6	NM	20.8	57.8	20.9	NM	21.3	5.8	20.5	25.3	21.4
4/20/2004	124	22.5	112	23.3	109	23.2	NM	23.8	61.7	24.0	NM	23.5	2.6	23.3	13.9	24.2
5/25/2004	128	27.8	79.1	28.3	68.8	28.4	NM	29.0	59.8	29.0	NM	28.8	7.6	28.3	24.3	27.5
7/1/2004	31.9	NA	94.1	NA	189	NA	NM	NA	124	NA	NM	NA	NM[a]	NA	NM[a]	NA
8/2/2004	141	NA	66.9	NA	91.1	NA	NM	NA	178	NA	NM	NA	51.2	NA	58.3	NA
8/30/2004	121	NA	86.2	NA	90.4	NA	NM	NA	77.8	NA	NM	NA	8.9	NA	51.5	NA
9/29/2004	118	NA	NM	NA	NM	NA	NM	NA	NM	NA	NM	NA	2.0	NA	12.7	NA
5/3/2005	117	22.8	115	22.7	138	23.3	126	23.2	88.7	23.2	127	23.1	2.5	24.2	12.0	23.6
6/8/2005	126	30.5	113	30.8	113	30.7	NM	31.1	45.5	30.6	115	31.0	3.0	31.0	14.9	29.8
7/13/2005	112	NA	83.0	NA	104	NA	108	NA	48.9	NA	94.1	NA	2.2	NA	11.4	NA
8/17/2005	125	NA	133	NA	140	NA	88.0	NA	55.8	NA	104	NA	4.1	NA	23.0	NA
9/20/2005	NM[b]	NA	NM[b]	NA	NM[b]	NA	NM[b]	NA	NM[b]	NA	NM[b]	NA	3.8	NA	10.0	NA

[a] Not measured due to backwater from the Brazos River flooding.

[b] Not measured, water velocities too low due to no pumping at the Shannon Lift and Second Lift Stations prior to and during event.

Table 3-3 24-hr average and absolute minimum DO concentrations for all sampling dates and stations, the number of sample sets that exceed the DO criteria, and the use attainment assessment based on the binomial method (MD – Missing Data, NM – Not Measured, FS – Fully Supporting, NS – Not Supporting, nc – no concerns, pc – primary concerns, T2 – Tier 2; red font identifies values in exceedance; yellow shading indicates DO values that can not be used due to absence of flow measurements and occurrence of a DO exceedance; blue shading indicates an absence of flow measurements, but DO values can be used as no exceedance occurred; gray shading indicates values subject to the higher DO criteria)

Beginning Date of 24-hr DO event	Stations (assessment units)															
	12090 (6)		12087 (5)		12086 (5)		12083 (4)		12082 (3)		12079 (2)		12077 (1)		12074 (1)	
	Ave	Min	Ave	Min	Ave	Min	Ave	Min	Ave	Min	Ave	Min	Ave	Min	Ave	Min
	mg/L	Mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5/19/2003	**3.4**	**2.0**	5.7	4.9	6.6	5.2	5.9	4.8	6.5	5.4	7.2	6.0	7.0	0.4	6.6	4.1
6/16/2003	**3.9**	3.0	4.6	4.2	5.0	4.7	4.1	3.4	4.4	3.4	4.7	3.8	6.2	4.0	4.3	**2.9**
7/14/2003	MD	MD	6.2	5.9	5.4	4.7	5.8	4.8	6.1	3.9	6.2	4.9	6.8	**2.9**	5.0	3.8
8/11/2003	5.0	4.5	4.6	4.1	4.2	4.0	**3.5**	**2.9**	**3.6**	**2.5**	4.2	3.4	6.9	2.3	4.4	**2.8**
9/9/2003	5.6	5.3	5.8	5.4	5.7	5.4	4.5	4.3	4.4	3.5	5.2	3.6	7.6	**2.2**	4.1	**2.5**
3/23/2004	7.6	7.4	7.5	7.3	7.0	6.9	6.4	6.2	6.4	5.9	5.6	5.3	9.7	4.1	7.1	6.1
4/20/2004	6.8	6.6	6.7	6.5	6.4	6.3	5.8	5.5	5.6	5.3	6.0	5.7	8.3	**1.9**	6.7	5.3
5/25/2004	4.9	4.6	5.0	4.6	4.5	4.3	4.8	4.2	4.8	4.4	5.4	4.7	8.3	**2.5**	4.9	3.4
7/1/2004	**3.2**	**2.8**	**3.0**	**2.7**	**2.5**	**2.4**	**1.8**	**1.2**	**2.4**	**1.9**	**3.2**	**2.4**	4.1	3.3	4.4	3.5
8/2/2004	4.6	**2.8**	4.6	3.9	**3.9**	3.6	**2.7**	**2.1**	**3.5**	**2.1**	4.7	3.2	5.0	3.4	**3.6**	**1.7**
8/30/2004	5.4	5.2	4.8	4.3	**3.5**	**2.8**	**1.8**	**1.4**	**2.8**	**2.0**	4.5	3.4	7.4	3.5	5.6	3.8
9/29/2004	6.3	6.0	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	9.0	**1.4**	6.9	5.3
5/03/2005	7.9	6.9	7.5	7.0	7.4	7.2	6.6	5.4	6.7	5.9	7.5	6.9	7.8	**2.0**	9.2	7.0
6/08/2005	5.0	4.9	4.8	4.1	4.4	4.2	4.2	**2.4**	5.9	3.9	6.3	3.4	7.1	**1.2**	6.3	4.2
7/13/2005	**3.4**	**1.3**	5.0	3.4	5.2	4.6	4.7	3.4	5.8	3.9	4.7	**2.9**	5.4	**0.9**	4.8	3.3
8/17/2005	4.6	4.2	4.2	4.0	**3.9**	3.7	**3.3**	3.0	**3.1**	**1.8**	4.7	**2.9**	8.2	**1.3**	4.0	3.0
9/20/2005	3.4	1.7	8.6	6.8	5.0	3.1	7.1	3.0	7.3	4.8	5.4	4.1	7.8	**0.6**	**3.3**	**1.8**
Exceedance	5/15		1/16		4/16		6/16		5/16		3/16		10/15		5/17	
Assessment	NS		FS (nc)		NS		NS		NS		FS (pc)		NS		NS	

SECTION 3

FIGURES

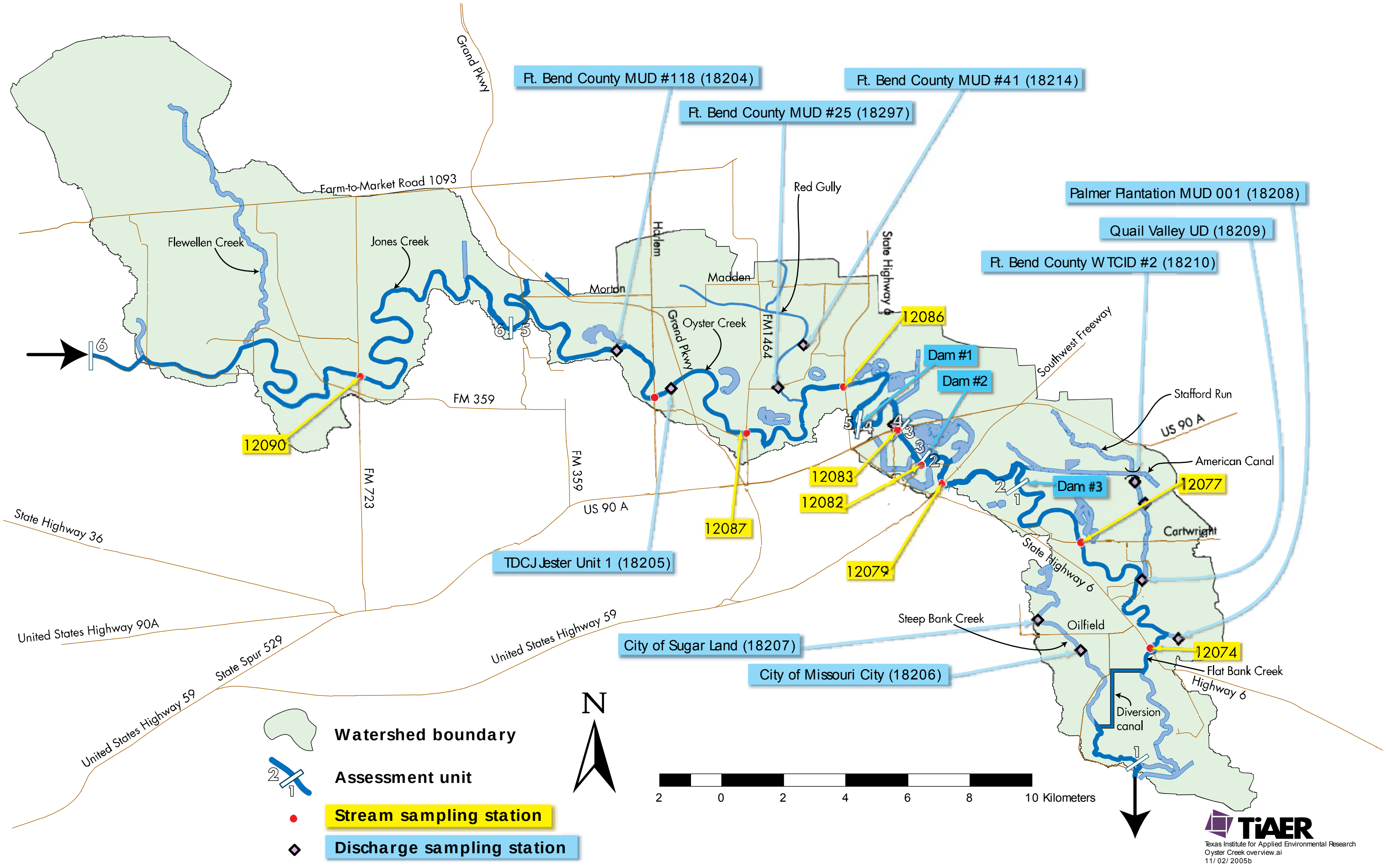

Figure 3-1 Upper Oyster Creek watershed (Segment 1245) with assessment stations.

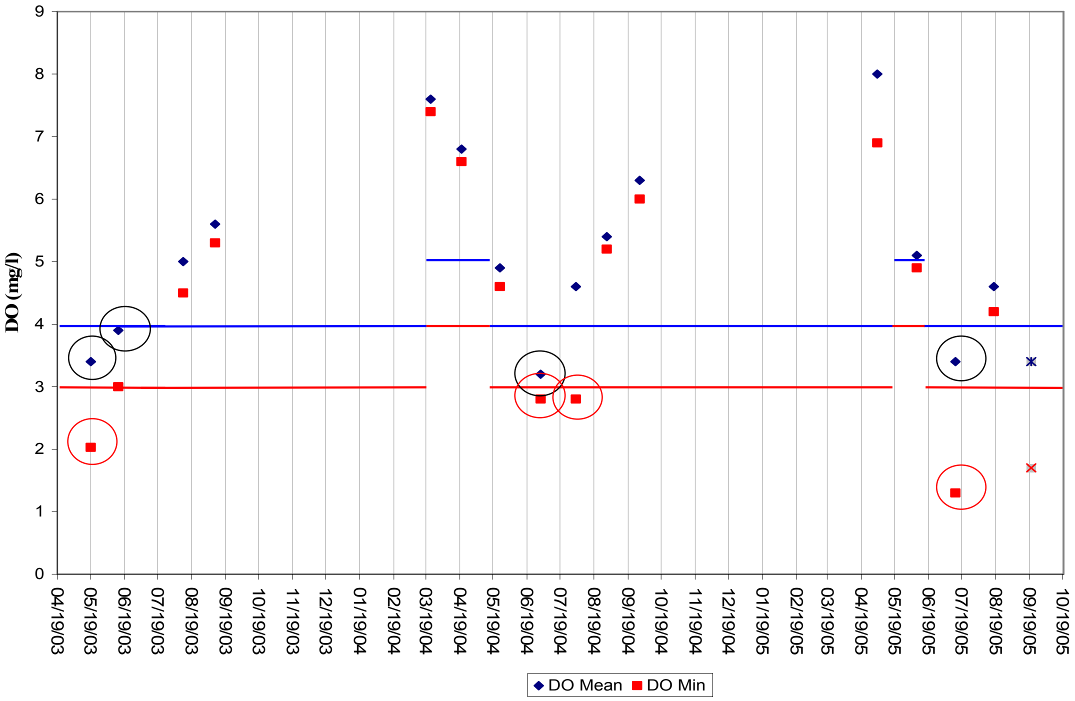

Figure 3-2 **Station 12090 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled). Values that could not be used in the assessment are marked with an "x."**

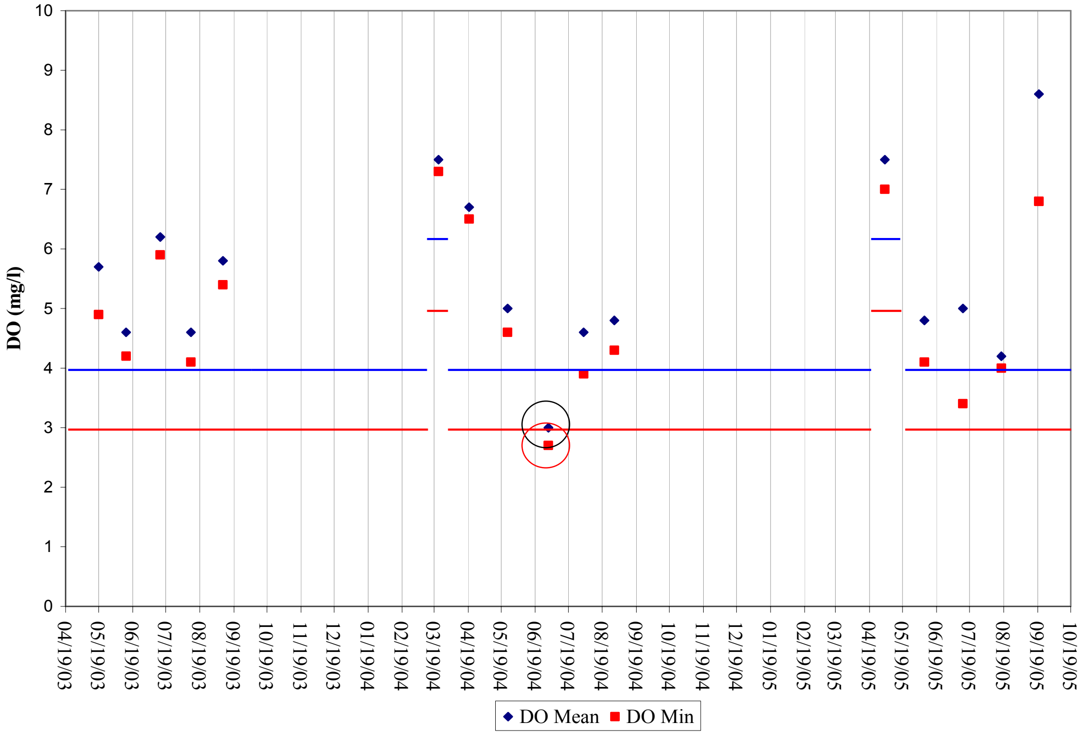

Figure 3-3 **Station 12087 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled).**

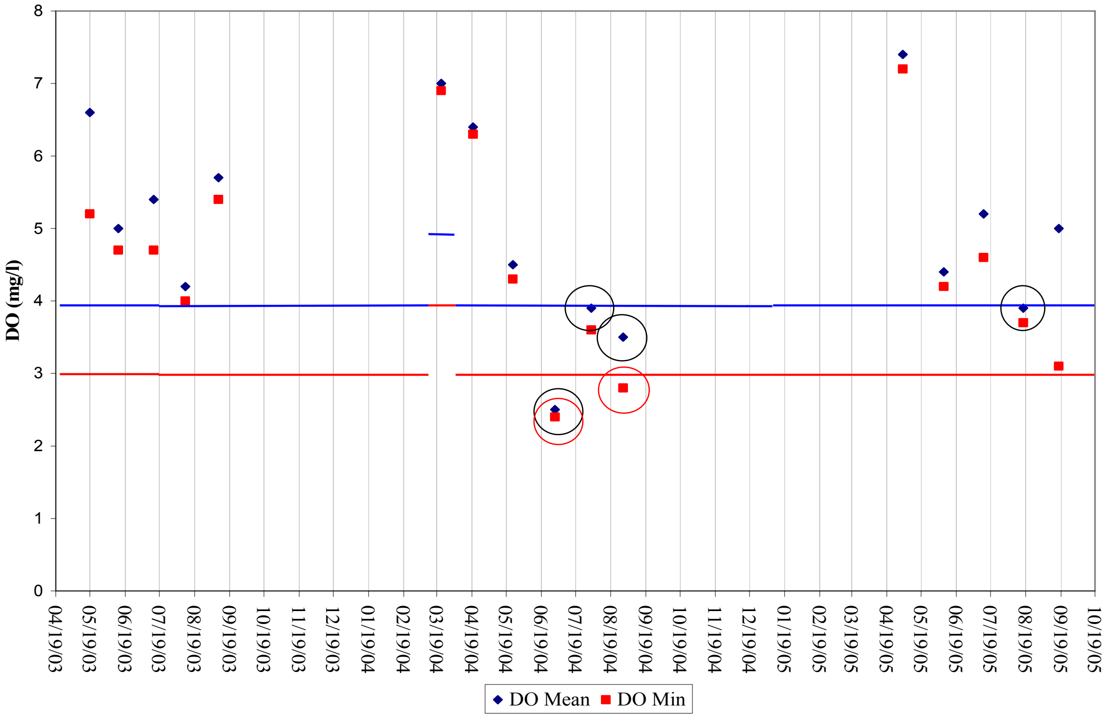

Figure 3-4 **Station 12086 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled).**

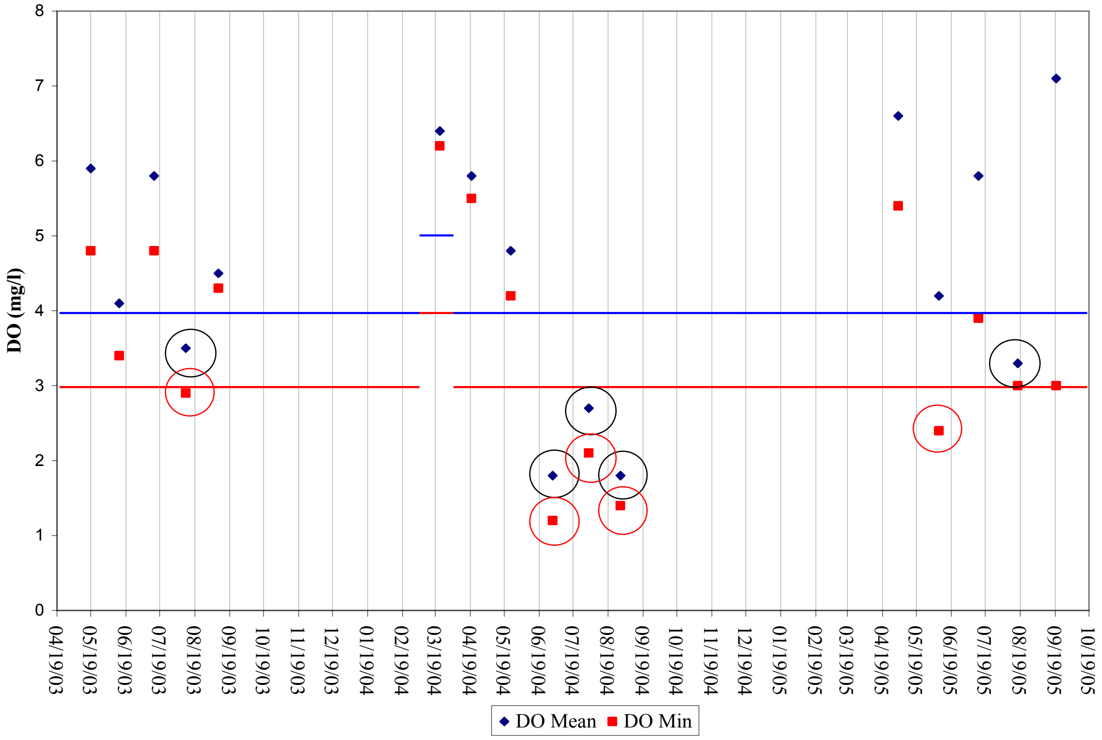

Figure 3-5 **Station 12083 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled).**

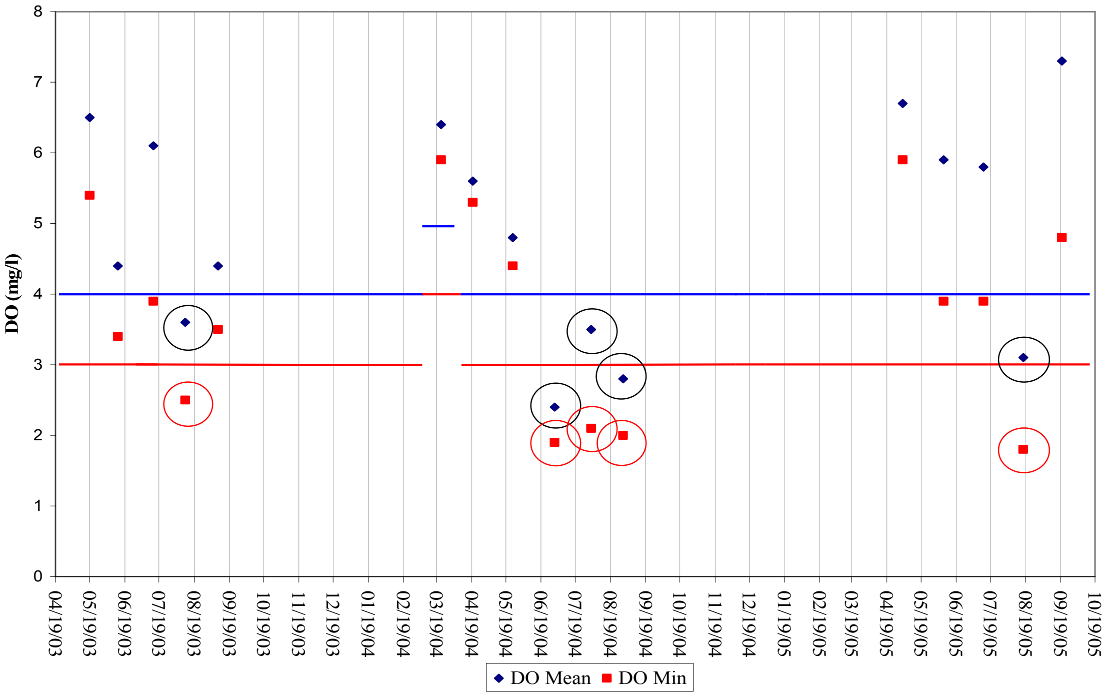

Figure 3-6 **Station 12082 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled).**

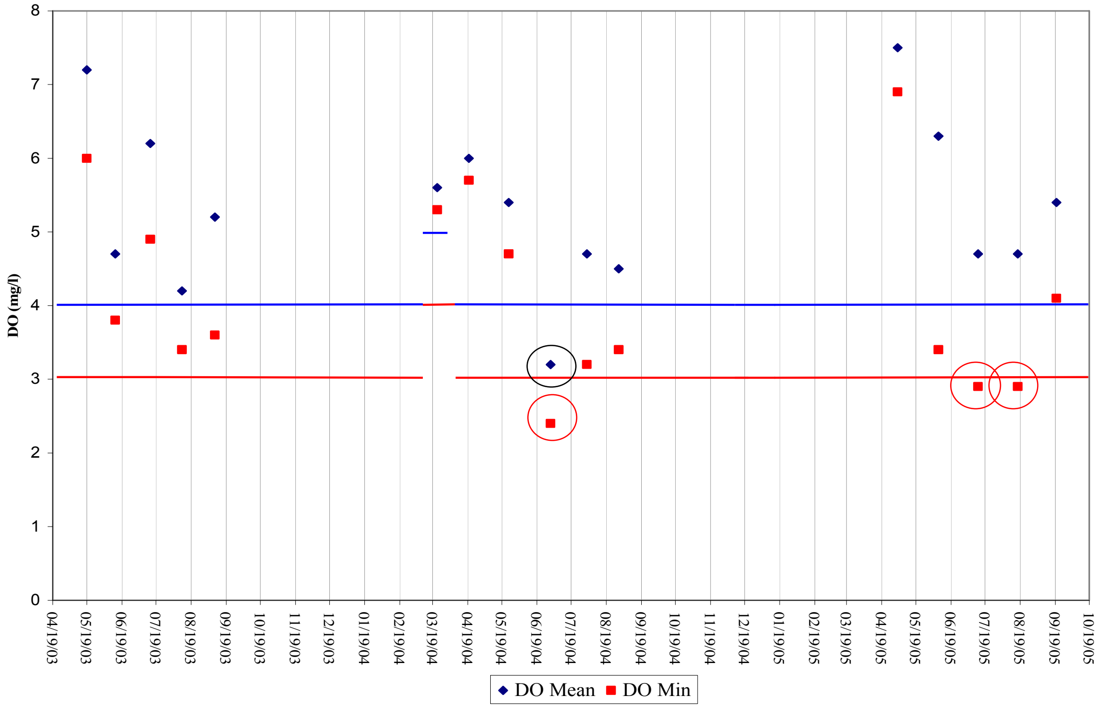

Figure 3-7 **Station 12079 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled).**

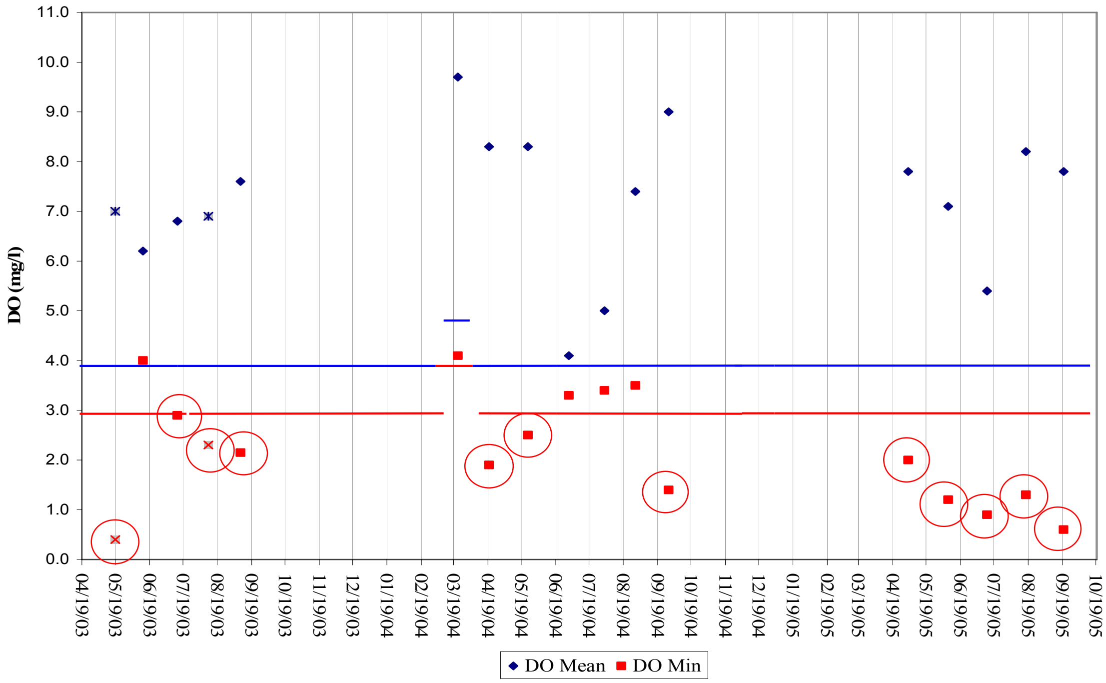

Figure 3-8 **Station 12077 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled). Values that could not be used in the assessment are marked with an "x."**

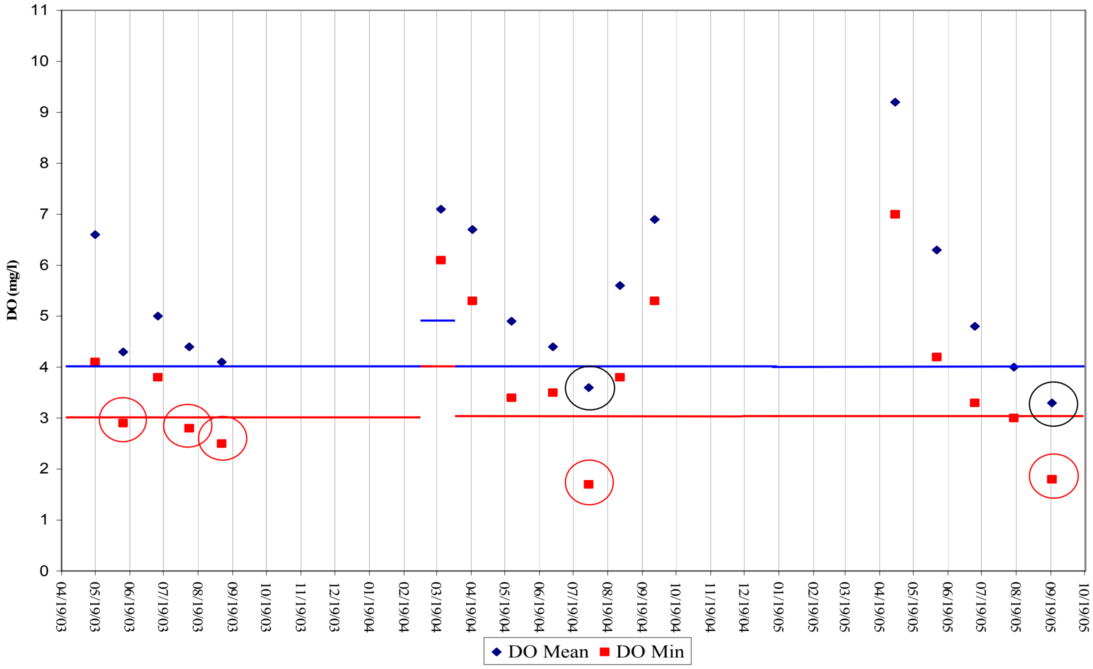

Figure 3-9 **Station 12074 24-hr average and absolute minimum DO, showing average (blue line) and minimum (red line) criteria (values in exceedance are circled - values that could not be used due to low flow conditions have an "x" in them).**

SECTION 4

INVESTIGATIONS OF THE RELATIONSHIPS BETWEEN DO AND OTHER VARIABLES

4.1 Summary of DO Impairments

Within the previous section on DO assessment, it was established that nonsupport of the designated intermediate aquatic life use was occurring in several areas of Upper Oyster Creek. Considering the previously developed hydrologic separation of Segment 1245 into a Lower Reach and an Upper Reach and considering the 24-hr DO averages and minimums from the DO assessment (Table 3-3), the following may be summarized from the DO assessment data:

- In the Lower Reach, the DO exceedances during the assessment monitoring conducted in year 2003–2005 were usually associated with the 24-hr absolute minimum DO criterion, though for a couple of 24-hr data events the exceedance involved both the minimum DO criterion and the 24-hr average DO criterion. For the two stations used in assessing the Lower Reach and a total of 32 assessment events, 15 DO 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 DO exceedances in the Upper Reach during the same assessment monitoring period occurred predominately with both the average criterion and the absolute minimum criterion for a 24-hr data event. For the six stations used during the assessment monitoring of the Upper Reach and a total of 95 assessment events, a total of 24 exceedances were observed. Four exceedances involved only the 24-hr average DO concentration, 4 exceedances involved only the absolute minimum criterion, 16 exceedances involved the average and minimum criteria, and on 6 occasions the 24-hr average DO was actually lower than the minimum criterion. Two of the exceedances involving only the absolute minimum criterion were observed at station 12079 where the data indicated full support of intermediate aquatic life use.

A reasonable conclusion from this summary of DO exceedance characteristics for the Lower and Upper Reaches is that the two reaches are not only hydrologically distinct, but the manifestation of the DO impairments and exceedances are also distinct. The observed exceedances in the Lower Reach were predominately associated only with the DO minimum criterion, and these minima occurred within cyclic diel (24-hr) patterns that are a signature from photosynthesis and respiration of the prevalent dense aquatic plant (i.e., submersed macrophytes, periphyton, and phytoplankton) communities (i.e., peak DO concentrations occur in mid to late afternoon and minimum concentrations occur in the early morning about sunrise). In contrast, the diel fluctuations are not nearly as pronounced in the Upper Reach—as previously mentioned only 4 of 24 exceedances in this reach involved minimum DO alone, and 2 of those exceedances occurred at station 12079 where the aquatic life use was indicated to be fully supported. Also, in the Upper Reach in 11 out of 16 instances where the exceedance during a survey involved both the average and minimum criteria, the observed average DO concentration departed from the relevant criterion more than the observed minimum. The assessment data indicate that average DO is a more central concern than 24-hr minimum DO for the Upper Reach.

Because casual review of available data indicated no obvious causative factors for the DO exceedances in the Upper Reach, available data are analyzed in this section to explore such factors, and the Lower Reach is included to provide additional insight into potential factors important to the occurrence of DO exceedances in that reach.

4.2 Methods

To investigate possible causative and relational factors associated with the low dissolved oxygen (DO) concentrations measured occasionally in Upper Oyster Creek, linear regression analyses of the relationship between DO and other variables, such as nutrients, total suspended solids, chlorophyll-α, water temperature, precipitation, and GCWA pumping. The measurements of DO, nitrite-nitrate nitrogen (NO_2+NO_3-N), ammonia nitrogen (NH_3-N), orthophosphate phosphorus (PO_4-P), total phosphorus (Total-P), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), chlorophyll-α (Chla), and water temperature were made at stations 12090, 12086, 12087, 12082, 12083, 12079, 12077, and 12074 (Figure 3-1). These data were collected during the assessment surveys discussed in the previous section. All surveys entailed deployment of multisondes for 24 hrs at each station in order to obtain average and minimum DO concentrations and average water temperatures over the deployment period. The assessment surveys were scheduled in advance during the Index Period of each year and occurred as scheduled regardless of prevailing weather and streamflow conditions, including a near miss by Hurricane Claudette (July 2003 survey) and a major backwater event on the Lower Reach from high Brazos River water levels (July 2004 survey). Surveys were also conducted in the Upper Reach during February 2003, December 2003, January 2004, and February 2004, because of previously observed occurrences of low DO during the winter in the 1980s and 1990s. A grab water sample was collected at each station during each survey and analyzed for the aforementioned water quality constituents. Historical precipitation and GCWA pumping records were also used in the linear regression analysis.

The goal of these analyses is to investigate the relationships of 24-hr average DO (DOavg) in the Lower and Upper Reaches to other variables and the relationships between the minimum DO during the 24-hr deployment period (DOmin) in the Lower Reach and other variables. DOavg was selected as the only dependent variable in the Upper Reach, because it has historically been a more traditional assessment measure in Texas than DOmin and DOavg is indicated to be a more important and central indicator of DO exceedances in this reach than DOmin. For the Lower Reach the additional dependent variable of DOmin was included in addition to DOavg, because all DO exceedances involved the minimum and only 2 of 15 exceedances involved both the minimum and average.

4.2.1 Correlation Analysis

Linear regression methods employing least-squares criterion were used to perform the desired analysis. The correlation coefficient was used to evaluate the strength and direction (i.e., negative or positive correlation) of relationships between DO as the dependent variable and various independent variables. The correlation coefficient, r, is a measure of how well two sample populations vary jointly and can have values over the interval of -1.0 to 1.0. A value of r close to +1 or -1 indicates a highly positive or negative degree of correlation and a good fit to a linear model, whereas a value of r close to 0 indicates a poor fit to a linear model. For these analyses a weak, moderate, or good strength of linear relationship between two variables is defined by r in the ranges shown in Table 4-1.

While linear regression analysis does not establish cause and effect responses, the approach does lend itself into gaining insights into relationships of DO to other variables within Upper Oyster Creek. These relationships can then be interpreted based on established responses from principles and observations of aquatic biology, water chemistry, and environmental engineering that indicate likely cause and effect responses and infer conditions favorable to the occurrence of DO exceedance and low DO concentration.

4.2.2 Adjustment for Relationship of DO to Water Temperature

Because of the inverse relationship of the saturation concentration of DO to water temperature, DO concentrations are often correlated with season and water temperature. This inverse relationship of DO concentration to water temperature could have undesirable and unintended impacts on the intended analyses. In order to reduce the impact of water temperature, the ratio of DO to saturation DO (defined as the variable DOavg_%sat) rather than DO was employed as the dependent variable when investigating DOavg, and the ratio of minimum DO to saturation DO (defined as variable DOmin_%sat) was employed when investigating DOmin. Use of percent DO saturation in analyses is commonly employed to minimize the confounding influences of water temperature on DO concentrations.

As justification of the need to use percent saturation variables to compensate for temperature influences on DO, some initial analyses were performed. First the DOavg data and DOavg_%sat data from the two stations where the DO assessment indicated full support of the aquatic life use, stations 12079 and 12087, were evaluated using water temperature as the independent variable (Figure 4-1a). As demonstrated in Figure 4-1a, the absolute r value of the DOavg_%sat regression line is 0.35, which is much smaller than the absolute r value of 0.73 for the DOavg regression line, indicating DOavg_%sat has less dependence on water temperature than DOavg. Also, r = -0.35 indicates that water temperature had only a weak correlation to DOavg_%sat at stations 12079 and 12087. This weak correlation supports the use of DOavg_%sat as a means to compensate for unintended temperature correlations in the subsequent analyses. A moderately strong relationship (r = -0.73) of DOavg to temperature further supports the need for an adjustment to avoid the confounding influence of water temperature. Similarly for the Lower Reach where minimum DO is the concern, Figure 4-1b indicates DOmin_%sat for the data from the two stations in that reach has less dependence on water temperature (r = -0.58, weak strength) than DOmin (r = -0.82, good strength). Thus, the difference between the strength of the relationship of percent saturation variable and concentration for minimum DO to temperature again confirmed the value of this adjustment.

In the subsequent presentation of the analysis, results are presented in terms of the percent saturation variables (i.e., DOavg_%sat and DOmin_%sat) to the independent variables.

By using percent saturation as opposed to actual concentrations, the confounding influences of temperature are at least partially removed from the analyses.

4.2.3 Groupings of Data

Because of differences in hydrology, hydraulics, water quality, and the nature of DO exceedances in Upper Oyster Creek, the data analyses were performed on various groupings of the eight monitoring stations for which data were available.

- Station 12090 – representing the portion of the Upper Reach where influence of the water from the Brazos River is anticipated to be most pronounced due to proximity to the Shannon Pump Station.
- Stations 12086 and 12087 – representing a portion of the Upper Reach located between close proximity to the Shannon Pump Station and the lake-like region.
- Stations 12079, 12082, and 12083 – representing the lake-like region with wider stream widths and much lower water velocities than the upstream portion of the Upper Reach.
- Upper Reach (Stations 12090, 12097, 12086, 12083, 12082, and 12079) – representing the aggregation of data from all stations along the Upper Reach.
- Station 12077 – representing the Lower Reach above the confluence with Stafford Run, immediately downstream of Dam #3, and without any influences of discharges from WWTFs.
- Station 12074 – representing the Lower Reach where effluent from WWTFs dominates under lower streamflow regimes.

Because hydrologic and water quality conditions at stations 12077 and 12074 were so different due to closer proximity of station 12077 to Dam #3 and the effluent dominance at station 12074, the stations were not evaluated as a combined data grouping.

4.3 Relationship of DO to Water Quality Variables

Separate analyses were performed to evaluate the influence of water-column constituents on DO for the various groupings of data from stations in the Lower and Upper Reaches as previously described under methods. The independent variables considered were NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS, and Chla. The DOavg, DOmin, nutrients, TSS and Chla data for Stations 12090, 12086, 12087, 12079, 12082, 12083, 12077 and 12074 can be referenced in Appendix A, Table A-1. Correlation coefficients among the independent variables are provided in Appendix B. Water temperature is analyzed as an independent variable separately from the other water quality variables and the data are provided in Appendix A, Table A-2.

Because 90% of the ambient $CBOD_5$ concentrations were below the detection limit (2 mg/L), the relationship of $CBOD_5$ and DO is not considered. While $CBOD_5$ at high concentrations depletes instream DO concentration, it is reasonable to assume for the predominately low concentrations observed in Upper Oyster Creek that $CBOD_5$ is not appreciably impacting DO at present concentrations.

4.3.1 Average DO Results

The r values for individual stations and grouping of stations in the Upper Reach (Figures 4-2 – 4-5 and Table 4-2) were small ($-0.46 < r < 0.40$) and indicate only weak relationships of DOavg_%sat to NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TSS and Chla. Also, NH_3-N concentrations are generally low with the majority of measured concentration less than 0.2 mg/L, which indicates only a small amount of oxygen demand from this constituent. Though all the relationships are considered to have a weak strength, there is a subtle indication of decreased DO with increasing nutrient concentrations.

Results at the station 12077 (Table 4-2; Figure 4-6) indicate a negative relationship of moderate strength ($r = -0.70$) between DOavg_%sat and chlorophyll-α, but DOavg_%sat was indicated to have only weak strength of relationships with other constituents (r values of -0.46 to 0.09). The moderate negative correlation of DOavg_%sat to Chla is in the opposite direction anticipated, i.e., higher average DO with more suspended algae present was anticipated. Two insights are presented. First, the relationship might be influenced by the high Chla concentration (approximately 12 µg/L) that was acting as a single leverage point to statistically force a higher r value. Second, the stream at station 12077 is typically observed to be dominated by macrophytes and their abundance is anticipated to be more important regarding DO concentrations than the suspended algae as measured by chlorophyll-α. Supporting the second insight are the data in Table 3-3 showing that after the Brazos River backwater event of June and early July 2004 that was observed to have killed almost all the macrophytes at station 12077, DOmin concentrations did not exceed the criterion at that location for the remainder of the summer. Finally, all NH_3-N concentration at this station were less than 0.2 mg/L indicating limited oxygen demand potential from this constituent.

At station 12074 the r value of 0.88 indicates that DOavg_%sat has a good strength of positive linear relationship to Chla (Table 4-2; Figure 4-7g). This finding must be tempered with the observational information that macrophytes and periphyton are very abundant in much of Segment 1245 and possible existence of confounding positive correlation of Chla to the attached aquatic vegetation should not be discounted. NO_2+NO_3-N was indicated to be positively correlated to DOavg_%sat ($r = 0.73$; Table 4-2) at a moderate strength of relationship. The r values for other constituents indicate only a weak relationship to DOavg_%sat levels (Table 4-2). NH_3-N concentrations are higher at station 12074 than at the other monitored stations in Segment 1245, though most concentrations are less than 0.3 mg/L. The higher NH_3-N concentrations observed at this station are sufficient to result in the exertion of sufficient oxygen demand to have some impact on DO concentrations, though this observation should be tempered by the fact that exceedance of the average DO criterion is not the central issue in the Lower Reach.

4.3.2 Minimum DO Results

The scatter plots of DOmin_%sat vs. other water quality constituents for stations 12077 and 12074 are displayed in Figures 4-8 and 4-9. The correlation coefficients for the two stations are listed in Table 4-3.

The high r values (Table 4-3) for NO_2+NO_3-N indicate that DOmin_%sat is positively correlated to NO_2+NO_3-N at station 12077 with a good strength of the relationship, and positively correlated to NO_2+NO_3-N at station 12074 with a moderate relationship strength. The relationship between chlorophyll-α and DOmin_%sat at station 12074 indicates a good strength based on r value. NH_3-N is correlated to DOmin_%sat positively at station 12077, but negatively at station 12074, though the strength of both relationships is weak. Other constituents have very weak relationships to DOmin_%sat at the both stations. Despite the good correlation, a cause and effect association of the positive relation of NO_2+NO_3-N and DOmin_%sat is not readily apparent, i.e., it is not readily apparent how or why higher NO_2+NO_3-N concentrations cause higher minimum DO concentrations.

4.3.3 Water Temperature Analysis

To investigate the relation of DO concentrations to 24-hr average water temperature, a different approach was taken than was used with the other water quality constituents where percent saturation DO was used to at least partially alleviate the confounding influences of temperature. For the analysis of water temperature, DOavg and DOmin were used without conversion to percent saturation and only the aggregated data for the Lower Reach and Upper Reach were considered. In the Lower Reach data for stations 12074 and 12077 were aggregated, unlike the analysis for other constituents, because water temperatures did not differ as much between these stations as did the other water quality constituents.

For the Lower Reach, the available data were obtained during the months of March through September, which resulted in a relatively narrow water temperature range (approximately 19° C to 32° C). The analysis indicates the anticipated negative relationship of both DOavg and DOmin to water temperature and in both instances the strength of the relationship is weak (Figure 4-10). Of more interest, it can be observed from Figure 4-10 that exceedance of the 24-hr average DO criterion occurs generally at higher temperatures (> 28° C) whereas exceedance of the minimum DO criterion appear to occur more frequently at higher temperatures, though still occasionally at temperatures below 25°C. While insufficient data exist at lower temperatures to strongly support the following statement, it is anticipated that lower water temperatures result in fewer minimum DO exceedances because of its association with reduced aquatic plant growth rates, higher saturation DO concentrations than with warmer water temperatures, and times of the year with less incident solar radiation.

For the Upper Reach, data are available for winter months, which provides for a range of observed average temperatures from approximately 10° C to 33° C. The analysis indicates a negative relationship of both DOavg and DOmin to water temperature with moderate to good strength of the relationships (Figure 4-11). As in the Lower Reach, the DO exceedances in the Upper Reach occur at the warmer water temperatures, which based on available data is at temperatures above 26° to 27° C, and this occurs for exceedances of both the average criterion and minimum criterion.

4.3.4 Discussion of Water Quality Analysis

For most water quality constituents and groupings of data sets, the linear regression analysis indicated only weak strength of relationships to DO in Segment 1245. For the two constituents that directly exert an oxygen demand, $CBOD_5$ concentrations were almost always below the detection limit, which precluded analysis and strongly suggests only minor implications of this constituent on DO concentrations, and NH_3-N concentrations were generally at less than 0.2 mg/L, again strongly suggesting only minor implications on DO concentrations. NH_3-N concentrations at station 12074 occasionally exceeded 0.4 mg/L suggesting that infrequently levels could have moderate implications on average DO concentrations; however, this occurred in a portion of the stream where exceedances of the minimum DO criterion are the concern and not exceedances of the average criterion. Aberrant positive relationships of NO_2+NO_3-N to DOavg_%sat at station 12074 and of DOmin_%sat at stations 12074 and 12077, which were evaluated as being of moderate to good strength, can not readily be explained with the available data set. At station 12074, a positive correlation between NO_2+NO_3-N and Chla of moderate strength (see Appendix B) offers a partial explanation regarding the average DO relationship, since higher suspended algae biomass and associated oxygen production can increase average DO concentrations though lower minimum DO concentrations would also be anticipated.

DO concentrations in the Upper Reach were negatively correlated with water temperatures. Exceedance of the average and minimum criteria in the existing data set were only observed at temperatures above 26° to 27° C indicating that DO exceedances occur only during the months of warmer water temperatures. Perusal of Table 3-3 supports this indication, for with the exceptions of observations at station 12090, all exceedances in the Upper Reach occurred during the months of June, July, and August. In the Lower Reach, the exceedances are largely associated with the minimum DO criterion and the regression analysis and visual interpretation of Figure 4-10, while admittedly not as convincing as for the Upper Reach, suggest that exceedances occur over a broader range of water temperatures than in the Upper Reach and likely occurrences of exceedances diminish with the cooler temperatures and less incident solar radiation of fall, winter and early spring.

4.4 Relationship of DO to Antecedent Precipitation

Because gauged streamflow data records are not available for Upper Oyster Creek, daily precipitation was used as a surrogate indicator to flow in order to investigate whether DO exceedances during assessment events were associated with rainfall-runoff.[3] For this evaluation, precipitation data were organized into six groups of cumulative antecedent precipitation of 1-day, 2-days, 3-days, 4-days, 5-days and 6-days (1d, 2d, 3d, 4d, 5d and 6d) prior to the day when

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[3] As presented in Section 2, the SWAT model was applied for the bacteria TMDL to estimate flows at several locations within Segment 1245. Since SWAT predicted runoff is determined from historical precipitation records, for this analysis the decision was to go to the primary data (i.e., the precipitation record) rather than to use the secondarily derived SWAT runoff predictions that are determined by the model using daily precipitation as input.

24-hr DO measurement was begun.[4] The cumulative precipitation data sets were calculated for the 2003-2005 assessment surveys (Appendix A, Table A-3).

4.4.1 Average and Minimum DO Results

The scatter plots of DOavg_%sat vs. cumulative precipitation (1, 2, 3, 4, 5, and 6 days) were developed for each of the seven groupings of stations provided under the discussion of methods (Figures 4-12 — 4-17). These plots provide a visual presentation of the strength of linear relationship between DOavg_%sat and the various cumulative precipitation variables. Corresponding r values of the linear regressions are provided in Table 4-4.

In the lake-like area (stations 12079, 12082, and 12083), r values between -0.63 and -0.65 indicate a moderate strength of the negative relationship of DOavg_%sat to cumulative antecedent rainfall for 3, 4, 5 and 6 days (Table 4-4; Figure 4-14). Similarly, 3 out of 6 cases of cumulative precipitation for stations 12077 have r values between -0.79 and -0.60, which again indicates a moderate, negative strength of relations of DOavg_%sat to cumulative antecedent rainfall (Table 4-4; Figure 4-16). Only weak relationships of DOavg_%sat to cumulative antecedent rainfall were indicated at the other groupings of stations, including the aggregated data sets for the Upper Reach (Table 4-4).

The scatter plots of DOmin_%sat vs. precipitation for stations 12077 and 12074 are displayed in Figures 4-19 and 4-20 and the corresponding correlation coefficients are provided in Table 4-5. The low r values indicate that DOmin_%sat is only weakly correlated to cumulative precipitation.

4.4.2 DO Exceedance Results

The linear regression results from both the lake-like area (stations 12079, 12082, and 12083) and station 12077 indicate a moderate strength and negative relationship of average DO to various days of cumulative antecedent rainfall. However, at station 12077, the minimum DO, which is the condition under which DO exceedances occurred at this location, showed a weak, positive relationship to precipitation. Since some cause and effect relationship of precipitation to average DO is potentially indicated for the lake-like area, additional plots were developed for that area. For cumulative antecedent precipitation variables of 1, 2, 4, and 6 days plots were developed of DOavg to cumulative precipitation (similar to Figure 4-14) with different symbols depicting the conditions under which exceedances occurred (Figure 4-20). The various graphs in Figure 4-20 show that exceedance events occur under a wide distribution of antecedent rainfall occurrences, though with some clustering of exceedances for higher cumulative precipitation for days 4 and 6.

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[4] DO assessment surveys were conducted with deployment of the multisonde during the daylight hours of the first day and retrieval a little over 24 hours later on the second day.

4.4.3 Discussion of Cumulative Precipitation Analysis

For the stations in the Lower Reach with the central focus on 24-hr minimum DO associated exceedances, only weak relationships of minimum DO concentrations are related to antecedent precipitation. Antecedent rainfall does not appear to be a major factor influencing the occurrence of low DO and DO exceedances in the Lower Reach.

Concerning DO exceedances in the Upper Reach, regression results of 24-hr average DO indicate a more complex situation than for the Lower Reach. For the portion of the Upper Reach upstream of the lake-like area (stations 12086, 12087, and 12090), only weak strength of relationships of average DO to antecedent precipitation are indicated, though these weak relationships indicate a tendency toward lower DO concentrations with increasing precipitation. For stations 12079, 12082, and 12083 in the lake-like area, the same indication of lower DO with increased antecedent rainfall is indicated and a moderate strength of the relationship exists.

Based on these results of negative correlation of DO concentrations in the Upper Reach and the moderate strength of that relationship in the lake-like area, further investigations were preformed to see if potentially some explanatory variable exists to establish cause and effect. If oxygen demanding water-column constituents, namely NH_3-N and $CBOD_5$, were the cause of the lower DO concentration, then higher concentrations of these constituents would be anticipated at stations with DO exceedances during surveys that are associated with the higher antecedent precipitation amounts. Generally it has already been demonstrated in Section 4.3 that water column constituents are not of sufficient concentrations to be the cause of low DO in the Upper Reach; however, a more focused analysis was performed from the perspective of antecedent rainfall. The assessment surveys associated with the higher amounts of antecedent precipitation and in which DO exceedances occurred at various stations are those beginning on the following dates: July 1, 2004; August 2, 2004; and August 30, 2004 (Table 3-3 & Appendix A, Table A-3). Water quality concentrations of oxygen demanding substances (NH_3-N and BOD_5) indicate that concentrations are not sufficiently high to explain the low DO concentrations observed in the Upper Reach during the July 1st, August 2nd, and August 30th surveys (Table 4-6). TSS concentrations during these three surveys, which might be anticipated to be elevated during rainfall-runoff events, are not notably high for the Upper Reach (Table 4-6). The NH_3-N and TSS concentrations during these surveys are also well within the range of data observed during the assessment surveys (Figures 4-2 – 4-5).

Limited data were also available to investigate the possibility of higher sediment oxygen demand (SOD) in the Upper Reach during and following precipitation as a result of measurement of SOD in support of the model validation efforts as discussed in Section 5 – Selection and Validation of the Dissolved Oxygen Model. One reasonable hypothesis is that rainfall runoff carries a high load of oxygen demanding organic matter that would settle out in the Upper Reach, especially in the lake-like area where velocities slow, causing the DO exceedances through high SOD. While far from conclusive because of the limited data and anticipated variability, several SOD measurements were made in 2004 and 2005 (Section 5, Table 5-2). These measurements give no indication of a prevalence of higher SODs during 2004 than 2005, even though many more DO exceedances occurred during the 2004 surveys than the 2005 surveys. Nonetheless, SOD values are higher in Segment 1245 than in many lotic systems.

There are likely several sources of the SOD in the Upper Reach, including rainfall-runoff moving organic matter from urban and rural landscapes within the watershed, Brazos River water, natural die-off of macrophytes, and die-off from chemical spraying of these same macrophytes as required periodically to maintain conveyance capacity in the Upper Reach. Also resuspension of sediments in the Upper Reach during runoff events and relocation of those sediments further downstream, especially to the lake-like area with its lower water velocities, seems highly probable, but no data exists to support this hypothesis.

4.5 Relationship of DO to Brazos River Water Pumping

The strength of linear relationships between DOavg_%sat in the Upper Reach and the cumulative amount of water pumped from the Brazos River was also investigated. Similar to the precipitation analysis, cumulative antecedent pumping from the Brazos River at the Shannon Pump Station was considered for the following time periods: 1, 2, 3, 4, 5, and 6 days. The units of cumulative pumping are in acre-feet (ac-ft), and the pumping data were supplied by the GCWA. The Shannon Pump Station cumulative data are provided in Appendix A (Table A-4). This analysis was restricted to the Upper Reach groupings of station data: station 12090; stations 12086 and 12087; stations 12079, 12082, and 12083; and Upper Reach (Figures 4-21 — 4-24, respectively). The corresponding r values are provided in Table 4-7. Also, plots of DOavg with exceedances indicated with different symbols are provided in Figure 4-25 for a subset of the time periods: 1, 2, 4, and 6 days. The analysis was not performed on the Lower Reach, because of the hydrologic separation of the two reaches at Dam # 3 under most flow conditions.

All r values from the linear regressions were very small, between -0.03 and 0.36, indicating a weak relationship between the water pumping of Shannon Pump Station and DOavg_%sat. Also, DO exceedances were evenly distributed across different water pumping levels and no unique trends of DO exceedance vs. water pumping were observed, i.e., DO exceedances occurred in both low and high levels of water pumping.

Unfortunately what can not be determined are the water quality implications of the pumped Brazos River water on DO exceedances in the Upper Reach. Brazos River water quality is generally of good quality though the water is typically very turbid. Based on historical data in TCEQ SWQM database for Brazos River stations near the Shannon Pump Station, NH_3-N concentrations are generally very low (<0.1 mg/L) and DO concentrations high, but CBOD data are essentially nonexistent. Data were not obtained in the Brazos River or immediately downstream of the Shannon Pump Station during the assessment surveys and in hindsight this was a likely oversight in understanding the water quality issues in the Upper Reach.

What is difficult to decipher from this simple analysis and resulting graphs is the GCWA management of the pumping of the Shannon Pump Station during and following rainfall runoff events in the Upper Reach. As discussed briefly in Section 2, during runoff events pumping at the Shannon Pump Station may be curtailed, sometimes entirely, for one or more days immediately following a runoff event even though pumping continues to occur out of the system at the Second Lift Station. Direct runoff originating within the watershed provides a source of water that is more efficiently obtained than water from the Brazos River, i.e., this runoff water does not have to be pumped into the Jones Creek/Oyster Creek conveyance saving the expense of operating the Shannon Pump Station. During the July 1, 2004 survey, which corresponded with DO exceedances at every station in the Upper Reach and the lowest DO concentrations encountered during an assessment survey, the Shannon Pump Station was not operated for over 6 days prior to the survey, though pumping persisted daily at the Second Lift Station (Appendix A, Table A-4). The Shannon Pump Station pumping curtailment occurred to a lesser amount during August 30, 2004 survey in which DO exceedances occurred at station 12082, 12083, and 12086. Therefore the possibility can not be ignored that there could exist some connection of curtailed pumping at the Shannon Pump Station with observed DO exceedances.

Further insight into the use of runoff in lieu of Brazos River water was supplied by Mr. Vince Voelkel of the GCWA in the following (personal communication, September 20, 2007). Mr. Voelkel indicated that only limited storage capacity is afforded within the Upper Reach through operation of Dams #2 and 3 and the Old Second Lift Station immediately downstream of the junction of Jones and Oyster Creeks, so most runoff is either pumped at the Second Lift Station or exits the Upper Reach in one of three ways: (1) released at Dam #3 into the Lower Reach, (2) released out of Segment 1245 through flood control gates when Dam #2 water levels reach a trigger level, and (3) released over a low water dam through the remainder of Jones Creek that is not in Segment 1245 when water levels at the Old Second Lift Station are sufficiently high to allow overtopping of the low water dam. Despite that lack of significant storage capacity in the Upper Reach, in a counterintuitive manner, Mr. Voelkel indicated that increased urbanization in the watershed has resulted in prolonging of the periods of curtailed pumping at the Shannon Lift Station. The runoff from the impervious cover associated with urbanization would be anticipated, however, to occur more quickly, albeit in greater amounts, than runoff from the rural landscape, and in the absence of significant storage capacity in the Upper Reach, this additional runoff would be lost from the system, because of the quicker runoff response from urbanized lands. However, stormwater detention structures are associated with new development in the Upper Oyster Creek watershed, and it seems feasible that these structures act as sufficient delay to actually extend the runoff period and extend the curtailment of pumping at Shannon Lift Station from runoff events.

4.6 Conclusions of Investigations

This investigation to determine possible relationships of DO concentrations and exceedances in the Lower and Upper Reaches provides some insights into the nonsupport of the intermediate aquatic life use in Segment 1245. Causal variables that appear to be negatively effecting DO concentrations in the system, however, remain elusive, especially in the Upper Reach. The following items are based not only on the analysis provided in this section, but also on information contained in Sections 2 and 3:

- The Lower Reach experiences hydrologic modifications as a result of Dam #3 and the Second Lift Station, which together eliminate everything but very minor seepage through the dam except during rainfall-runoff events.
- The Lower Reach experiences periodic backwater flooding events from the Brazos River, which have unknown implications on water quality, though it has been observed that these events can temporarily greatly reduce macrophyte and periphyton densities.

- Exceedances of the 24-hr minimum DO criterion are common at the two stations monitored in the Lower Reach, and these exceedances are highly suspected to be in response to abundant aquatic vegetation that is found as submersed macrophytes and periphyton and to a lesser extent suspended algae.
- The Lower Reach actually experiences a greater frequency of DO exceedances at station 12077 that is above the influence of any WWTFs than at station 12074 that is highly influenced by discharges from WWTFs.
- The oxygen demanding substances of NH_3-N and $CBOD_5$ and other water quality constituents were found to be in generally low concentrations in the Lower Reach. On occasion the concentrations of NH_3-N were sufficiently high at station 12074 to have some effect on DO concentrations, but 24-hr average DO concentrations only exceeded the criterion during 2 out of 15 assessment surveys at the station.
- In the Lower Reach DOmin concentrations are negatively related to water temperature, and though this relationship has only a weak strength, DO exceedances do seem to be more commonly associated with water temperatures above 25° C.
- Antecedent precipitation was only weakly correlated with DO concentrations in the Lower Reach.
- For the Lower Reach, it is concluded that low flow conditions not associated with rainfall runoff is the hydrologic condition of concern regarding DO exceedances of the minimum DO criterion, and these exceedances have a tendency to occur most commonly, though not exclusively, during the warmer months when water temperatures exceed 25 ° C.
- The Upper Reach serves as a conveyance for water pumped from the Brazos River, and the amount of this pumped water is both significant and follows a seasonal pattern with highest pumped amounts in the summer and lowest amounts in the winter.
- Brazos River water contains high turbidity and sedimentation results in decreasing turbidity in the downstream direction of the Upper Reach and in the need for periodic maintenance dredging in portions of the reach.
- The lake-like region in the vicinity of Dams #2 and 3 represents an area distinct from the rest of the Upper Reach, because stream width is wider and water velocities are appreciably less. Thus the lake-like region, especially above Dam #2, effectively functions from a water quality perspective like the transition zone in a large reservoir where the water body contains both stream and reservoir characteristics.
- Rainfall runoff directly within the Upper Reach watershed is used in lieu of pumping water from the Brazos River to meet water requirements at the Second Lift Station, resulting in complex hydrologic patterns of curtailed pumping of Brazos River water when runoff is occurring.
- Aquatic vegetation in the form of macrophytes is abundant in most of the Upper Reach necessitating from spring through early fall vegetation control in the form of periodic herbicide applications. Quantification of effects of vegetation control practices on DO in the Upper Reach has not occurred.
- Water quality constituents that cause oxygen demand are at low concentrations in the Upper Reach based on the assessment survey data, as are the other constituents monitored during these surveys, with the possible exception of TSS. TSS concentrations can be high in the pumped Brazos Water and generally decrease in the downstream direction. These water quality constituents were indicated to have only weak strength of relationship with DO.

- There is insufficient information on water quality in the Brazos River when both pumping and DO exceedances are occurring in the Upper Reach to determine implications on the DO exceedances.
- In the Upper Reach, water temperatures of about 26º to 27º C define a threshold for the present data set and above this threshold exceedances of the DO criteria occur and below this threshold exceedances were not observed.
- In the lake-like area, there is a moderate strength of the negative relationship of DO to antecedent precipitation, which is used as a surrogate for streamflow and runoff in lieu of actual streamflow records in the Upper Reach. While this relationship alludes to the possibility of rainfall-runoff having a detrimental effect on DO concentrations, neither water quality data nor SOD measurements provide a cause for lower DO concentrations following runoff events.
- The Upper Reach presents a complex system with interacting influences that include transfer of water from the Brazos River wherein these pumping rates are curtailed during rainfall-runoff events in the watershed, areas of dredging to maintain stream conveyance capacity, periodic herbicide treatment of the extensive macrophyte communities in the system, and a lake-like area that functions similarly to the transition zone of a large reservoir and where reduced water velocities also reduce natural reaeration rates.
- For the Upper Reach, the 24-hr average DO as opposed to the minimum DO is the more central water quality issue and exceedances of the average DO criterion occur at warmer water temperatures that would most typically occur from late spring through late summer. Likely because of the complexity of the system, the actual causes of DO exceedances is not readily apparent or understood based on available data. Existing data do not indicate that water-column constituents are a major factor. SOD rates are high, but transferred Brazos River water as well as herbicide treatment of macrophytes could contribute to these rates as well as runoff from within the watershed. While there are indications that some DO exceedances may be associated with rainfall-runoff events, no physical, chemical, or biological cause can be found in existing data that provide causative factor to result in low DO concentrations. Further complicating the understanding of the DO exceedances is the fact that the common practice of curtailing pumping of Brazos River water during and following runoff events may play a role in the exceedances.

SECTION 4

TABLES

Table 4-1 Values of r and corresponding strength of linear relationship (Broadly based on Cohen (1988); Santhi et al. (2001); Van Liew et al. (2003))

Correlation Coefficient (r)	Negative	Positive
Weak	-0.59 to 0.00	0.00 to 0.59
Moderate	-0.79 to -0.60	0.60 to 0.79
Good	-0.80 to -1.00	0.80 to 1.00

Table 4-2 Correlation coefficients of linear regression analyses of DOavg_%sat vs. nutrients, TSS and chlorophyll-α

Stations	NO_2+NO_3-N	NH_3-N	PO_4-P	Total-P	TKN	TSS	Chla
12090	-0.18	-0.46	-0.34	-0.07	-0.14	0.30	0.32
12086.12087	0.01	-0.15	-0.34	-0.22	-0.13	0.02	0.40
12079.12082.12083	-0.10	-0.45	-0.50	-0.39	-0.28	-0.27	0.28
Upper Reach	-0.08	-0.35	-0.36	-0.22	-0.21	0.03	0.31
12077	-0.24	-0.36	-0.22	0.09	-0.42	-0.46	-0.70
12074	0.73	-0.53	-0.24	-0.19	-0.06	-0.03	0.88

Table 4-3 Correlation coefficients of DOmin_%sat vs. nutrients, TSS and chlorophyll-α

Stations	NO_2+NO_3-N	NH_3-N	PO_4-P	Total-P	TKN	TSS	Chla
12077	0.91	0.58	0.06	0.26	-0.03	0.35	-0.15
12074	0.76	-0.47	-0.27	-0.21	0.03	-0.04	0.83

Table 4-4 Correlation coefficients of DOavg_%sat vs. cumulative precipitation for number of indicated antecedent days

Cumulative days prior to DO measurement	1	2	3	4	5	6
12090	-0.32	-0.29	-0.38	-0.39	-0.34	-0.30
12086.12087	-0.09	-0.11	-0.53	-0.55	-0.53	-0.52
12079.12082.12083	-0.07	-0.14	-0.63	-0.65	-0.64	-0.63
Upper Reach	-0.12	-0.15	-0.55	-0.57	-0.55	-0.53
12077	-0.67	-0.75	-0.50	-0.50	-0.46	-0.63
12074	-0.15	-0.30	-0.19	-0.22	-0.19	-0.33

Table 4-5 Correlation coefficients of DOmin_%sat vs. cumulative precipitation for number of indicated antecedent days

Cumulative days prior to DO measurement	1	2	3	4	5	6
12077	-0.12	0.03	0.35	0.35	0.36	0.47
12074	-0.14	-0.32	-0.22	-0.24	-0.22	-0.39

Table 4-6 Water quality associated with DO exceedances during high cumulative antecedent precipitation

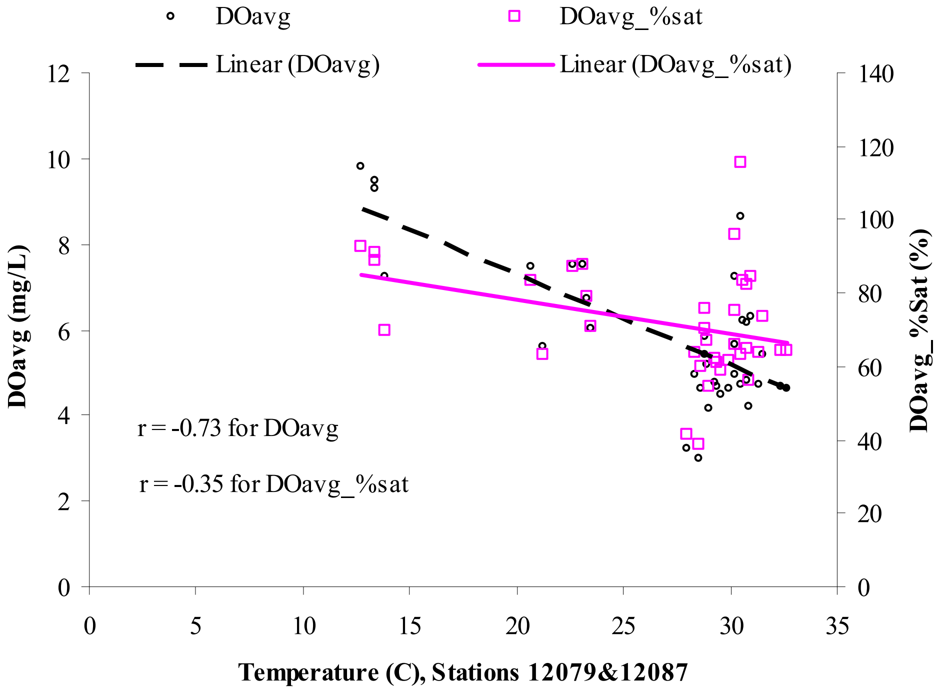
Survey Deployment Start Date	Station	NH_3-N (mg/L)	$CBOD_5$ (mg/L)	TSS (mg/L)
7/1/2004	12090	0.125	<2	48
	12087	0.109	<2	47
	12086	0.151	3.8	41
	12083	0.142	<2	42
	12082	0.142	<2	25
	12079	0.131	<2	19
8/2/2004	12090	0.128	<2	48
	12086	0.074	<2	23
	12083	0.093	<2	27
	12082	0.103	<2	19
8/30/2004	12086	0.129	<2	65
	12083	0.245	<2	20
	12082	0.129	<2	13

Table 4-7 Correlation coefficients of DOavg_%sat vs. water pumping at Shannon Pump Station

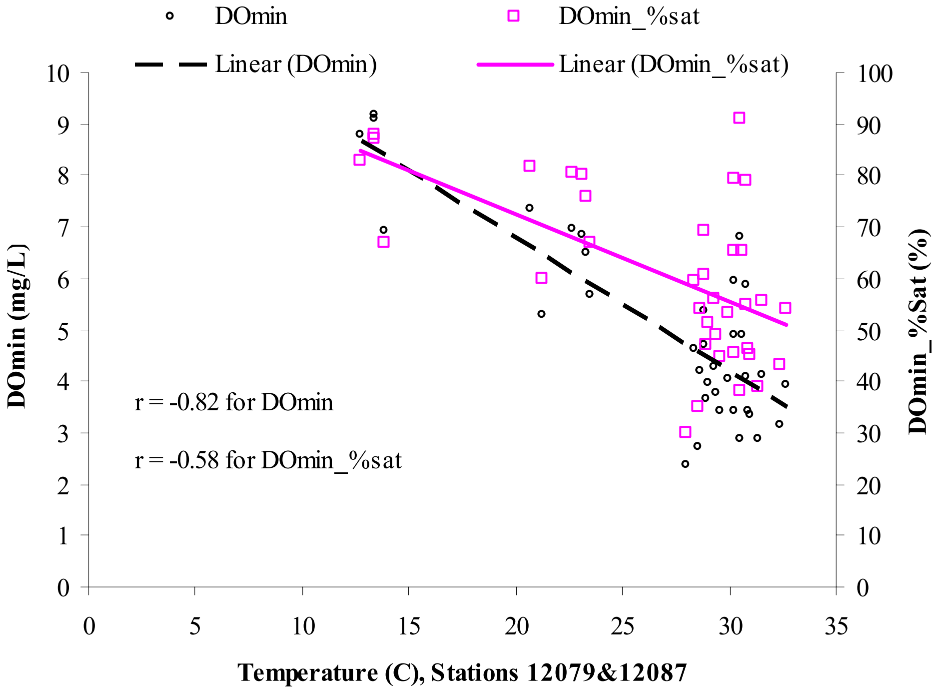
Days of cumulative precipitation prior to DO measurement	1	2	3	4	5	6
12090	0.36	0.34	0.29	0.28	0.26	0.24
12086.12087	0.01	0.06	0.08	0.05	0.01	-0.03
12079.12082.12083	0.04	0.13	0.17	0.13	0.08	0.03
Upper Reach	0.07	0.13	0.15	0.12	0.07	0.03

SECTION 4

FIGURES



(a)



(b)

Figure 4-1 Relationship between (a) DOavg/DOavg_%sat and water temperature and (b) DOmin/DOmin_%sat and water temperature (stations 12079 and 12087)

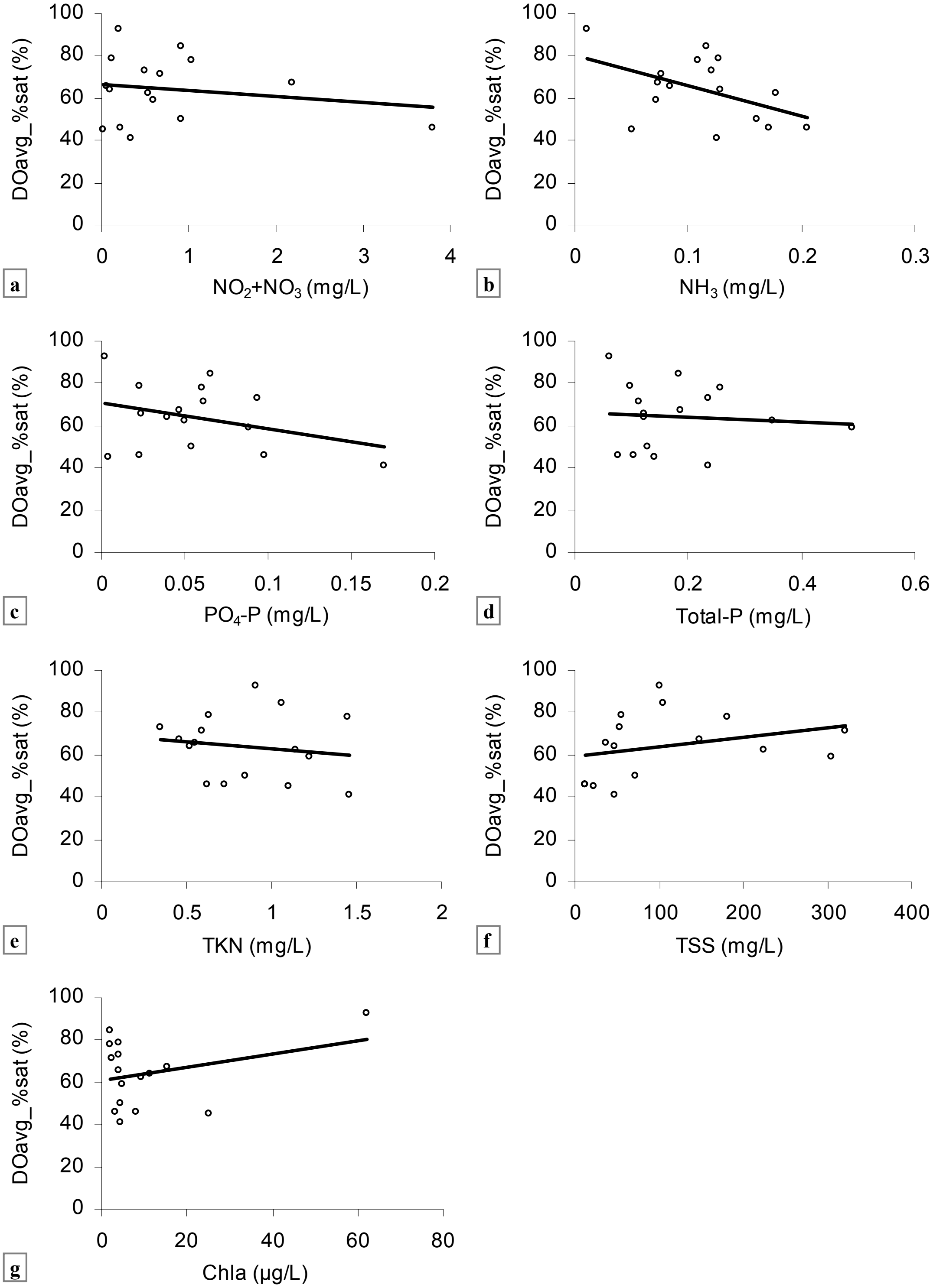


Figure 4-2 **DOavg_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations at station 12090**

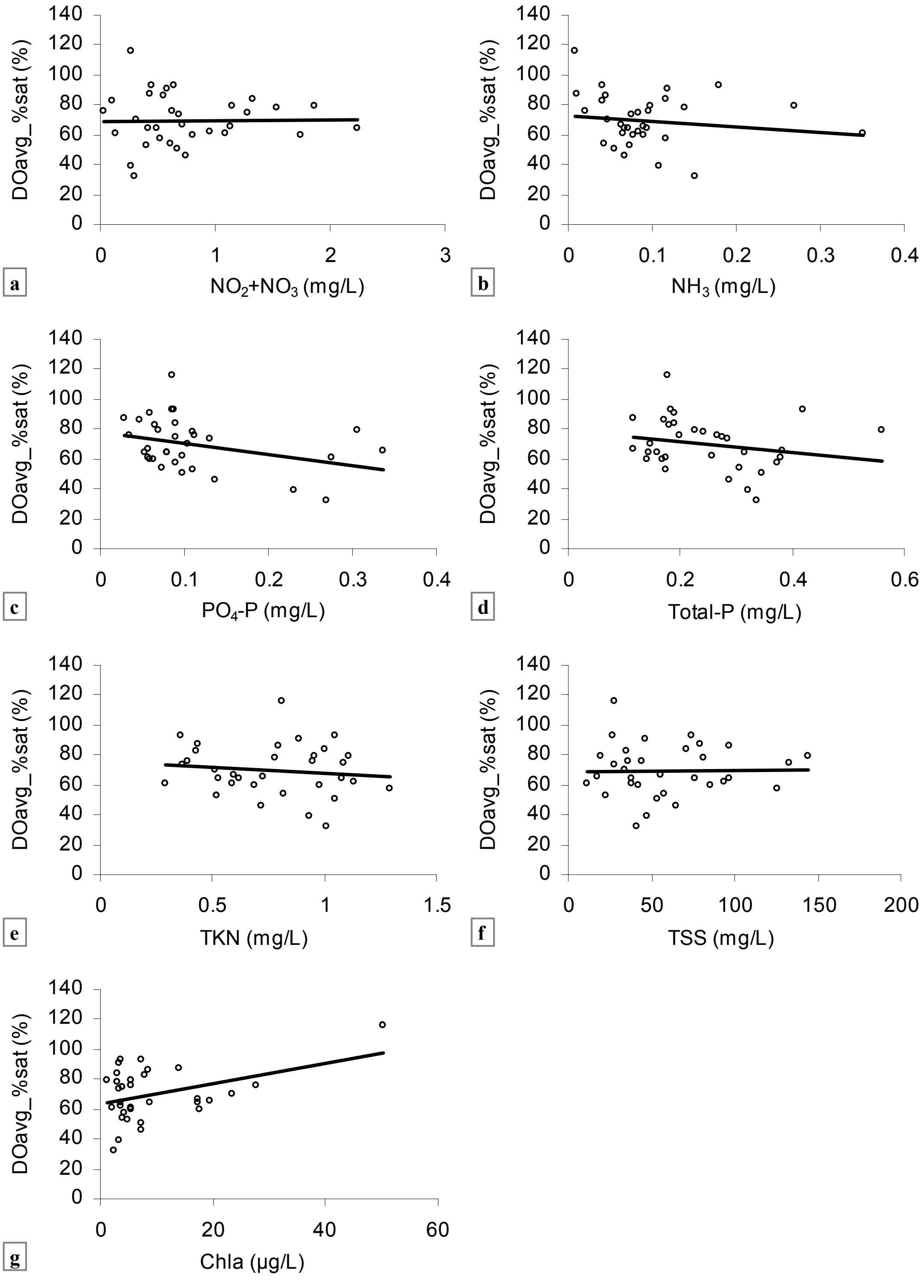


Figure 4-3 **DOavg_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations at stations 12086 and 12087**

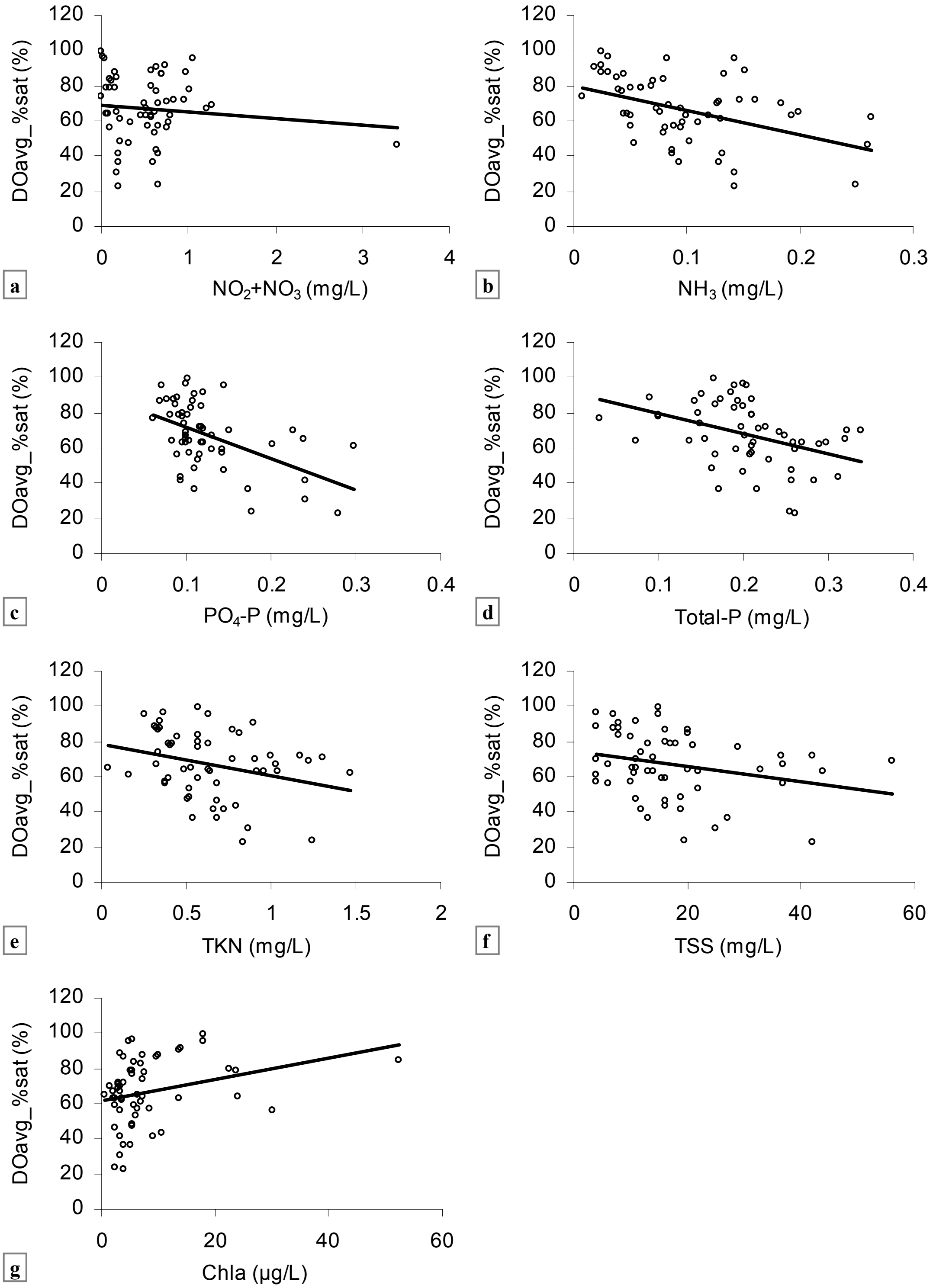


Figure 4-4 **DOavg_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations at stations 12079, 12082 and 12083**

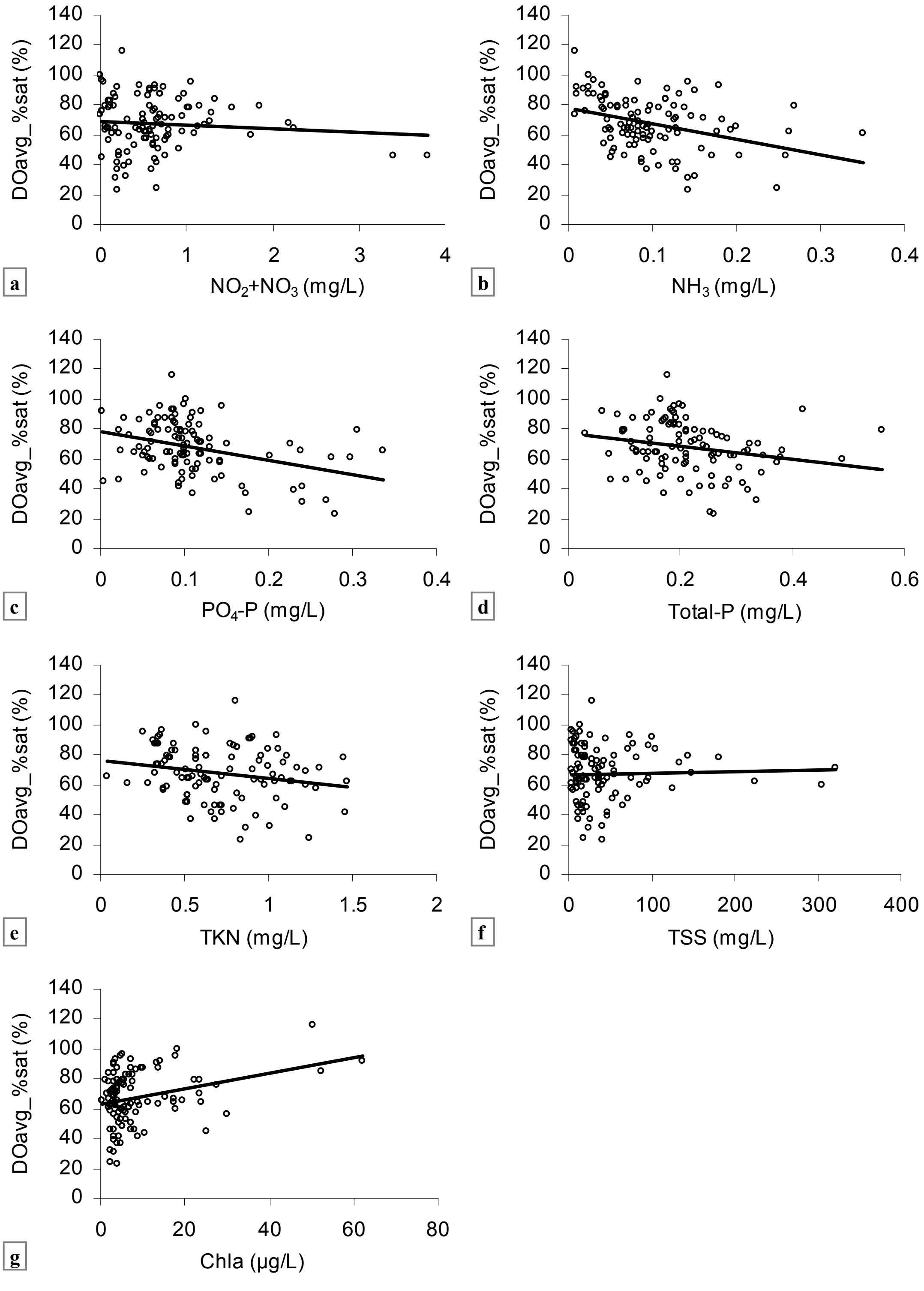


Figure 4-5 DOavg_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations in the Upper Reach

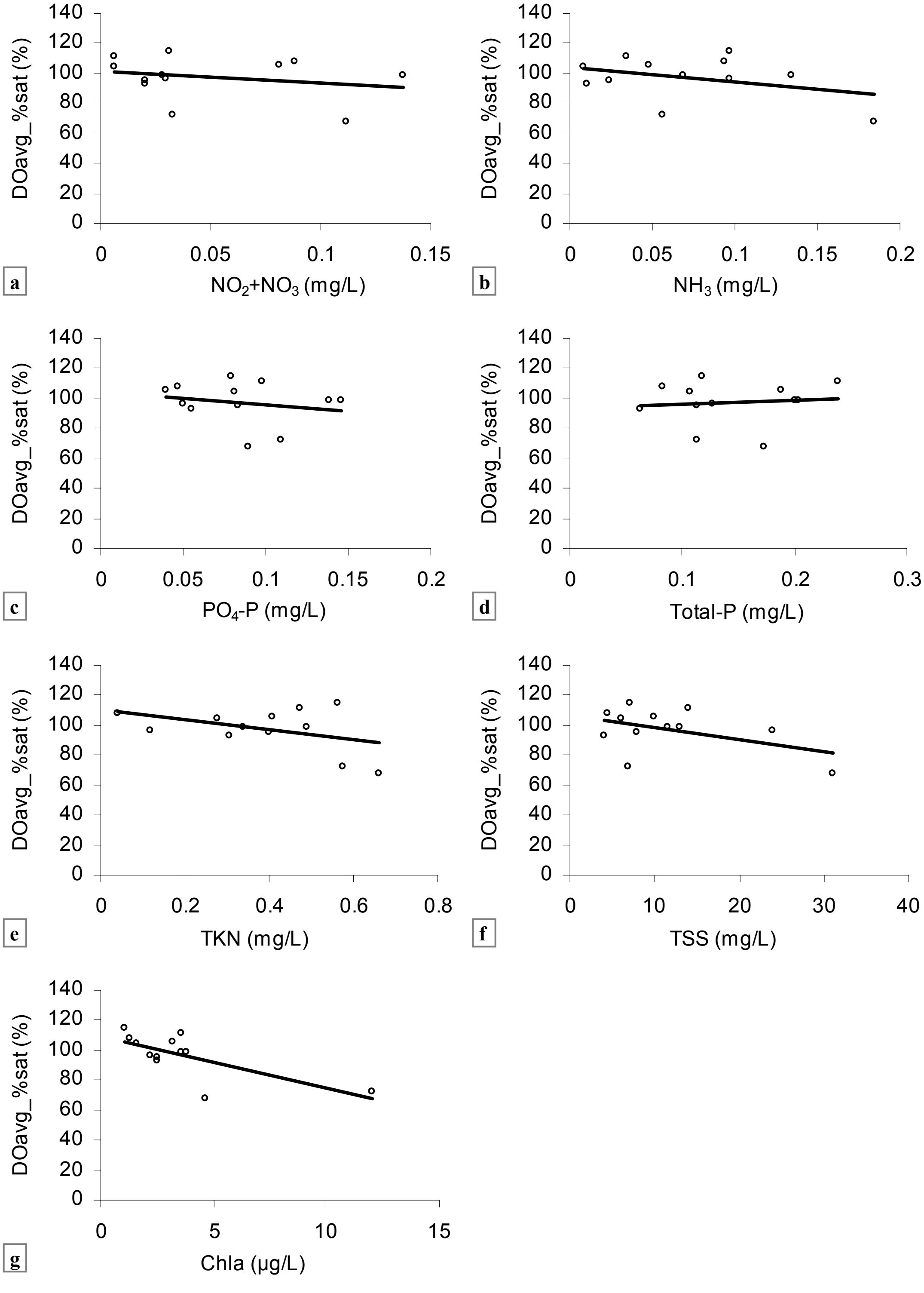


Figure 4-6 **DOavg_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations at station 12077**

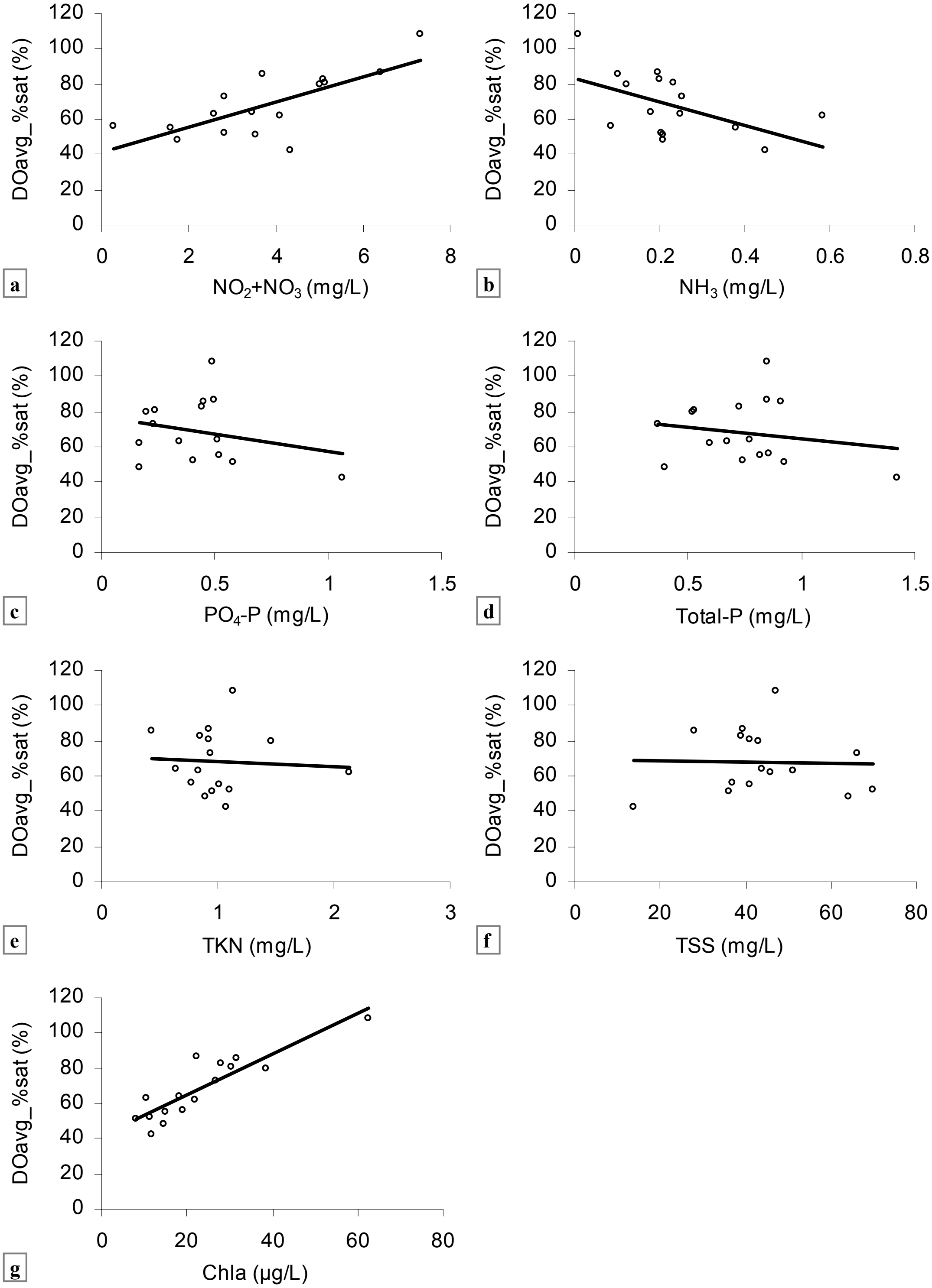


Figure 4-7 **DOavg_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations at station 12074**

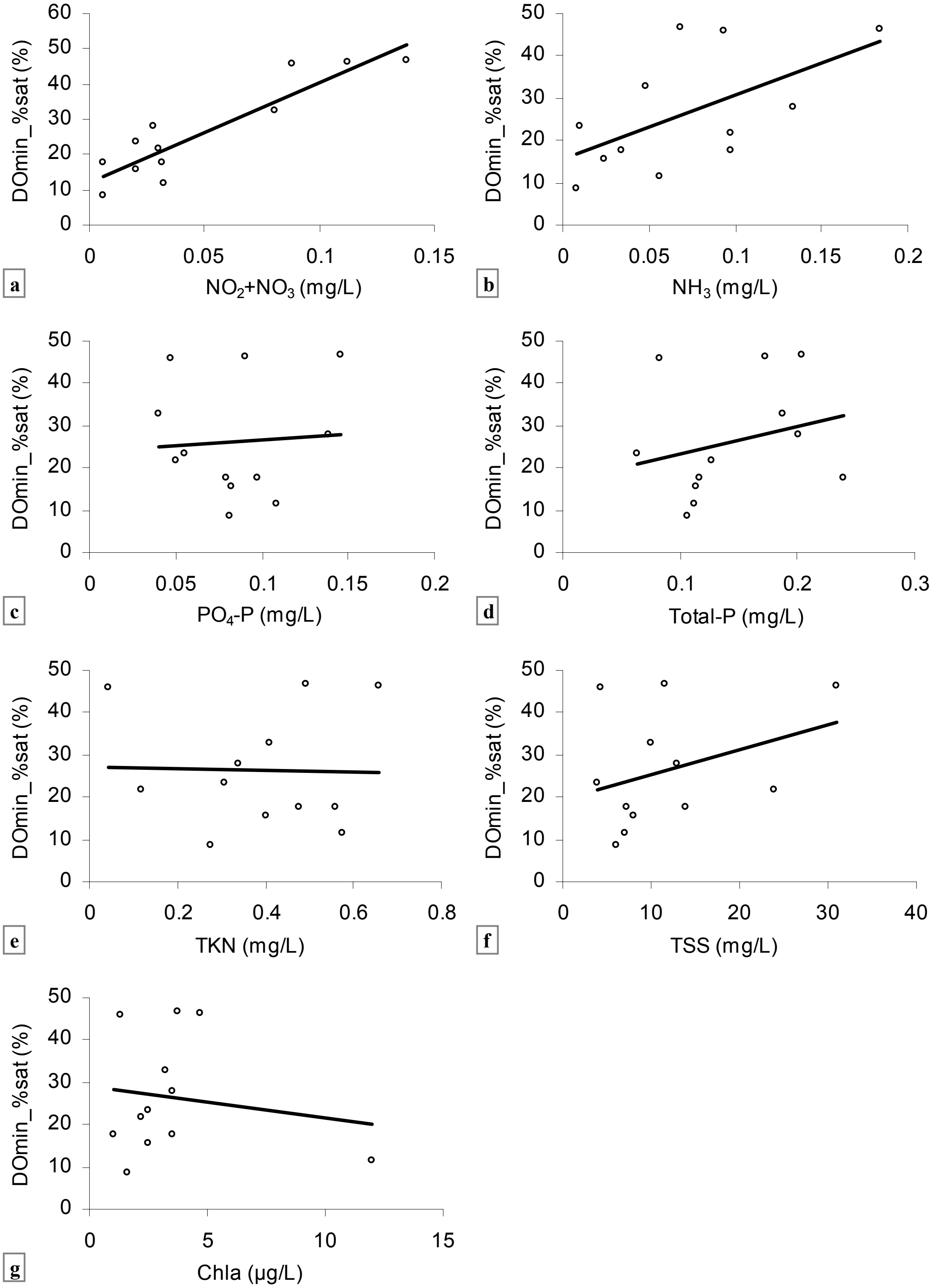


Figure 4-8 DOmin_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations at station 12077

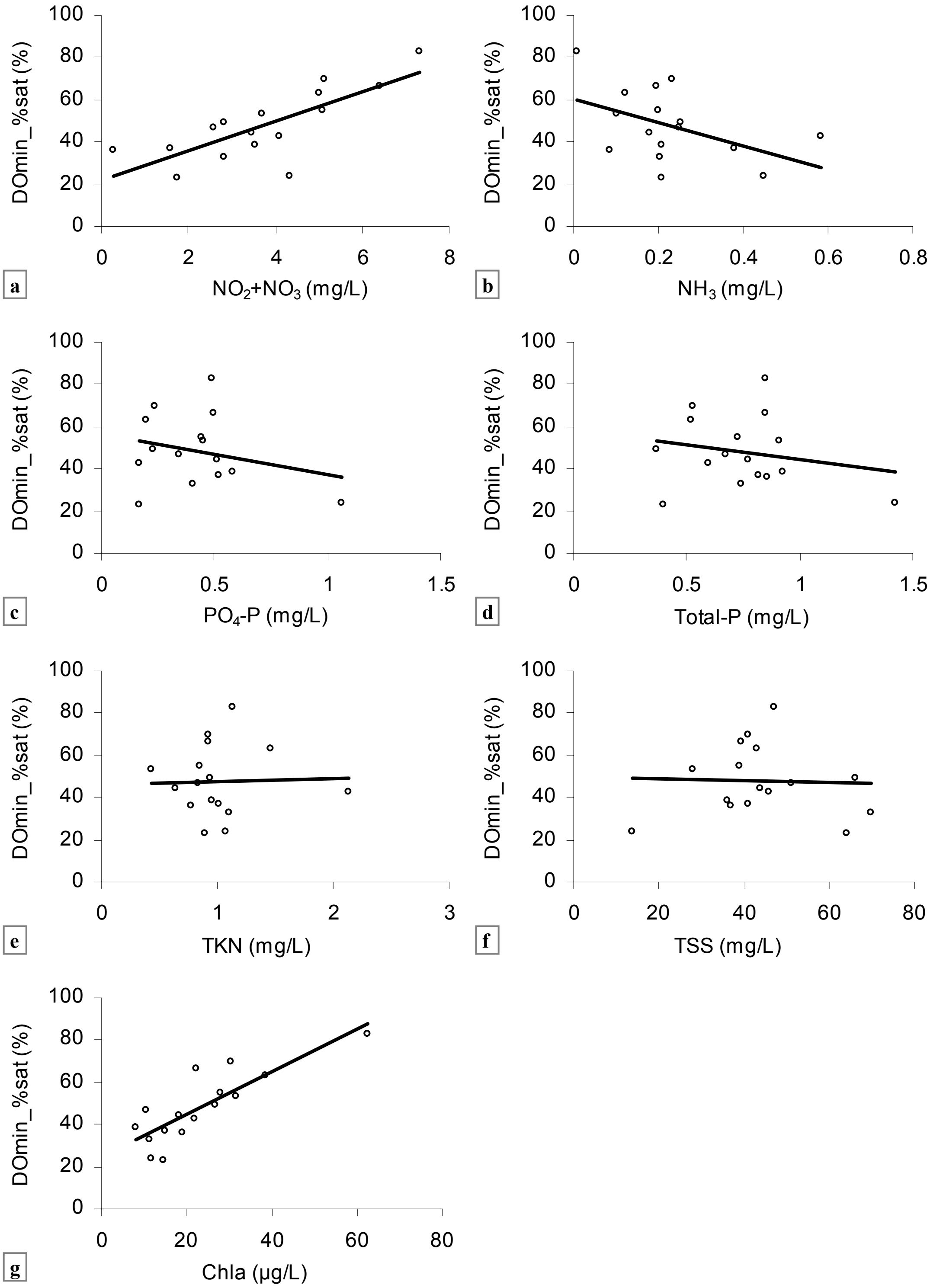


Figure 4-9 DOmin_%sat vs. NO_2+NO_3-N, NH_3-N, PO_4-P, Total-P, TKN, TSS or chlorophyll-α concentrations at station 12074

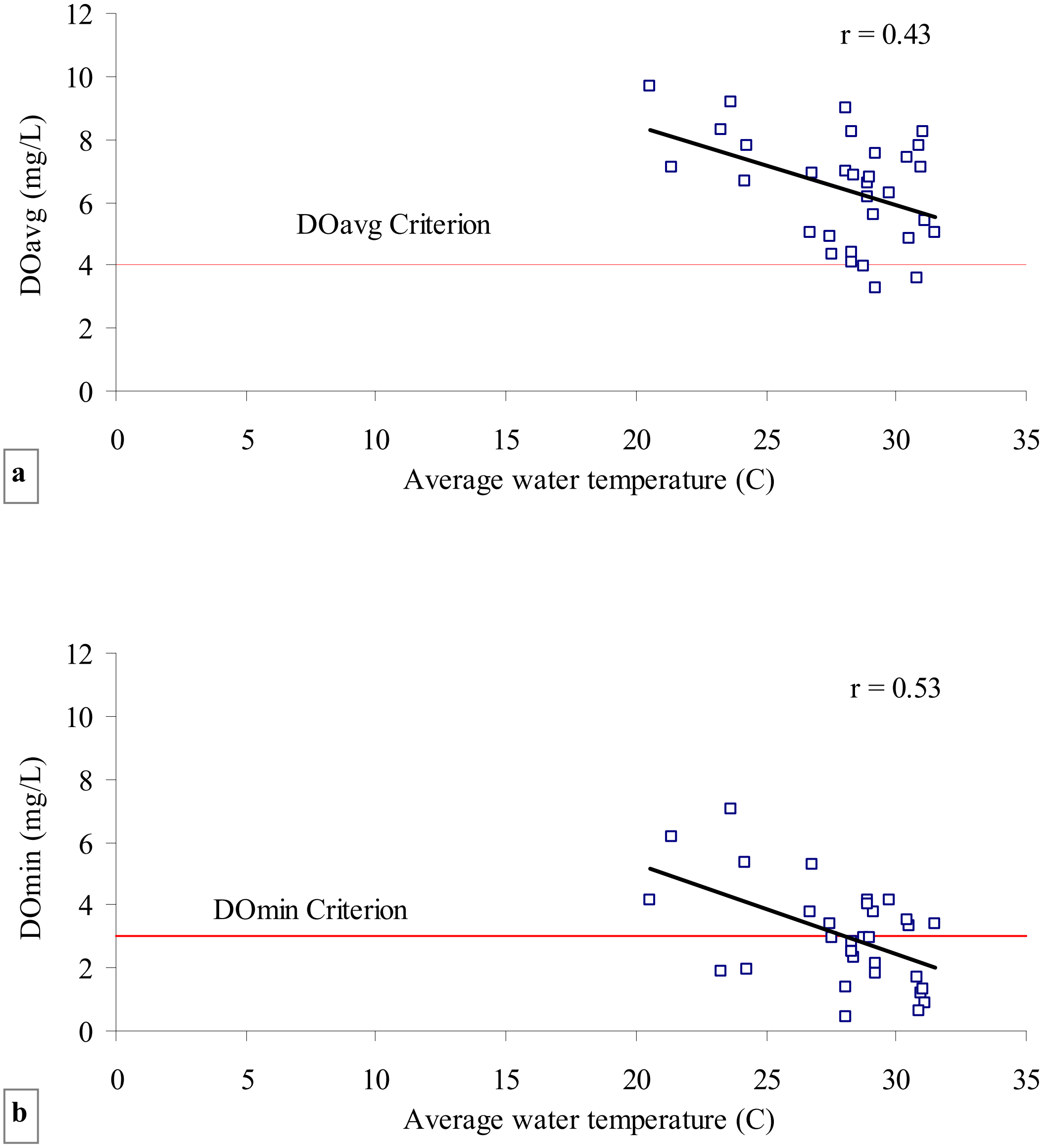


Figure 4-10 Average dissolved oxygen (DOavg) and minimum dissolved oxygen (DOmin) vs. average water temperature in Lower Reach.

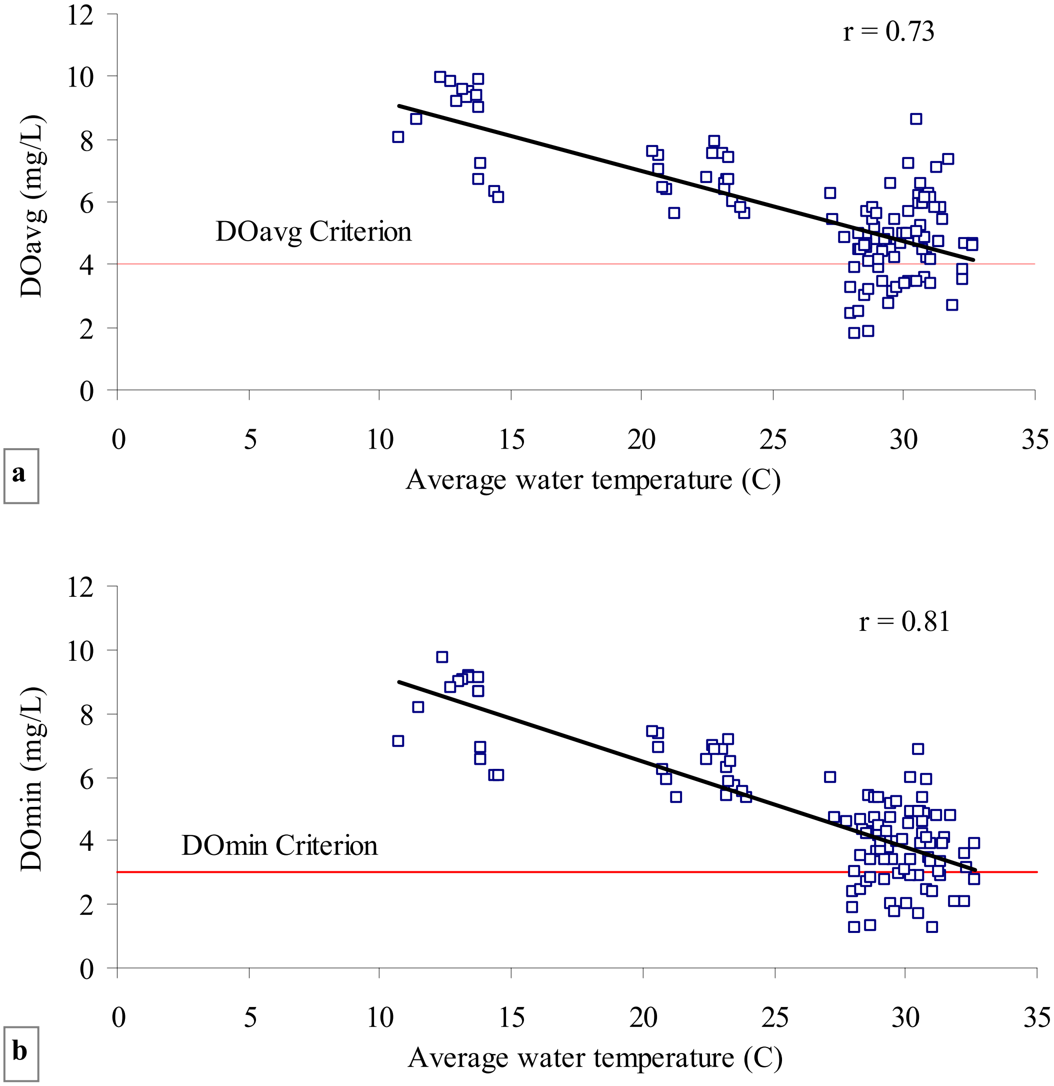


Figure 4-11 Average dissolved oxygen (DOavg) or minimum dissolved oxygen (DOmin) vs. average water temperature in Upper Reach.

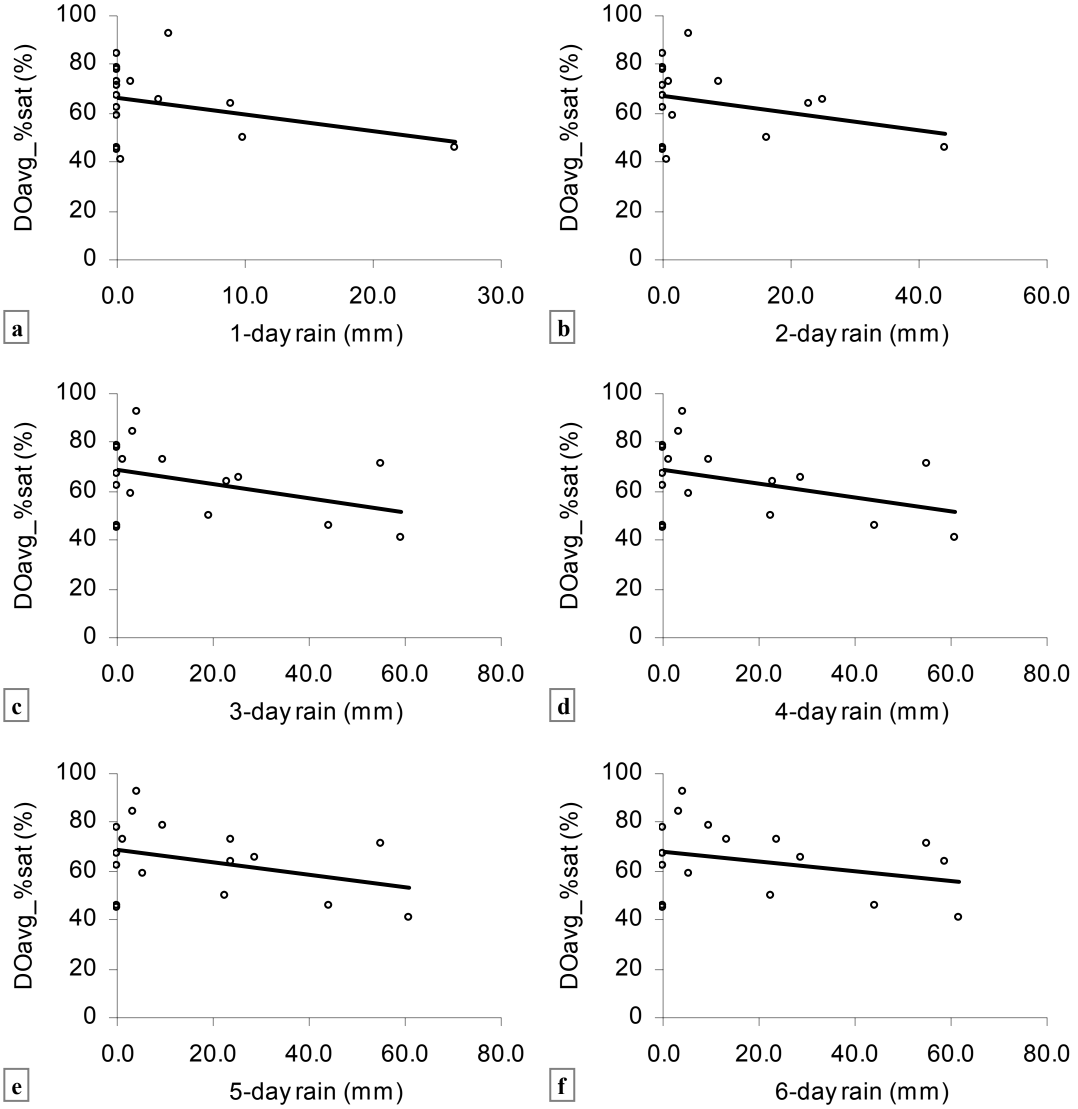


Figure 4-12 DOavg_%sat vs. cumulative precipitation at station 12090

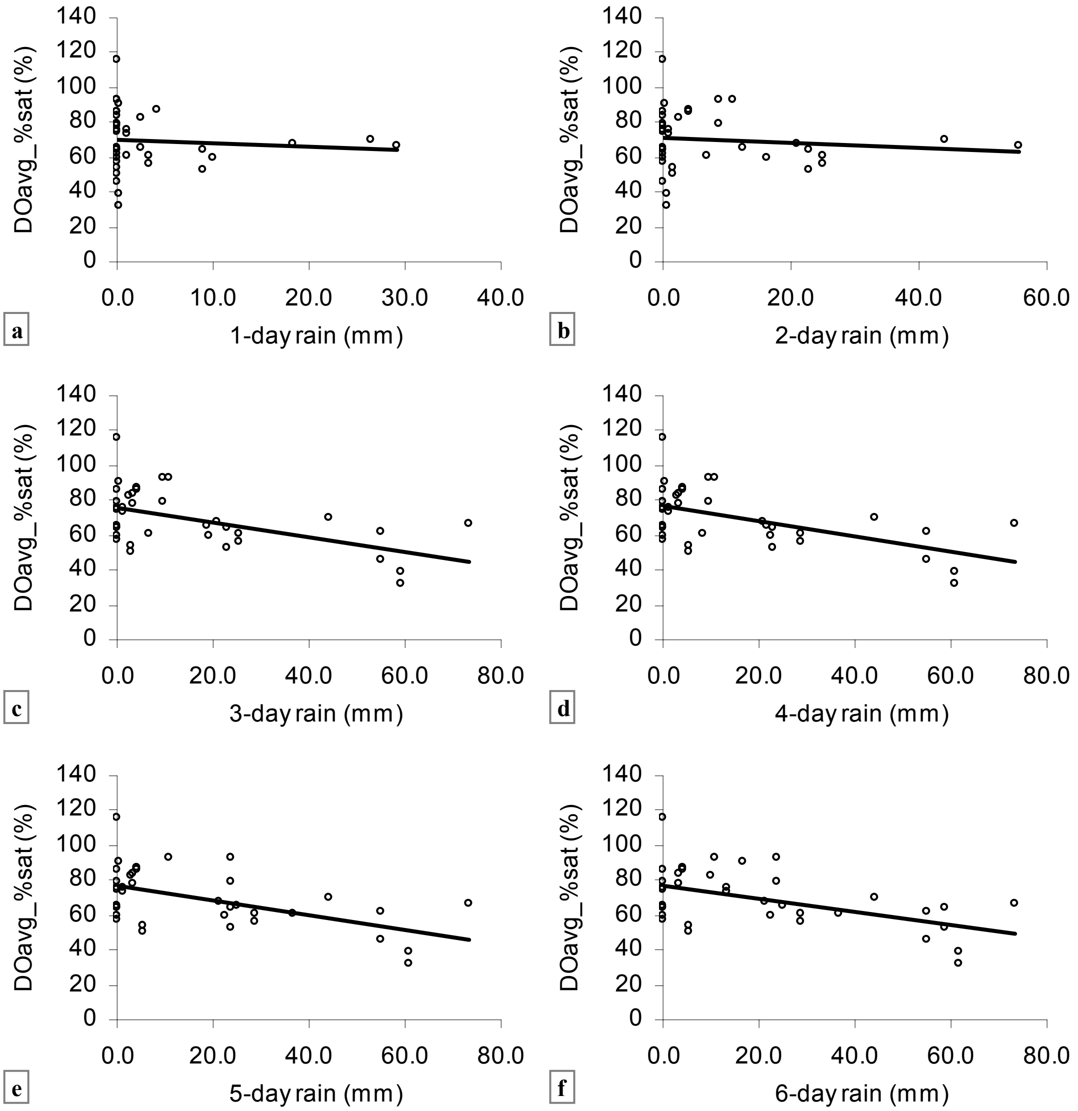


Figure 4-13 DOavg_%sat vs. cumulative precipitation at stations 12086 and 12087

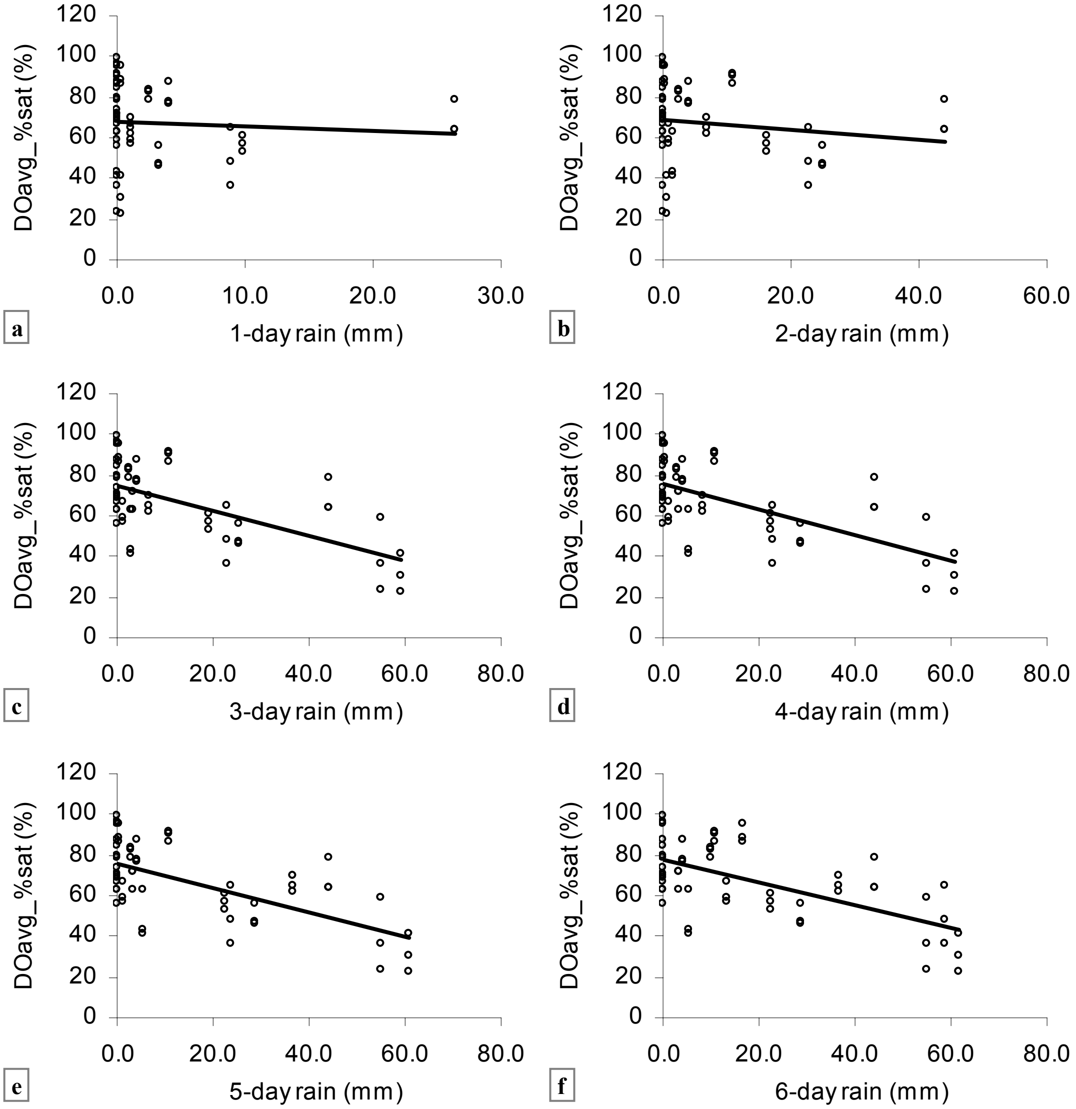


Figure 4 -14 DOavg_%sat vs. cumulative precipitation at stations 12079, 12082 and 12083

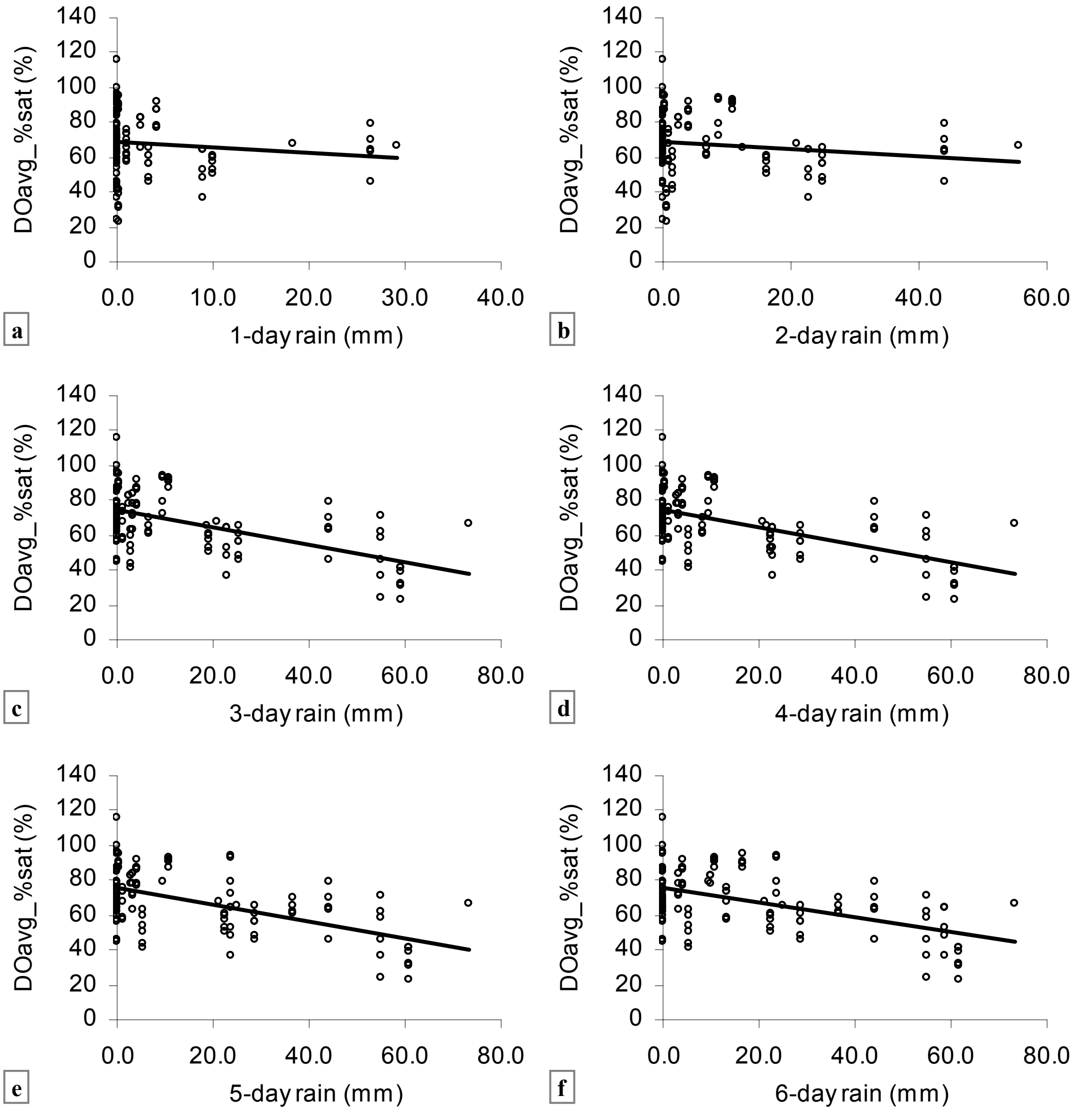


Figure 4-15 DOavg_%sat vs. cumulative precipitation in the Upper Reach

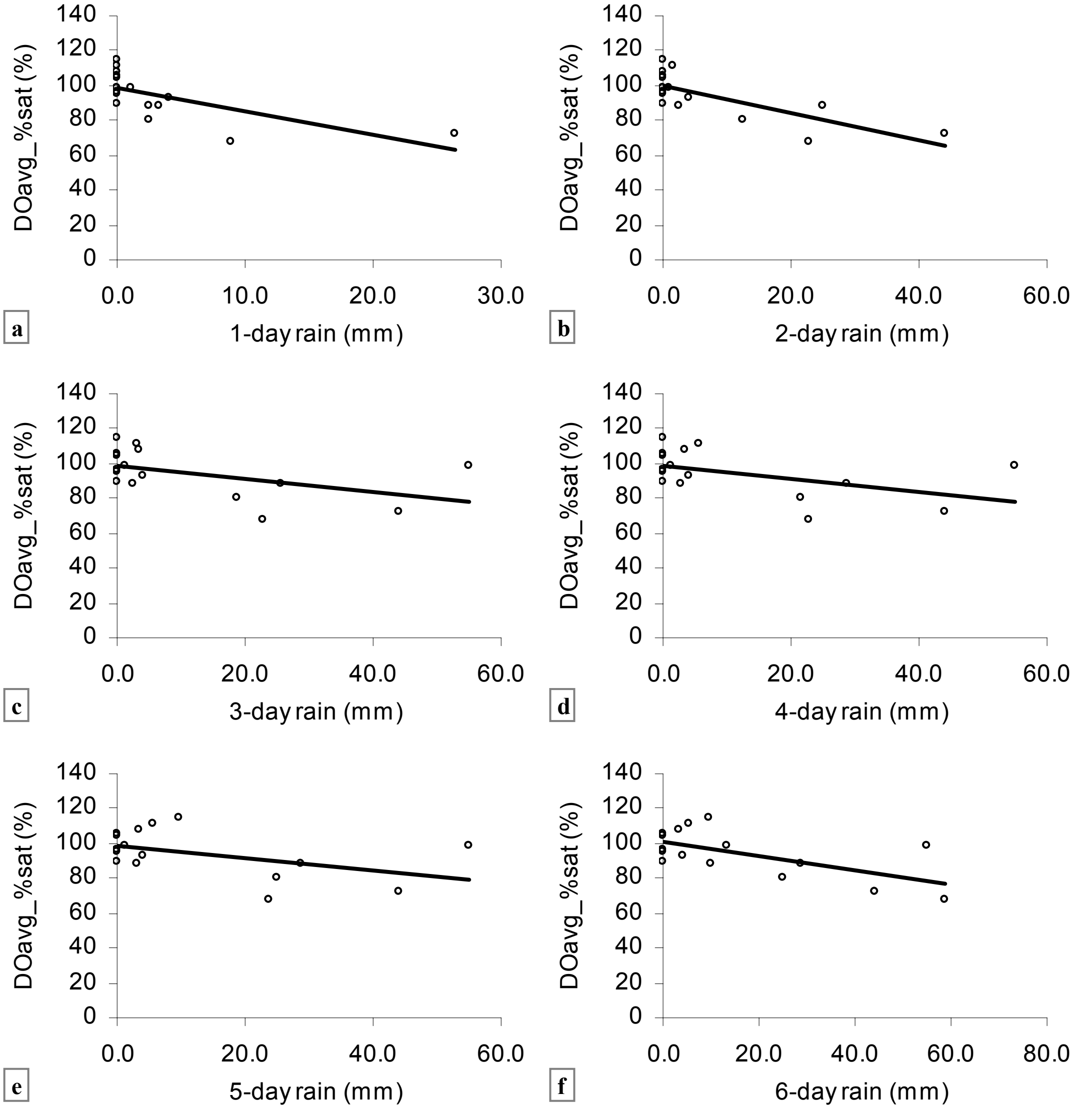


Figure 4-16 DOavg_%sat vs. cumulative precipitation at station 12077

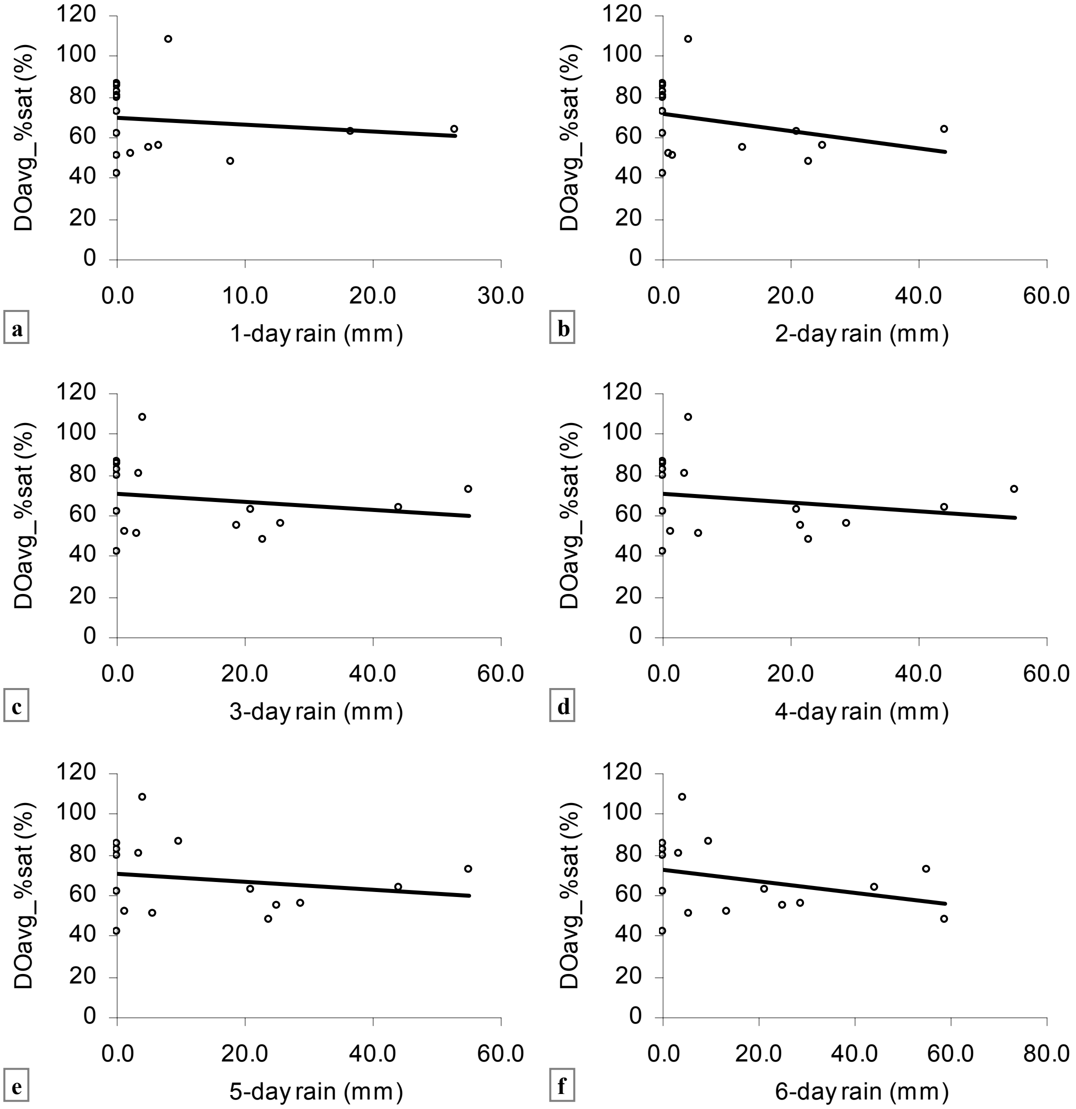


Figure 4-17 DOavg_%sat vs. cumulative precipitation at station 12074

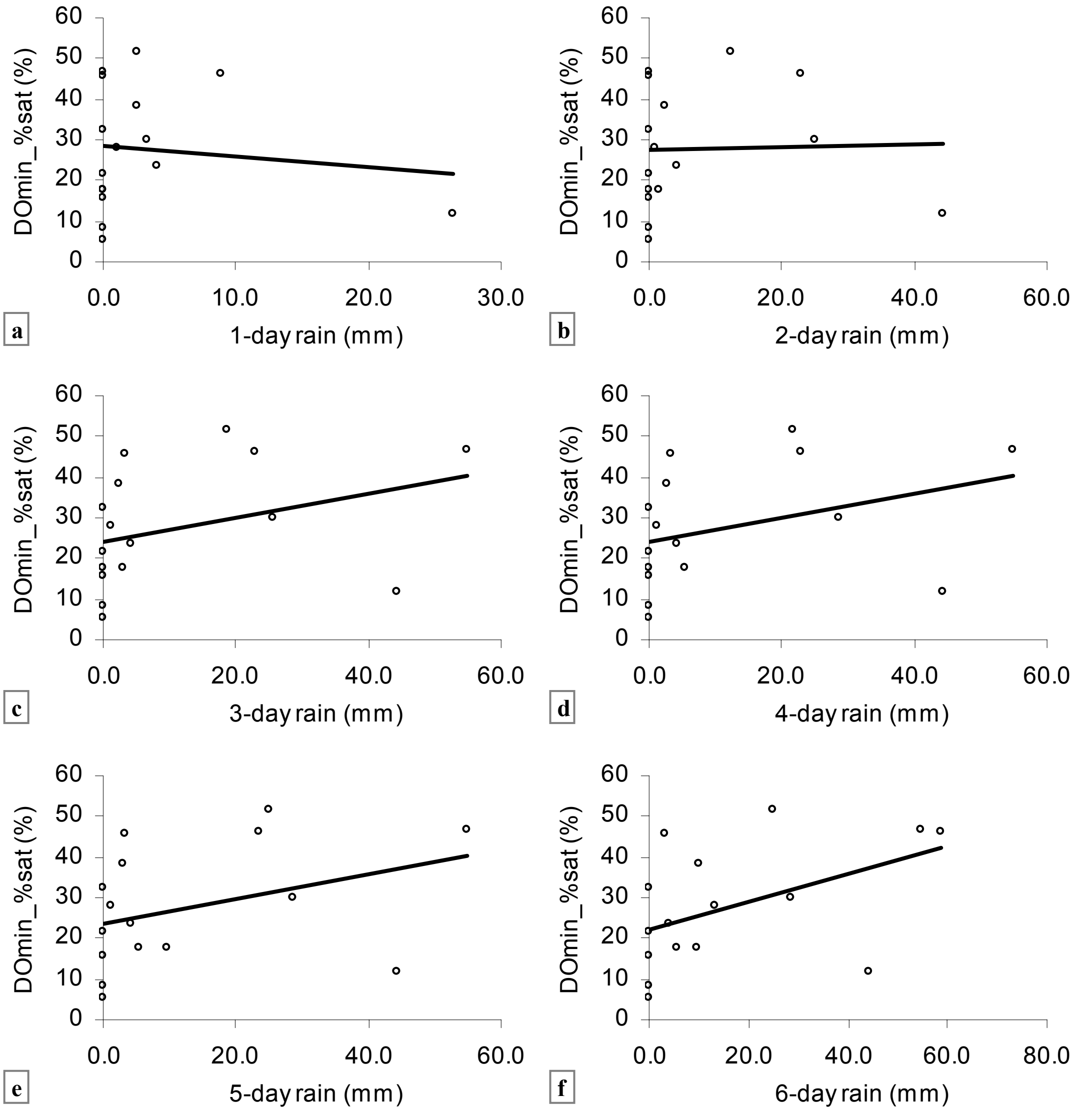


Figure 4-18 DOmin_%sat vs. cumulative precipitation at station 12077

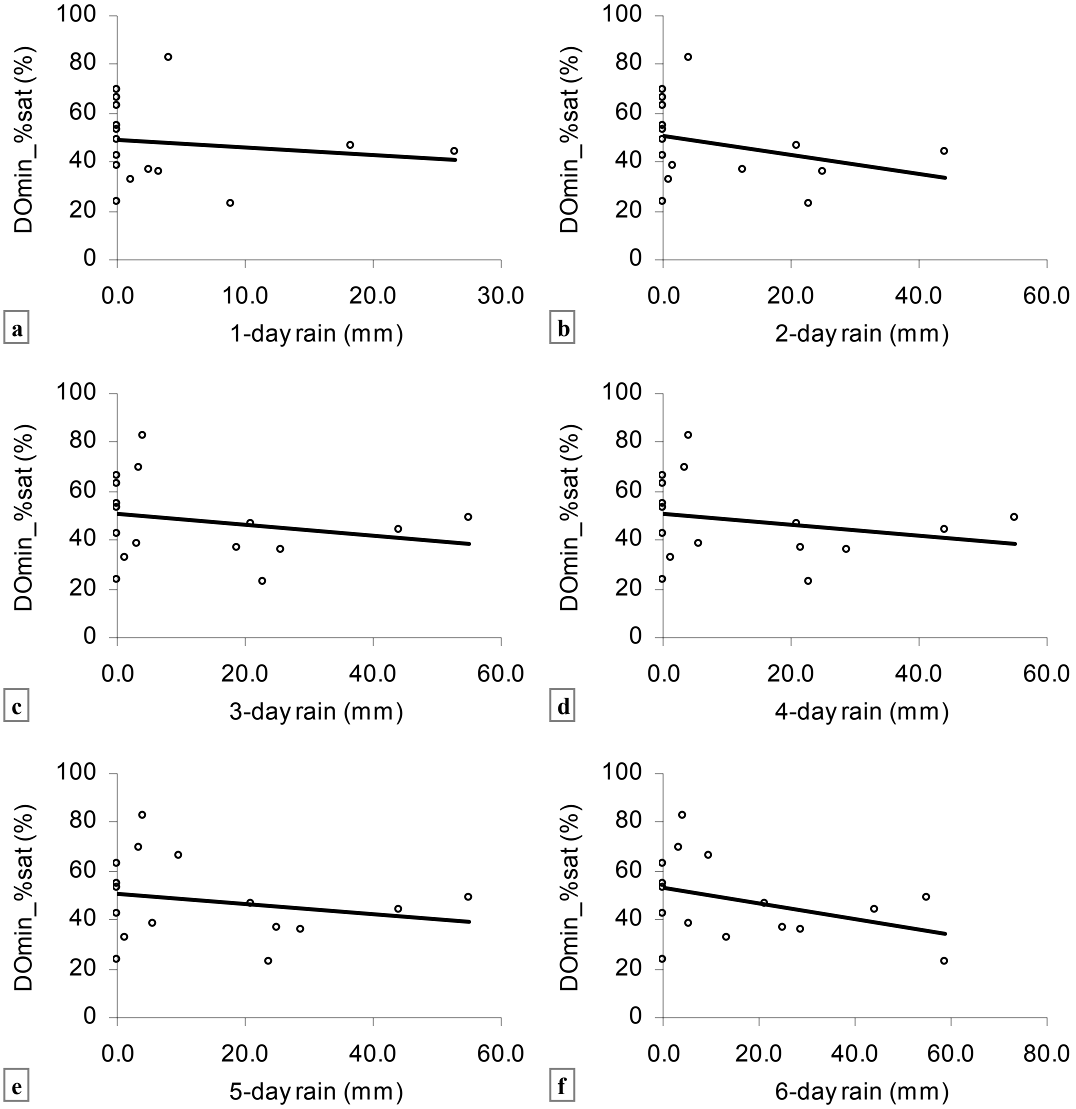


Figure 4-19 DOmin_%sat vs. cumulative precipitation at station 12074

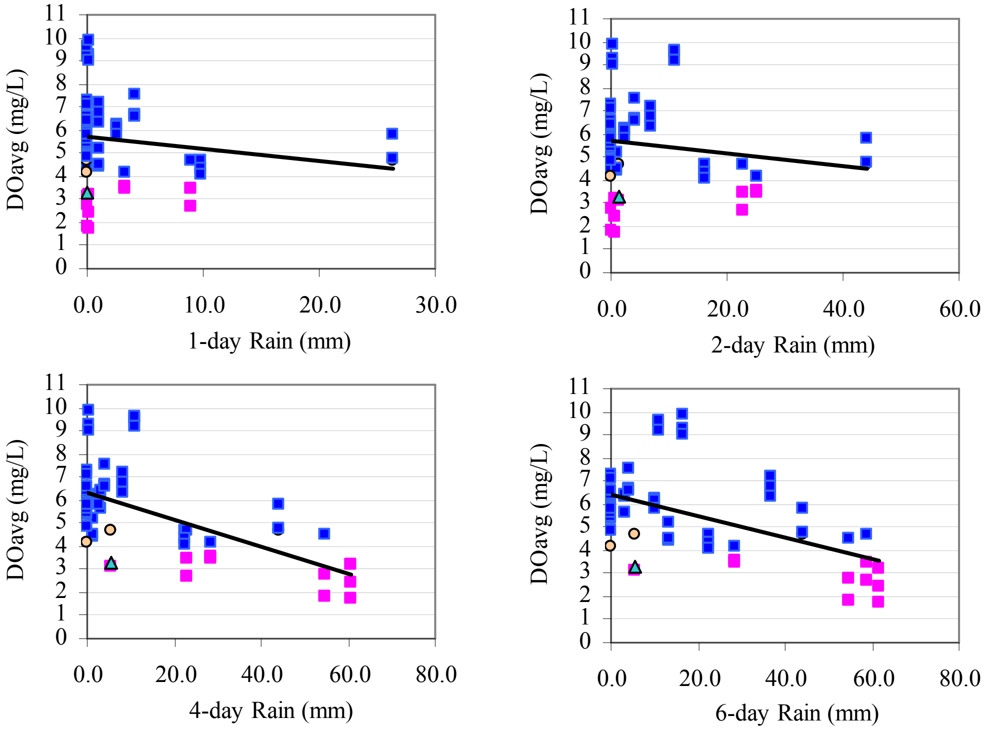


Figure 4-20 **Relationship of DOavg to cumulative precipitation at stations 12079, 12082 and 12083. Note that pink square refers to DO exceedance of both average and minimum criteria; circle to DO exceedance of minimum criterion only; triangle to DO exceedance of average criterion only; and blue square to no exceedance.**

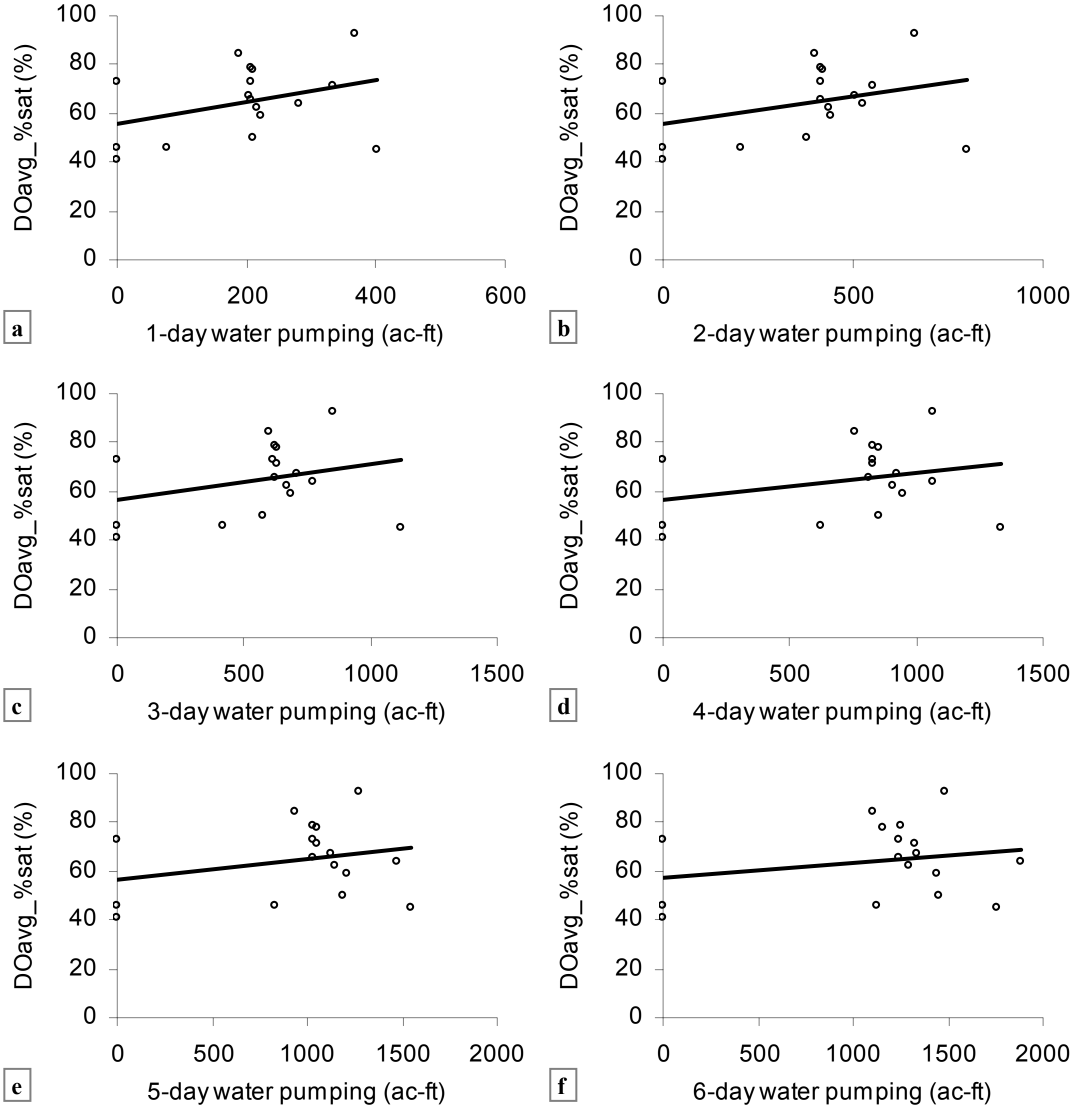


Figure 4-21 Relationship of DOavg_%sat to water pumping at Shannon Pump Station, station 12090

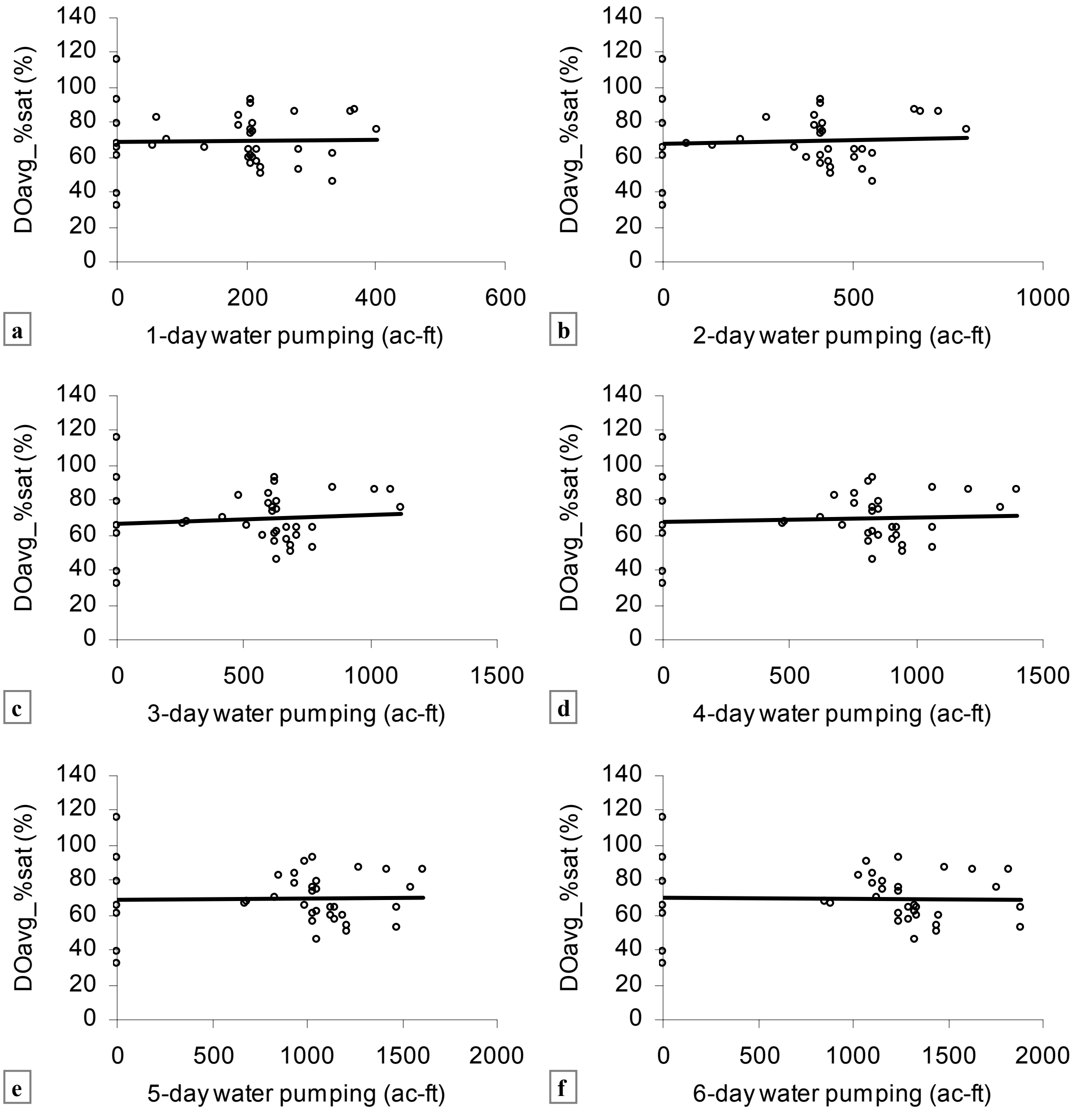


Figure 4-22 Relationship of DOavg_%sat to water pumping at Shannon Pump Station, stations 12086 and 12087

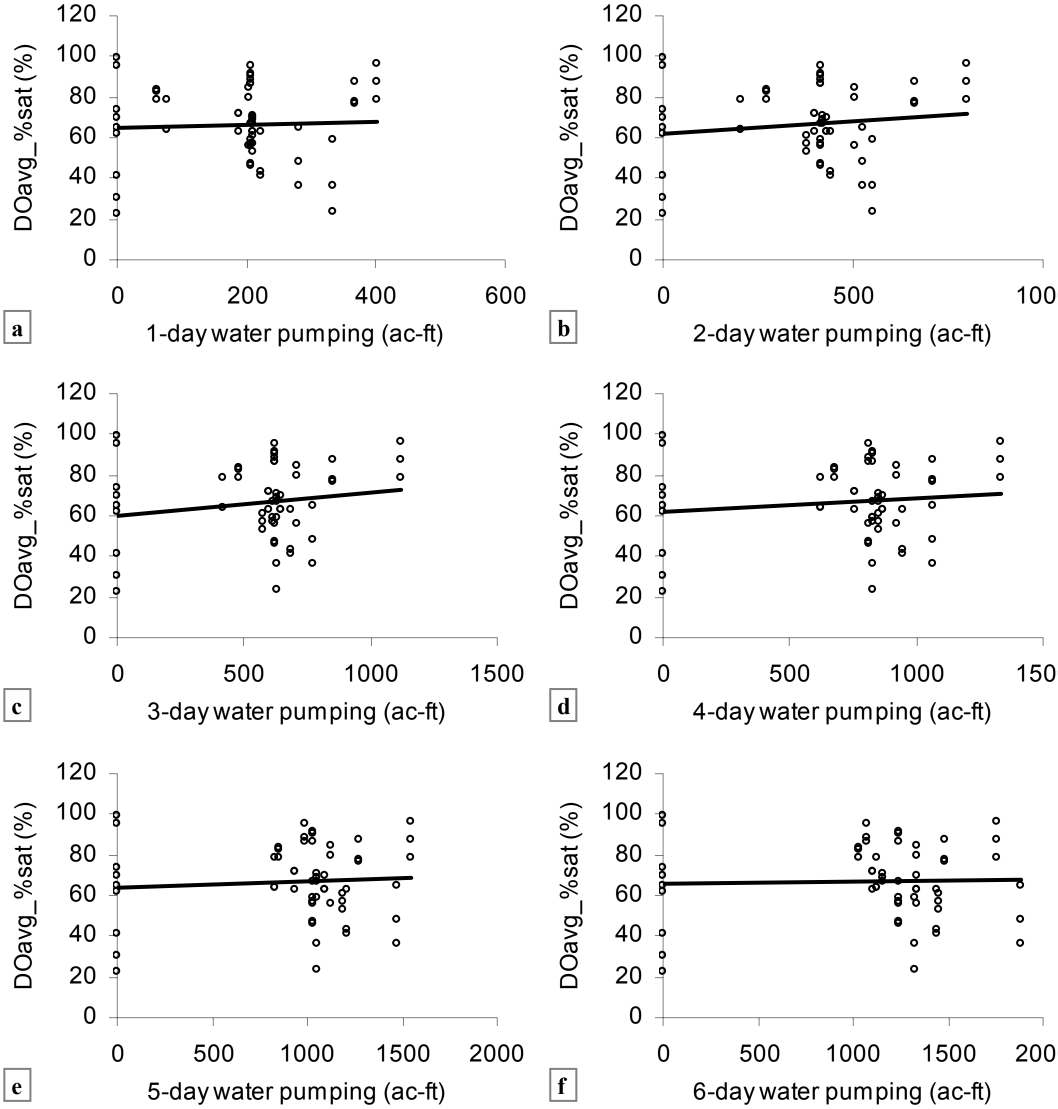


Figure 4-23 Relationship of DOavg_%sat to water pumping at Shannon Pump Station, stations 12079, 12082 and 12083

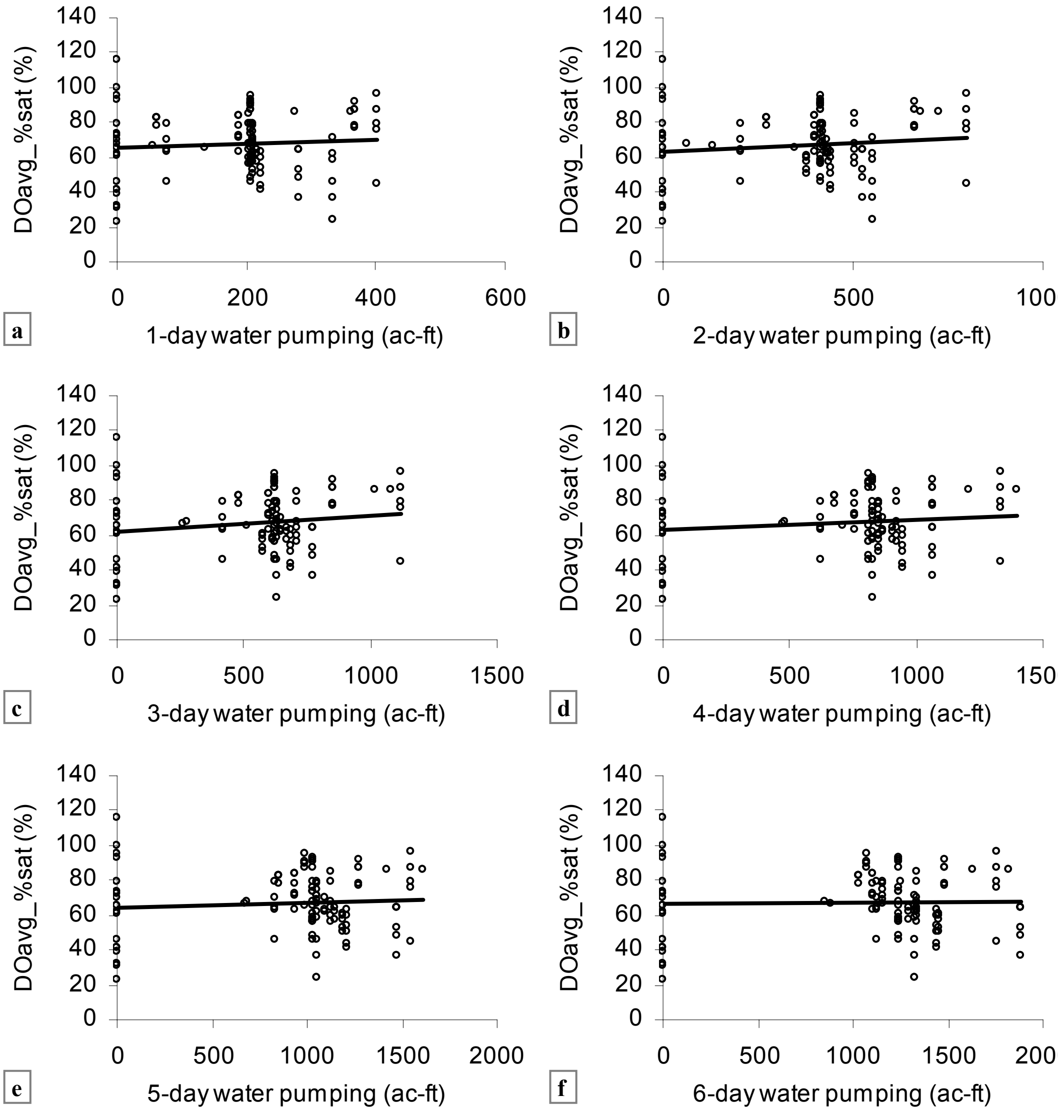


Figure 4-24 Relationship of DOavg_%sat to water pumping at Shannon Pump Station, Upper Reach

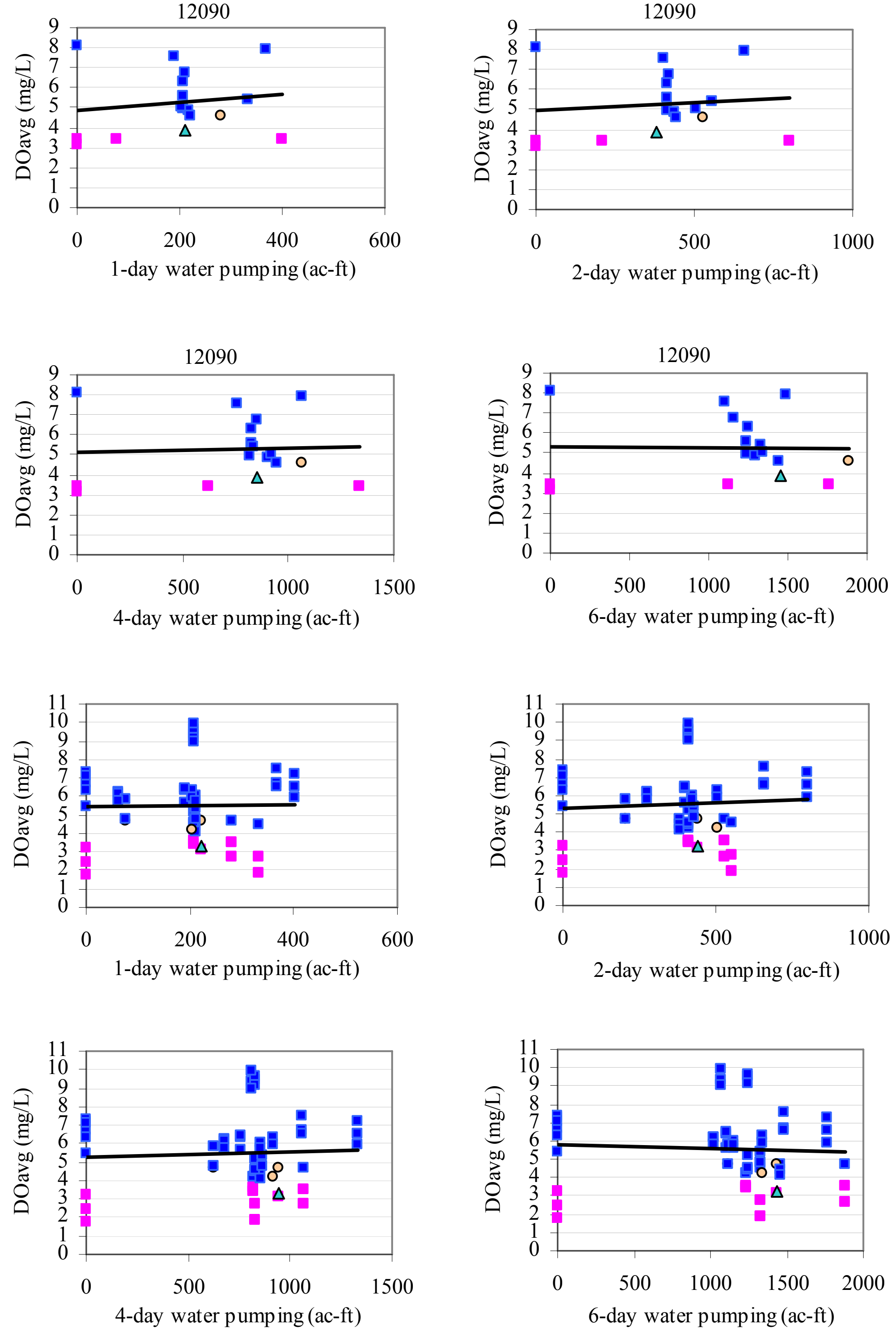


Figure 4-25 **Relationship of DOavg to water pumping at Shannon Pump Station; station 12090; stations 12086 and 12087; and stations 12079, 12082 and12083. Note that red square refers to DO exceedance at both avg and min; circle to DO exceedance at min; triangle to DO exceedance at avg; and blue square to non-exceedance.**

SECTION 5

SELECTION AND VALIDATION OF THE DISSOLVED OXYGEN MODEL

For dissolved oxygen TMDLs the allocation process is typically conducted using mechanistic computer models. These models provide analytical abstractions (or simulations) of the real system—for this situation Upper Oyster Creek. Mechanistic models, also referred to as process models, are based on theoretical principles that provide for representation of governing processes that determine the response of certain state variables (model outputs). For this project, dissolved oxygen (DO) is the primary output of interest, though other state variables (e.g., streamflow, water temperature, biochemical oxygen demand, ammonia, and phytoplankton) will also be of interest. Under circumstances where the governing processes are acceptably quantifiable, as is the case for dissolved oxygen, the mechanistic model provides understanding of important biological, chemical, and physical processes in the real system (that is, Upper Oyster Creek) and predictive capabilities to evaluate alternative allocations of pollutant load sources to meet TMDL objectives.

This report section includes two topics. First, the selection process and selected dissolved oxygen model will be discussed. Second, the validation process for the selected model will be discussed and results of the validation process presented, including a sensitivity analysis.

5.1 Model Selection Process

Three models accepted by TCEQ and EPA Region 6 (QUALTX, QUAL2K, and Hydrologic Simulation Program–FORTRAN or HSPF) were considered for use on this project. 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-hr average DO is the primary state variable of concern. 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), and has replaced QUAL2E. QUAL2K has similar capabilities to those of QUALTX with the added dimension of simulating diel variations in water quality. HSPF is supported in BASINS and is a dynamic watershed and hydrologic/water quality model with capabilities to simulate pollutant loadings and water quality on a watershed basis in a continuous mode that includes wet-weather conditions. All three models would be considered reliable and in conformance to best available, practicable science as defined in EPA (2003).

The objective of the model selection process for the DO TMDL is to determine the simplest mathematical model that represents the conditions under which DO exceedances occur and that can be applied to perform the TMDL allocation. By their nature and inherent construct, all three DO models provide the predictive capabilities necessary to perform TMDL allocations. Hence, factors determining model selection concerned the hydrologic and water quality characteristics of Upper Oyster Creek, particularly those characteristics during times of exceedance of the DO criteria. Pertinent factors considered in the model selection process and largely presented earlier in this report 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 DO exceedances during the assessment monitoring conducted in year 2003–2005 (Table 3-3) were usually associated with the 24-hr absolute minimum DO criterion, though for a couple of 24-hr data events the exceedance involved both the minimum DO criterion and the 24-hr average DO criterion. For the 2 stations used in assessing the Lower Reach and a total of 32 assessment events, 15 DO exceedances were observed. Thirteen exceedances involved solely the minimum criterion and 2 exceedances included both the minimum and average criteria.
- In contrast to the Lower Reach, the DO exceedances in the Upper Reach during the same assessment monitoring period occurred predominately with both the average criterion and the absolute minimum criterion for a 24-hr data event. For the six stations used during the assessment monitoring of the Upper Reach and 95 assessment events, a total of 24 exceedances were observed. Four exceedances involved only the 24-hr average DO concentration, 4 exceedances involved only the absolute minimum criterion, and 16 exceedances involved the average and minimum criteria.
- In both reaches, the temporal DO concentration pattern for the vast majority of 24-hr events exhibited lowest concentrations about the time of sunrise and maximum concentrations in mid to late afternoon. The DO 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 DO concentrations. This cyclic pattern of the DO results from dominance of photosynthetic activity and oxygen production during daylight hours and a dominance of respiration and oxygen utilization in the absence of sunlight.
- The occurrences of DO 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 DO exceedances are associated with increased water temperatures that prevail from approximately May through September. Available data indicate that DO exceedances occur under non-runoff influenced conditions but also in association with runoff conditions. Despite a relative abundance of data, what can not be deciphered from existing data are the factors that are causing the DO exceedances, since elevated water column concentrations of oxygen demanding substances (i.e., NH_3-N and CBOD) and SOD rates do no 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 to potentially 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 area all add to the complexities of that system and all these have some role of unknown extent in the observed exceedances.

Model selection for the Lower Reach was based on the prevalence of exceedances associated with the 24-hr minimum DO criterion and the occurrence of these exceedances under low and base flow conditions. The dominance of exceedances of the absolute minimum DO criterion in the Lower Reach necessitated choice of a model that allowed the simulation of diel fluctuations in DO. The QUALTX model is the standard steady-state dissolved oxygen model employed by TCEQ; however, that model does not have capabilities to simulate diel water quality fluctuations. For the Lower Reach QUAL2K was selected as the model of choice for the DO TMDL based on its capabilities to simulate diel DO fluctuations under low and base flow conditions.

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 the dynamic model HSPF, but the poorly understood causes of DO 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 through the adaptive process of the implementation plan, it may become beneficial to develop and apply a dynamic water quality model to the Upper Reach.

QUAL2K is a relatively recent model that was developed to provide a modernized version of QUAL2E, a long standing EPA supported model that can not 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. QUAL2K version 2.04 was applied to develop this TMDL.

5.2 Background to Model Validation Process

Model calibration and verification, which collectively are referred to as validation, 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. (from Thomann and Mueller, 1987)

Hence, calibration is a systematic procedure of selecting model input parameters that result in model predictions that best match the observational data. In addition, the adjustments of input parameters should 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, expert judgment will be utilized.

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

In the event that the verification process indicates that the predictions of QUAL2K are unacceptable based upon visual inspection of graphical data comparisons, the model will be recalibrated to the original verification data sets and then verified against the original calibration data sets. While the recalibration process is not the preferred method of validating a model, this process recognizes the inherent difficulties of simulating dissolved oxygen in a receiving stream such as Upper Oyster Creek where under present conditions traditional point source contributions are of secondary importance and other sources and processes that are much more difficult to quantify dominate, regarding the dissolved oxygen exceedances that have been observed.

5.2.1 Validation Data

For purposes of obtaining data for validation of the selected DO model, intensive data collection efforts (intensive surveys) were conducted in the Upper Oyster Creek system in May and August 2004. In recognition of the hydrologic separation provided by Dam # 3, surveys were conducted separately for the Lower and Upper Reaches.

The two intensive DO 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 (Figure 5-1). These stations were located along the entire segment, since analyses of the 24-hr DO data collected in the Index Period of 2003 indicate DO excursions at several stations whose locations span the length of Segment 1245. One model support survey in each reach occurred within the 2004 Index Period (May 2004) and outside the Critical Period, and one occurred within the 2004 Critical Period (August 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 DO, 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,
- Flow determination from wastewater treatment facilities using on-site instrumentation and at two stream stations using GCWA records,
- Time-of-travel studies,
- Suspended algae productivity measurements, and
- Sediment oxygen demand (SOD) measurements (occurred August-September 2004 and May-July 2005).

Multisondes were deployed at all stations and programmed to log DO, temperature, specific conductance, and pH at 15-minute intervals. Automated samplers were deployed at all stations and programmed to retrieve four water quality samples at 6-hr intervals. Each set of four samples from stream stations were time composited into a single sample. At permitted discharge locations, each set of four wastewater effluent samples were flow composited based on discharge records. Due to the nature of the outfall at the Quail Valley Wastewater Treatment Plant, which discharges through a final detention pond that damps daily flow fluctuations, samples from this discharge were time composited. Composite samples were analyzed for nitrite+nitrate nitrogen (NO_2-N+NO_3-N), dissolved orthophosphate phosphorus (PO_4-P), total phosphorus (Total-P), dissolved ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), pheophytin-α, chlorophyll-α, 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), 20-day CBOD ($CBOD_{20}$), and chlorides. $CBOD_{20}$ was assumed to approximate ultimate CBOD (see for example, Ohio EPA, 2006). With the exception of the station at the Quail Valley Wastewater Treatment Plant, samples collected from wastewater treatment plant (WWTP) effluent stations were not analyzed for pheophytin-α or chlorophyll-α.

During each survey, a flow measurement was made at each stream station that had measurable velocities. However, accurate streamflow data were unattainable at station 12089 (old 2nd lift station) due to the complex nature of the GCWA's gate and culvert conveyance system. For stations 17685 (near the GCWA Shannon Pump Station) and 17373 (at the GCWA American Canal and the Second Lift Station), pumping records provided by the GCWA were used to determine streamflow. At the stations for monitoring effluent from permitted dischargers, the self-reporting data from each permit holder was used to obtain daily average discharge during the survey period. At the Quail Valley Wastewater Treatment Plant, effluent may be reclaimed for irrigation of a golf course. The irrigation water is removed from a detention pond that is downstream from the metering point of the Quail Valley discharge. Excess effluent beyond that used for irrigation purposes leaves the pond and enters Stafford Run through a conveyance that is not metered. During the surveys, the Quail Valley facility's effluent was sampled in the unmetered conveyance leaving the detention pond and effluent reaching Stafford Run was determined as the difference between the metered effluent and the metered irrigation pumping using records provided by Quail Valley Utility District.

Ancillary studies included suspended algae productivity studies at stations 12075, 12079, and 12083 (May and August 2004) and a sediment oxygen demand studies at stations 12090, 12086, 12083, 12079 and 12075 (August-September 2004). Additional SOD studies were performed at stations 12090, 12087, 12083, 12079, and 12074 during the 2005 Index Period (May-July). With the exception of the 2005 SOD study, each study was performed contemporaneously with the model surveys.

The data collected during each model support survey is provided in Adams and Hauck (2007).

5.2.2 Model Formulation and Input Data Requirements

QUAL2K solves a mass transport equation that describes the effects of advection, dispersion, sources, sinks, and kinetics for all water quality constituents being modeled. The model simulates non-uniform, steady flow, which does not allow flow to vary temporally, but does allow it to vary longitudinally due to discharges, tributary inflows, withdrawals (or abstractions), and incremental (or diffuse) flows (e.g., groundwater inflows). For this application the major water quality state variables (output) included in the QUAL2K applications were:

- dissolved oxygen
- temperature
- fast reacting CBOD
- organic nitrogen (equivalent to TKN – NH_3-N from measured data)
- ammonia nitrogen
- nitrate nitrogen (assumed equivalent to NO_2-N+NO_3-N from measured data)
- organic phosphorus (equivalent to total-P – PO_4-P from measured data)
- inorganic phosphorus (assumed equivalent to PO_4-P from measured data)
- phytoplankton (measured as chlorophyll-α in measured data)
- bottom algae biomass (only very qualitative measured data)
- total suspended solids
- specific conductance

As discussed in Section 2.7 (Aquatic Vegetation), portions of Upper Oyster Creek contain an abundance of aquatic plants. In addition to phytoplankton and bottom (or benthic) algae, which are both included in QUAL2K, the creek also contains sections that have an abundance of emersed and submersed macrophytes. While not the optimal solution, the practical necessity of including macrophytes in the modeling effort necessitated that macrophytes be included in the bottom algae variable of QUAL2K. The response of macrophytes, especially rooted species, to changes in water column nutrients would not be the same as the response of bottom algae, and that limitation is acknowledged in this effort. However, the inclusion of both macrophytes and bottom algae within the bottom algae variable in QUAL2K was not considered to represent a substantive compromise to the model's predictive capabilities.

QUAL2K represents CBOD as having both dissolved organic carbon with both fast and slow components and particulate organic carbon components, which is a distinction not captured with the traditional unfiltered CBOD test. Since only unfiltered CBOD analyses were performed as part of the data collection activities for this project, the following approach was taken to use the available $CBOD_{20}$ data. The slow CBOD component of QUAL2K was turned off, which is specified in the model by not entering values for any slow CBOD input data (see p. 39 of Chapra et al., 2006) and all CBOD was assumed to be in the fast component with no CBOD in the particulate component. As will be demonstrated in sensitivity results, since CBOD concentrations were generally low and often below the detection limit of 2 mg/L, this approach to model CBOD had virtually no impact on the model validation process. For the subsequent applications of the model, this approach of assuming all CBOD is in the fast component represents a conservative approach regarding DO predictions. For input to the model to describe stream headwater conditions and the effluent from point sources, the unfiltered $CBOD_{20}$ measurements were considered as representing the model's fast CBOD. For comparison to model predictions of ultimate CBOD, the $CBOD_{20}$ measured data from Upper Oyster Creek and its tributaries were used.

QUAL2K uses standard meteorological data and accepted heat-balance functions to predict water temperature on a diel basis. For Upper Oyster Creek, water temperatures predictions were initially consistently low when compared to observed temperatures despite concerted adjustment efforts that involved using various combinations of the alternative heat-budget functions and coefficients provided as options in QUAL2K. Acceptable water temperature predictions were obtained by adding a wind-sheltering coefficient that could be varied longitudinally along Upper Oyster Creek. The wind sheltering coefficient (WS) effectively reduced the wind speed acting upon the water surface, which reduced evaporation and consequentially reduced diel water temperature variations and increased average temperatures. The wind sheltering coefficient (WS) was implemented according to the following equation:

$$[\text{Wind speed used in heat budget}] = [\text{Observed wind speed}] * (1 - \text{WS})$$

where WS can have values between 0.0 and 1.0.

The use of the wind sheltering coefficient is defensible from two perspectives. First, the need for this project is not to develop the ability of QUAL2K for prediction of water temperature, but rather that reasonable water temperatures can be assigned that are reflective of the water quality conditions being simulated. In the State of Texas, applications of the other steady state model considered for the project, QUALTX, typically do not include temperature simulation, but rather the user specifies input to assign water temperatures in the system being modeled. Second, in the majority of instances, the wind sheltering coefficient values used in the model were higher in areas where trees were abundant along stream banks or the channel was more deeply incised. Therefore, the actual coefficient values often had a physically defensible basis for their magnitude.

QUAL2K contains a sediment diagenesis component that determines sediment oxygen demand (SOD) and sediment release rates of NH_3-N and PO_4-P. There are no model adjustment input coefficients controlling the sediment diagenesis component that allow the user means of adjusting predicted SOD rates and sediment nutrient releases. QUAL2K does, however, have an input switch that allows that component to be turned off. Because the sediment diagenesis component did not appear to give reasonable SOD and sediment nutrient releases for Upper Oyster Creek, the component was turned off, and the model feature was used that allows direct input of SOD rates and sediment release rates of NH_3-N and PO_4-P.

QUAL2K allows user specification of several options for calculation of atmospheric reaeration (or simply reaeration) rates on a global basis and also allows the user to prescribe unique reaeration rates on an individual stretch basis through data input.[5] For this application the Texas reaeration equation (Cleveland, 1989) was used whenever water depths were within the range for which the equation was developed (0.2 m to 1.0 m):

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[5] QUAL2K in a similar fashion to QUALTX uses the nomenclature of reach to specify a portion of a conveyance channel that is represented in the model as having the same channel dimensions and hydraulic characteristics. To avoid confusion with the designation of Upper Oyster Creek into a Lower Reach and an Upper Reach, the term "stretch" will be used in place of "reach" within the body of the text. Notwithstanding this distinction, some tables taken directly from QUAL2K retained the conventional labeling of "reach."

$$k_\alpha = 1.923 \frac{U^{0.273}}{H^{0.894}}$$

where k_α is reaeration rate at a temperature of 20°C, U is velocity (m/s); and H is depth (m). For water depths over 1.0 m, the O'Connor-Dobbins equation was used. In the area around the dams in the Upper Reach, stream velocities and water depths resulted in calculated reaeration rates less than those determined from a minimum oxygen transfer coefficient of 0.6 m d^{-1} (Thomann and Mueller, 1987). Note that to convert to a reaeration rate, the minimum oxygen transfer coefficient was be divided by average water depth. Because Oyster Creek is also wide in the area around the dams and has open exposure to the wind, the Banks-Herrera formula (Chapra et al., 2006) was used to incorporate an additive amount of reaeration due to the wind. Because some wind sheltering does occur in this area from adjacent homes and trees, only 75 % of the wind reaeration determined from the Banks-Herrera formula was used. The minimum oxygen transfer coefficient with wind enhanced reaeration was also applied to a pond system on Stafford Run that is described in more detail in Section 5.3.1 (Background Discussion of Lower Reach).

In practice, the definition of appropriate reaeration methods and values required multiple operations (runs) of the model for a given condition. The multiple runs were necessitated by the fact that QUAL2K does not allow user specification of multiple reaeration methods (e.g., both the Texas reaeration equation and O'Connor Dobbins equation) in the same run, though the user can prescribe a reaeration rate to override the method specified within a stretch (reach). Hence to define reaeration rates for a given condition, the model was first run with the Texas reaeration equation. The second run was made with the O'Connor Dobbins equation specified. If appropriate, wind enhanced reaeration was added based on average wind conditions during the simulated period to the lake-like region and any other appropriate locations. Both sets of predicted reaeration equations were then checked to be sure they equaled or exceeded the default minimum rate determined considering a minimum oxygen transfer rate of 0.6 m d^{-1}. The final specification of reaeration was then set up with the Texas reaeration equation as the user specified method and prescribed reaeration rates input based on O'Connor Dobbins equation, wind reaeration, and minimum oxygen transfer rate as appropriate.

Segmentation and hydraulics input: QUAL2K provides its representation of Upper Oyster Creek by dividing the creek longitudinally into stretches that can be represented as having constant hydraulic characteristics (e.g., bottom width, rating curves for the two relationships of velocity and water depth to flow). A stretch can be subdivided into a user specified number of equal-length elements. It is at the element level that the model provides its water quality and hydraulic predictions. The characterization of segmentation and hydraulics used for this project benefited from availability of previous modeling efforts by TCEQ staff who had applied QUALTX to Upper Oyster Creek. The input data, including segmentation, was made available to this project by TCEQ (Rudolph, 2006). The overall length of the Lower Reach and Upper Reach obtained from the TCEQ was confirmed using geographic information system (GIS) data and, where necessary, adjustments to some stretches were made to reflect distances obtained from present databases. Overall, the adjustments to lengths were minor. The hydraulic rating curve information was also taken from the previous TCEQ efforts and updates were made in particular areas where more recent information was available from the model support surveys and reconnaissance associated with this project. Somewhat similar to QUALTX, power equations are used in QUAL2K to relate average velocity (U) and depth (H) to flow (Q) using the following two equations:

$$U = aQ^b$$
and
$$H = cQ^d$$

where a, b, c and d are constants. In the Upper Reach for the area around the dams, water depths do not significantly change with change in flow, because of the channel is both wide and relatively deep (generally widths over 50 m wide and average depths over 1 m deep). For this circumstance, the constant d was set to 0.001, which effectively results in $Q^d \approx 1.0$, and c to the average water depth. The segmentation for QUAL2K of the Lower Reach and Upper Reach are provided in Figures 5-2 and 5-3, respectively.

Meteorological input: In order to simulate water temperature and available light for photosynthesis, QUAL2K requires hourly meteorological data over a 24-hr (one day) period. Those data requirements include air temperature, dew-point temperature, wind speed, cloud cover, and shade. Shade is considered here as non-traditional meteorological data. The traditional meteorological data were downloaded from the National Climatic Data Center (NCDC, 2005). The approach taken with the meteorological data was to average conditions on the last two days of each survey in order to provide representative conditions over the deployment period of the multisondes. Typically multisondes were deployed during daylight hours of one day and retrieved 24-hrs later on the next day. The shade data were estimated from observations made alongside streams banks and investigations of recent aerial photographs.

Kinetics and Temperature Effects: Within QUAL2K fist-order kinetic rates can be specified globally for the entire modeled system and individually for specific stretches. Further the model contains a temperature effect correction for all first-order reactions that is defined as follows:

$$k_T = k_{20}\,\theta^{(T-20)}$$

where k_T = the reaction rate, T = water temperature, and θ = temperature coefficient.

Several of the more important temperature-effect factors follow:

Reaction	θ
Atmospheric Reaeration	1.024
CBOD Decay	1.047
Organic Nitrogen Decay Rate	1.047
Ammonia Decay Rate	1.083
All Phytoplankton and Benthic Algae Rates (growth, respiration, death)	1.047

Specification of Headwater Conditions: QUAL2K requires specification of a headwater flow and hourly values for each water quality constituent. Four headwater conditions were defined for the Lower Reach—Oyster Creek immediately downstream of Dam #3 and three tributary headwaters: Stafford Run, Steep Bank Creek and the remnant of Flat Bank Creek downstream of the cutoff that resulted from the diversion canal. Three headwater conditions were designated for the Upper Reach—upstream terminus of Jones Creek, which is at the GCWA pumping station, Flewellen Creek, and Red Gully.

Point and Diffuse Sources: QUAL2K requires specification of a flow and water quality constituents for each point and diffuse source. A diel pattern may be described to each source as the input allows specification of a mean value, a range and time of maximum value. Both point and diffuse sources may be entered as an inflow or an abstraction (withdrawal). The survey data used as model input for the wastewater treatment facilities are summarized in Table 5-1.

Sediment Oxygen Demand and Sediment Release Rates: The sediment diagenesis component of QUAL2K was not used because it gave results that did not seem appropriate for Upper Oyster Creek. Consequently, prescribed input by stretch was used for SOD rates and sediment release rates of NH_3-N and PO_4-P. The SOD values prescribed for the Lower and Upper Reaches were guided by measured values (Table 5-2).

5.3 Model Validation and Sensitivity Analysis—Lower Reach

5.3.1 Background Discussion of Lower Reach

The Lower Reach of Upper Oyster Creek begins at its upstream headwater defined as immediately downstream of Dam # 3 and continues downstream in Oyster Creek, hence into Flat Bank Creek, hence to the diversion canal, and then to Steep Bank Creek until its confluence with the Brazos River. While a contiguous downstream flowing stream, the stream name changes reflect the flat relief of the watershed and anthropogenic activities that have connected previously unconnected streams for the purposes of rapid conveyance and containment of high streamflows. Within the last several years, improvements at Dam # 3 have greatly reduced the seepage from the dam resulting in very limited flow under dry-weather conditions in Oyster Creek below Dam #3 to its confluence with Stafford Run. Stafford Run is an effluent dominated stream that receives the discharges from the WWTFs of Ft. Bend County WCID # 2 and Quail Valley Utility District (UD). As a result of these discharges streamflow in Oyster Creek below Stafford Run is substantively increased. The next major increase in dry-weather streamflow comes when the portion of Steep Bank Creek that acts as a tributary to the Oyster Creek stream complex enters where the diversion canal connects to Steep Bank Creek. Steep Bank Creek receives the effluent from the WWTFs of the cities of Sugar Land and Missouri City.

A refinement to the TCEQ segmentation was made in the portion of Oyster Creek from Dam #3 down to Dulles Avenue. An approximately 2-m (7-foot) high heavy corrugated steel dam was located immediately above the Dulles Avenue bridge crossing of Oyster Creek. The dam effectively backs up Oyster Creek to the base of Dam # 3.

The Lower Reach contains an abundance of aquatic vegetation. Large portions of the Lower Reach creek bed were dominated by macrophytes, such as pondweed and coontail, and attached algae were almost as abundant (Figure 2-7). The observed phytoplankton abundance in the Lower Reach and especially Stafford Run was markedly greater than the anticipated low abundance for a stream system with short travel times that do not provide ample time for establishment of high levels of phytoplankton. For the model support surveys of May 5–9, 2004 and August 9–10, 2004 similar phytoplankton abundance (chlorophyll-α) patterns were indicated (Figure 5-4). Chlorophyll-α concentrations for both surveys showed a generally downstream decreasing pattern from the monitoring station in Stafford Run (station 17688) through the Oyster Creek system (stations 12075, 12074, and 17690). High chlorophyll-α concentrations were measured in the effluent from Quail Valley UD (76.6 µg/L during the May survey and 81.8 µg/L during the August survey) due to the detention pond that is used to provide additional oxygenation through a fountain and to serve as a pool for reclamation of the water for irrigation on a nearby golf course. The high chlorophyll-α concentrations in Stafford Run, however, were observed upstream of the discharge point for Quail Valley UD and then concentrations generally decreased in the downstream direction through Oyster Creek. In contrast to Stafford Run, the portion of Steep Bank Creek upstream of the diversion canal experienced low chlorophyll-α concentrations during both surveys (1.3 µg/L in May and 1.5 µg/L in August), which were much more in agreement with a typical low-order, effluent dominated stream that is nutrient enriched but where travel times are too short to allow establishment of abundant phytoplankton.

For this modeling effort, the high observed chlorophyll-α concentrations in Stafford Run were considered to originate from a pond system that Stafford Run flows through (Figure 5-5). Stafford Run enters the pond system at its northwest extremity and exits the system at the southwest extremity. The system consists of a west pond and an east pond that are connected by a conveyance channel (Holifield, 2007a). TIAER was not aware of the pond system until late fall 2006. Staff subsequently visited the system on December 14, 2006 and May 9, 2007. On both visits, an algal bloom was observed in the conveyance channel between the two ponds, and there was a notable difference between the relatively clear water in Stafford Run entering the ponds and the brownish-green tinge of the water exiting the ponds through Stafford Run. Based on no other reasonable explanation, this pond system is considered the source of the high phytoplankton concentrations observed in Stafford Run at station 17688 during the two model support surveys. The pond system is sufficiently large to provide adequate detention time for growth of an abundance of phytoplankton.

Also evidence regarding the influence of the pond system on water quality in Stafford Run is the chlorophyll-α trend from an August 1989 survey of the Lower Reach (TWC, 1991b). This August 1989 survey is the only other discovered survey in the Lower Reach that included multiple stations and also occurred during the warmer months (April-October) when phytoplankton growth would be expected. The August 1989 survey predated construction of the pond system on Stafford Run, which occurred in approximately 1995-1996 (Holifield, 2007b). The most upstream data point from this survey is in Stafford Run, and its value is appreciably lower than the values measured in Stafford Run during the more recent surveys (Figure 5-4). While not enough pre- and post-pond system data exist to make a definitive conclusion, extant data support the premise that the pond system is the primary source of the high chlorophyll-α concentrations experienced in Stafford Run and portions of Oyster Creek during the May and August 2004 surveys.

The relatively high TSS concentrations observed in Stafford Run and Upper Oyster Creek under low flow conditions were considered to originate from the pond system in a similar manner to the chlorophyll-α concentrations. Existing information do not indicate the source of TSS concentrations observed in Stafford Run and downstream into Oyster Creek. The portions of Stafford Run below Fort Bend County WCID # 2 WWTF discharge are effluent dominated during low flow conditions. For example, during the May and August 2004 intensive surveys at least 80 % of the streamflow in Stafford Run came from the discharge of Fort Bend WCID # 2 WWTF. However, during these two periods the measured TSS in the effluent from the WWTF was below the reporting limit of 4 mg/L, yet the downstream TSS concentrations in Stafford Run were 55 mg/L during the May survey and 37 mg/L during the August survey. During each survey, less than 30 % of the observed TSS can be accounted for in the active suspended algal biomass estimated from chlorophyll-α concentrations. Collectively, data indicate that unaccounted for sources and processes supply the TSS observed in the system. Because the purpose of this modeling effort is not to focus on TSS, but rather to have it appropriately represented in the model to reflect its shading effects on aquatic vegetation, the representation of TSS was accomplished through the representation of the pond system.

The pond system was approximated in the segmentation of the Lower Reach by assuming that a portion of the west most pond served as detention for Stafford Run inflows. Further a very small point source discharge of 0.0001 cms (0.0000028 cfs) with very high chlorophyll-α and inorganic suspended solids (ISS) concentrations was added to the model to represent the interaction and mixing of streamflow leaving the pond system through Stafford Run. This modeling nuance will be discussed more subsequently.

Finally, during both model support surveys, the monitored data of the effluents from WWTFs indicated that all were operating well within their permit limits for NH_3-N and BOD_5. In fact, most NH_3-N concentrations were in the range of 0.2 mg/L as compared to effluent limits of 2 or 3 mg/L, and BOD_5 concentrations were often below the detection limit of 2 mg/L as compared to typical limits of 10 mg/L. Under present levels of operation, the effluents from WWTFs are suspected to only be slightly to moderately impacting average DO concentrations in the Lower Reach and its tributaries.

5.3.2 Model Validation for Lower Reach

The QUAL2K model of the Lower Reach was validated to the data obtained from the surveys conducted May 5–9, 2004 and August 9–10, 2004. For both surveys the model was operated for 30-days repeating the hourly meteorological input data set for each day. By trial and error it was determined that it takes several days for the relatively slow growing benthic algae to reach equilibrium conditions, and, to ensure equilibrium biomass conditions were reached, the model was operated for 30-days. According to Dr. Steve Chapra, primary author of QUAL2K, a common error in applying QUAL2K is to not simulate a sufficient number of days to allow benthic algae to reach equilibrium (Chapra, 2006).

The independent calibration step using the August survey data followed by a verification step using the May data was largely, though not totally, successful. Phytoplankton, as measured by chlorophyll-α, was determined to be the water quality constituents largely compromising model verification. Further investigations of the model response indicated that the same set of input coefficients and kinetic rates for both surveys achieved good model validation, when the point source input describing the influx of phytoplankton from the pond system was allowed to vary between surveys. While not an optimal validation procedure, this solution recognizes the stochastic nature of phytoplankton concentrations in any system and inherent limitations of even dynamic water quality models, much less a steady state model, to predict the timing and magnitude of phytoplankton concentrations. Additionally, investigations of model response indicated that defining an influx of ISS from the pond provided greatly improved predictions of TSS. For the two surveys the point source characteristics to define the influx of phytoplankton as measured by chlorophyll-α and of ISS were as follows:

Survey Date	Flow	Chlorophyll-a	ISS
May 5-9, 2004	0.0001 cms	100,000 µg/L	75,000 mg/L
August 9-10, 2004	0.0001 cms	300,000 µg/L	75,000 mg/L

While these chlorophyll-α and ISS values are notably higher than any concentrations conceivable, the purpose of the influx terms were that the flow be sufficiently small so as to not impact the water balance in the system and at the same time contain sufficient chlorophyll-α and ISS to provide the necessary influxes to produce the concentrations observed in Stafford Run.

For the Lower Reach, the validation process proceeded as a calibration and verification with a recalibration required for the phytoplankton and ISS influxes from the ponds. The recalibration was necessitated by the need to define the chlorophyll-α and ISS influxes from the pond system, and this need was not completely realized until the unsatisfactory verification results were obtained regarding predicted chlorophyll-α and TSS concentrations.

The August 2004 calibration results comparison to observational data for the Lower Reach are provided in a series of figures. DO is provided in Figure 5-6, and streamflow, water temperature, specific conductance, and TSS are presented in Figure 5-7. Organic-N, NH_3-N, NO_2+NO_3-N, and total-N are provided in Figure 5-8, and organic-P, PO4-P, and total-P are presented in Figure 5-9. Phytoplankton and ultimate CBOD predictions and observational data and graphical display of QUAL2K reaeration and SOD rates are provided in Figure 5-10. To more accurately replicate streamflow, input of diffuse source inflow was added between stations 12074 and 17690 with water quality characteristics specified as similar to those used for headwaters. Addition of diffuse inflows to bring a closer flow balance is an often required process for applications of these types of models due to the presence of unaccounted inflows from small tributaries and stream interactions with shallow groundwater. Overall the model predictions indicated good agreement with all observational data with the exception of organic P, which was under predicted by the model (Figure 5-9a). The most important state variable, DO, was reasonably predicted also. Also, the DO was reasonably predicted against the limited data available for the two major tributaries of the Lower Reach — Stafford Run and Steep Bank Creek above its confluence with the diversion canal (Figure 5-11).

The model, however, could not replicate the very low DO at station 12075 (at kilometer 11.3 along x-axis of Figure 5-6). The very low DO at this station could not be attributed to water quality concentrations observed at this station as concentrations were not that different at 12075 from upstream and downstream stations. A partial explanation of the low DO at station 12075 can be gleaned from the meteorological data and the graphic of the measured DO data (Figure 5-12). Cloudy conditions prevailed the morning of August 10th until approximately 10 am, which effectively reduced photosynthesis during the hours immediately following sunrise as indicated by the absence of DO increase as the morning progressed. In addition, it was possible that abnormal oxygen demanding effects were still being exerted in the vicinity of station 12075 as an aftermath of a high-flow event in the Brazos River that peaked about July 3, 2004 and resulted in water levels in the Brazos River measured at the USGS gauge at Richmond, TX (near the vicinity where Oyster Creek debouches into the Brazos) nearly 30 feet above typical summer base flow conditions. On July 1st, TIAER field crews, unaware of the magnitude of the rise on the Brazos River, began a 24-hr DO assessment survey at stations 12077 and 12074, but could not obtain flow measurements at either station. The water at both stations was deeper than typical, rising, and streamflow was in the upstream direction as a result of backwater from the high water levels in the Brazos River. This high-flow event was of sufficient duration that it greatly reduced macrophyte presence in portions of the Lower Reach, presumably as a result of heavy sediment load and turbid water in the Lower Reach for a period of several days. Observations made July 13, 2004 indicated that waters had receded and visible effects remained regarding reduced macrophytes densities and occurrences of embankment sloughing into Oyster Creek. These observations on creek conditions resulted in postponement of the scheduled July model support survey until August in order to give the creek several weeks to reestablish macrophytes and benthic algae and to recover from the embankment sloughing. In conclusion, the particularly low DO concentrations at station 12075 during the August 9-10, 2004 survey could not be replicated by the model, did not appear to be caused by measured water quality constituents, and potentially could be attributable to both morning cloud cover on August 10th and residual effects from the late June and early July high-flow event on the Brazos River.

The May 2004 verification results with observational data for the Lower Reach are provided in a series of figures. DO is provided in Figure 5-13, and streamflow, water temperature, specific conductance, and TSS are presented in Figure 5-14. Organic-N, NH_3-N, NO_2+NO_3-N, and total-N are provided in Figure 5-15, and organic-P, PO4-P, and total-P are presented in Figure 5-16. Phytoplankton and ultimate CBOD predictions and observational data and graphical display of QUAL2K reaeration and SOD rates are provided in Figure 5-17. Note that because prescribed SOD rates are not internally temperature corrected by QUAL2K, the SOD data were input with the external temperature effects correction based on average observed temperature for the stations along the Lower Reach. Because water temperatures were greater during the August survey than the May survey, the graphically displayed SOD values will be greater for August than May by an amount equivalent to the difference caused by the temperature-effects adjustment (compare Figures 5-10b and 5-17b).

Streamflow was not predicted accurately for the last two stations on Oyster Creek (stations 12074 and 17690) during the May verification. The measured streamflows at both stations are appreciably greater than measured flow at station 12075, the next upstream station. The same amount of diffuse flows was added between 12074 and 17690 as for the August survey. Careful review of the field data sheets and streamflow calculation data sheets for these three stations gave no indication of error at any station during the May survey. However, a three-fold increase in flow under dry-weather conditions from diffuse sources and other sources between stations 12075 and 12074 does not seem feasible. In addition measured specific conductance remained extremely constant at all there stations (Figure 5-14c). The longitudinal consistency in measured specific conductance indicates that if a large amount of flow did enter the system, its specific conductance was by happenstance nearly identical to that at station 12075 where the specific conductance in the water was a result of the mixing of WWTF discharges with water from other contributions, such as those from shallow groundwater. Because it seemed unlikely that such a large flow increase between stations 12075 and 12074 could have gone unnoticed by trained field crews and also not result in some discernible signature in measured water quality constituents, the most reasonable conclusion was that the flow measurements at stations 12074 and 17690 were in error—possibly due to an undetected failure with the velocity measurement instrument.

Dissolved oxygen predictions along the Lower Reach compared very favorably with measured data (Figure 5-13). For both Stafford Run and Steep Bank Creek above its confluence with the diversion canal, DO predictions were acceptable (Figure 5-18), though the supersaturation conditions on Stafford Run were conservatively under predicted (Figure 5-18a). For most other water quality constituents, the comparisons of predicted and observed data were favorable, though organic-N and NH_3-N concentration (Figure 15a & b) were not predicted as well as was the case for the August survey.

The global rate kinetics and temperature-effect coefficients used as input to QUAL2K for the Lower Reach are provided in Table 5-3. Because of the nutrient enrichment prevalent in much of the Lower Reach, the default stoichiometry specified in QUAL2K, which is the Redfield ratio, for dry weight : carbon : nitrogen : phosphorus : chlorophyll-α was modified from 100 : 40 : 7.2 : 1 : 1 to 100 : 40 : 7.2 : 1.2 : 1.2. The 20 % increase in the phosphorus and chlorophyll-α reflects the propensity of phytoplankton to exhibit luxury uptake of phosphorus; a phenomenon observed in nutrient enriched streams of the Brazos River watershed (King et al., 2007). The model input description of each stretch (reach), stretch length, and other data used to define the segmentation of the Lower Reach are provided in Table 5-4. Hydraulic rating curve coefficients, percent bottom cover for SOD and benthic algae, and prescribed SOD rates and sediment release rates for NH_3-N and PO_4-P input are provided in Table 5-5 for the August survey. Because the input values in Table 5-5 are externally adjusted for temperature-effects, the August and May surveys will have different values even though the 20° C values for these rates are identical. The same input data for the May survey are provided in Table 5-6. Stretch (or reach) specific kinetic rate input are provided in Table 5-7. The kinetic rates in Table 5-7 are input at a value for 20° C and internally adjusted in QUAL2K based on simulated temperatures.

5.3.3 Model Sensitivity Analysis for Lower Reach

A sensitivity analysis was performed for several input parameters, which were each varied +/- 50 % of their model validation values using the August 2004 calibration case as the baseline for comparison. The sensitivity results are presented for daily average and absolute minimum DO concentrations along the Lower Reach of Oyster Creek. The parameters varied for the sensitivity analysis were CBOD decay rate, NH_3-N decay rate, reaeration rate, SOD rate, phytoplankton maximum growth rate, benthic algae maximum growth rate, point source CBOD loading, and point source ammonia loading (Figures 5-19a – 5-19h). The sensitivity analysis indicated little sensitivity to either decay rates or loadings associated with CBOD and NH_3-N. Maximum growth rates of phytoplankton and benthic algae were indicated to have greater sensitivity than CBOD and NH_3-N parameters. The reaeration and SOD rates showed highest sensitivity.

An additional sensitivity test was performed on the point source that is used to define the phytoplankton and ISS fluxes from the ponds on Stafford Run into the Lower Reach of Upper Oyster Creek. The chlorophyll-α flux term was varied +/- 100 % for this analysis, and the ISS flux term was varied +/- 50 %. Phytoplankton concentrations on Oyster Creek above its confluence with Stafford Run (i.e., above km 13 on Figure 5-20b) were not impacted by changes in the chlorophyll-α flux term. Below the confluence in Stafford Run, phytoplankton concentrations did show a strong response that diminished in the downstream direction. The sensitivity of DO concentrations to the chlorophyll-α flux term, however, was shown to be minor. Analogous to the sensitivity analysis for the chlorophyll-α flux term, the TSS concentrations along the mainstem below Stafford Run were much more sensitive to the variations of the ISS flux term than were DO concentrations along the mainstem (Figure 5-21).

5.4 Model Validation and Sensitivity Analysis—Upper Reach

5.4.1 Background Discussion of Upper Reach

From upstream to downstream, the Upper Reach of Upper Oyster Creek begins at the GCWA Shannon Pump Station on the Brazos River, continues in a downstream direction through Jones Creek, and then to Oyster Creek where the creek has a series of three dams in the City of Sugar Land area. The Upper Reach has its downstream boundary at Dam #3. Within the pool formed by Dam #3, the GCWA Second Lift Station pumps water into the American Canal, which provides conveyance to the Texas City area. Brazos River water is pumped from the Shannon Pump Station and the Upper Reach of Oyster Creek provides a conveyance for this water to the Second Lift Station. Based on pumping records for both stations, there is approximately 5 to 10 % less water pumped at the Second Lift Station than at the Shannon Pump Station. Some small portion of this flow difference is likely the result of water rights and usage along the Upper Reach, though water rights are minor along Oyster Creek. For modeling purposes this flow difference was assumed to be the result of transmission losses, which were included as part of the diffuse source input specification in QUAL2K.

Portions of the Upper Reach experience extensive growth of macrophytes, especially alligator weed, adjacent to the creek banks and often encroaching upon the open channel (Figure 2-8). Water hyacinth can become prolific along the shoreline and backwaters in vicinity of the series of dams. During the growing season of roughly April through October, the GCWA periodically uses an herbicide accepted for use in public water supplies that is sprayed on emersed macrophytes to partially control the encroachment of vegetation on the channel and to maintain the necessary water transport capacity in the system (Chapman, 2007).

The GCWA was also performing channel maintenance with a drag line along Jones Creek between stations 12090 and 12091 (Figure 5-1) during the period of approximately 2002 through 2005 (Chapman, 2007). The channel maintenance was necessitated because of settling of suspended sediments contained in the water pumped out of the Brazos River. Water velocities in the Upper Reach are typically insufficient to maintain suspension of these solids, and a decrease in TSS is generally observed in an upstream to downstream direction within the Upper Reach (see Section 2.8 for more details).

Finally, during both model support surveys, the monitored data of the effluents from WWTFs indicated that all were operating well within their permit limits for NH_3-N and BOD_5. In fact, most NH_3-N concentrations were in the range of 0.1 mg/L as compared to effluent limits of 1 to 3 mg/L, and BOD_5 concentrations were often below the detection limit of 2 mg/L as compared to typical limits of 10 mg/L. Under present levels of operation, the effluents from WWTFs are suspected to only be slightly to moderately impacting average DO concentrations in the Upper Reach and its tributaries.

5.4.2 Model Validation for Upper Reach

The QUAL2K model of the Upper Reach was validated to the data obtained from the surveys conducted May 25–28, 2004 and August 16–19, 2004. For both surveys the model was operated for 30-days repeating the hourly meteorological input data set for each day to allow benthic algae biomass (being used as a surrogate for macrophytes) to reach equilibrium concentrations. Similar to the validation process for the Lower Reach, the calibration step using the August survey data was followed by a verification step using the May data. The calibration and verification steps were largely, though not totally, successful. The verification step indicated that TSS concentrations could not be replicated with one set of settling velocities for both surveys.

The longitudinal TSS concentrations were also determined to be important in determining where along the creek diel DO fluctuations became more pronounced. Both the measured data and model predictions indicated that when TSS concentrations were above about 30-50 mg/L, diel DO fluctuations were not large, and at lower TSS concentrations diel DO fluctuations became more pronounced. The damped DO pattern at higher TSS concentrations was attributed to light limitations on photosynthetic activities imposed by the suspended solids—a process reasonably reproduced by the model.

As a result of the difficulties with verifying TSS concentrations, the validation process proceeded as a calibration and verification with recalibration required. During the recalibration process is was confirmed that observed TSS concentrations from the two model support surveys could not be predicted with the same set of settling velocities specified for the ISS portion of TSS. Therefore a unique set of ISS settling velocities was specified for each survey in order to provide for reasonable prediction of TSS concentrations and diel DO patterns. With the notable exception of the ISS settling velocities, one specification of kinetic rates and other input provided acceptable comparisons of predicted water quality constituents to those observed.

In several ways the lack of a unique set of settling velocities that was acceptable under all conditions could have been anticipated. QUAL2K does not allow specification of sand, silt, and clay fractions to ISS, whereas it may be reasonably considered that the ISS in the water pumped from the Brazos River would vary over time in its particle size distribution dependent upon magnitude of river flow and perhaps other factors, such as proximity to the Shannon Pump Station of high rainfall runoff events into the Brazos. Therefore, while less than optimal, the necessity of having to determine a unique set of ISS settling velocities on a survey-by-survey basis represented a reality of the limitation of not only QUAL2K, but also QUALTX, if it had been applied. Even if the model allowed ISS separation by particle size distribution, available data in both Oyster Creek and the lower Brazos River do not provide this type of detailed information except for a very few measurements.

The August 2004 calibration results with observational data for the Lower Reach are provided in a series of figures. DO is provided in Figure 5-22, and streamflow, water temperature, specific conductance, and TSS are presented in Figure 5-23. Organic-N, NH_3-N, NO_2+NO_3-N, and total-N are provided in Figure 5-24, and organic-P, PO_4-P, and total-P are presented in Figure 5-25. Phytoplankton and ultimate CBOD predictions and observational data and graphical display of QUAL2K reaeration and SOD rates are provided in Figure 5-26.

To more accurately replicate the streamflow conditions along the Upper Reach that were actually experienced at the various monitoring stations during the August survey, a diffuse source abstraction was added through model input along the entire length of the Upper Reach. During the August 16-19 survey, pumping rates into the Upper Reach were relatively constant with daily average pumping rates for the Shannon Pump Station ranging from 2.9 cms to 4.1 cms (100 cfs to 140 cfs). However, from approximately noon August 17 until noon August 18, patch pumping was implemented wherein an additional pump was in operation for 12 hrs each day, and during those periods of each day the pumping rate was 5.3 cms (190 cfs).[6] The period of patch pumping coincided with the time when the upper stations were being monitored and when flow measurements occurred at stations 12091 and 12090. The further downstream stations had been monitored over various 24-hr time periods beginning 6:00 hrs August 16 and ending 14:30 hrs August 18. If travel time from the Shannon Lift Station is considered, all monitoring had been completed at these downstream stations prior to any effects of the increased flow from patch pumping reaching these stations. The model's diffuse source abstraction was used to provide a more representative flow to that encountered during actual monitoring at each station. The diffuse source abstraction input was set to provide a linear decrease of flow starting at 5.3 cms at the Shannon Pump Station and decreasing to 2.9 cms at the Second Lift Station (Figure 5-23a). The flow of 2.9 cms at the Second Lift Station was its average pumping rate during the survey. The pumping of water out of Oyster Creek into the American Canal at the Second Lift Station was represented in QUAL2K for both validations surveys as a point source abstraction. The effect of this abstraction on flows during the August survey is readily apparent in Figure 5-23a at approximately kilometer 20.5.

For the August survey, the model performed acceptably in predicting daily average and absolute minimum DO concentrations. The average DO was under predicted in the region around

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[6] The Gulf Coast Water Authority (GCWA) provided total cooperation during both model support surveys. The statements herein are in no means intended to detract from the high level of cooperation they provided. GCWA did their best to provide steady state flow conditions during both of our surveys. TIAER remains appreciative of GCWA's commitment in assisting our surveys, and we understood that unanticipated water demands on their system often necessitate abrupt changes in pumping rates.

stream kilometers 50-40 (Figure 5-22). Absolute minimum DO concentrations were not predicted as well as the average; however, it must be recalled that, unlike the Lower Reach, proper prediction of average concentrations would capture conditions under which most exceedances occurred during the assessment monitoring. Other water quality constituents were generally replicated well. The average DO concentrations on Flewellen Creek and Red Gully were also acceptably predicted at the single calibration location on each creek (Figure 5-27); however, the diel DO fluctuations were under predicted on Red Gully (Figure 5-27b). While ammonia concentrations were over predicted between stream kilometers 20 to 40, the predicted pattern was similar to that observed (Figure 5-24b). The model reasonably predicted the rising patterns in both NO_2+NO_3-N and PO_4-P within the area around the dams (Figures 5-24c and 5-25b, respectively).

The May 2004 verification results with observational data for the Lower Reach are also provided in a series of figures. DO is provided in Figure 5-28, and streamflow, water temperature, specific conductance, and TSS are presented in Figure 5-29. Organic-N, NH_3-N, NO_2+NO_3,-N, and total-N are provided in Figure 5-30, and organic-P, PO4-P, and total-P are presented in Figure 5-31. Phytoplankton and ultimate CBOD predictions and observational data and graphical display of QUAL2K reaeration and SOD rates are provided in Figure 5-32. As for the Lower Reach, since prescribed SOD rates and sediment release rates of NH_3-N and PO_4-P are not internally temperature corrected by QUAL2K, these input data were externally temperature corrected based on average observed temperature for the stations along the Upper Reach. Because water temperatures were somewhat greater during the August survey than the May survey, the graphically displayed SOD values will be greater for August than May by an amount equivalent to the difference caused by the temperature-effects adjustment (compare Figures 5-26b and 5-32b).

Dissolved oxygen predictions compared very favorably with the observed data (Figure 5-28), except the absolute minimum DO at station 12091 at approximately stream kilometer 81. The measured DO at station 12091 was almost constant at 5.5 mg/L until the last 2-½ hrs of the survey, when from about 9:00 hrs to 11:30 hrs a monotonic decline occurred to 3.7 mg/L, and that decline was still occurring when the multisonde was retrieved. Interestingly, and to a degree ruling out instrumentation malfunction, at station 12090 (kilometer 77), the next downstream station, a sudden decline in DO of about 0.2 mg/L begins the last half hour of deployment at around noon. When that multisonde was retrieved the decline was still occurring. The DO decline measured at the end of the deployment at station 12090 could be the downstream movement of the DO decline measured at station 12091 with a time delay resulting from the travel time between the two stations. Also, at station 12090, the measured DO data indicated a second anomalous DO decline and then a rise that occurred over a range of nearly 0.5 mg/L. This rise and decline at station 12090 occurred over a period of about two hours beginning about the time of the multisonde deployment at 13:00 hrs. No totally plausible explanation was determined for these DO declines at stations 12091 and 12090. While it was determined that a drag line could have been performing channel maintenance during the time of this survey, our best available information was that the drag line should have been operating between the two station locations and not above both of them (Chapman, 2007). Channel maintenance operations would seem to have the potential to resuspend bottom sediments and could cause immediate high oxygen demand similar to that observed at both stations; however, the information remains inconclusive as to the actual source of these atypical DO declines. Nonetheless, with the exception of station 12091, the model accurately predicted both observed daily average DO concentration and the damped diel DO pattern, which was considered to result from the high TSS concentrations observed and predicted along all but the extreme downstream portion of the Upper Reach. Tributary DO predictions were reasonable (Figure 5-33), though the average DO was over predicted about 1 mg/L on Flewellen Creek in May as compared to under predicted about 0.5 mg/L in August (Figures 5-33b and 5-27b). Other water quality constituents were likewise very reasonably predicted by QUAL2K, except ultimate CBOD (Figure 5-32d). For the August survey, ultimate CBOD concentrations were over predicted (Figure 5-26d). Measured $CBOD_{20}$ (ultimate) were generally low (< 7 mg/L).

The global rate kinetics and temperature-effect coefficients used for the Upper Reach are provided in Table 5-8. The model input description of each stretch (reach), stretch length, and other data used to define the segmentation of the Upper Reach are provided in Table 5-9. Hydraulic rating curve coefficients, percent bottom cover for SOD and benthic algae, and prescribed SOD rates and sediment release rates for NH_3-N and PO_4-P input are provided in Table 5-10 for the August survey. Because the input values in Table 5-10 are externally adjusted for temperature-effects, the August and May surveys will have different values even though the 20° C values for these rates are identical. The same input data for the May survey are provided in Table 5-11. For the August survey, stretch (or reach) specific kinetic rate input are provided in Table 5-12. Because of limitations in QUAL2K where the different methods of computing reaeration rates can not occur by stretch, the kinetic rate input for the May survey is provided in Table 5-13. The only differences between Tables 5-12 and 5-13 are the prescribed reaeration coefficients. The rates in Tables 5-12 and 5-13 are at 20° C and are internally adjusted in the model to the water temperature being simulated.

5.4.3 Model Sensitivity Analysis for Upper Reach

Similar to the approach for the Lower Reach, a sensitivity analysis was performed for the Upper Reach using several input parameters, which were varied +/- 50 % of their model validation values. The August 2004 calibration case was used as the baseline for comparison. The sensitivity results are presented for DO concentrations along the Upper Reach of Oyster Creek. The parameters considered were CBOD decay rate, NH_3-N decay rate, reaeration rate, SOD rate, phytoplankton maximum growth rate, benthic algae maximum growth rate, point source CBOD loading, and point source ammonia loading (Figures 5-34a – 5-34h). Similar to the sensitivity for the Lower Reach, this analysis indicated low sensitivity of predicted average and absolute minimum DOs to CBOD and NH_3-N loadings from point sources and decay rates. Maximum growth rates for phytoplankton and benthic algae resulted in greater sensitivity and large response in DO than the CBOD and NH_3-N factors. Reaeration and SOD rates showed the greatest sensitivity on DO response.

In addition, the sensitivity analysis was expanded to include the ISS settling velocities, which were varied +/- 50 % from the values in the input set applied in August (Figure 5-35). The sensitivity response of DO to changing settling velocities was similar to that for phytoplankton and benthic algae growth rates.

5.5 Evaluation of Modeling

The validation of QUAL2K to both the Lower and Upper Reaches of Oyster Creek (Segment 1245) indicated that the model could successfully predict the critical output variable of DO concentrations. For both reaches, however, external factors resulted in one portion of the input that had to be varied to provide satisfactory prediction of water quality constituents. For the Lower Reach, the influx of phytoplankton from the area of ponds on Stafford Run was tailored uniquely to each of the two validation surveys through point source specification in the model. In an analogous manner, model input of ISS settling velocities were tailored uniquely for both validation surveys to allow proper prediction of TSS in the Upper Reach. In both instances the need for flexibility in one aspect of model input was necessitated by factors beyond the capabilities of QUAL2K. For the Lower Reach, this factor was a system of ponds that appeared to be the source of a temporally variable flux of phytoplankton into Stafford Run and hence into Oyster Creek. Suspected differences over time in particle size distribution and suspended sediment concentration of waters pumped from the Brazos River seemed to be the determining factor in the Upper Reach that necessitated tailoring of ISS settling velocities to each model support survey.

With the exception of the data input mentioned immediately above, one set of input kinetic coefficients were successfully determined to calibrate and then verify QUAL2K to the Lower and Upper Reaches. One set of input coefficients was similarly determined for the Upper Reach through the validation process.

The model of both reaches 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. 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 DO in a stream system that is insensitive to these decay rates because instream concentrations of CBOD and NH_3-N are low.

The validated models for both reaches provided sufficiently good predictions of all relevant water quality constituents that it is reasonable to consider each model acceptable for use in determining TMDL allocations. Because of the necessity to vary the model's input of phytoplankton flux for the Lower Reach and of ISS settling velocities for the Upper Reach, the TMDL allocation applications of the model will apply the most conservative (i.e., the values that give the lowest DO concentrations) values from the validation process.

SECTION 5

TABLES

Table 5-1 Data for wastewater treatment facilities for May and August survey periods

Facility Name	Survey	Flow (cms)	Avg. Temp (°C)	Avg. DO (mg/L)	NO_2 +NO_3 (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TKN (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	$CBOD_{20}$ (mg/L)	Chl-α (µg/L)	Pheo-α (µg/L)	Cl (mg/L)
FBC WCID #2	May	0.147	25.6	7.8	19.9	0.117	1.75	1.97	1.02	<4	2.7	MD	—	—	106
FBC WCID #2	Aug	0.164	29.6	7.3	18.6	0.233	2.18	2.32	1.05	<4	<2	3.6	—	—	135
QVUD	May	0.018	25.5	14.1	8.37	0.117	0.057	0.191	1.50	7	6.6	MD	76.6	35.2	69.4
QVUD	Aug	0.044	30.3	9.0	8.70	0.810	0.331	0.490	2.60	24	5.6	8.7	81.8	62.4	67.2
PP MUD	May	0.013	25.7	6.4	15.5	0.060	4.12	4.32	0.483	<4	<2	MD	—	—	87.3
PP MUD	Aug	0.014	29.8	6.1	18.0	0.094	3.87	3.91	0.625	<4	2.4	<2	—	—	86.4
Sugar Land	May	0.193	23.6	7.5	17.4	0.088	3.39	3.66	0.760	<4	<2	MD	—	—	91.7
Sugar Land	Aug	0.193	28.0	7.4	14.5	0.138	3.98	3.77	0.756	<4	<2	<2	—	—	88.8
Missouri City	May	0.045	25.5	6.9	12.6	0.116	3.72	3.91	0.822	<4	<2	MD	—	—	81.5
Missouri City	Aug	0.048	29.7	6.3	21.0	0.298	3.63	3.9	0.649	<4	2.3	3.9	—	—	94.9
FBC MUD #118	May	0.008	27.1	6.1	7.99	0.068	3.61	3.79	0.807	5	<2	2.9	—	—	98.3
FBC MUD #118	Aug	0.006	27.9	6.4	17.8	<0.023	3.56	3.60	0.423	10	<2	<2	—	—	110
TDCJ Jester	May	0.008	26.6	8.3	11.1	0.041	3.89	4.13	0.752	6	4.2	6.8	—	—	70.9
TDCJ Jester	Aug	0.008	26.4	8.3	12.2	0.066	4.06	4.18	0.378	6	<2	<2	—	—	92.6
FBC MUD #41	May	0.011	27.5	5.4	16.2	0.046	2.39	2.69	0.944	6	4.7	5.4	—	—	83.7
FBC MUD #41	Aug	0.011	28.7	6.8	16.9	0.066	3.03	3.15	0.894	<4	<2	2.4	—	—	87.6
FBC MUD #25	May	0.028	27.4	7.7	21.9	0.086	3.41	3.99	1.78	26	7.1	10.7	—	—	114
FBC MUD #25	Aug	0.028	28.7	7.6	12.9	0.052	MD	2.71	0.611	<4	<2	<2	—	—	136

MD = missing date

Table 5-2 Measured SOD rates in Upper Oyster Creek

Station	Deployment	Date	Deployment Time Span (minutes)	Average Temperature (°C)	Measured SOD (gDO/m^2/day)	SOD$_{20}$ (gDO/m^2/day
12090	A	30Aug04	375	29.9	0.2	0.1
12090	B	30Aug04	375	29.9	0.6	0.3
12090	A	03May05	235	22.9	2.3	1.0
12090	B	03May05	245	23.1	1.3	1.0
12087	A	07Jun05	280	31.9	2.1	0.9
12087	B	08Jun05	255	31.3	4.4	2.0
12086	A	29Sep04	300	27.4	4.3	2.6
12086	B	29Sep04	300	25.6	3.3	2.2
12083	A	10Aug04	250	31.5	3.6	1.6
12083	B	10Aug04	250	31.6	1.9	0.8
12083	A	12Jul05	205	31.9	5.1	2.2
12083	B	12Jul05	200	31.7	3.5	1.5
12079	A	11Aug04	260	30.3	Failed QC	—
12079	B	11Aug04	245	30.2	3.4	1.6
12079	A	13Jul05	235	30.9	4.5	2.1
12079	B	13Jul05	235	31.0	5.1	2.3
12075	A	16Aug04	325	29.2	2.7	1.4
12075	B	16Aug04	325	28.7	2.9	1.5
12074	A	04May05	400	23.8	1.5	1.1
12074	B	08Jun05	310	29.0	1.9	1.0

Table 5-3 QUAL2K Rates spreadsheet of globally specified rates for validation process on the Lower Reach

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1.2	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1.2	gA	gA
Inorganic suspended solids:			
Settling velocity		m/d	*vi*
Oxygen:			
Reaeration model	User specified		
User reaeration coefficient α	1.923		*α*
User reaeration coefficient β	0.273		*β*
User reaeration coefficient γ	0.894		*γ*
Temp correction	1.02		*qa*
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO2/gC	*roc*
O2 for NH4 nitrification	4.57	gO2/gN	*ron*
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.6	L/mgO2	*Ksocf*
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.6	L/mgO2	*Ksona*
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.6	L/mgO2	*Ksodn*
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.6	L/mgO2	*Ksop*
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.6	L/mgO2	*Ksob*
Slow CBOD:			
Hydrolysis rate	2	/d	*khc*
Temp correction	1.07		*qhc*
Oxidation rate		/d	*kdcs*
Temp correction	1.047		*qdcs*
Fast CBOD:			
Oxidation rate		/d	*kdc*
Temp correction	1.047		*qdc*
Organic N:			
Hydrolysis		/d	*khn*
Temp correction	1.047		*qhn*
Settling velocity		m/d	*von*
Ammonium:			
Nitrification		/d	*kna*
Temp correction	1.083		*qna*
Nitrate:			
Denitrification		/d	*kdn*
Temp correction	1.047		*qdn*
Sed denitrification transfer coeff		m/d	*vdi*
Temp correction	1.07		*qdi*
Organic P:			
Hydrolysis		/d	*khp*
Temp correction	1.047		*qhp*
Settling velocity		m/d	*vop*

Table 5-3. (cont.)

Inorganic P:			
Settling velocity		m/d	*vip*
Inorganic P sorption coefficient	0	L/mgD	*Kdpi*
Sed P oxygen attenuation half sat constant	0.05	mgO2/L	*kspi*
Phytoplankton:			
Max Growth rate		/d	*kgp*
Temp correction	1.047		*qgp*
Respiration rate		/d	*krp*
Temp correction	1.047		*qrp*
Death rate		/d	*kdp*
Temp correction	1.047		*qdp*
Nitrogen half sat constant	25	ugN/L	*ksPp*
Phosphorus half sat constant	5	ugP/L	*ksNp*
Inorganic carbon half sat constant	0.000013	moles/L	*ksCp*
Light model	Half saturation		
Light constant	100	langleys/d	*KLp*
Ammonia preference	25	ugN/L	*khnxp*
Settling velocity	0.05	m/d	*va*
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate		mgA/m2/d or /d	*Cgb*
Temp correction	1.047		*qgb*
First-order model carrying capacity	1000	mgA/m2	*ab,max*
Respiration rate		/d	*krb*
Temp correction	1.047		*qrb*
Excretion rate		/d	*keb*
Temp correction	1.047		*qdb*
Death rate		/d	*kdb*
Temp correction	1.047		*qdb*
External nitrogen half sat constant	300	ugN/L	*ksPb*
External phosphorus half sat constant	100	ugP/L	*ksNb*
Inorganic carbon half sat constant	0.000013	moles/L	*ksCb*
Light model	Half saturation		
Light constant	100	langleys/d	*KLb*
Ammonia preference	25	ugN/L	*khnxb*
Subsistence quota for nitrogen	0.72	mgN/mgA	*q0N*
Subsistence quota for phosphorus	0.1	mgP/mgA	*q0P*
Maximum uptake rate for nitrogen	72	mgN/mgA/d	*rmN*
Maximum uptake rate for phosphorus	5	mgP/mgA/d	*rmP*
Internal nitrogen half sat constant	0.9	mgN/mgA	*KqN*
Internal phosphorus half sat constant	0.13	mgP/mgA	*KqP*
Detritus (POM):			
Dissolution rate		/d	*kdt*
Temp correction	1.07		*qdt*
Fraction of dissolution to fast CBOD			*Ff*
Settling velocity		m/d	*vdt*
Pathogens:			
Decay rate	0.8	/d	*kdx*
Temp correction	1.07		*qdx*
Settling velocity	1	m/d	*vx*
Light efficiency factor	1		*apath*
pH:			
Partial pressure of carbon dioxide	347	ppm	*pCO2*

Table 5-4 Lower Reach of Upper Oyster Creek segmentation information

		Reach	**Reach**	**Location**		**Element**
Reach Name		**Number**	**length**	**Begin**	**End**	**Number**
From	*To*		*(km)*	*(km)*	*(km)*	
FBC WCID DAM #3 - 1	RKM 21.5	1	0.81	21.46	20.65	1
FBC WCID DAM #3 - 2	RKM 21	2	0.50	20.65	20.15	1
FBC WCID DAM #3 - 3	RKM 20.5	3	0.50	20.15	19.65	1
FBC WCID DAM #3 - 4	RKM 20	4	0.50	19.65	19.15	1
FBC WCID DAM #3 - 5	RKM 19.5	5	0.50	19.15	18.65	1
RKM 19.5	DULLES RD.	6	1.00	18.65	17.65	1
DULLES RD	RKM 17.0	7	1.50	17.65	16.15	3
RKM 17.0	RKM 16.5	8	0.50	16.15	15.65	1
RKM 16.5	RKM 15.0	9	1.50	15.65	14.15	3
RKM 15.0	STAFFORD RUN	10	1.93	14.15	12.22	3
FM 1092	RKM 4.0	11	2.00	6	4	4
RKM 4.0	CARTWRIGHT RD	12	1.34	4	2.665	5
CARTWRIGHT RD	RKM 0.5	13	0.29	2.665	2.375	1
RKM 0.5	OYSTER CREEK	14	2.38	2.375	0	6
STAFFORD RUN	HAMPTON RD	15	0.20	12.22	12.02	2
HAMPTON RD	GLENLAKE DRIVE	16	0.63	12.02	11.39	1
GLENLAKE DRIVE	RKM 10.75	17	0.64	11.39	10.75	1
RKM 10.75	RKM 10	18	0.75	10.75	10	1
RKM 10.0	RKM 9.0	19	1.00	10	9	2
RKM 9.0	RKM 8.5	20	0.50	9	8.5	1
RKM 8.5	RKM 8.0	21	0.50	8.5	8	1
DIVERSION CHANNEL	RKM 3.5	22	4.50	8	3.5	9
RKM 3.5	RKM 3.3	23	0.20	3.5	3.3	2
UPPR STEEP BANK CREEK	RKM 5.3	24	2.20	7.5	5.3	22
RKM 5.3	RKM 3.5	25	1.80	5.3	3.5	18
RKM 3.5	RKM 0	26	3.50	3.5	0	7
DIVERSION CHANNEL	STEEP BANK CR	27	2.80	3.3	0.5	28
REMNANT FLAT BANK CREEK	REMNANT FLAT BANK CREEK	28	6.40	6.4	0	8
STEEP BANK CR	BRAZOS RIVER	29	0.50	0.5	0	1

Table 5-5 August 2004 QUAL2K Reach spreadsheet with hydraulic rating curves and other input data of Lower Reach

Reach				Rating Curves				Bottom	Bottom	Prescribed	Prescribed	Prescribed
No.	begin	end	Element	Velocity		Depth		Algae	SOD	SOD	NH4 flux	Inorg P flux
	km	km		Coefficient	Exponent	Coefficient	Exponent	Cover	Cover	gO2/m2/d	mgN/m2/d	mgP/m2/d
1	21.46	20.65	1	0.047	0.500	0.332	0.001	50%	100%	0.61	10.21	4.08
2	20.65	20.15	1	0.047	0.500	0.691	0.001	50%	100%	0.61	10.21	4.08
3	20.15	19.65	1	0.047	0.500	1.051	0.001	50%	100%	0.61	10.21	4.08
4	19.65	19.15	1	0.047	0.500	1.411	0.001	40%	100%	0.61	10.21	4.08
5	19.15	18.65	1	0.047	0.500	1.770	0.001	20%	100%	0.61	10.21	4.08
6	18.65	17.65	1	0.047	0.500	1.539	0.400	10%	100%	0.61	10.21	4.08
7	17.65	16.15	3	0.179	0.500	0.450	0.400	70%	100%	0.61	10.21	4.08
8	16.15	15.65	1	0.179	0.500	0.450	0.400	70%	100%	0.61	10.21	4.08
9	15.65	14.15	3	0.179	0.500	0.450	0.400	70%	100%	0.61	10.21	4.08
10	14.15	12.22	3	0.179	0.500	0.450	0.400	70%	100%	0.61	10.21	4.08
11	6.00	4.00	4	0.259	0.500	0.516	0.400	50%	100%	0.61	10.21	4.08
12	4.00	2.67	5	0.259	0.500	0.516	0.400	50%	100%	3.27	10.21	4.08
13	2.67	2.38	1	0.010	1.000	1.830	0.001	10%	100%	2.22	10.21	4.08
14	2.38	0.00	6	0.259	0.500	0.516	0.400	50%	100%	0.61	10.21	4.08
15	12.22	12.02	2	0.243	0.500	0.633	0.400	30%	100%	3.27	10.21	4.08
16	12.02	11.39	1	0.209	0.500	0.666	0.400	30%	100%	3.27	10.21	4.08
17	11.39	10.75	1	0.214	0.500	0.720	0.400	40%	100%	3.27	10.21	4.08
18	10.75	10.00	1	0.167	0.500	0.937	0.400	50%	100%	3.27	10.21	4.08
19	10.00	9.00	2	0.121	0.500	0.959	0.400	60%	100%	3.27	10.21	4.08
20	9.00	8.50	1	0.102	0.500	0.681	0.400	60%	100%	3.27	10.21	4.08
21	8.50	8.00	1	0.102	0.500	0.681	0.400	60%	100%	3.27	10.21	4.08
22	8.00	3.50	9	0.255	0.500	0.428	0.400	60%	100%	3.27	10.21	4.08
23	3.50	3.30	2	0.255	0.500	0.500	0.400	60%	100%	3.27	10.21	4.08
24	7.50	5.30	22	0.226	0.500	0.500	0.400	30%	100%	0.61	10.21	4.08
25	5.30	3.50	18	0.226	0.500	0.500	0.400	30%	100%	3.27	10.21	4.08
26	3.50	0.00	7	0.226	0.500	0.500	0.400	30%	100%	3.27	10.21	4.08
27	3.30	0.50	28	0.226	0.500	0.500	0.400	60%	100%	3.27	10.21	4.08
28	6.40	0.00	8	0.255	0.500	0.428	0.400	40%	100%	1.84	10.21	4.08
29	0.50	0.00	1	0.255	0.500	0.428	0.400	60%	100%	3.27	10.21	4.08

Table 5-6 May 2004 QUAL2K Reach spreadsheet with hydraulic rating curves and other input data of Lower Reach

Reach				Rating Curves				Bottom	Bottom	Prescribed	Prescribed	Prescribed
No.	begin	end	Element	Velocity		Depth		Algae	SOD	SOD	NH4 flux	Inorg P flux
	km	km		Coefficient	Exponent	Coefficient	Exponent	Cover	Cover	gO2/m2/d	mgN/m2/d	mgP/m2/d
1	21.46	20.65	1	0.047	0.500	0.332	0.001	50%	100%	0.43	7.14	2.86
2	20.65	20.15	1	0.047	0.500	0.691	0.001	50%	100%	0.43	7.14	2.86
3	20.15	19.65	1	0.047	0.500	1.051	0.001	50%	100%	0.43	7.14	2.86
4	19.65	19.15	1	0.047	0.500	1.411	0.001	40%	100%	0.43	7.14	2.86
5	19.15	18.65	1	0.047	0.500	1.770	0.001	20%	100%	0.43	7.14	2.86
6	18.65	17.65	1	0.047	0.500	1.539	0.400	10%	100%	0.43	7.14	2.86
7	17.65	16.15	3	0.179	0.500	0.450	0.400	70%	100%	0.43	7.14	2.86
8	16.15	15.65	1	0.179	0.500	0.450	0.400	70%	100%	0.43	7.14	2.86
9	15.65	14.15	3	0.179	0.500	0.450	0.400	70%	100%	0.43	7.14	2.86
10	14.15	12.22	3	0.179	0.500	0.450	0.400	70%	100%	0.43	7.14	2.86
11	6.00	4.00	4	0.259	0.500	0.516	0.400	50%	100%	0.43	7.14	2.86
12	4.00	2.67	5	0.259	0.500	0.516	0.400	50%	100%	2.29	7.14	2.86
13	2.67	2.38	1	0.010	1.000	1.830	0.001	10%	100%	1.55	7.14	2.86
14	2.38	0.00	6	0.259	0.500	0.516	0.400	50%	100%	0.43	7.14	2.86
15	12.22	12.02	2	0.243	0.500	0.633	0.400	30%	100%	2.29	7.14	2.86
16	12.02	11.39	1	0.209	0.500	0.666	0.400	30%	100%	2.29	7.14	2.86
17	11.39	10.75	1	0.214	0.500	0.720	0.400	40%	100%	2.29	7.14	2.86
18	10.75	10.00	1	0.167	0.500	0.937	0.400	50%	100%	2.29	7.14	2.86
19	10.00	9.00	2	0.121	0.500	0.959	0.400	60%	100%	2.29	7.14	2.86
20	9.00	8.50	1	0.102	0.500	0.681	0.400	60%	100%	2.29	7.14	2.86
21	8.50	8.00	1	0.102	0.500	0.681	0.400	60%	100%	2.29	7.14	2.86
22	8.00	3.50	9	0.255	0.500	0.428	0.400	60%	100%	2.29	7.14	2.86
23	3.50	3.30	2	0.255	0.500	0.500	0.400	60%	100%	2.29	7.14	2.86
24	7.50	5.30	22	0.226	0.500	0.500	0.400	30%	100%	0.43	7.14	2.86
25	5.30	3.50	18	0.226	0.500	0.500	0.400	30%	100%	2.29	7.14	2.86
26	3.50	0.00	7	0.226	0.500	0.500	0.400	30%	100%	2.29	7.14	2.86
27	3.30	0.50	28	0.226	0.500	0.500	0.400	60%	100%	2.29	7.14	2.86
28	6.40	0.00	8	0.255	0.500	0.428	0.400	40%	100%	1.29	7.14	2.86
29	0.50	0.00	1	0.255	0.500	0.428	0.400	60%	100%	2.29	7.14	2.86

Table 5-7 QUAL2K Reach Rate spreadsheet for August 2004 and May 2004 surveys of Lower Reach

			ISS	Fast CBOD	Organic N		NH4	Nitrate		Organic P		Inorganic P
Reach	**Reach**	**Prescribed**	**Settling**	**Oxidation**	**Hydrolysis**	**Settling**	**Nitrif.**	**Denitri**	**Sed Denitri**	**Hydrolysis**	**Settling**	**Settling**
Number	**Distance**	**Reaeration**	**Velocity**	**Rate**	**Rate**	**Velocity**	**Rate**	**Rate**	**transfer coeff**	**Rate**	**Velocity**	**Velocity**
	km	*/d*	*m/d*	*/d*	*/d*	*m/d*	*/d*	*m/d*	*m/d*	*/d*	*m/d*	*m/d*
1	21.5	1.81/1.81*	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
2	20.7	0.87/	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
3	20.2	0.57/0.57	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
4	19.7	0.43/0.43	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
5	19.2	0.34/0.34	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
6	18.7	0.3/0.29	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
7	17.7		0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
8	16.2		0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
9	15.7		0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
10	14.2		0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
11	6.0		0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
12	4.0		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
13	2.7	0.65/0.72	0.005	0.1	0.4	0.1	0.3	0.05	0.1	0.2	0.05	0.2
14	2.4		0.005	0.1	0.4	0.1	0.3	0.05	0.1	0.2	0.05	0.2
15	12.2		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
16	12.0		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
17	11.4		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
18	10.8		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
19	10.0		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
20	9.0		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
21	8.5		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
22	8.0		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
23	3.5		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
24	7.5	4.51/7.47	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.05
25	5.3		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
26	3.5		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2
27	3.3		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.05
28	6.4	8.84/14.65	0.005	0.1	0.2	0.1	0.1	0.05	0.1	0.2	0.05	0.2
29	0.5		0.005	0.1	0.3	0.1	0.3	0.05	0.1	0.2	0.05	0.2

* August/May values

Table 5-7 (cont.)

	Phytoplankton				**Bottom Algae**				**Detritus**		
Reach Number	**Max Growth Rate**	**Respiration Rate**	**Death Rate**	**Settling Velocity**	**Max Growth Rate**	**Respiration Rate**	**Excretion Rate**	**Death Rate**	**Dissolution Rate**	**Settling Velocity**	**Fraction fast CBOD**
	/d	*/d*	*/d*	*m/d*	*mgA/m2/d*	*mgA/m2/d*	*mgA/m2/d*	*mgA/m2/d*	*/d*	*m/d*	
1	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
2	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
3	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
4	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
5	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
6	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
7	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
8	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
9	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
10	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
11	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
12	2	0.1	0.05	0.3	30	0.6	0.05	0.05	0.1	0.1	1
13	2.5	0.3	0.05	0.3	30	0.5	0.05	0.05	0.1	0.1	1
14	2	0.4	0.05	0.3	30	0.5	0.05	0.05	0.1	0.1	1
15	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
16	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
17	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
18	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
19	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
20	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
21	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
22	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
23	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
24	2	0.1	0.05	0.3	20	0.6	0.05	0.05	0.1	0.1	1
25	2	0.3	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
26	2	0.3	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
27	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1
28	2	0.1	0.05	0.3	20	0.6	0.05	0.05	0.1	0.1	1
29	2	0.5	0.05	0.3	20	0.8	0.05	0.05	0.1	0.1	1

Table 5-8 QUAL2K Rates spreadsheet of globally specified rates for validation process on the Upper Reach

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity		m/d	*vi*
Oxygen:			
Reaeration model	User specified		
User reaeration coefficient α	1.923		*α*
User reaeration coefficient β	0.273		*β*
User reaeration coefficient γ	0.894		*γ*
Temp correction	1.02		*qa*
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO2/gC	*roc*
O2 for NH4 nitrification	4.57	gO2/gN	*ron*
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.6	L/mgO2	*Ksocf*
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.6	L/mgO2	*Ksona*
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.6	L/mgO2	*Ksodn*
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.6	L/mgO2	*Ksop*
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.6	L/mgO2	*Ksob*
Slow CBOD:			
Hydrolysis rate	0.1	/d	*khc*
Temp correction	1.07		*qhc*
Oxidation rate		/d	*kdcs*
Temp correction	1.047		*qdcs*
Fast CBOD:			
Oxidation rate		/d	*kdc*
Temp correction	1.047		*qdc*
Organic N:			
Hydrolysis		/d	*khn*
Temp correction	1.047		*qhn*
Settling velocity		m/d	*von*
Ammonium:			
Nitrification		/d	*kna*
Temp correction	1.083		*qna*
Nitrate:			
Denitrification		/d	*kdn*
Temp correction	1.047		*qdn*
Sed denitrification transfer coeff		m/d	*vdi*
Temp correction	1.07		*qdi*
Organic P:			
Hydrolysis		/d	*khp*
Temp correction	1.047		*qhp*
Settling velocity		m/d	*vop*

Table 5-8 (cont.)

Inorganic P:			
Settling velocity		m/d	*vip*
Inorganic P sorption coefficient	0.1	L/mgD	*Kdpi*
Sed P oxygen attenuation half sat constant	0.05	mgO2/L	*kspi*
Phytoplankton:			
Max Growth rate		/d	*kgp*
Temp correction	1.047		*qgp*
Respiration rate		/d	*krp*
Temp correction	1.047		*qrp*
Death rate		/d	*kdp*
Temp correction	1.047		*qdp*
Nitrogen half sat constant	25	ugN/L	*ksPp*
Phosphorus half sat constant	5	ugP/L	*ksNp*
Inorganic carbon half sat constant	0.000013	moles/L	*ksCp*
Light model	Half saturation		
Light constant	57.6	langleys/d	*KLp*
Ammonia preference	25	ugN/L	*khnxp*
Settling velocity	0.1	m/d	*va*
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate		mgA/m2/d or /d	*Cgb*
Temp correction	1.047		*qgb*
First-order model carrying capacity	1000	mgA/m2	*ab,max*
Respiration rate		/d	*krb*
Temp correction	1.047		*qrb*
Excretion rate		/d	*keb*
Temp correction	1.047		*qdb*
Death rate		/d	*kdb*
Temp correction	1.047		*qdb*
External nitrogen half sat constant	300	ugN/L	*ksPb*
External phosphorus half sat constant	100	ugP/L	*ksNb*
Inorganic carbon half sat constant	0.000013	moles/L	*ksCb*
Light model	Half saturation		
Light constant	60	langleys/d	*KLb*
Ammonia preference	25	ugN/L	*khnxb*
Subsistence quota for nitrogen	0.72	mgN/mgA	*q0N*
Subsistence quota for phosphorus	0.1	mgP/mgA	*q0P*
Maximum uptake rate for nitrogen	72	mgN/mgA/d	*rmN*
Maximum uptake rate for phosphorus	5	mgP/mgA/d	*rmP*
Internal nitrogen half sat constant	0.9	mgN/mgA	*KqN*
Internal phosphorus half sat constant	0.13	mgP/mgA	*KqP*
Detritus (POM):			
Dissolution rate		/d	*kdt*
Temp correction	1.07		*qdt*
Fraction of dissolution to fast CBOD			*Ff*
Settling velocity		m/d	*vdt*
Pathogens:			
Decay rate	0.8	/d	*kdx*
Temp correction	1.07		*qdx*
Settling velocity	1	m/d	*vx*
Light efficiency factor	1		*apath*
pH:			
Partial pressure of carbon dioxide	347	ppm	*pCO2*

Table 5-9 Upper Reach of Upper Oyster Creek segmentation information

Reach Name		Reach Number	Reach length	Location		Element Number
From	*To*		*(km)*	Begin *(km)*	End *(km)*	
BRAZOS RIVER	BRA GAUGE	1	2.00	87	85	2
BRA GAUGE	FLEWELLEN CR.	2	3.35	85	81.65	3
Fulshear-Katy	HINES NURSERY	3	2.50	13	4.5	5
RKM 4.5	RKM 0.5	4	4.00	4.5	0.5	8
RKM 0.5	FLEWELLEN CR	5	0.50	0.5	0	1
FLEWELLEN CR	FM 359	6	7.65	81.65	74	7
FM359	RKM 72.0	7	2.00	74	72	2
FM359	JONES/OYSTER CR CONFL	8	15.00	72	57	15
JONES/OYSTER CR CONFL	OLD 2ND LD	9	1.49	57	55.51	2
OLD 2ND LIFT DAM	OLD 2ND LD	10	0.01	55.51	55.5	1
OLD 2ND LD	SHINER RD	11	3.50	55.5	52	7
SHINER RD	HARLEM RD	12	4.50	52	47.5	9
HARLEM RD	PRISON FARM DAM	13	0.49	47.5	47.01	1
PRISON FARM DAM	PRISON FARM DAM	14	0.01	47.01	47	1
PRISON FARM DAM	FM 1464	15	5.00	47	42	10
FM 1464	RED GULLY	16	4.10	42	37.9	8
FM 1464	UNNAMED ROAD	17	2.50	6	3.5	5
UNNAMED ROAD	OLD RICHMOND RD	18	2.00	3.5	1.5	4
OLD RICHMOND RD	OYSTER CR	19	1.50	1.5	0	3
RED GULLY	RKM 36	20	1.90	37.9	36	3
RKM36	FBCWCID DAM #1	21	3.99	36	32.01	7
FORT BEND COUNTY WCID DAM #1	Downstream-0.01km	22	0.01	32.01	32	1
FBC WCID DAM #1	HARMON ROAD	23	1.50	32	30.5	3
HARMON RD	RKM 29.5	24	1.00	30.5	29.5	2
RKM 29.5	RKM 29.4	25	0.10	29.5	29.4	1
RKM 29.4	US 90A	26	0.20	29.4	29.2	1
US 90A	FBC WCID DAM #2	27	1.57	29.2	27.63	13
FBC WCID DAM #2	Downstream-0.01km	28	0.01	27.63	27.62	1
RKM 27.62	BROOKS L. DISCH	29	0.30	27.62	27.32	3
BROOKS L DISCH	US 59	30	1.75	27.32	25.57	3
US 59	AMERICAN CANAL	31	3.50	25.57	22.07	7
AMERICAN CANAL	FBC WCID DAM #3	32	0.60	22.07	21.47	1
FBC WCID DAM #3	Downstream-0.01km	33	0.01	21.47	21.46	7

Table 5-10 August 2004 QUAL2K Reach spreadsheet with hydraulic rating curves and other input data of Upper Reach

Reach				Rating Curves				Bottom	Bottom	Prescribed	Prescribed	Prescribed
No.	begin	end	Element	Velocity		Depth		Algae	SOD	SOD	NH4 flux	Inorg P flux
	km	km		Coefficient	Exponent	Coefficient	Exponent	Cover	Cover	gO2/m2/d	mgN/m2/d	mgP/m2/d
1	87.00	85.00	2	0.204	0.500	0.472	0.400	20%	100%	4.40	18.35	3.67
2	85.00	81.65	3	0.204	0.500	0.472	0.400	20%	100%	4.40	18.35	3.67
3	13.00	4.50	5	0.320	0.500	0.591	0.400	10%	100%	1.83	18.35	3.67
4	4.50	0.50	8	0.320	0.500	0.591	0.400	20%	100%	3.12	18.35	3.67
5	0.50	0.00	1	0.030	0.500	0.450	0.001	30%	100%	4.40	18.35	3.67
6	81.65	74.00	7	0.180	0.500	0.480	0.400	20%	100%	4.40	18.35	3.67
7	74.00	72.00	2	0.180	0.500	0.480	0.400	20%	100%	4.40	18.35	3.67
8	72.00	57.00	15	0.075	0.500	0.787	0.400	20%	100%	4.40	18.35	3.67
9	57.00	55.51	2	0.075	0.500	0.787	0.400	20%	100%	4.40	18.35	3.67
10	55.51	55.50	1	0.075	0.500	0.787	0.400	20%	100%	3.67	18.35	3.67
11	55.50	52.00	7	0.104	0.500	0.540	0.400	20%	100%	3.67	18.35	3.67
12	52.00	47.50	9	0.079	0.500	0.640	0.400	20%	100%	3.67	18.35	3.67
13	47.50	47.01	1	0.079	0.500	0.640	0.400	20%	100%	3.67	18.35	3.67
14	47.01	47.00	1	0.079	0.500	0.640	0.400	20%	100%	3.67	18.35	3.67
15	47.00	42.00	10	0.079	0.500	0.640	0.400	20%	100%	3.67	18.35	3.67
16	42.00	37.90	8	0.079	0.500	0.640	0.400	20%	100%	3.67	18.35	3.67
17	6.00	3.50	5	0.320	0.500	0.591	0.400	10%	100%	1.83	18.35	3.67
18	3.50	1.50	4	0.320	0.500	0.591	0.400	10%	100%	3.12	18.35	3.67
19	1.50	0.00	3	0.030	0.500	0.900	0.001	20%	100%	3.67	18.35	3.67
20	37.90	36.00	3	0.079	0.500	0.640	0.400	5%	100%	4.04	91.73	18.35
21	36.00	32.01	7	0.079	0.500	0.640	0.400	5%	100%	4.04	91.73	18.35
22	32.01	32.00	1	0.079	0.500	0.640	0.400	30%	100%	4.04	91.73	18.35
23	32.00	30.50	3	0.010	1.000	1.920	0.001	30%	100%	4.04	91.73	18.35
24	30.50	29.50	2	0.009	1.000	1.790	0.001	30%	100%	4.04	91.73	18.35
25	29.50	29.40	1	0.016	1.000	1.830	0.001	30%	100%	4.04	91.73	18.35
26	29.40	29.20	1	0.012	1.000	1.820	0.001	30%	100%	4.04	91.73	18.35
27	29.20	27.63	10	0.008	1.000	1.580	0.001	30%	100%	4.04	91.73	18.35
28	27.63	27.62	1	0.008	1.000	1.340	0.001	30%	100%	4.04	91.73	18.35
29	27.62	27.32	3	0.007	1.000	1.980	0.001	30%	100%	4.04	91.73	18.35
30	27.32	25.57	1	0.012	1.000	1.440	0.001	30%	100%	4.04	91.73	18.35
31	25.57	22.07	7	0.015	1.000	1.150	0.001	30%	100%	4.04	91.73	18.35
32	22.07	21.47	1	0.018	1.000	0.890	0.001	30%	100%	4.04	91.73	18.35
33	21.47	21.46	1	0.047	0.500	1.539	0.400	10%	100%	4.04	91.73	18.35

Table 5-11 May 2004 QUAL2K Reach spreadsheet with hydraulic rating curves and other input data of Upper Reach

Reach				Rating Curves				Bottom	Bottom	Prescribed	Prescribed	Prescribed
No.	begin	end	Element	Velocity		Depth		Algae	SOD	SOD	NH4 flux	Inorg P flux
	km	km		Coefficient	Exponent	Coefficient	Exponent	Cover	Cover	gO2/m2/d	mgN/m2/d	mgP/m2/d
1	87.00	85.00	2	0.204	0.500	0.472	0.400	20%	100%	4.31	17.96	3.59
2	85.00	81.65	3	0.204	0.500	0.472	0.400	20%	100%	4.31	17.96	3.59
3	13.00	4.50	5	0.320	0.500	0.591	0.400	10%	100%	1.80	17.96	3.59
4	4.50	0.50	8	0.320	0.500	0.591	0.400	20%	100%	3.05	17.96	3.59
5	0.50	0.00	1	0.030	0.500	0.450	0.001	30%	100%	4.31	17.96	3.59
6	81.65	74.00	7	0.180	0.500	0.480	0.400	20%	100%	4.31	17.96	3.59
7	74.00	72.00	2	0.180	0.500	0.480	0.400	20%	100%	4.31	17.96	3.59
8	72.00	57.00	15	0.075	0.500	0.787	0.400	20%	100%	4.31	17.96	3.59
9	57.00	55.51	2	0.075	0.500	0.787	0.400	20%	100%	4.31	17.96	3.59
10	55.51	55.50	1	0.075	0.500	0.787	0.400	20%	100%	3.59	17.96	3.59
11	55.50	52.00	7	0.104	0.500	0.540	0.400	20%	100%	3.59	17.96	3.59
12	52.00	47.50	9	0.079	0.500	0.640	0.400	20%	100%	3.59	17.96	3.59
13	47.50	47.01	1	0.079	0.500	0.640	0.400	20%	100%	3.59	17.96	3.59
14	47.01	47.00	1	0.079	0.500	0.640	0.400	20%	100%	3.59	17.96	3.59
15	47.00	42.00	10	0.079	0.500	0.640	0.400	20%	100%	3.59	17.96	3.59
16	42.00	37.90	8	0.079	0.500	0.640	0.400	20%	100%	3.59	17.96	3.59
17	6.00	3.50	5	0.320	0.500	0.591	0.400	10%	100%	1.80	17.96	3.59
18	3.50	1.50	4	0.320	0.500	0.591	0.400	10%	100%	3.05	17.96	3.59
19	1.50	0.00	3	0.030	0.500	0.900	0.001	20%	100%	3.59	17.96	3.59
20	37.90	36.00	3	0.079	0.500	0.640	0.400	5%	100%	3.95	89.79	17.96
21	36.00	32.01	7	0.079	0.500	0.640	0.400	5%	100%	3.95	89.79	17.96
22	32.01	32.00	1	0.079	0.500	0.640	0.400	30%	100%	3.95	89.79	17.96
23	32.00	30.50	3	0.010	1.000	1.920	0.001	30%	100%	3.95	89.79	17.96
24	30.50	29.50	2	0.009	1.000	1.790	0.001	30%	100%	3.95	89.79	17.96
25	29.50	29.40	1	0.016	1.000	1.830	0.001	30%	100%	3.95	89.79	17.96
26	29.40	29.20	1	0.012	1.000	1.820	0.001	30%	100%	3.95	89.79	17.96
27	29.20	27.63	10	0.008	1.000	1.580	0.001	30%	100%	3.95	89.79	35.91
28	27.63	27.62	1	0.008	1.000	1.340	0.001	30%	100%	3.95	89.79	35.91
29	27.62	27.32	3	0.007	1.000	1.980	0.001	30%	100%	3.95	89.79	35.91
30	27.32	25.57	1	0.012	1.000	1.440	0.001	30%	100%	3.95	89.79	35.91
31	25.57	22.07	7	0.015	1.000	1.150	0.001	30%	100%	3.95	89.79	35.91
32	22.07	21.47	1	0.018	1.000	0.890	0.001	30%	100%	3.95	89.79	35.91
33	21.47	21.46	1	0.047	0.500	1.539	0.400	10%	100%	3.95	89.79	35.91

Table 5-12 QUAL2K Reach Rate spreadsheet for August 2004 calibration survey of Upper Reach

			ISS	Fast CBOD	Organic N		NH4	Nitrate		Organic P		Inorganic P
Reach Number	**Reach Distance**	**Prescribed Reaeration**	**Settling Velocity**	**Oxidation Rate**	**Hydrolysis Rate**	**Settling Velocity**	**Nitrif. Rate**	**Denitri Rate**	**Sed Denitri transfer coeff**	**Hydrolysis Rate**	**Settling Velocity**	**Settling Velocity**
	km	*/d*	*m/d*	*/d*	*/d*	*m/d*	*/d*	*m/d*	*m/d*	*/d*	*m/d*	*m/d*
1	87.0		0.9	0.1	0.1	0.1	0.3	0.2	0.1	0.05	0.1	0
2	85.0		0.9	0.1	0.1	0.1	0.3	0.2	0.1	0.05	0.1	0
3	13.0	8.044	0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
4	4.5	8.044	0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
5	0.5	1.340	0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
6	81.7		0.8	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
7	74.0		0.8	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
8	72.0	0.939	0.7	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
9	57.0	0.943	0.6	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
10	55.5	0.943	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
11	55.5		0.4	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
12	52.0	1.359	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
13	47.5	1.361	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
14	47.0	1.362	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
15	47.0	1.389	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
16	42.0	1.413	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
17	6.0		0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
18	3.5		0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
19	1.5	1.174	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
20	37.9	1.405	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
21	36.0	1.429	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
22	32.0	1.429	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
23	32.0	0.549	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
24	30.5	0.589	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
25	29.5	0.576	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
26	29.4	0.579	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
27	29.2	0.667	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
28	27.6	0.786	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
29	27.6	0.532	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
30	27.3	0.732	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
31	25.6	0.916	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
32	22.1	1.188	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
33	21.5	0.921	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0

Table 5-12 (cont.)

	Phytoplankton				Bottom Algae				Detritus		
Reach Number	**Max Growth Rate**	**Respiration Rate**	**Death Rate**	**Settling Velocity**	**Max Growth Rate**	**Respiration Rate**	**Excretion Rate**	**Death Rate**	**Dissolution Rate**	**Settling Velocity**	**Fraction fast CBOD**
	/d	*/d*	*/d*	*m/d*	*mgA/m2/d*	*mgA/m2/d*	*mgA/m2/d*	*mgA/m2/d*	*/d*	*m/d*	
1	1.5	0.2	0.2	0.8	60	0.3	0.1	0.2	0.1	1	1
2	1.5	0.2	0.2	0.7	60	0.3	0.1	0.2	0.1	1	1
3	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
4	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
5	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
6	1.5	0.2	0.2	0.6	60	0.3	0.1	0.2	0.1	1	1
7	1.5	0.2	0.2	0.5	60	0.3	0.1	0.2	0.1	1	1
8	1.5	0.2	0.2	0.4	60	0.3	0.1	0.2	0.1	1	1
9	1.5	0.2	0.2	0.4	60	0.3	0.1	0.2	0.1	1	1
10	1.5	0.2	0.2	0.3	60	0.3	0.1	0.2	0.1	1	1
11	1.5	0.2	0.2	0.3	60	0.3	0.1	0.2	0.1	1	1
12	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
13	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
14	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
15	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
16	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
17	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
18	2.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
19	2.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
20	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
21	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
22	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
23	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
24	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
25	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
26	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
27	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
28	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
29	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
30	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
31	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
32	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
33	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1

Table 5-13 QUAL2K Reach Rate spreadsheet for May 2004 verification survey of Upper Reach

			ISS	Fast CBOD	Organic N		NH4	Nitrate		Organic P		Inorganic P
Reach Number	**Reach Distance**	**Prescribed Reaeration**	**Settling Velocity**	**Oxidation Rate**	**Hydrolysis Rate**	**Settling Velocity**	**Nitrif. Rate**	**Denitri Rate**	**Sed Denitri transfer coeff**	**Hydrolysis Rate**	**Settling Velocity**	**Settling Velocity**
	km	*/d*	*m/d*	*/d*	*/d*	*m/d*	*/d*	*m/d*	*m/d*	*/d*	*m/d*	*m/d*
1	87.0		0.8	0.1	0.1	0.1	0.3	0.2	0.1	0.05	0.1	0
2	85.0		0.7	0.1	0.1	0.1	0.3	0.2	0.1	0.05	0.1	0
3	13.0	6.096	0.05	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
4	4.5	6.096	0.05	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
5	0.5	1.339	0.05	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
6	81.7		0.6	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
7	74.0		0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
8	72.0	1.059	0.4	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
9	57.0	1.060	0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
10	55.5	1.060	0.2	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
11	55.5		0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
12	52.0		0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.1	0
13	47.5		0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
14	47.0		0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
15	47.0		0.1	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
16	42.0		0.2	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
17	6.0		0.05	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
18	3.5		0.05	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
19	1.5	0.811	0.05	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
20	37.9		0.3	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
21	36.0		0.4	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
22	32.0		0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
23	32.0	0.691	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
24	30.5	0.741	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
25	29.5	0.725	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
26	29.4	0.729	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
27	29.2	0.840	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
28	27.6	0.990	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
29	27.6	0.670	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
30	27.3	0.921	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
31	25.6	1.154	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
32	22.1	1.498	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0
33	21.5	1.672	0.5	0.1	0.05	0.05	0.3	0.2	0.1	0.05	0.05	0

Table 5-13 (cont.)

	Phytoplankton				Bottom Algae				Detritus		
Reach Number	**Max Growth Rate**	**Respiration Rate**	**Death Rate**	**Settling Velocity**	**Max Growth Rate**	**Respiration Rate**	**Excretion Rate**	**Death Rate**	**Dissolution Rate**	**Settling Velocity**	**Fraction fast CBOD**
	/d	*/d*	*/d*	*m/d*	*mgA/m2/d*	*mgA/m2/d*	*mgA/m2/d*	*mgA/m2/d*	*/d*	*m/d*	
1	1.5	0.2	0.2	0.8	60	0.3	0.1	0.2	0.1	1	1
2	1.5	0.2	0.2	0.7	60	0.3	0.1	0.2	0.1	1	1
3	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
4	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
5	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
6	1.5	0.2	0.2	0.6	60	0.3	0.1	0.2	0.1	1	1
7	1.5	0.2	0.2	0.5	60	0.3	0.1	0.2	0.1	1	1
8	1.5	0.2	0.2	0.4	60	0.3	0.1	0.2	0.1	1	1
9	1.5	0.2	0.2	0.4	60	0.3	0.1	0.2	0.1	1	1
10	1.5	0.2	0.2	0.3	60	0.3	0.1	0.2	0.1	1	1
11	1.5	0.2	0.2	0.3	60	0.3	0.1	0.2	0.1	1	1
12	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
13	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
14	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
15	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
16	1.5	0.2	0.2	0.2	60	0.3	0.1	0.2	0.1	1	1
17	1.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
18	2.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
19	2.5	0.2	0.2	0.1	30	0.5	0.1	0.3	0.1	0.2	1
20	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
21	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
22	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
23	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
24	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
25	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
26	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
27	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
28	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
29	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
30	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
31	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
32	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1
33	1.5	0.2	0.2	0.1	60	0.3	0.1	0.2	0.1	1	1

SECTION 5

FIGURES

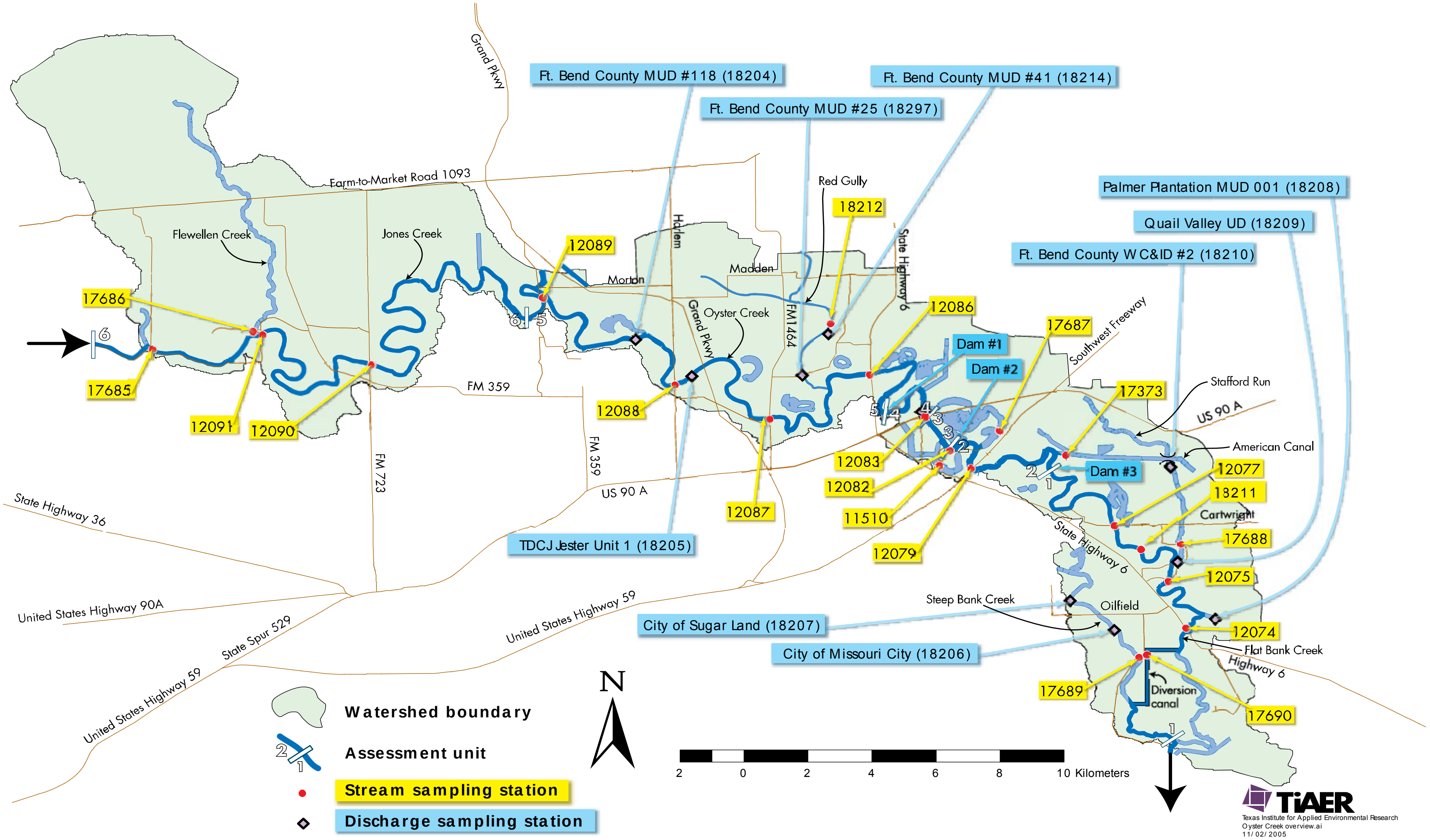


Figure 5-1 Map of Upper Oyster Creek showing monitoring stations and active point source discharges during model support surveys

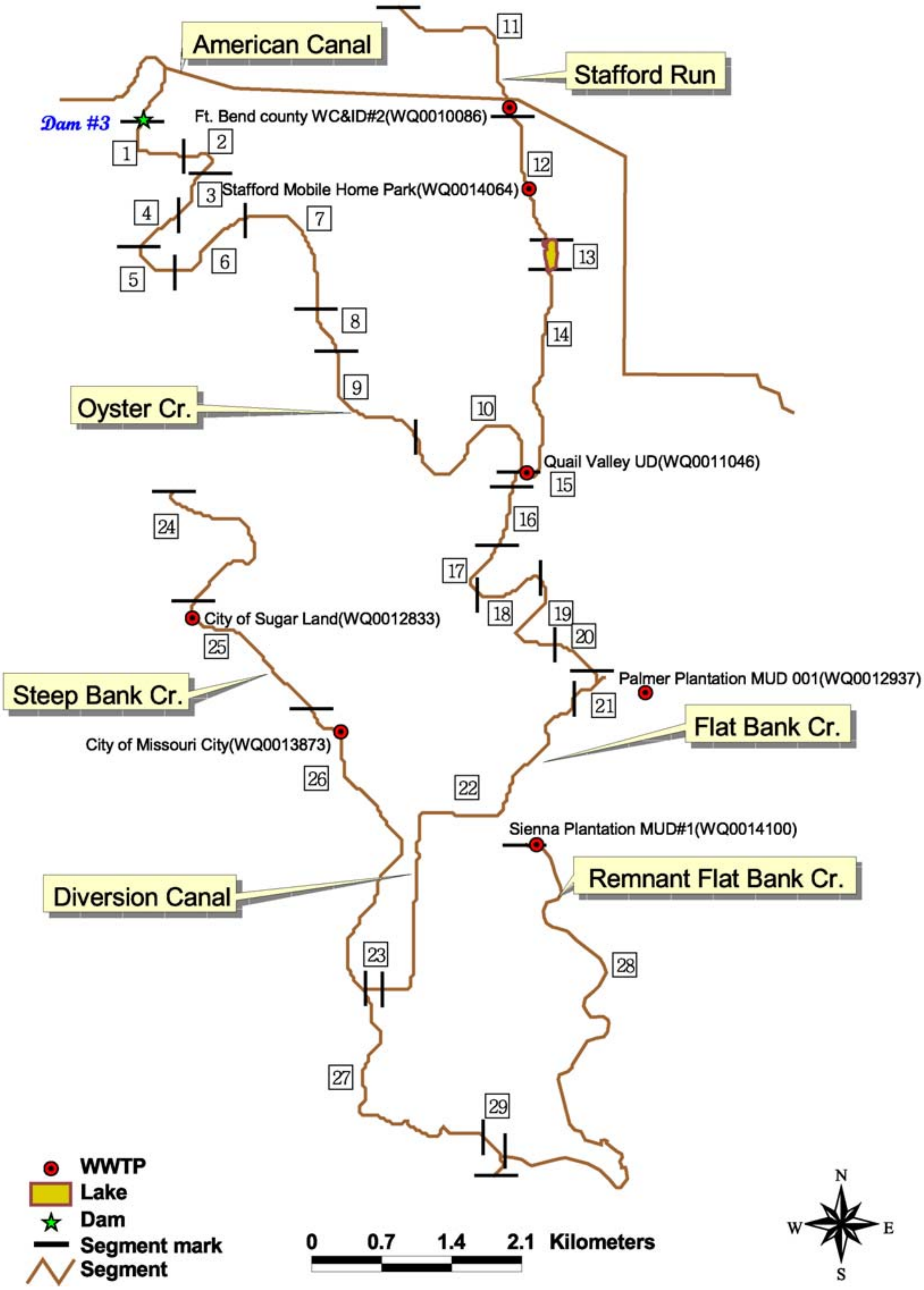


Figure 5-2 **QUAL2K segmentation of Lower Reach, Upper Oyster Creek**

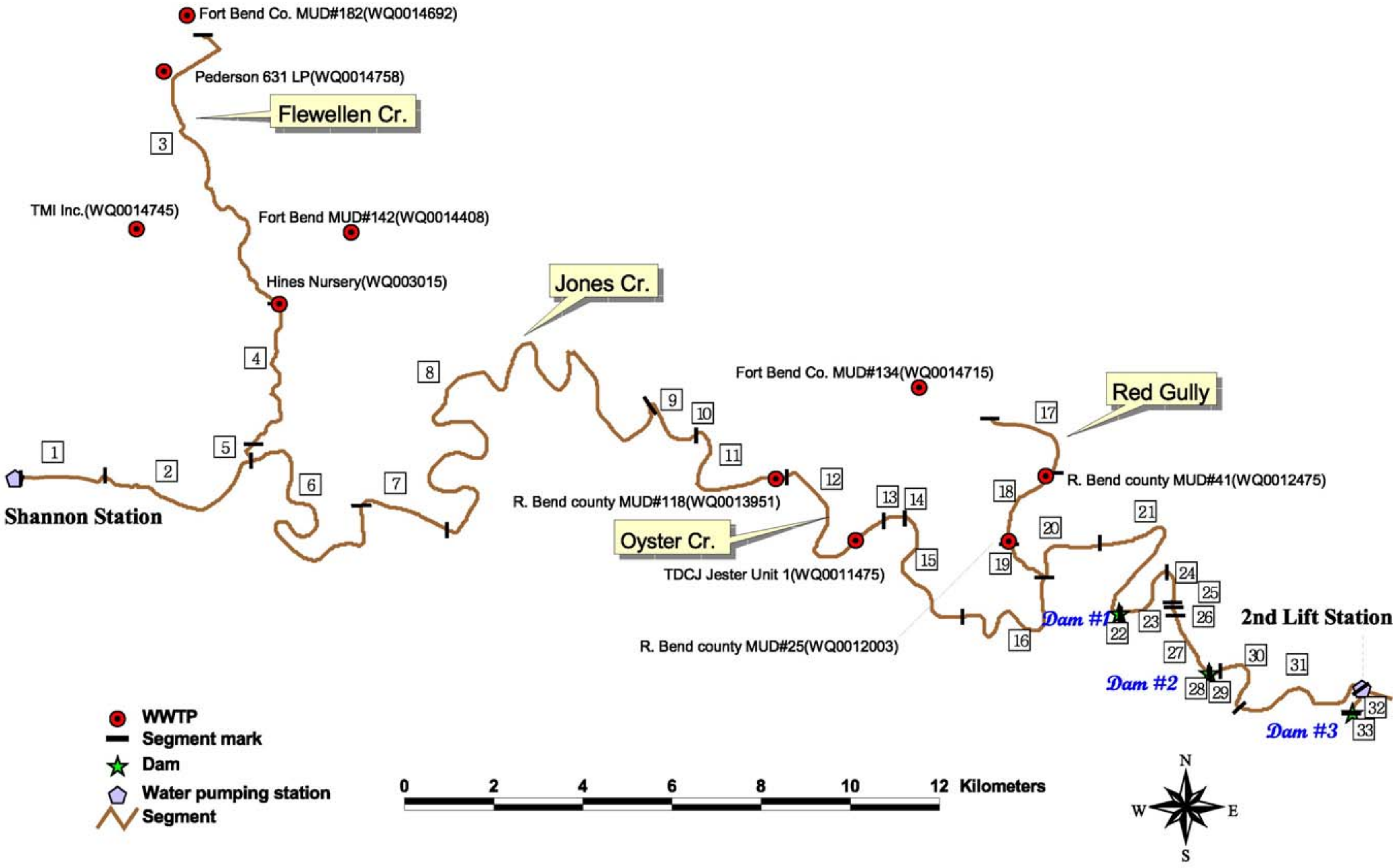


Figure 5-3 QUAL2K segmentation of Upper Reach, Upper Oyster Creek

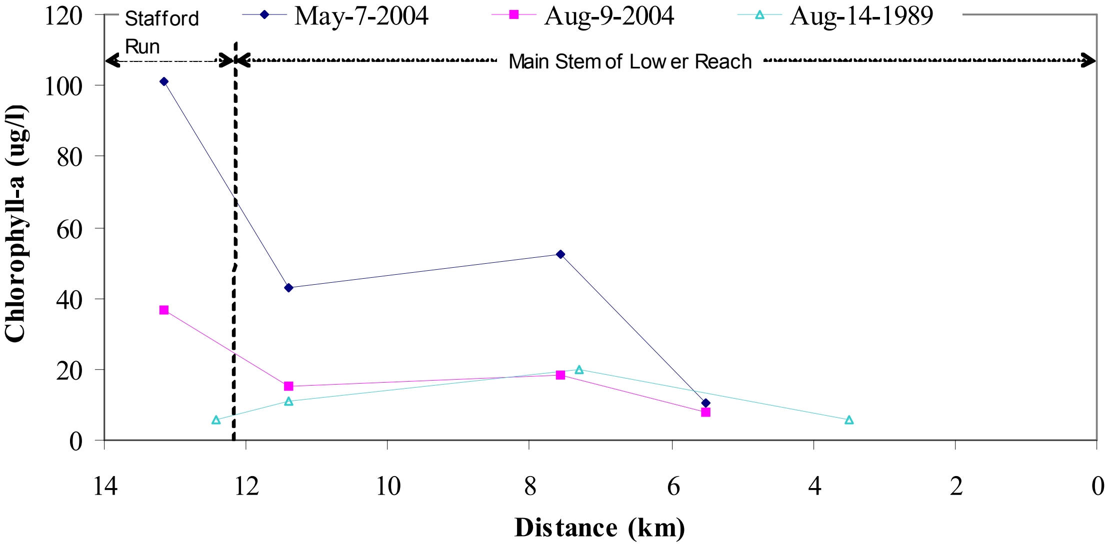


Figure 5-4 **Observed chlorophyll-α concentrations, Stafford Run through Oyster Creek. (The August 1989 data predate the pond-system on Stafford Run, which was constructed approximately 1995-1996.)**

Figure 5-5 **Map showing pond system in Independence Park and Stafford Run**

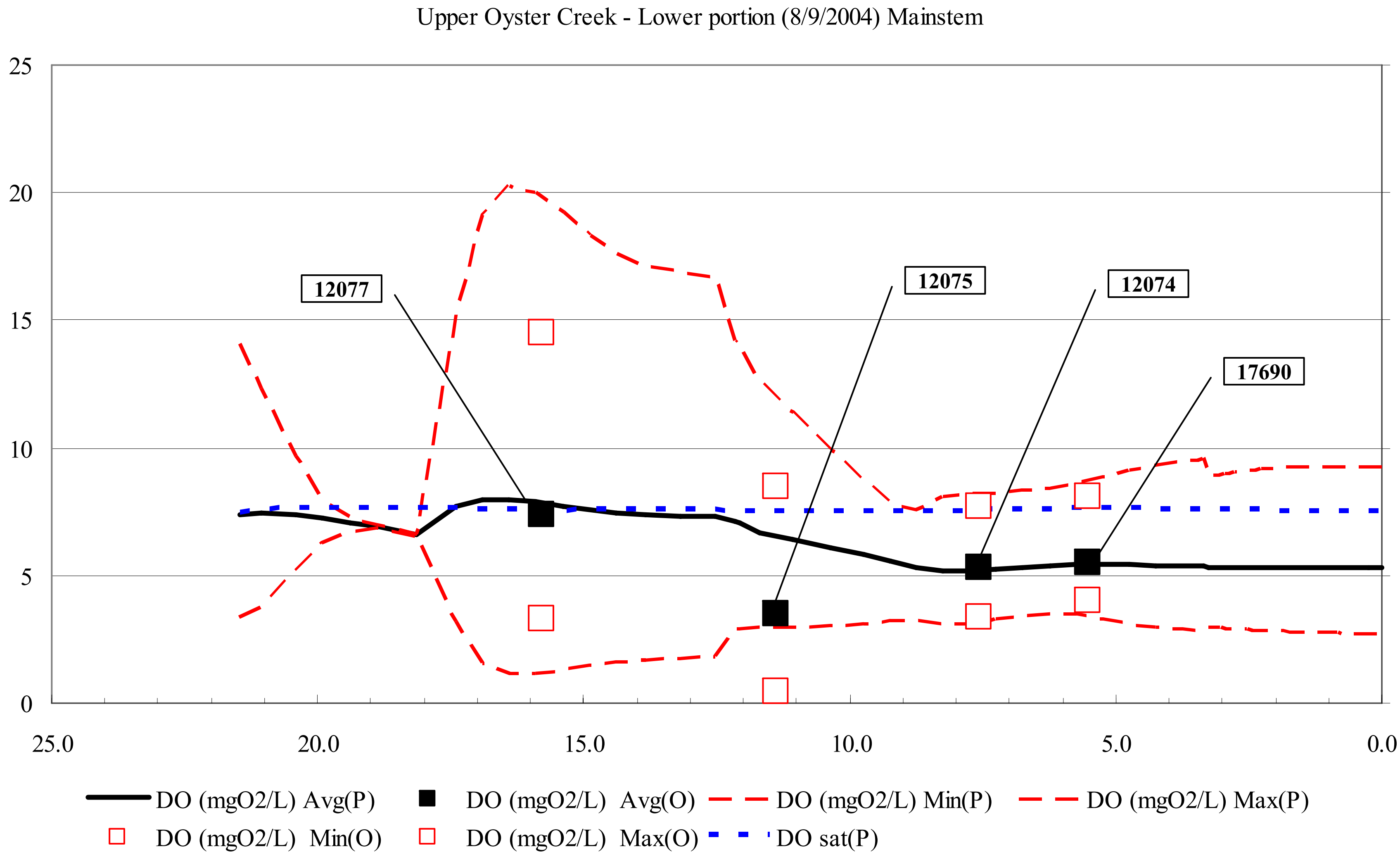
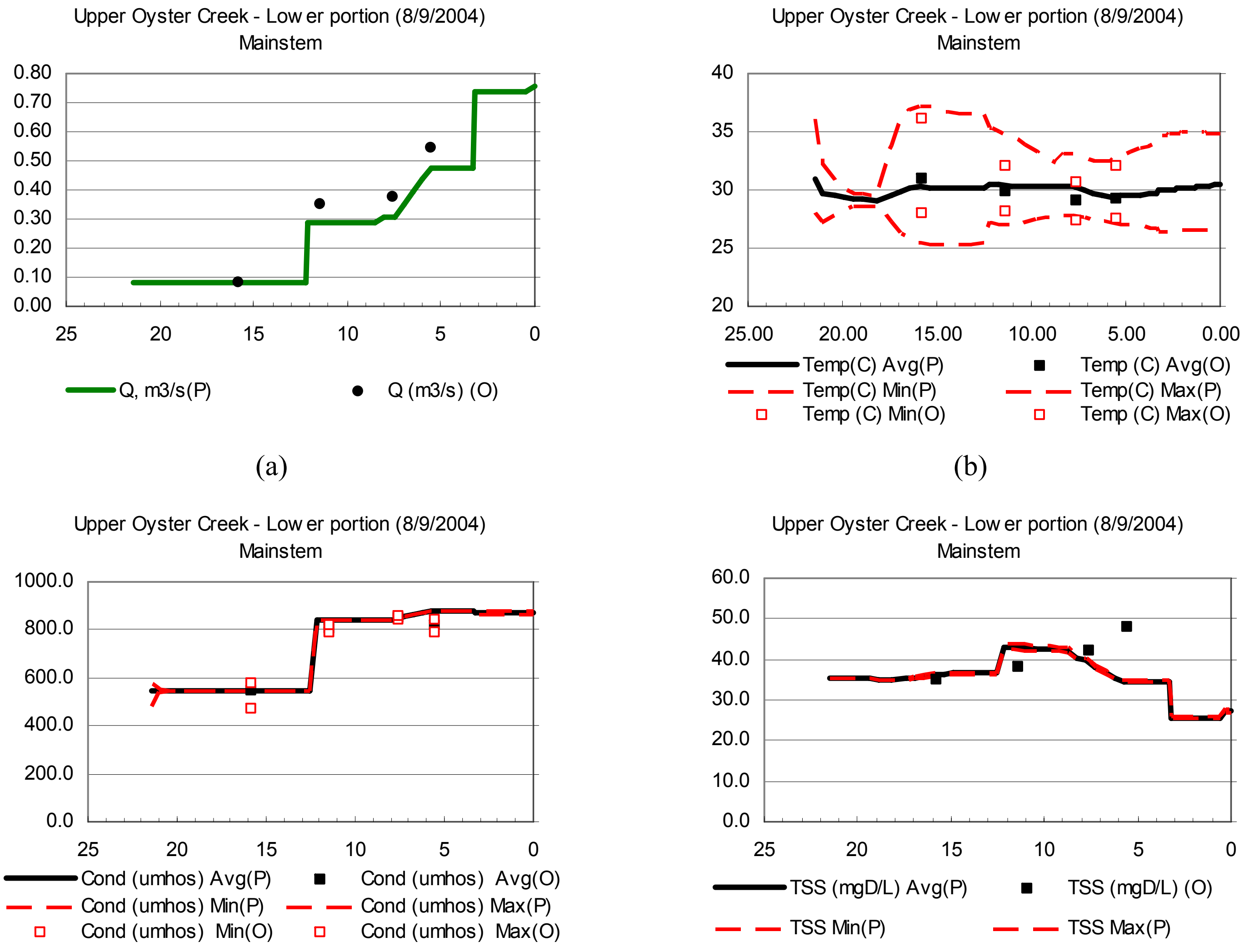


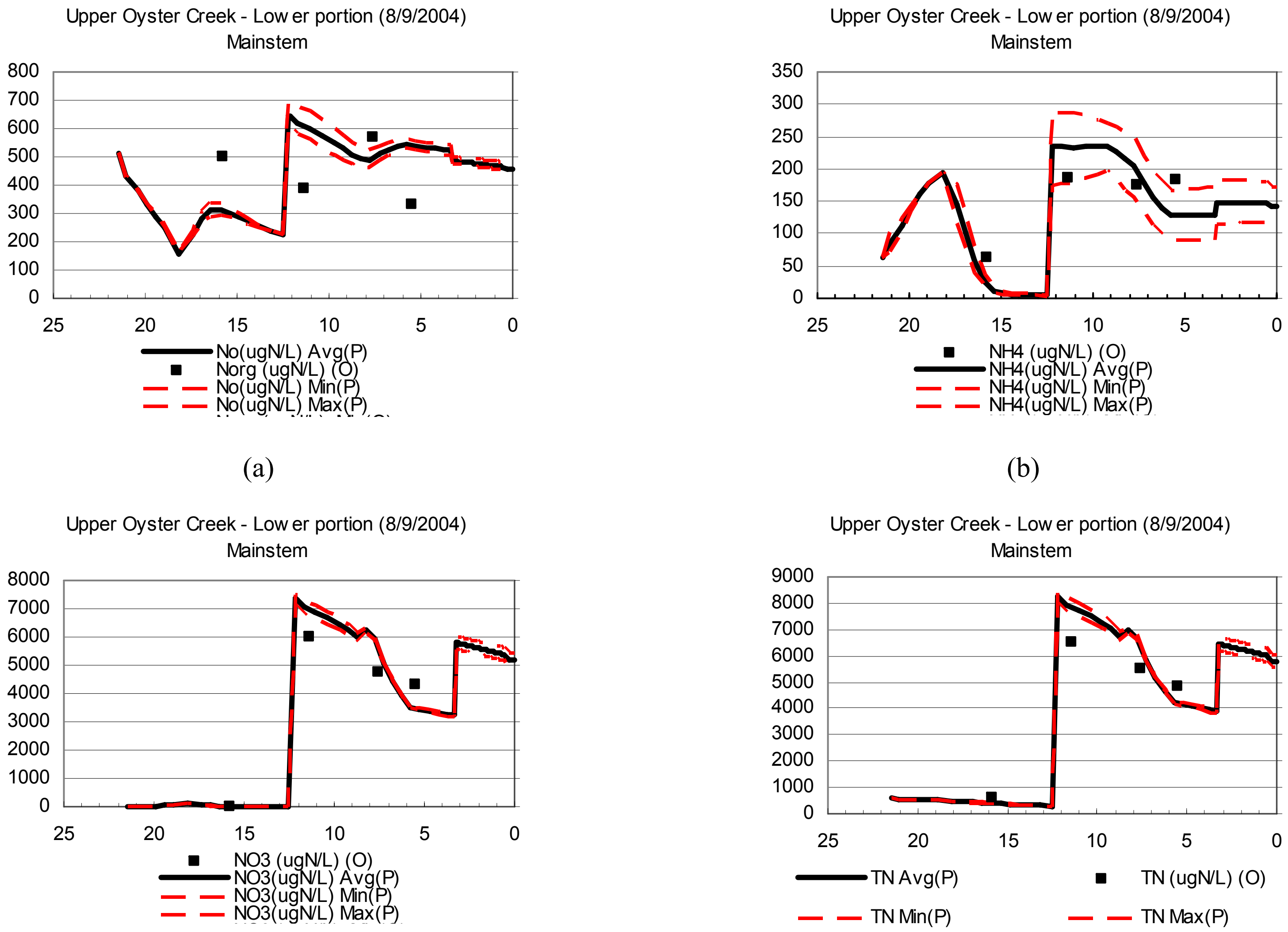
Figure 5-6 **Observed (O) vs. predicted (P) dissolved oxygen along the main stem of the Lower Reach, August 2004 calibration survey (x-axis in units of kilometers from downstream end of Segment 1245)**



(a) (b)

(c) (d)

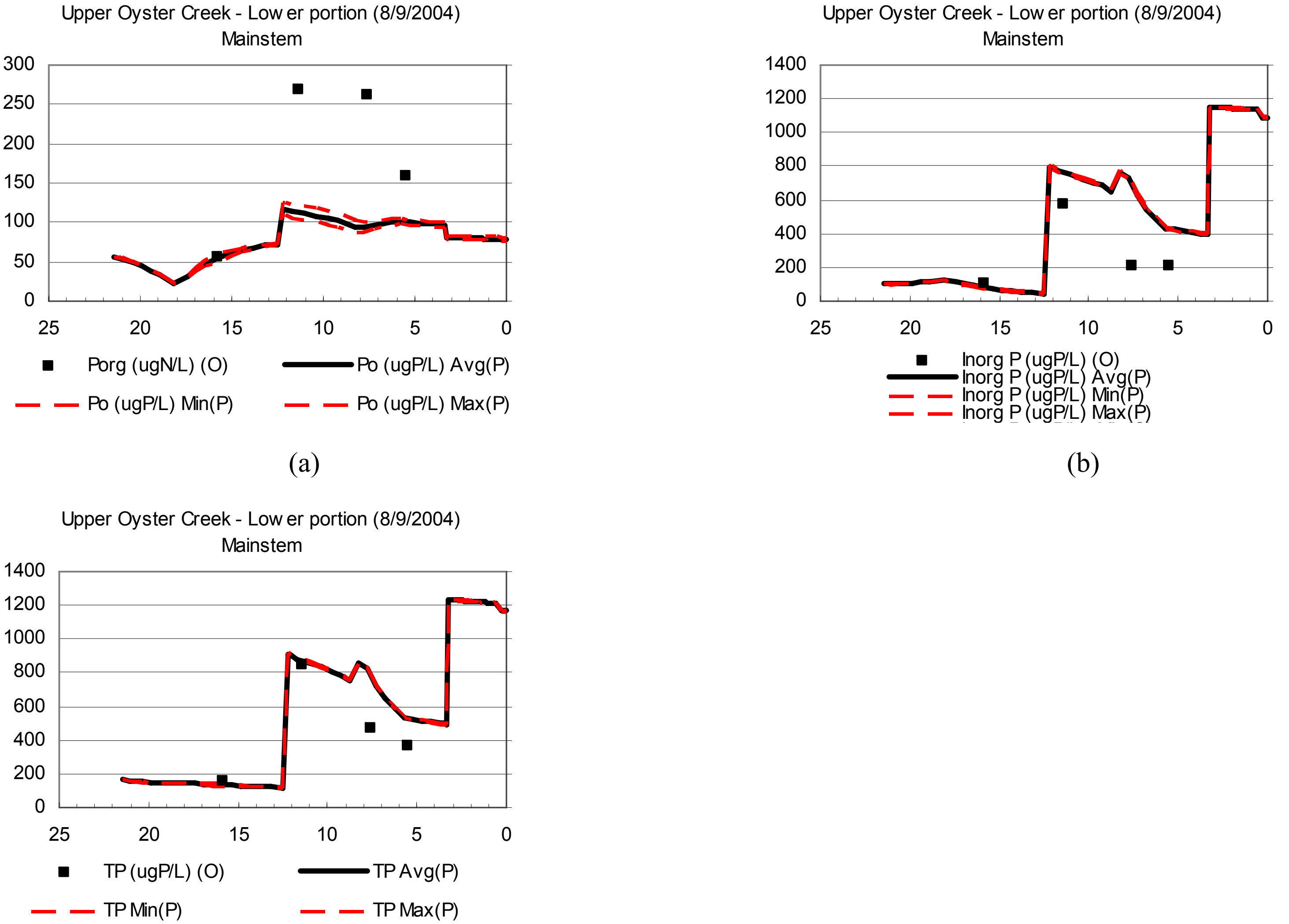
Figure 5-7 **Observed (O) vs. predicted (P): (a) flow, (b) temperature, (c) specific conductance, and (d) total suspended solids in the main stem of the Lower Reach, August 2004 calibration survey**



(a) (b)

(c) (d)

Figure 5-8 Observed (O) vs. predicted (P): (a) organic N, (b) ammonium N, (c) nitrate N, and (d) total N in the main stem of the Lower Reach, August 2004 calibration survey

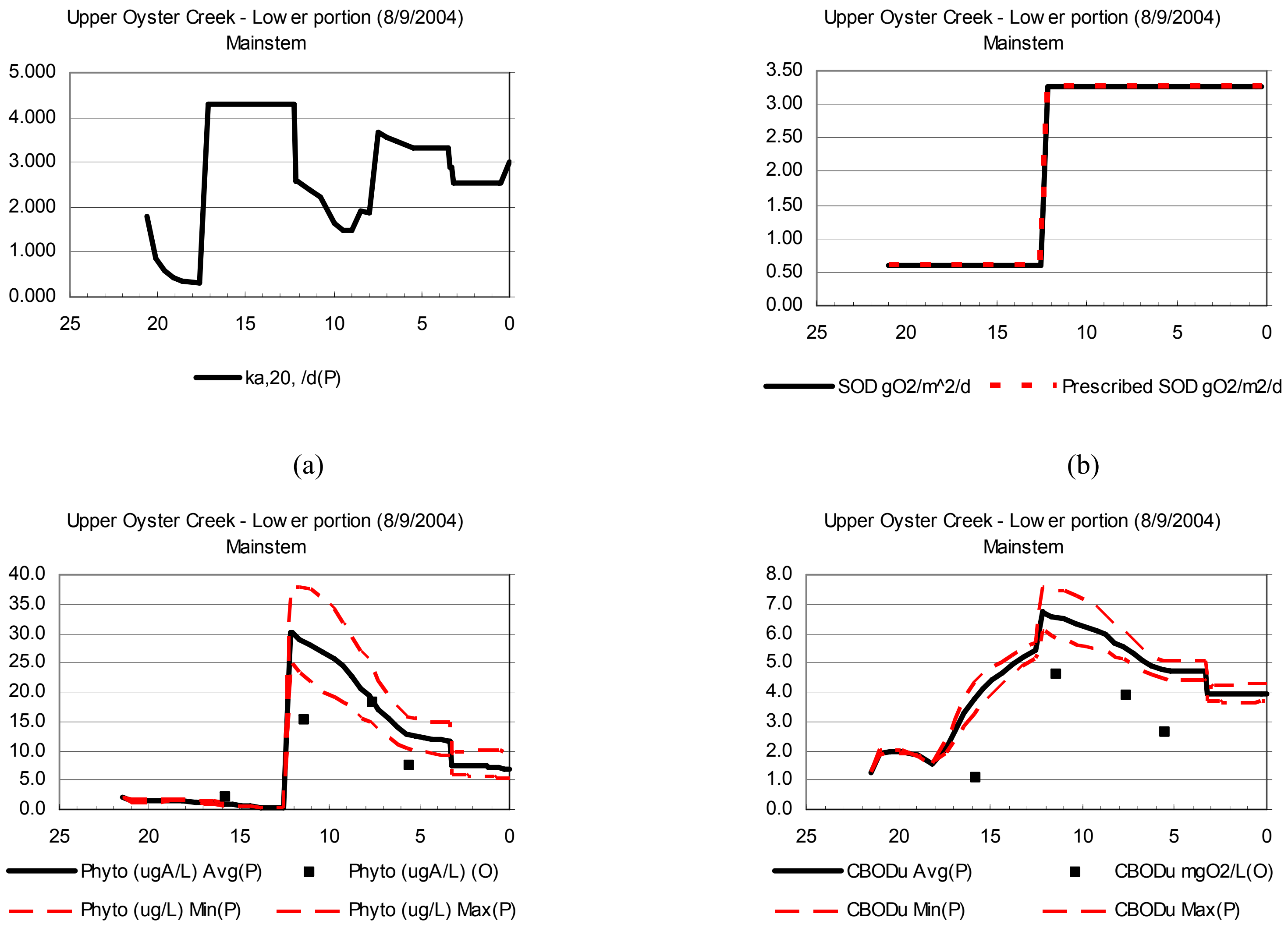


(a)

(b)

(c)

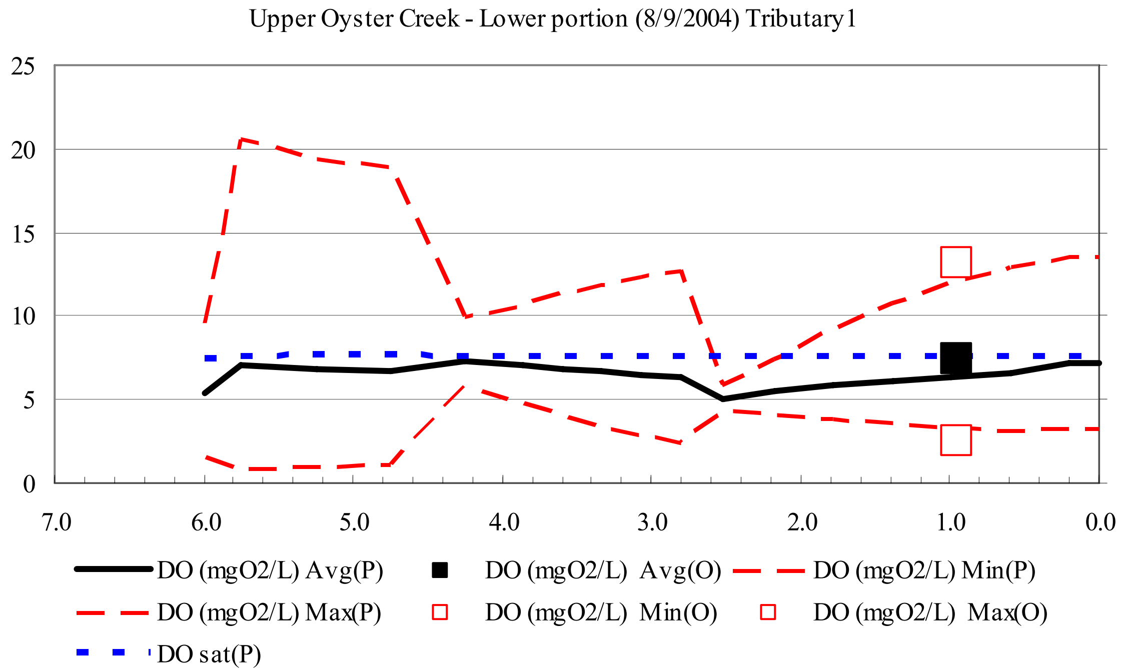
Figure 5-9 Observed (O) vs. predicted (P): (a) organic P, (b) inorganic P, and (c) total P in the main stem of the Lower Reach, August 2004 calibration survey



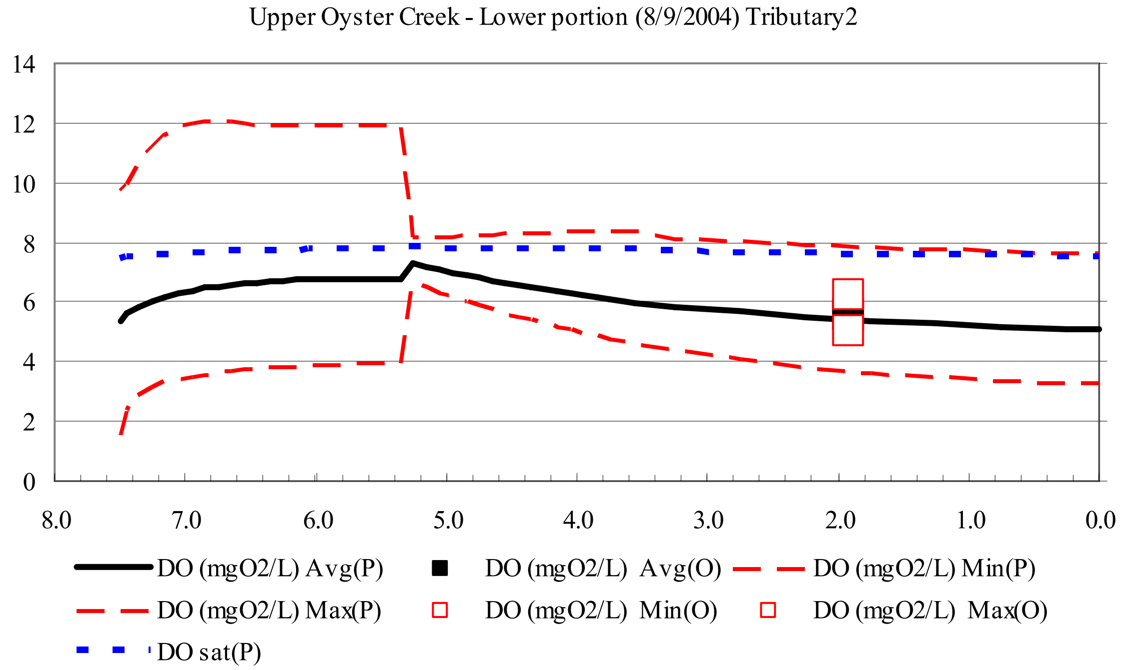
(a) (b)

(c) (d)

Figure 5-10 **Observed (O) vs. predicted (P): (a) aeration, (b) sediment oxygen demand, (c) phytoplankton, and (d) ultimate carbonaceous biochemical oxygen demand in the main stem of the Lower Reach, August 2004 calibration survey**



a) Stafford Run



b) Steep Bank Creek

Figure 5-11 Observed (O) vs. predicted (P) dissolved oxygen along a) Stafford Run and b) Steep Bank of the Lower Reach, August 2004 calibration survey (x-axis in units of kilometers from downstream end of creek)

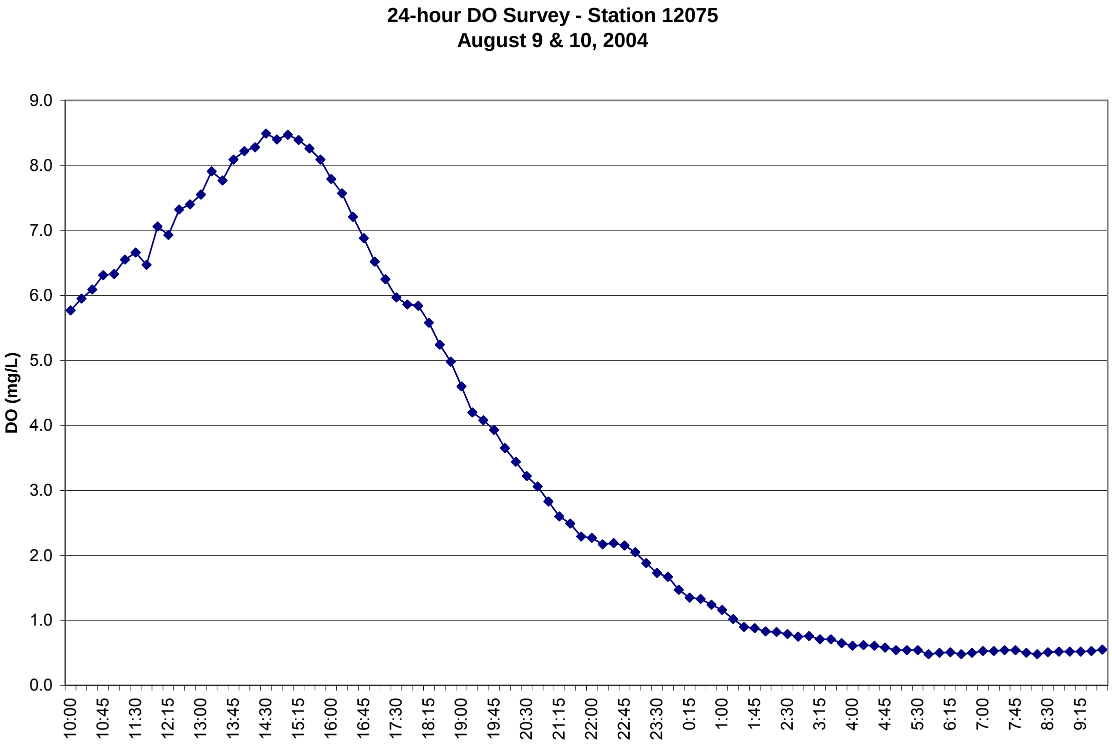


Figure 5-12 **Observed DO concentrations at station 12075 during August calibration survey**

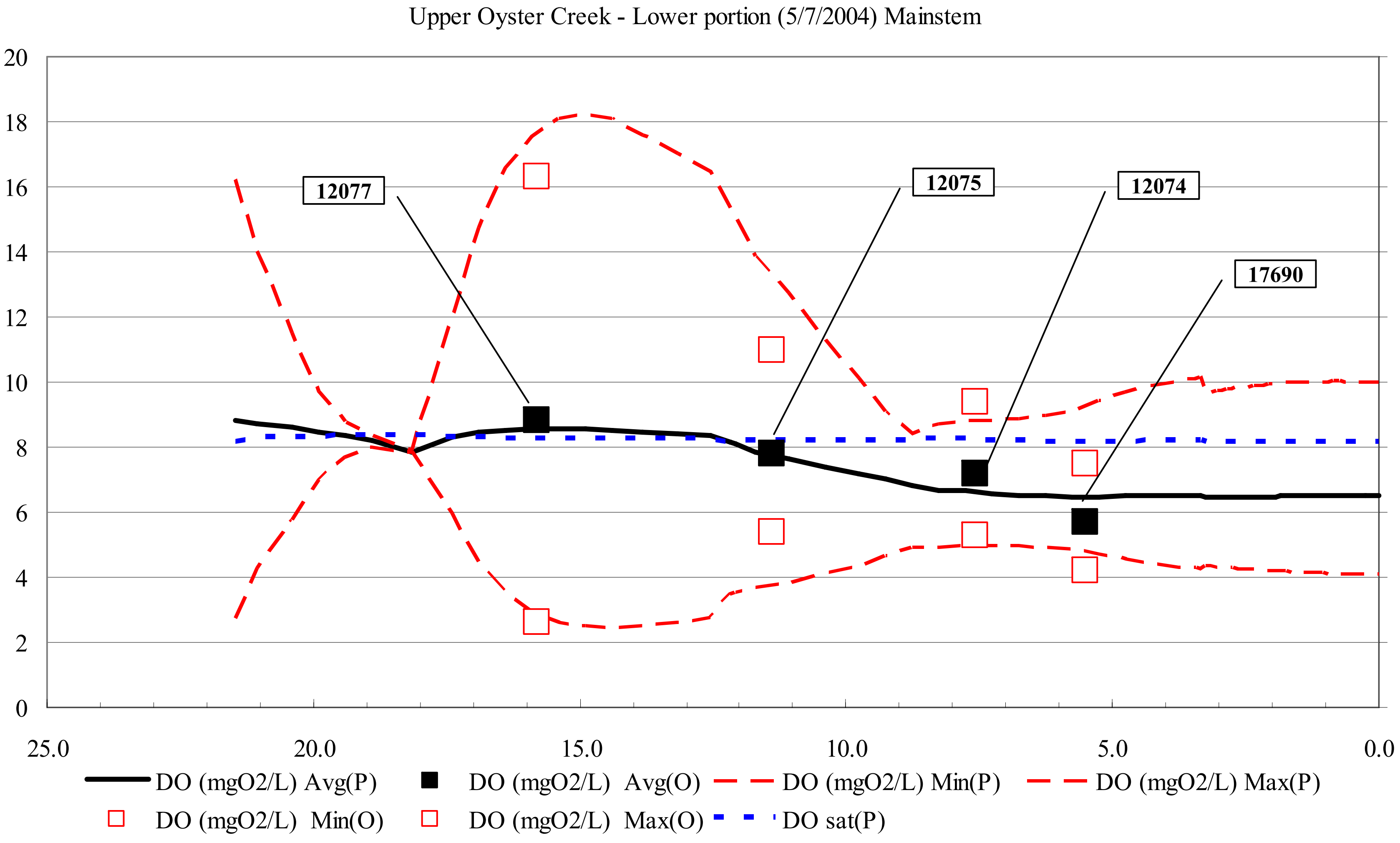
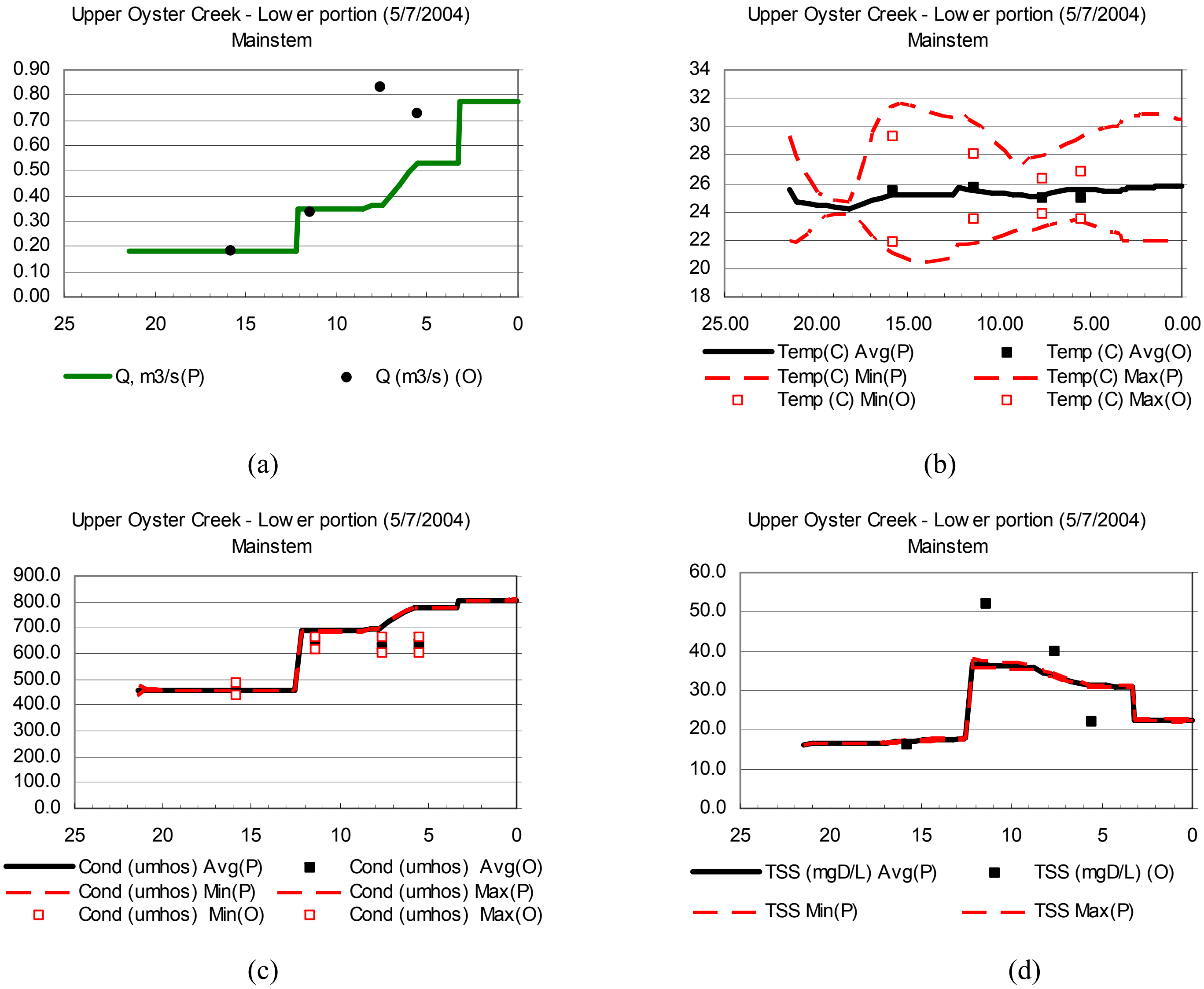


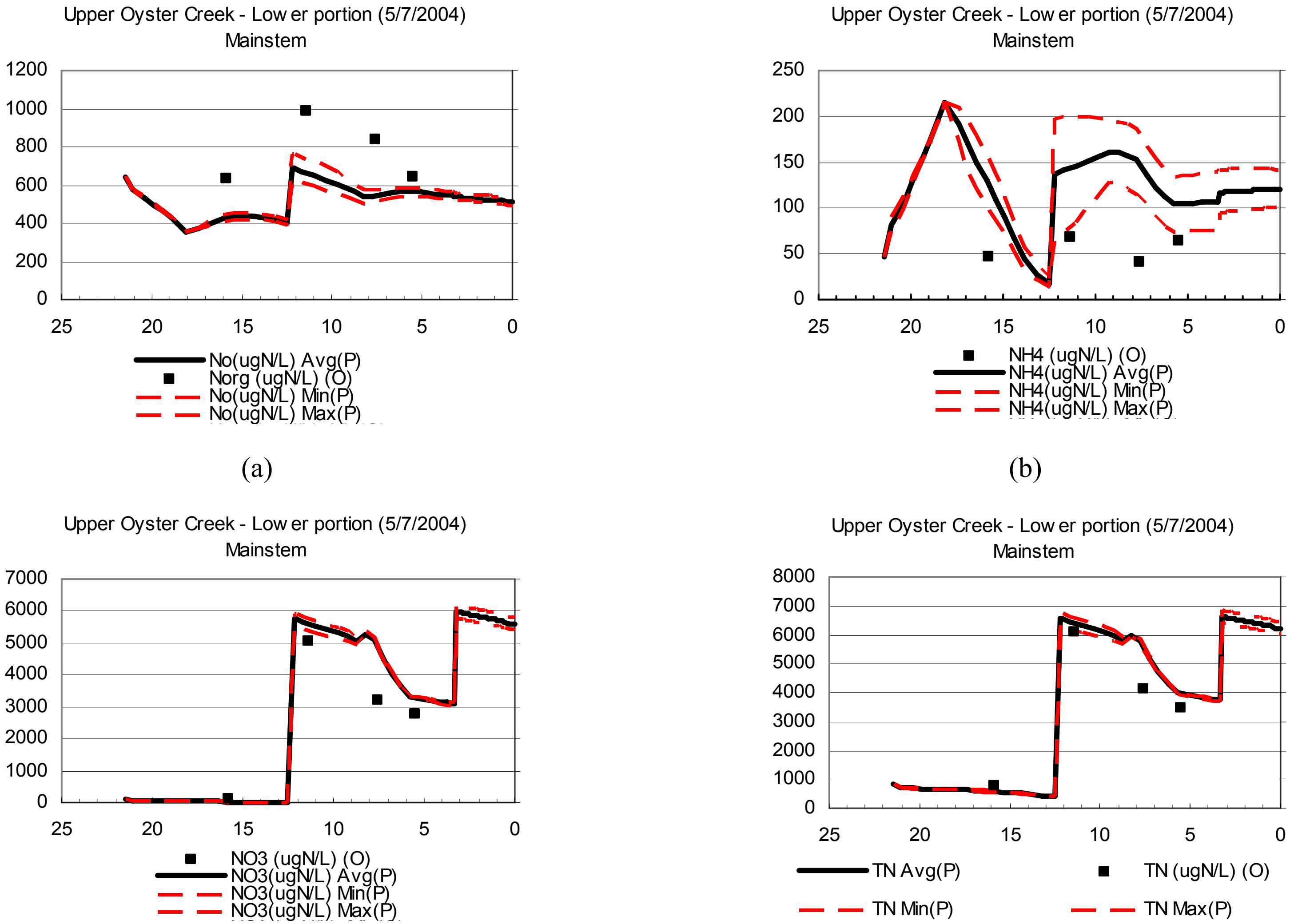
Figure 5-13 **Observed (O) vs. predicted (P) dissolved oxygen in the main stem of the Lower Reach, May 2004 verification survey (x-axis in units of kilometers from downstream end of Segment 1245)**



(a) (b)

(c) (d)

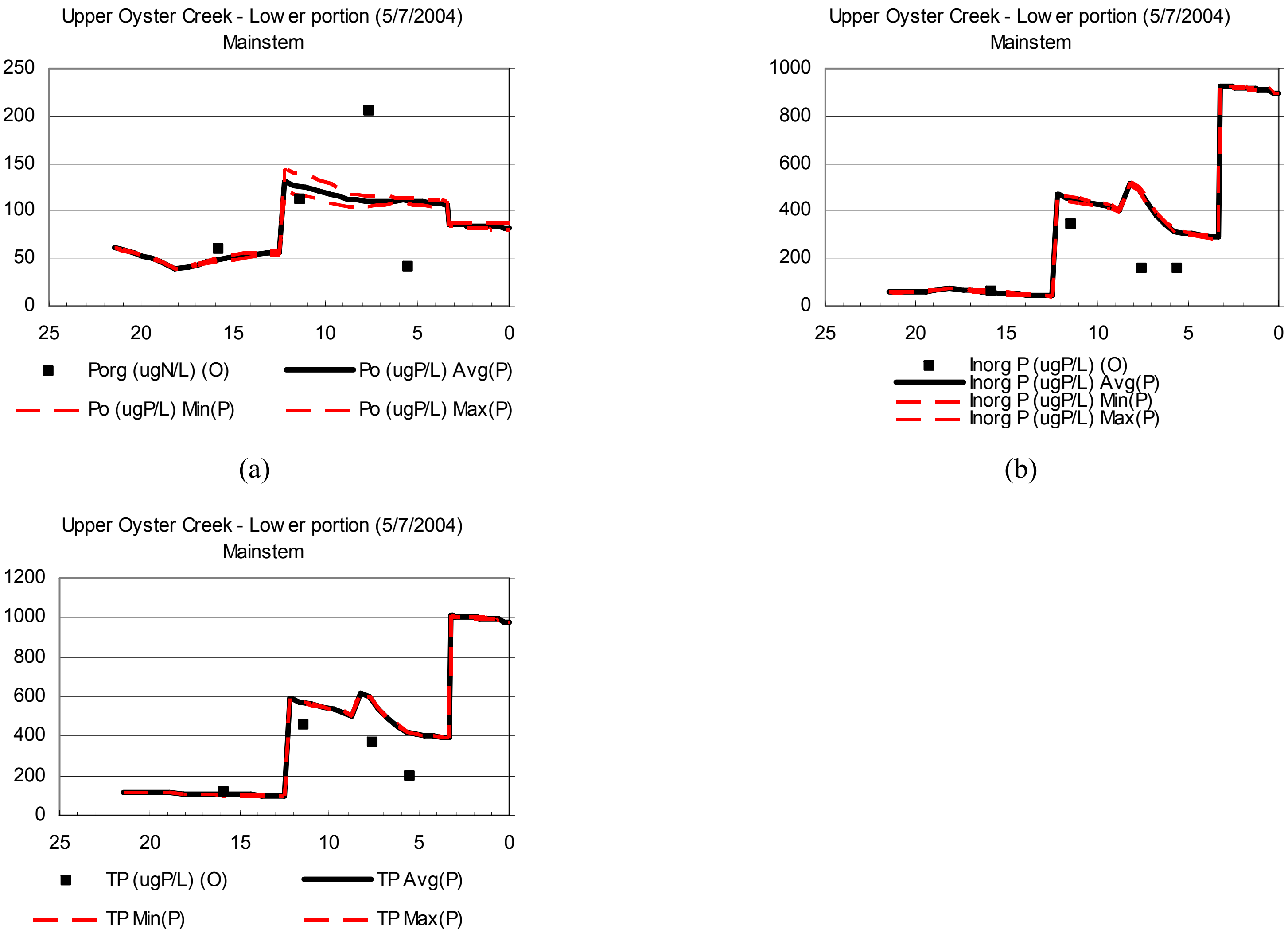
Figure 5-14 Observed (O) vs. predicted (P): (a) flow, (b) temperature, (c) conductivity, and (d) total suspended solid in the main stem of the Lower Reach, May 2004 verification survey



(a) (b)

(c) (d)

Figure 5-15 Observed (O) vs. predicted (P): (a) organic N, (b) ammonium N, (c) nitrate N, and (d) total N in the main stem of the Lower Reach, May 2004 verification survey

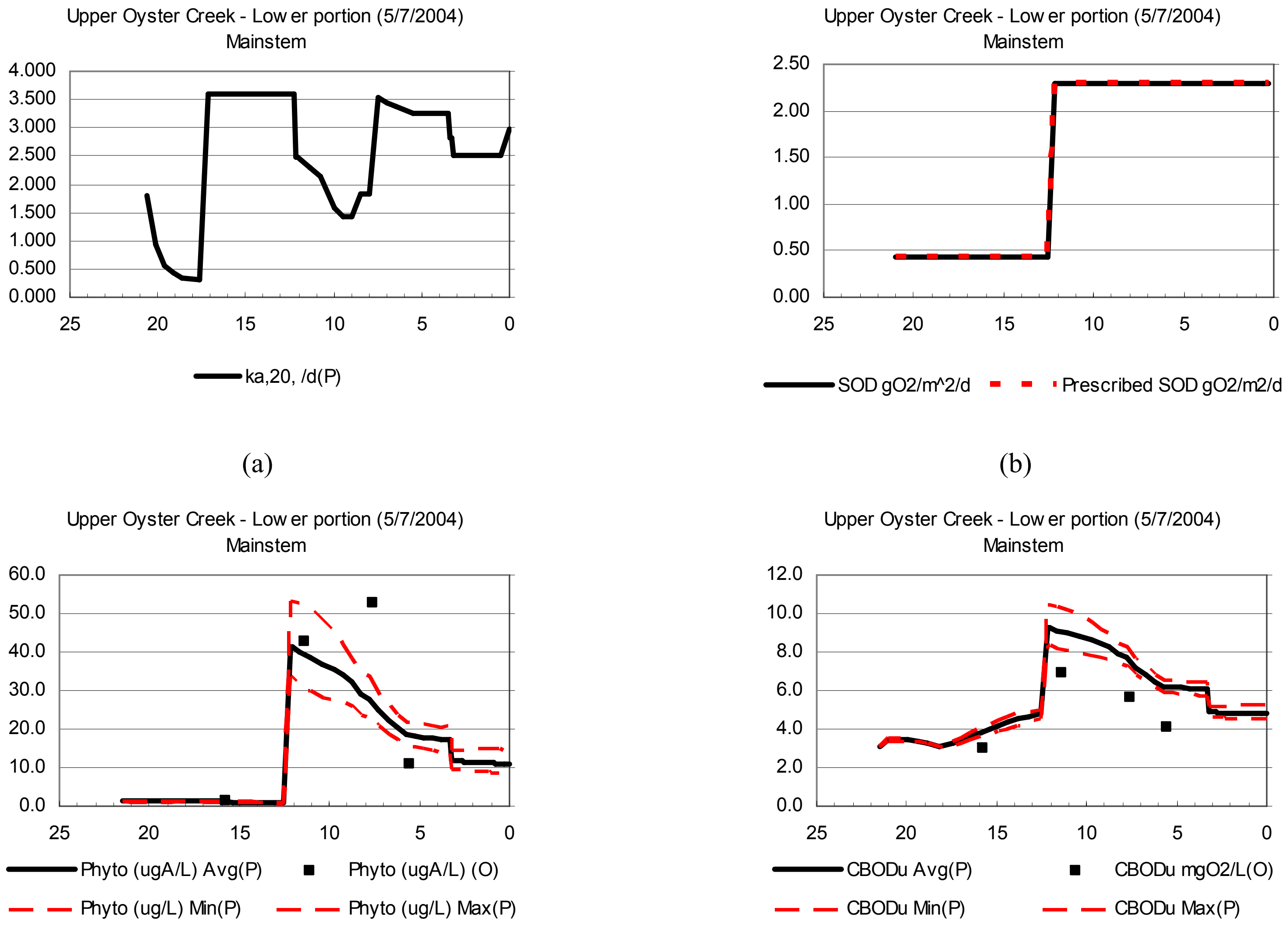


(a)

(b)

(c)

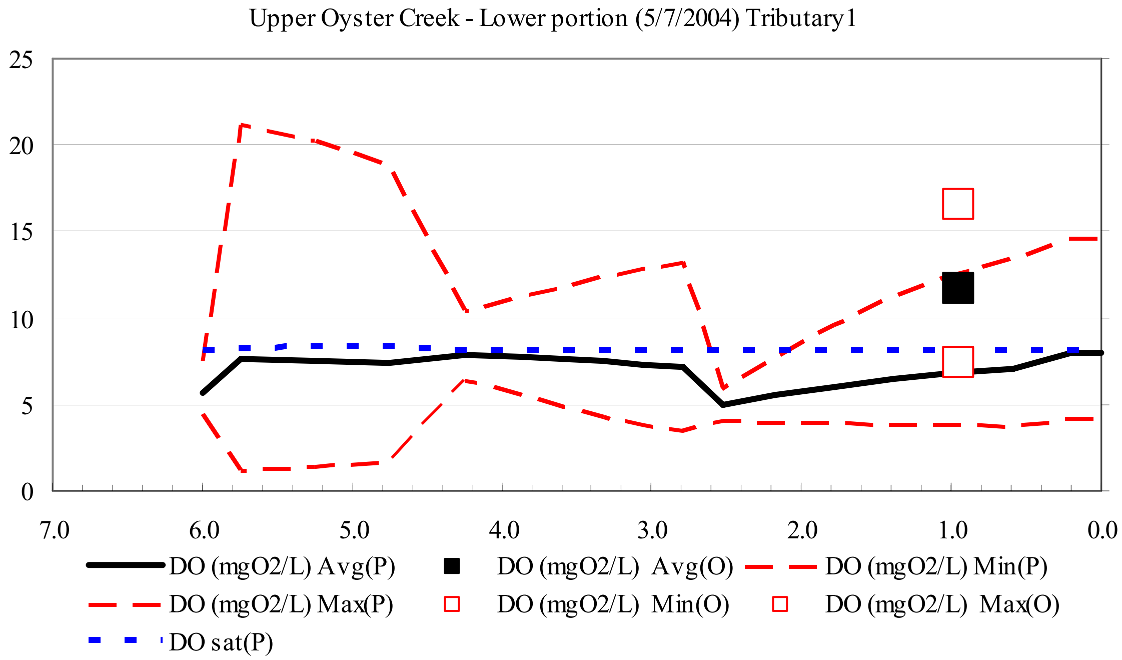
Figure 5-16 Observed (O) vs. predicted (P): (a) organic P, (b) inorganic P, and (c) total P in the main stem of the Lower Reach, May 2004 verification survey



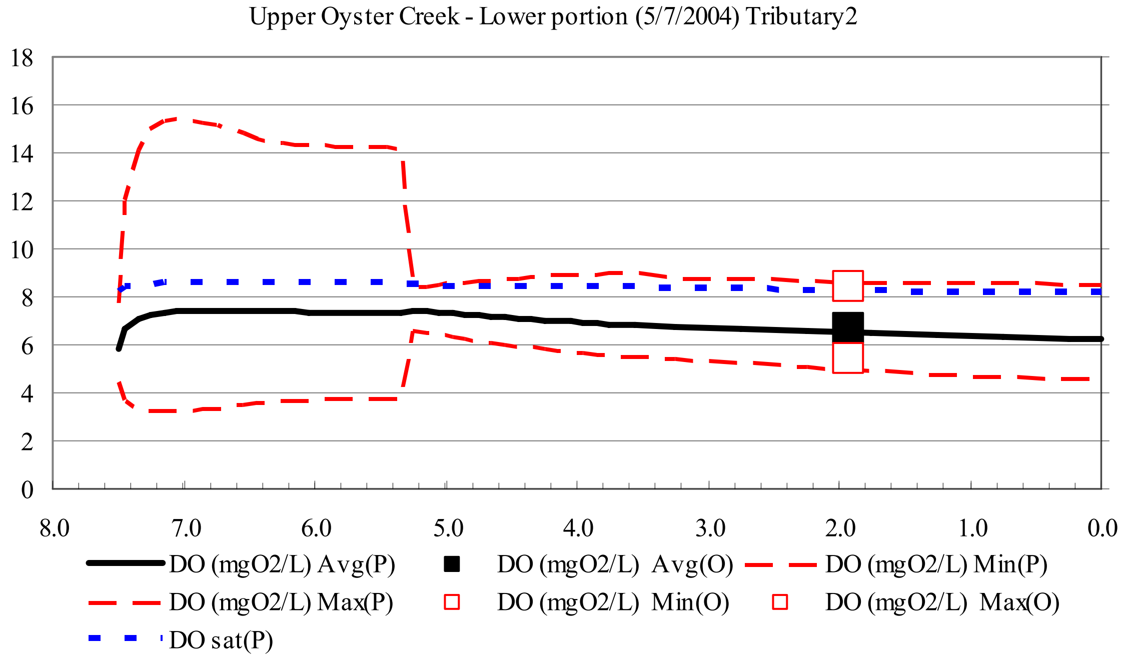
(a) (b)

(c) (d)

Figure 5-17 Observed (O) vs. predicted (P): (a) aeration, (b) sediment oxygen demand, (c) phytoplankton, and (d) ultimate carbonaceous biochemical oxygen demand in the main stem of the Lower Reach, May 2004 verification survey



a) Stafford Run



b) Steep Bank Creek

Figure 5-18 Observed (O) vs. predicted (P) dissolved oxygen along a) Stafford Run and b) Steep Bank of the Lower Reach, May 2004 verification survey (x-axis in units of kilometers from downstream end of creek)

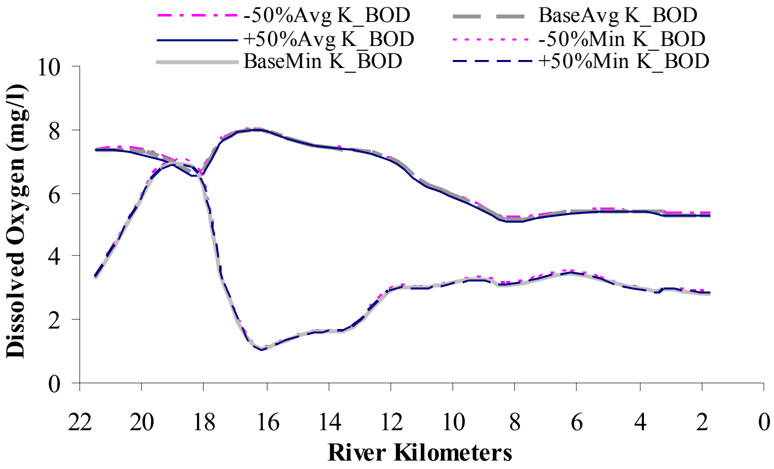


Figure 5-19a. Sensitivity analysis of BOD decay rate (K_BOD) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration

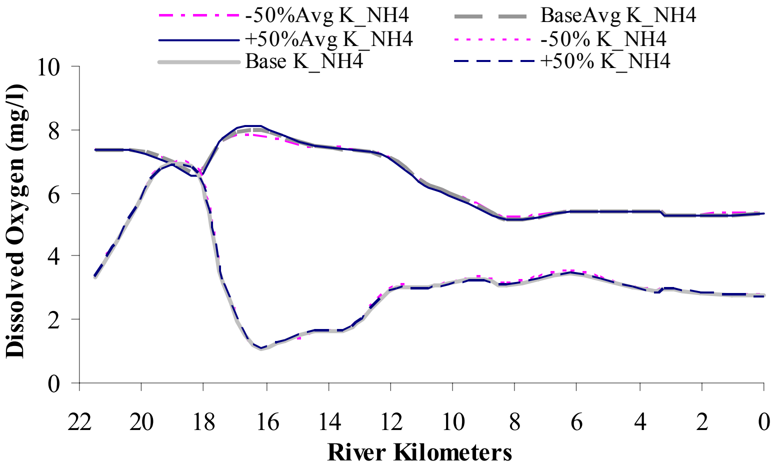


Figure 5-19b. Sensitivity analysis of ammonium decay rate (K_NH4) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration

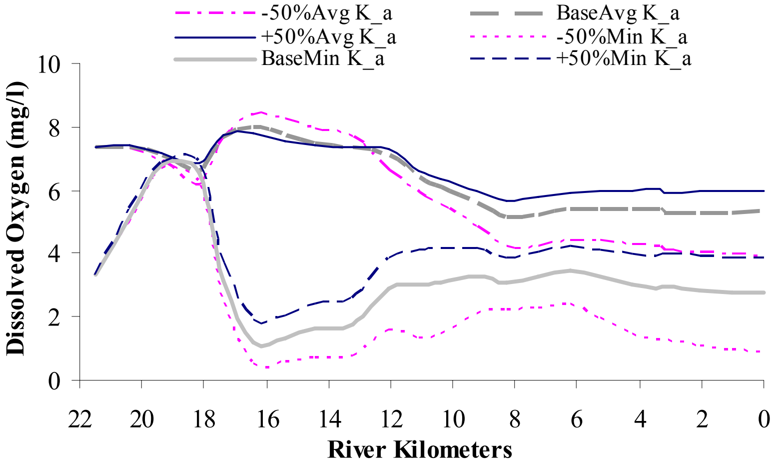


Figure 5-19c. Sensitivity analysis of reaeration (K_a) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration

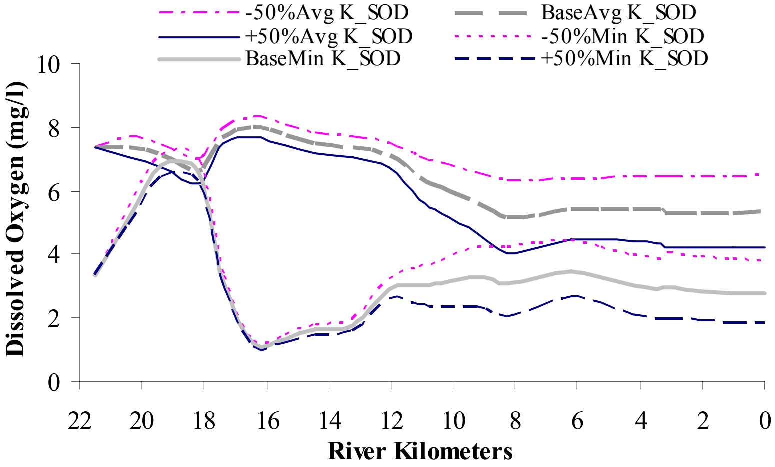


Figure 5-19d. Sensitivity analysis of sediment oxygen demand (K_SOD) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration

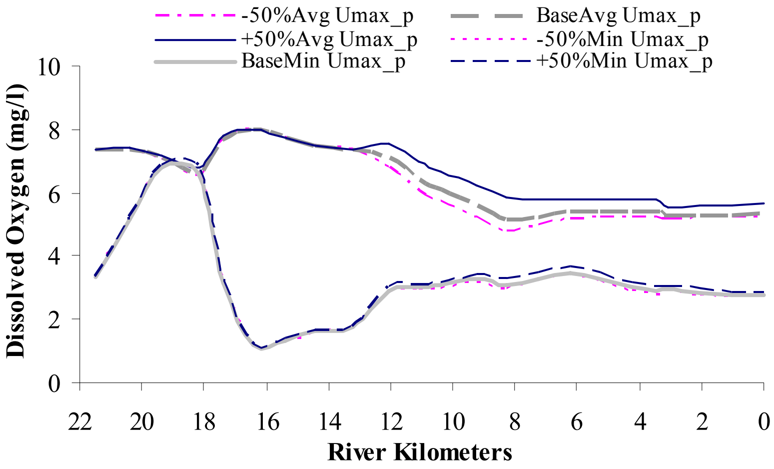


Figure 5-19e. Sensitivity analysis of phytoplankton max growth rate (Umax_p) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration

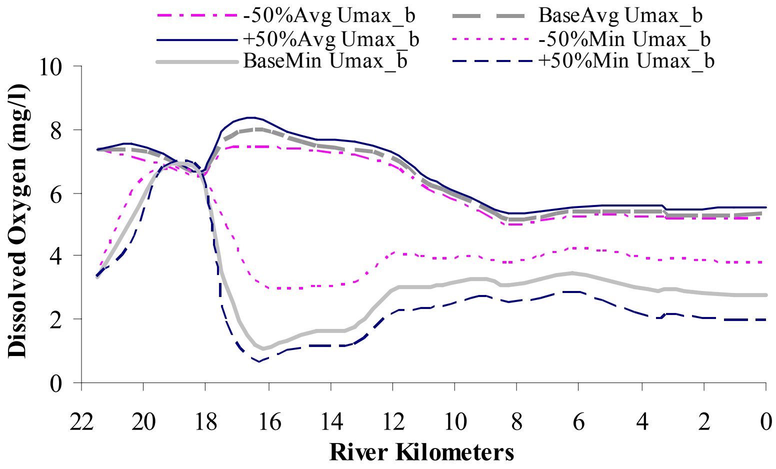


Figure 5-19f. Sensitivity analysis of benthic algae max growth rate (Umax_b) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration

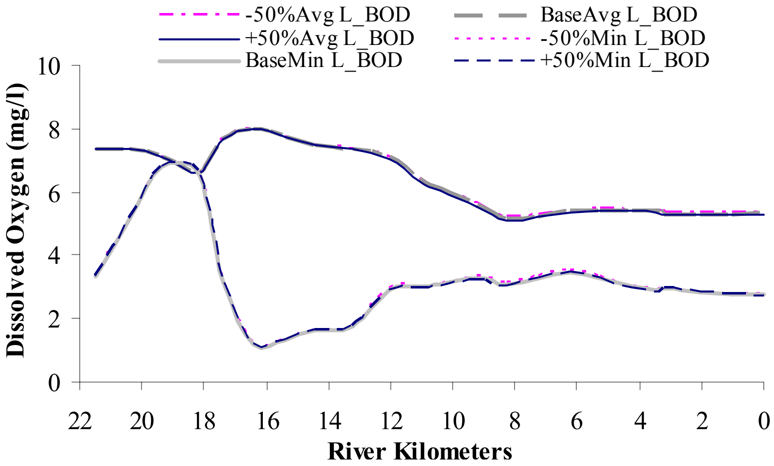


Figure 5-19g. Sensitivity analysis of point source BOD loading concentration (L_BOD) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration

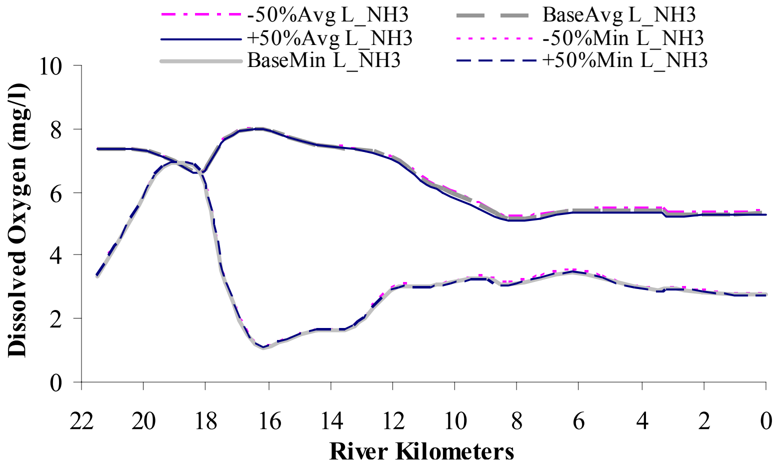
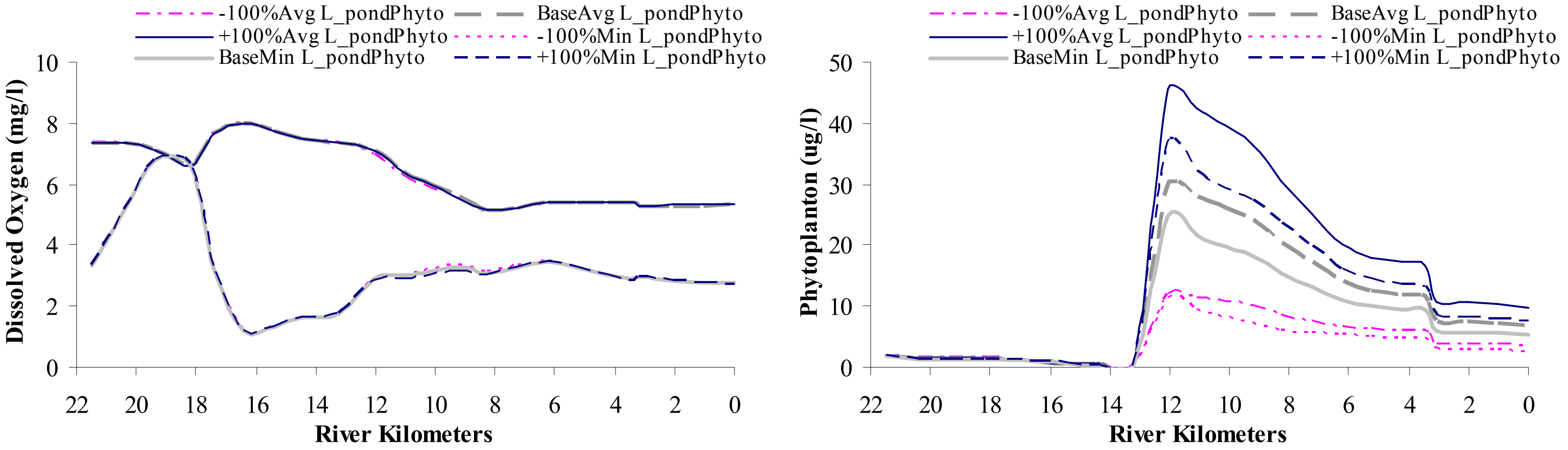
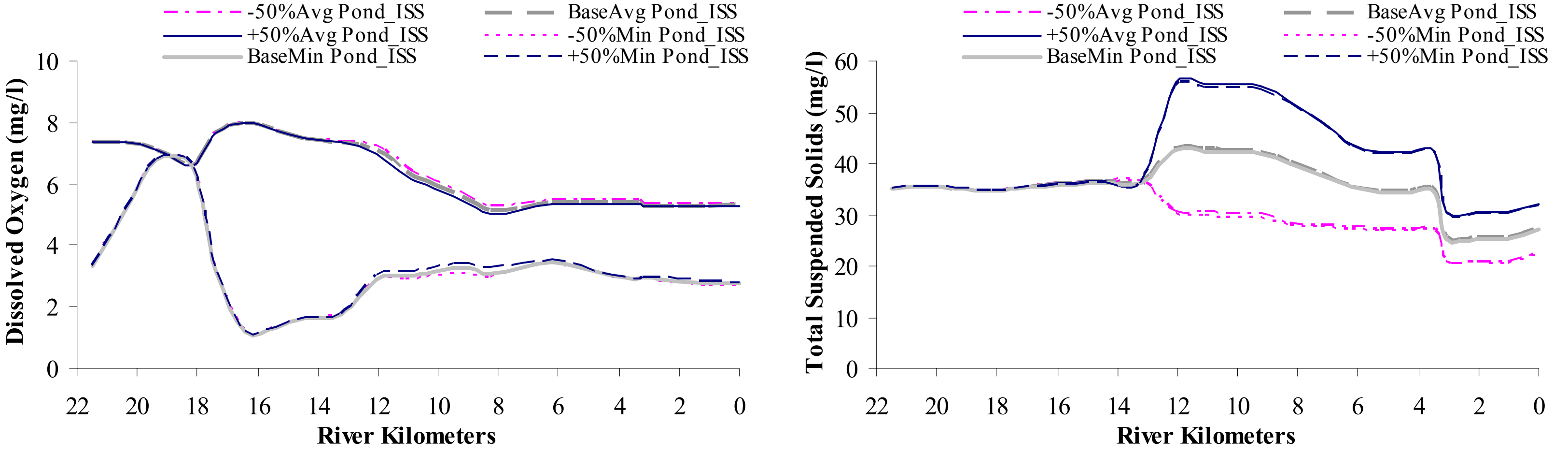


Figure 5-19h. Sensitivity analysis of point source ammonia loading concentration (L_NH3) on 24-hr average (Avg) and min (Min) DOs, 08-09-04 calibration



(a) **(b)**

Figure 5-20 Sensitivity analysis of chlorophyll-a flux from the pond system on Stafford Run. (L_pondPhyto) on 24-hr average (Avg) and min (Min) DOs (a) and phytoplankton (b), August calibration survey as baseline



(a) **(b)**

Figure 5-21 Sensitivity analysis of ISS flux from the pond system on Stafford Run (Pond_ISS) on 24-hr average (Avg) and minimum (Min) DOs (a) and TSS (b), August calibration survey as baseline

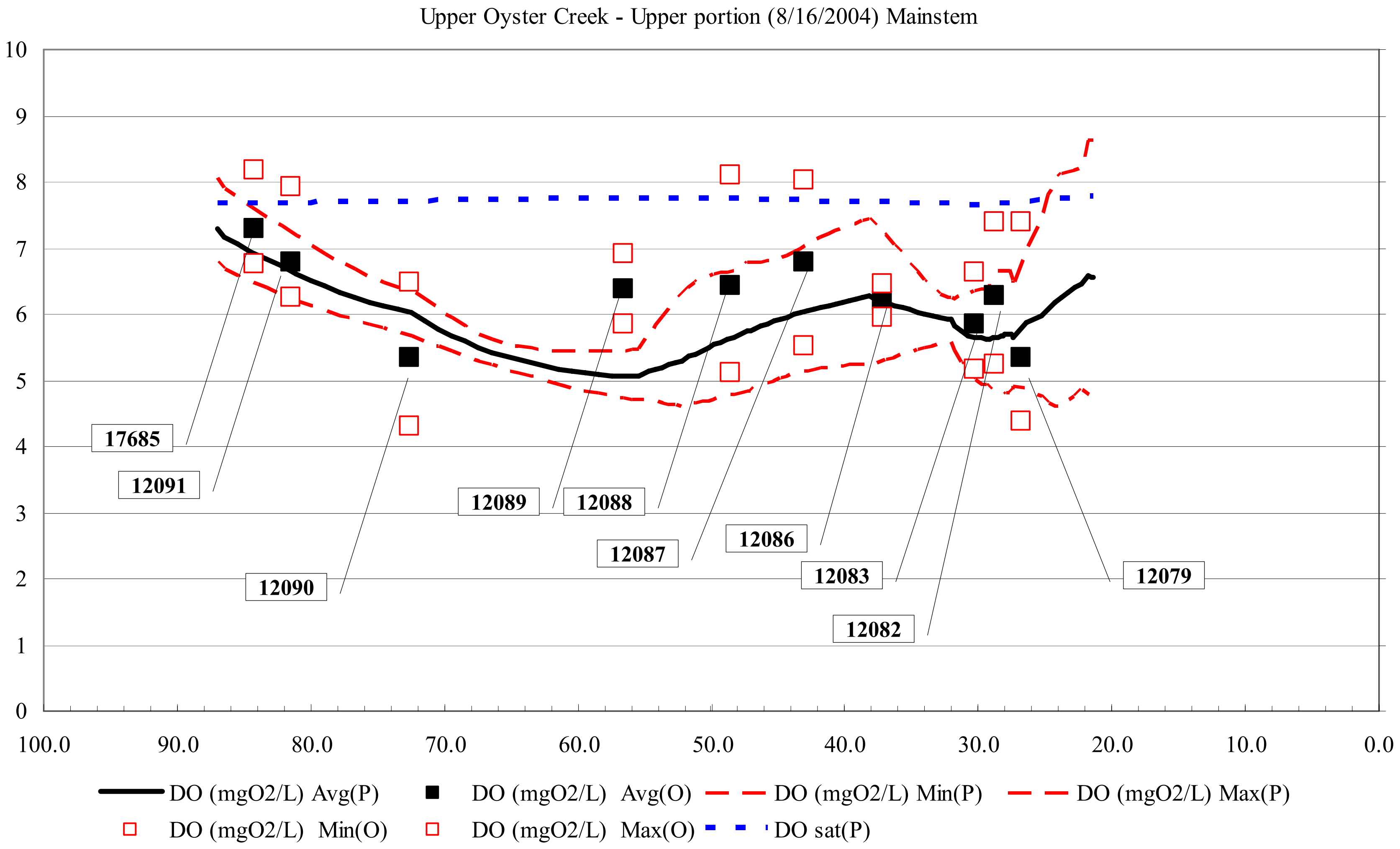
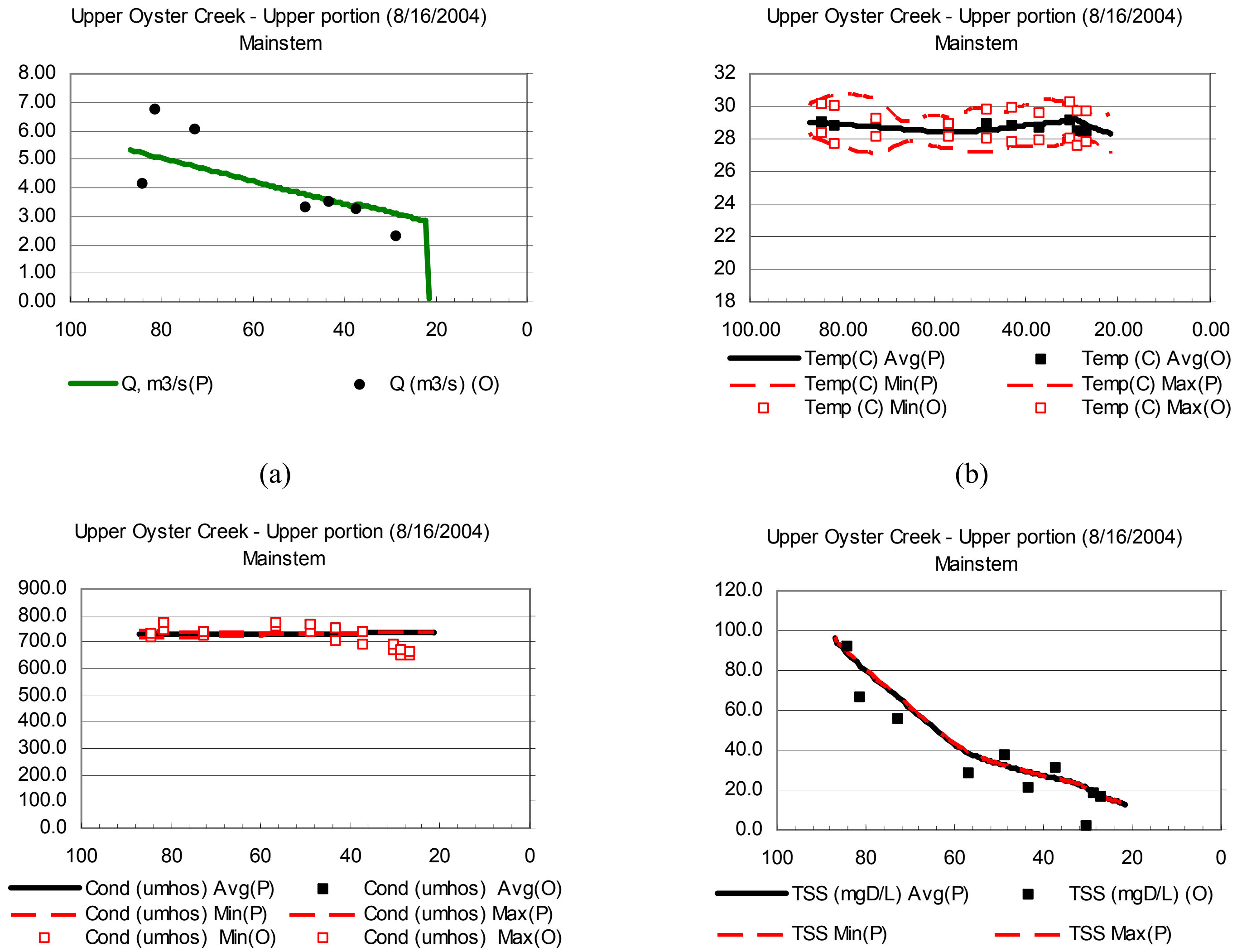


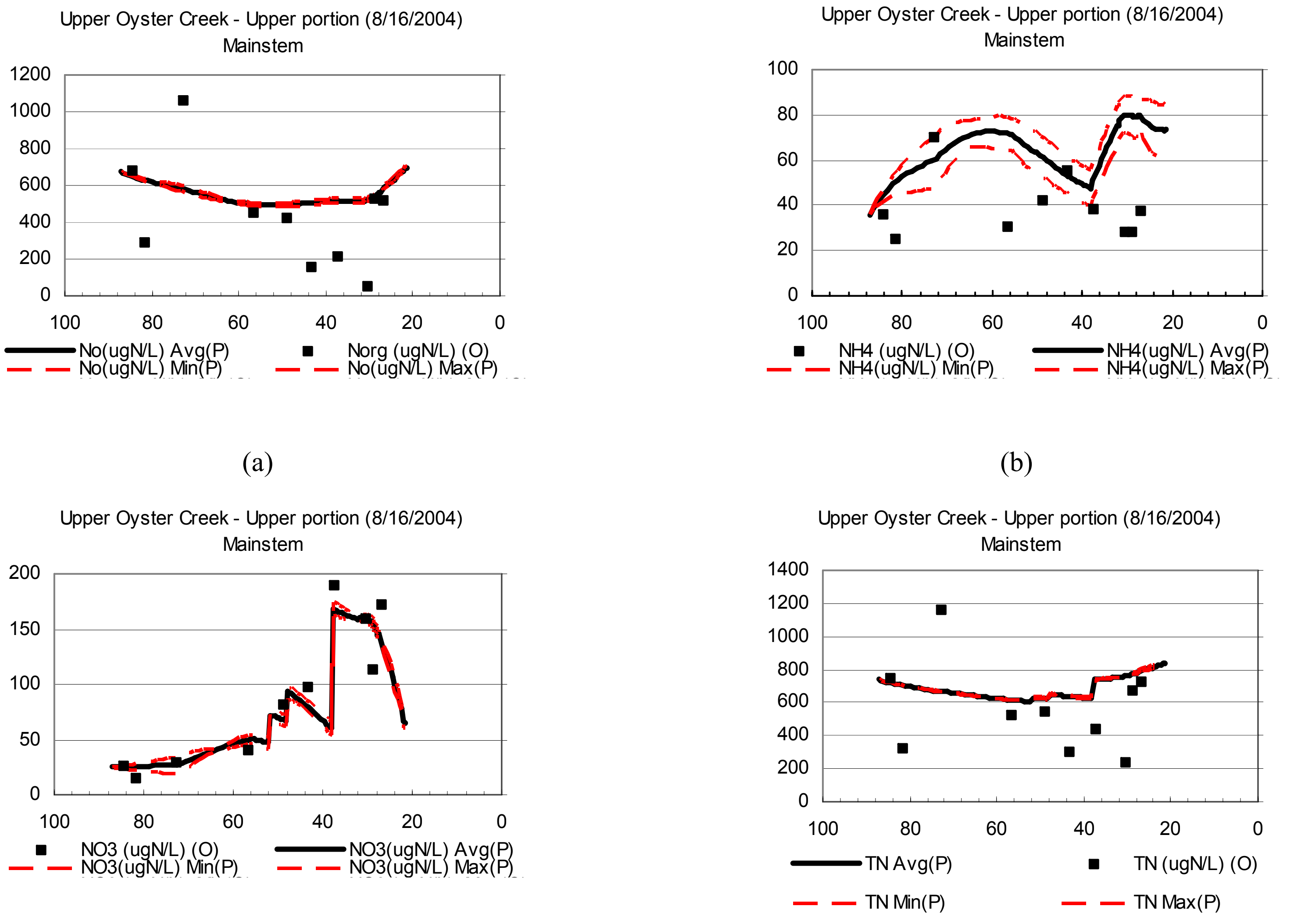
Figure 5-22 **Observed (O) vs. predicted (P) dissolved oxygen in the main stem of the Upper Reach, August 2004 calibration survey (x-axis in units of kilometers from downstream end of Segment 1245)**



(a) (b)

(c) (d)

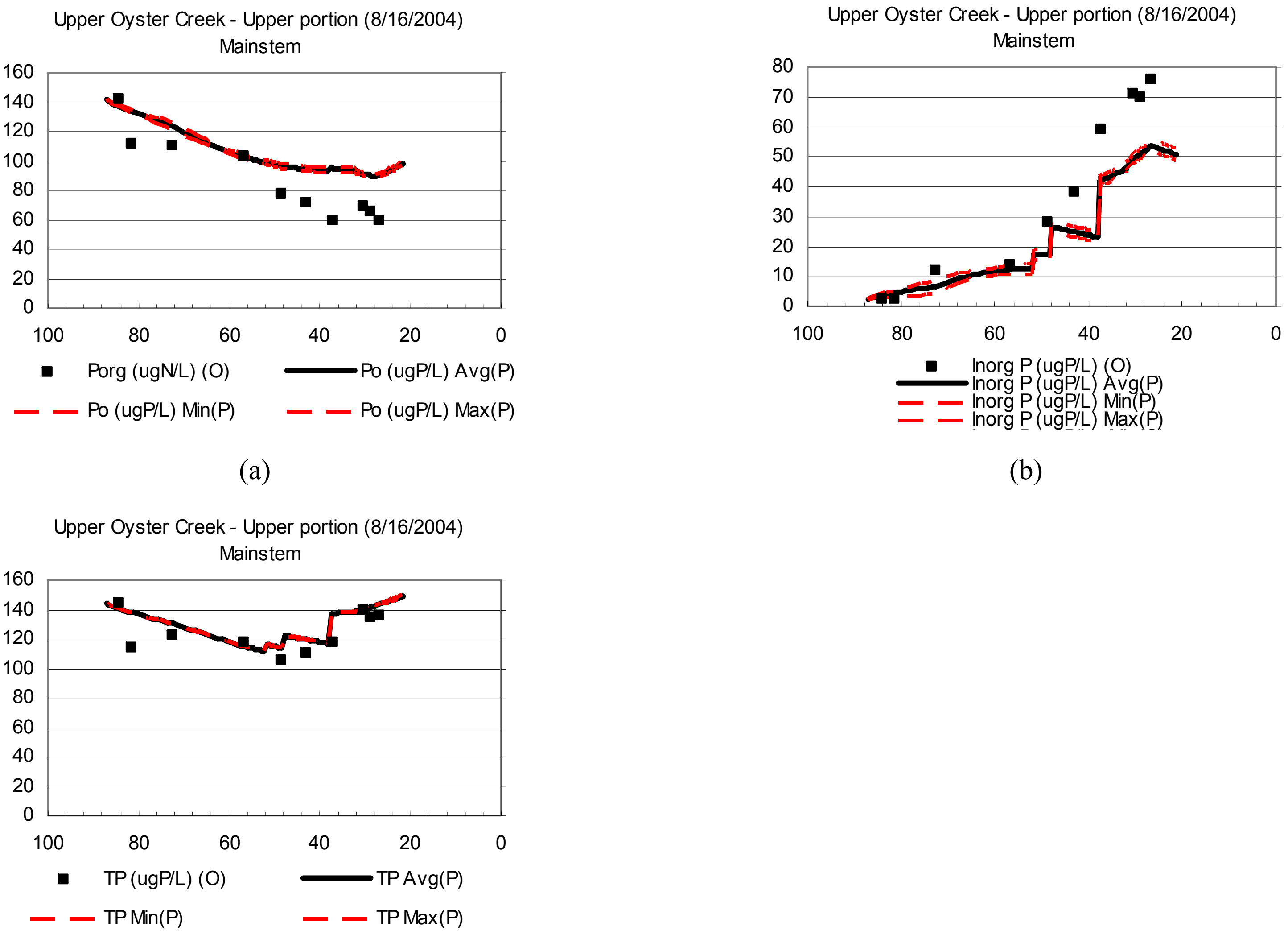
Figure 5-23 Observed (O) vs. predicted (P): (a) flow, (b) temperature, (c) conductivity, and (d) total suspended solid in the main stem of the Upper Reach, August 2004 calibration survey



(a) (b)

(c) (d)

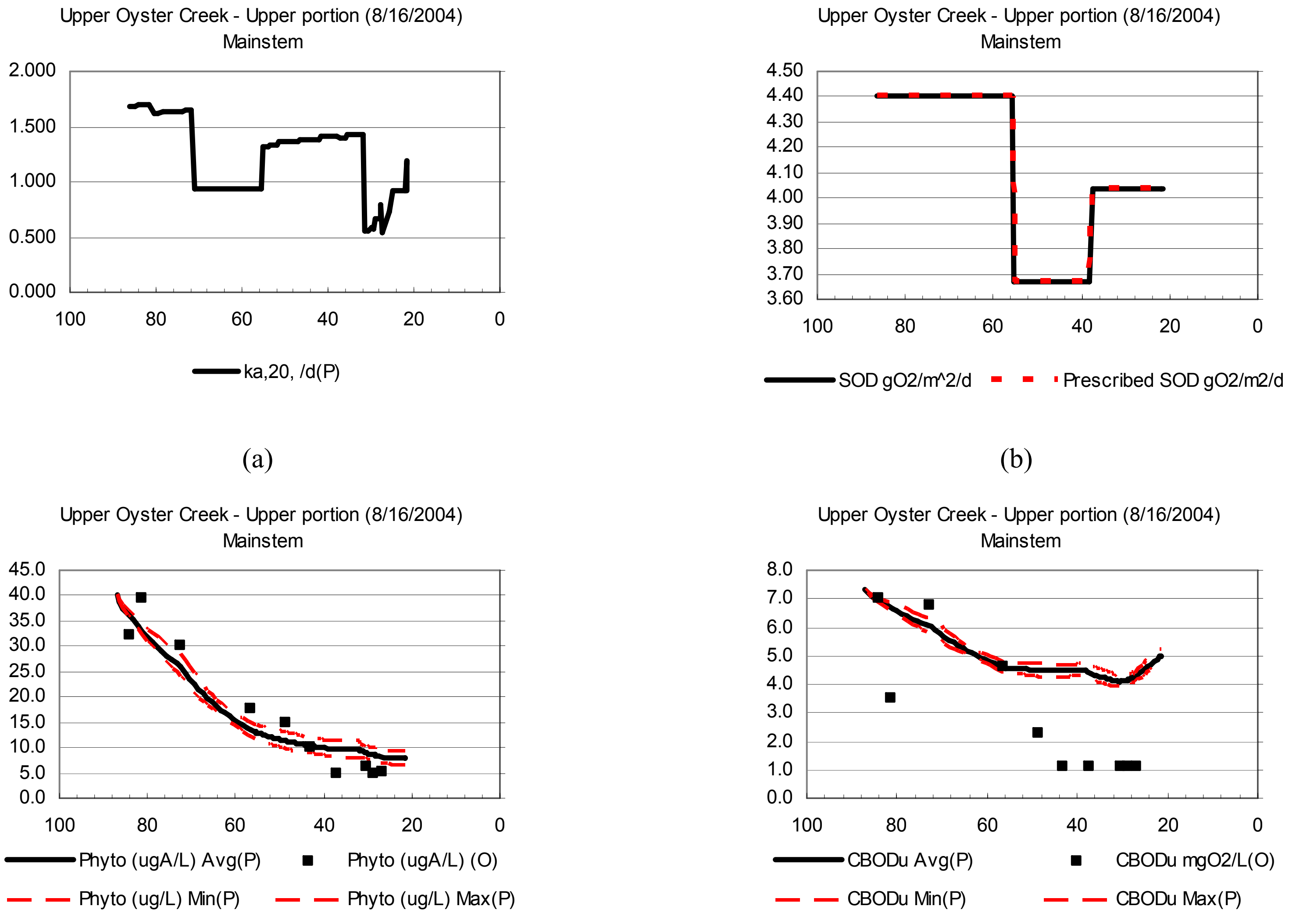
Figure 5-24 Observed (O) vs. predicted (P): (a) organic N, (b) ammonium N, (c) nitrate N, and (d) total N in the main stem of the Upper Reach, August 2004 calibration survey



(a) (b)

(c)

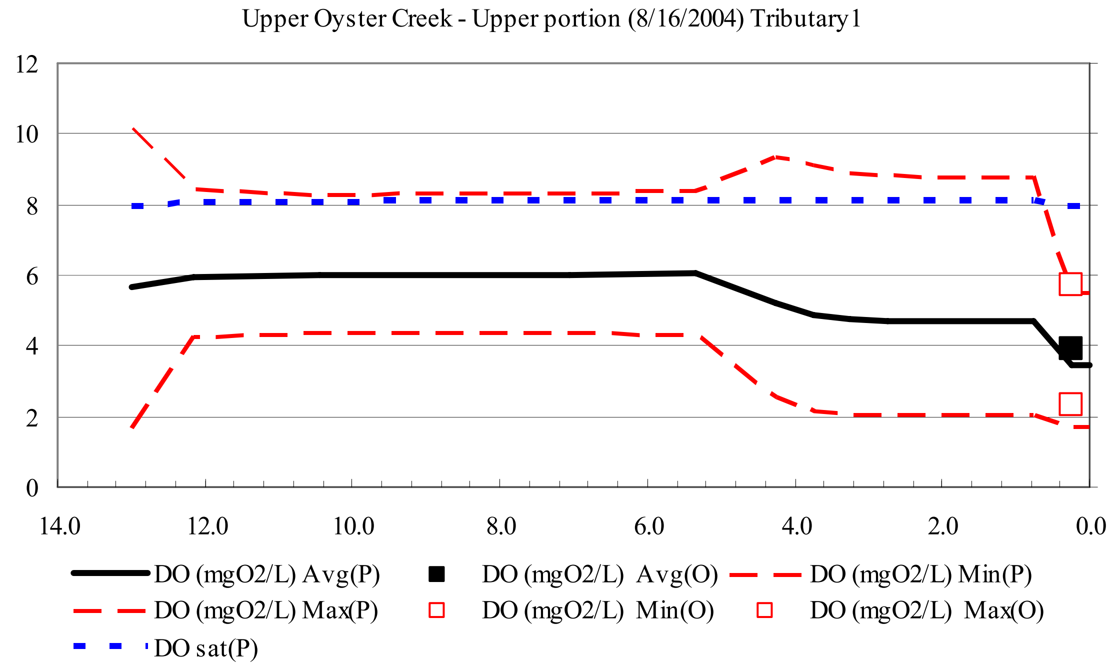
Figure 5-25 **Observed (O) vs. predicted (P): (a) organic P, (b) inorganic P, and (c) total P in the main stem of the Upper Reach, August 2004 calibration survey**



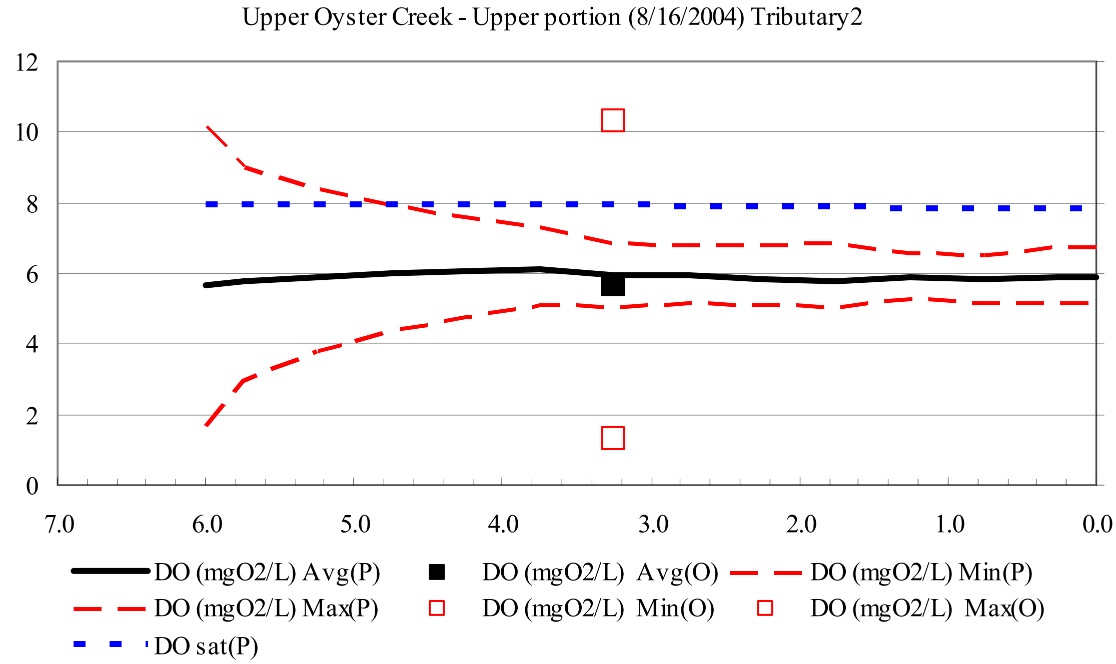
(a) (b)

(c) (d)

Figure 5-26 Observed (O) vs. predicted (P): (a) aeration, (b) sediment oxygen demand, (c) phytoplankton, and (d) ultimate carbonaceous biochemical oxygen demand in the main stem of the Upper Reach, August 2004 calibration survey



a) Flewellen Creek



b) Red Gully

Figure 5-27 Observed (O) vs. predicted (P) dissolved oxygen along a) Flewellen Creek and b) Red Gully of the Upper Reach, August 2004 calibration survey (x-axis in units of kilometers from downstream end of creek)

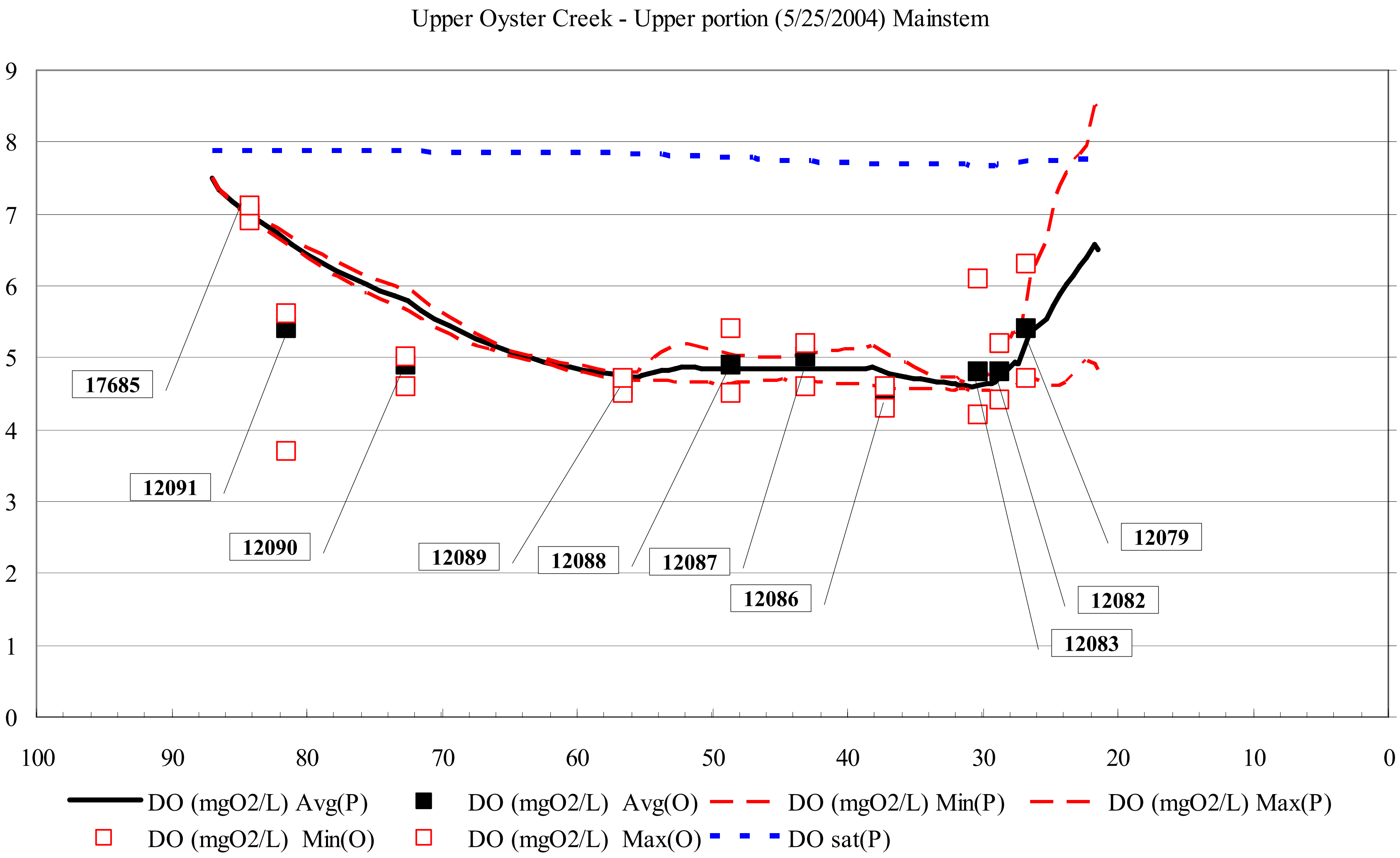
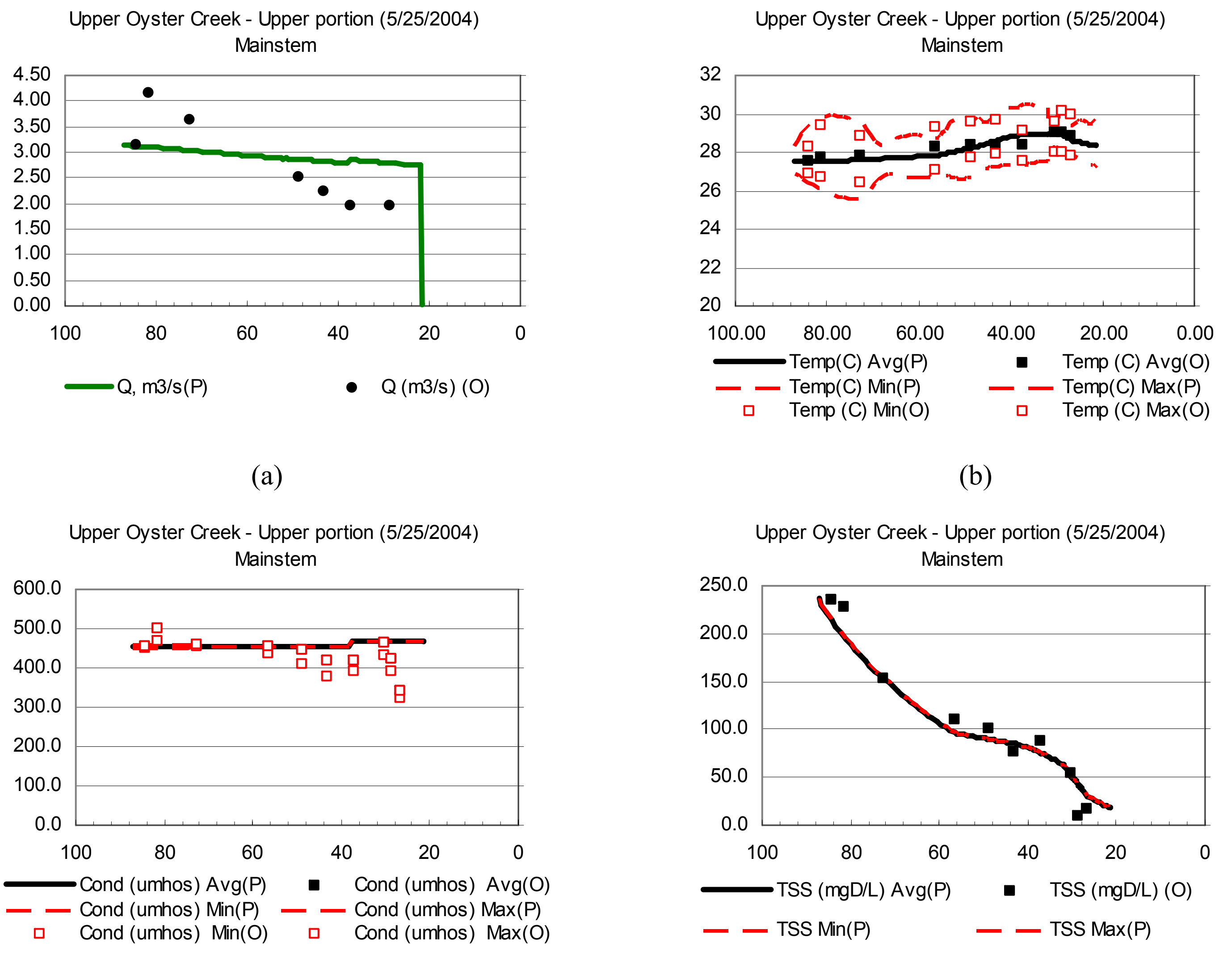


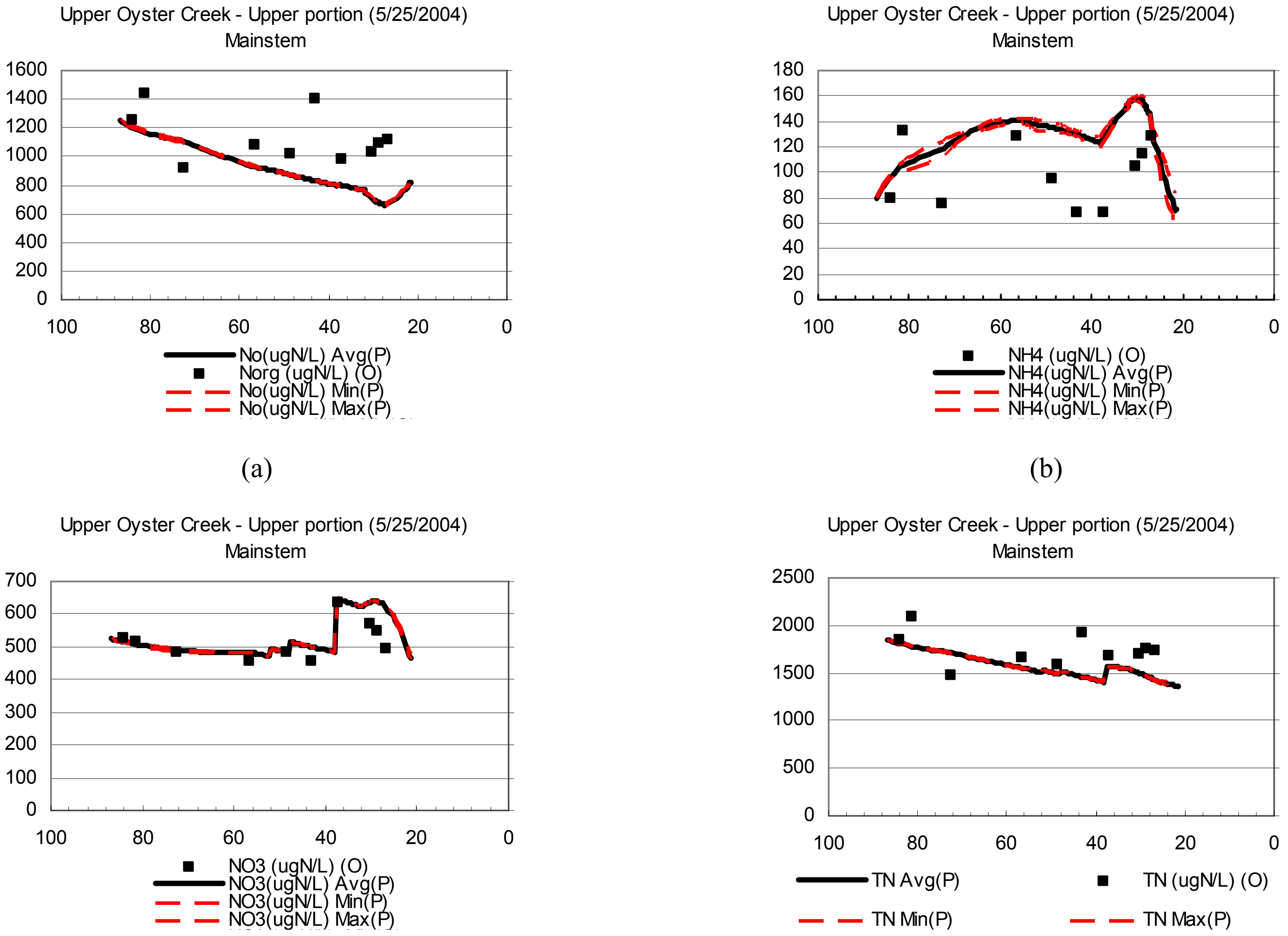
Figure 5-28 **Observed (O) vs. predicted (P) dissolved oxygen in the main stem of the Upper Reach, May 2004 verification survey (x-axis in units of kilometers from downstream end of Segment 1245)**



(a) (b)

(c) (d)

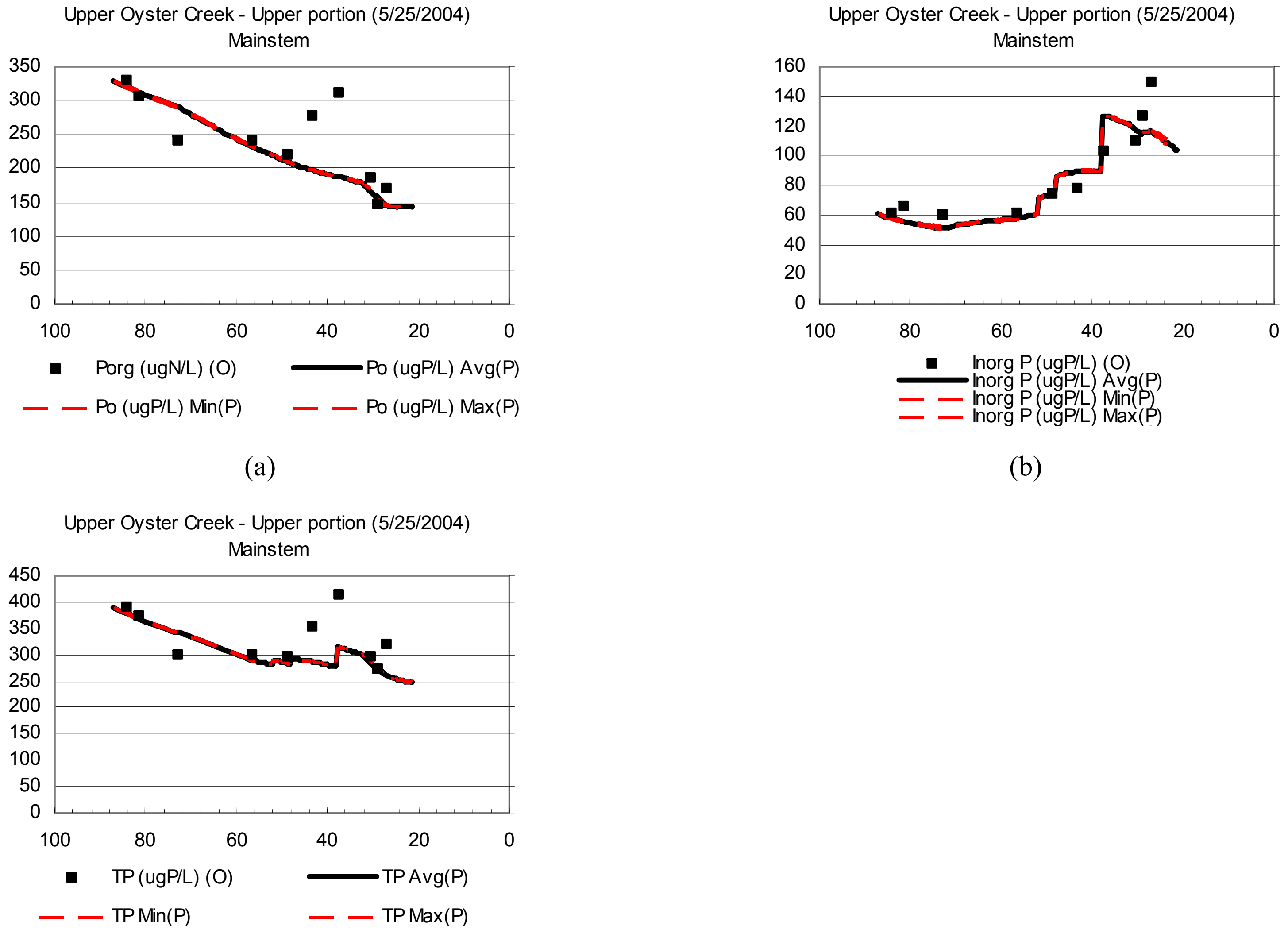
Figure 5-29 Observed (O) vs. predicted (P): (a) flow, (b) temperature, (c) conductivity, and (d) total suspended solid in the main stem of the Upper Reach, May 2004 verification survey



(a) (b)

(c) (d)

Figure 5-30 Observed (O) vs. predicted (P): (a) organic N, (b) ammonium N, (c) nitrate N, and (d) total N in the main stem of the Upper Reach, May 2004 verification survey

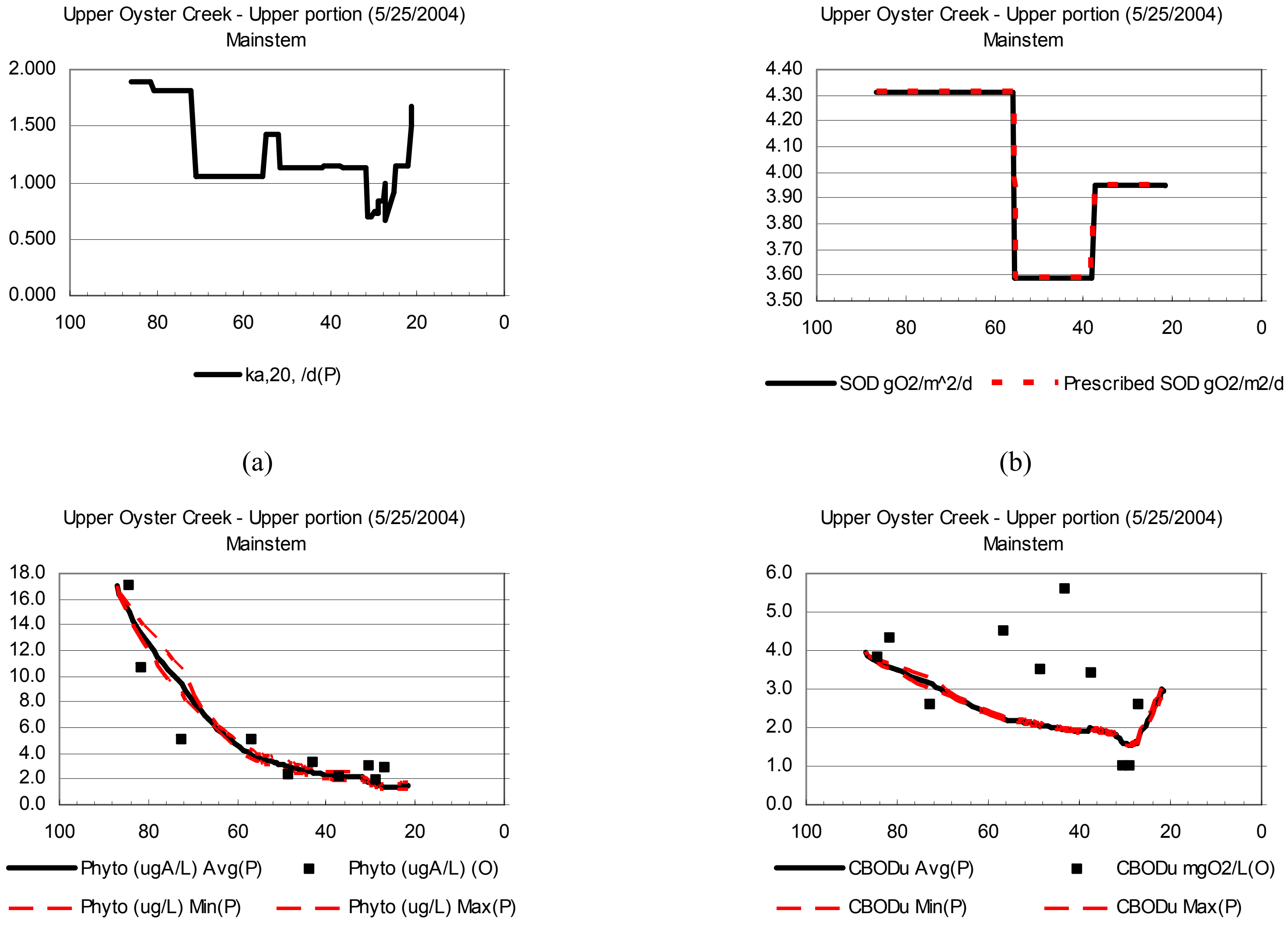


(a)

(b)

(c)

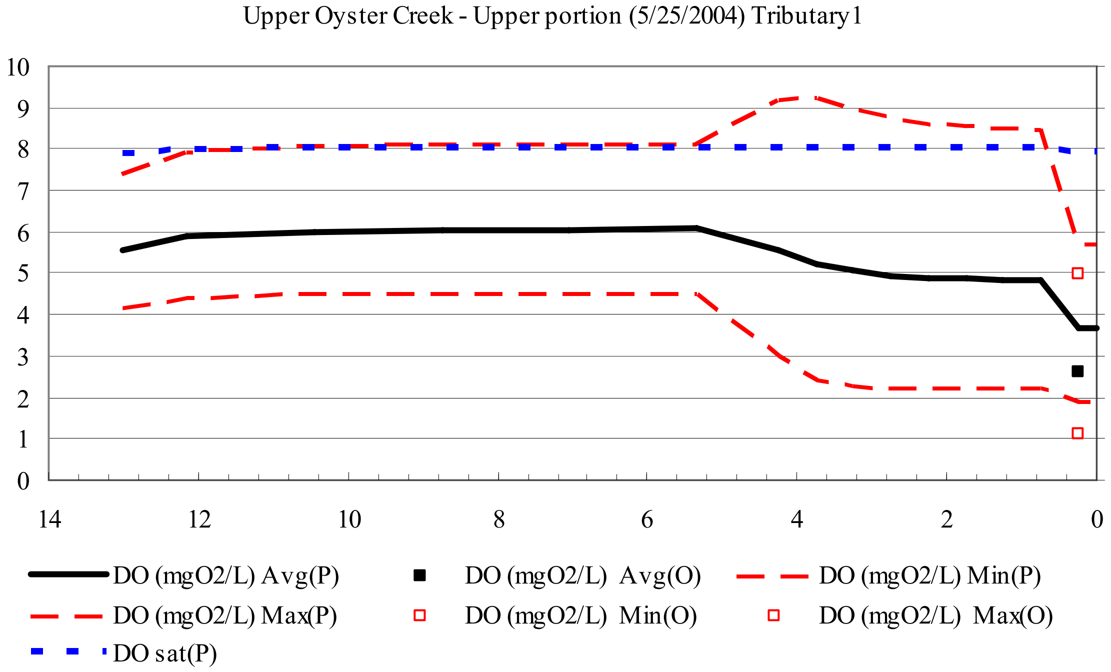
Figure 5-31 **Observed (O) vs. predicted (P): (a) organic P, (b) inorganic P, and (c) total P in the main stem of the Upper Reach, May 2004 verification survey**



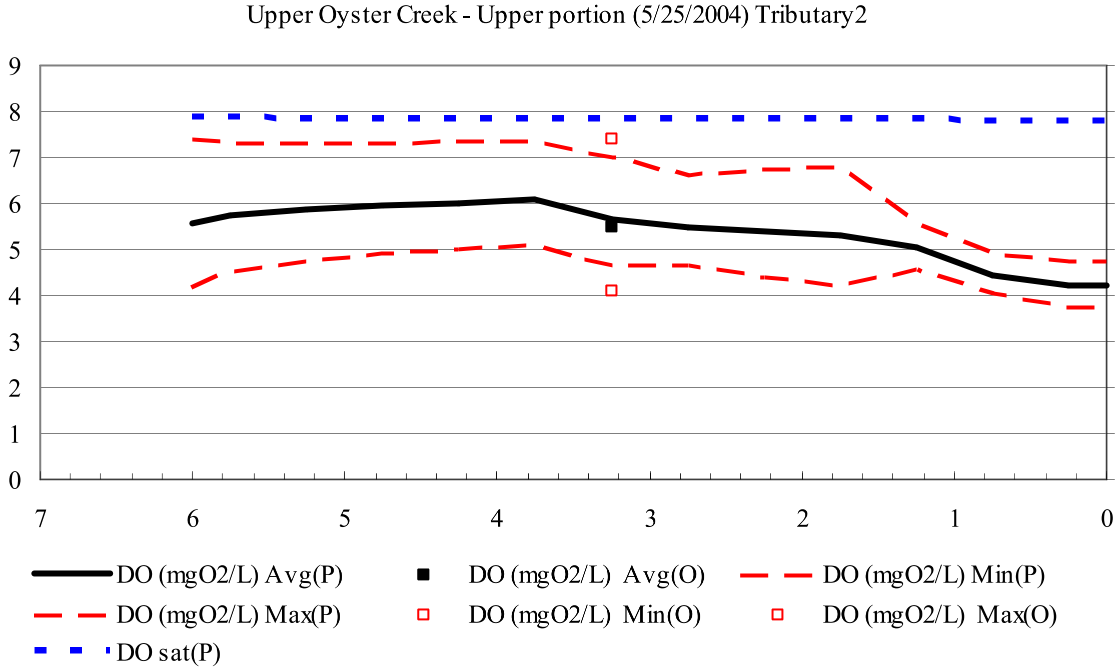
(a) (b)

(c) (d)

Figure 5-32 Observed (O) vs. predicted (P): (a) aeration, (b) sediment oxygen demand, (c) phytoplankton, and (d) ultimate carbonaceous biochemical oxygen demand in the main stem of the Upper Reach, May 2004 verification survey



a) Flewellen Creek



b) Red Gully

Figure 5-33 Observed (O) vs. predicted (P) dissolved oxygen along b) Flewellen Creek and b) Red Gully of the Upper Reach, May 2004 verification survey (x-axis in units of kilometers from downstream end of creek)

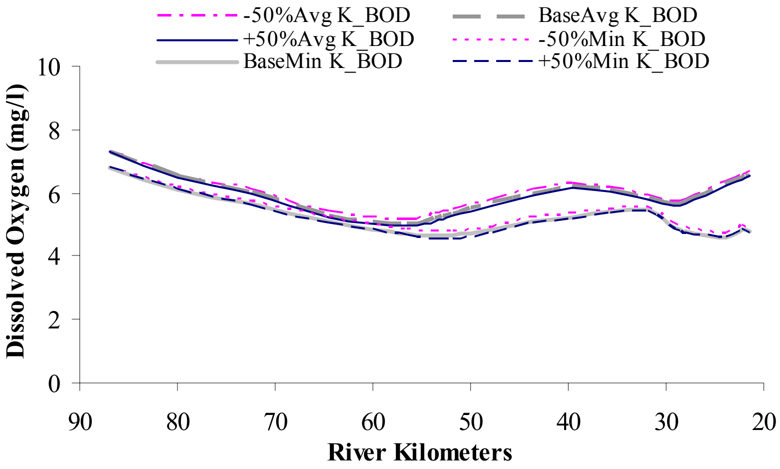


Figure 5-34a. Sensitivity analysis of BOD decay rate (K_BOD) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

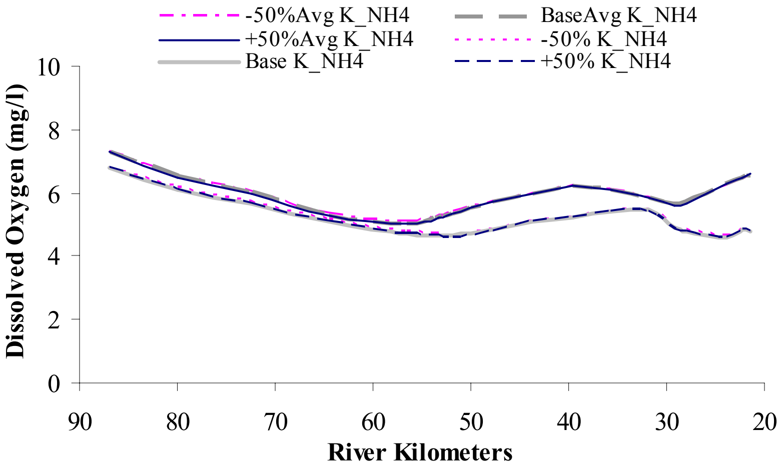


Figure 5-34b. Sensitivity analysis of ammonium decay rate (K_NH4) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

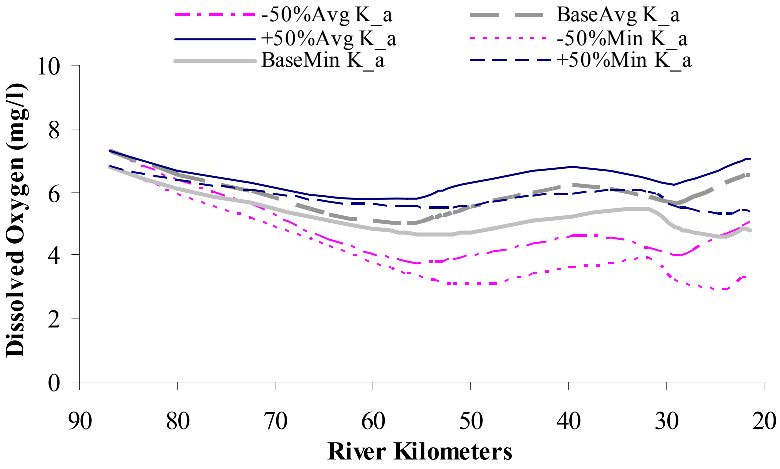


Figure 5-34c. Sensitivity analysis of reaeration (K_a) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

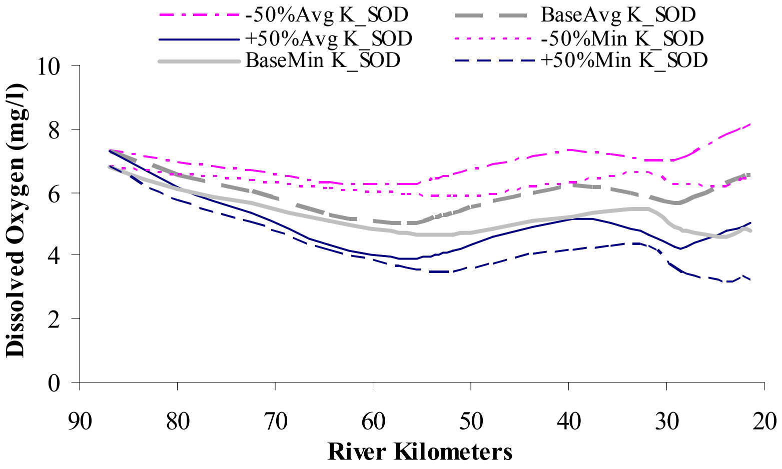


Figure 5-34d. Sensitivity analysis of sediment oxygen demand (K_SOD) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

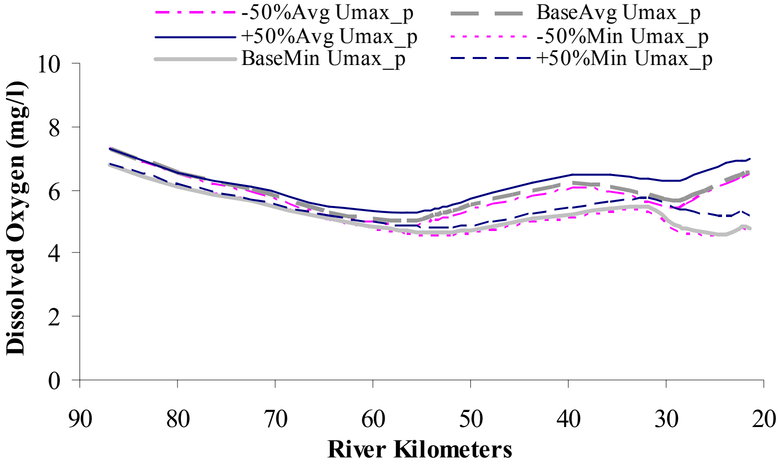


Figure 5-34e. Sensitivity analysis of phytoplankton max growth rate (Umax_p) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

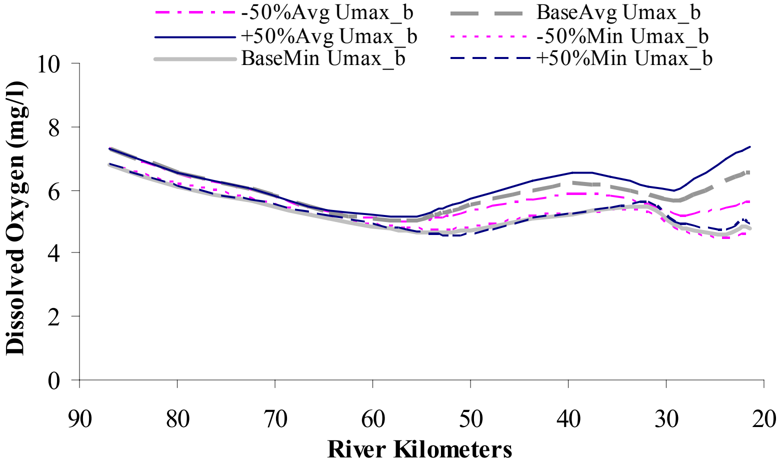


Figure 5-34f. Sensitivity analysis of benthic algae max growth rate (Umax_b) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

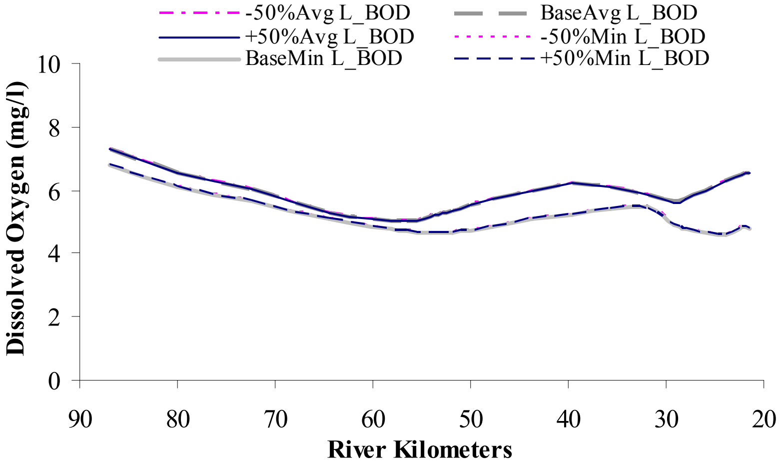


Figure 5-34g. Sensitivity analysis of point source BOD loading concentration (L_BOD) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

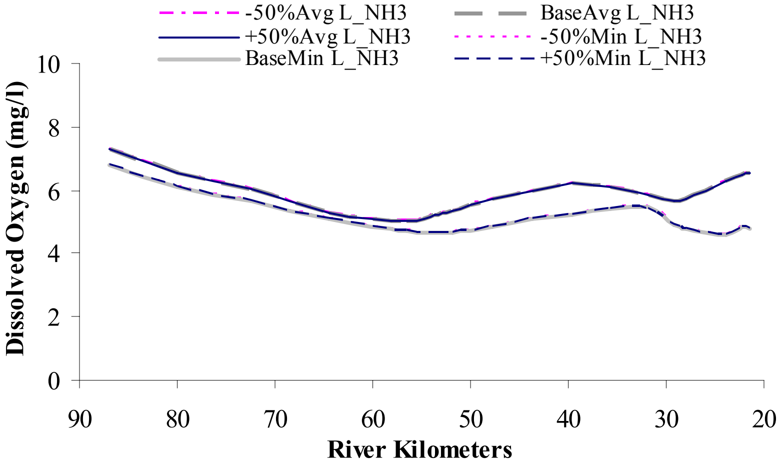


Figure 5-34h. Sensitivity analysis of point source ammonia loading concentration (L_NH3) on 24-hr average (Avg) and min (Min) DOs, 08-16-04 calibration

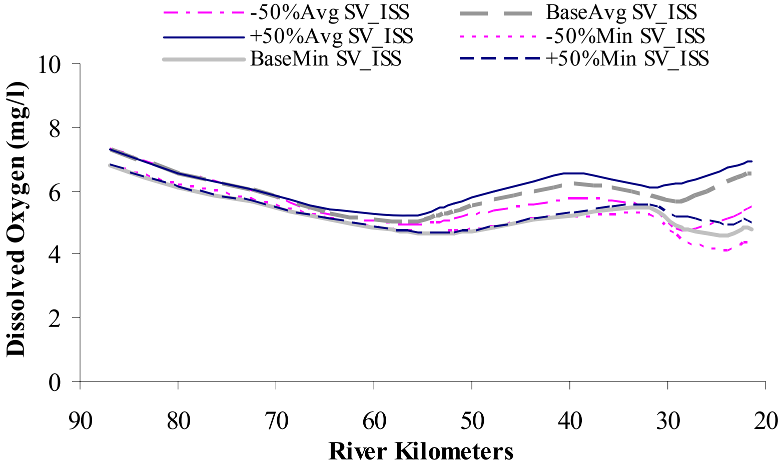


Figure 5-35. Sensitivity analysis of inorganic suspended solid settling velocity (SV_ISS) on 24-hr average (Avg) and min (Min) DOs, August 2004 calibration as baseline

SECTION 6

DEVELOPMENT OF TMDL ALLOCATION

Within this report section is presented the development of the dissolved oxygen TMDL allocation. As developed in portions of Sections 2 (Watershed Properties and Hydrology) and Section 4 (Investigations of the Relationships between DO and Other Variables), the water quality, hydrology, hydraulics, and several related parameters provide complexities to the understanding of DO impairments and exceedances in Upper Oyster Creek.

6.1 TMDL Allocation

The TMDL represents the maximum amount of pollutants that the stream can receive without exceeding the water quality standard. For purposes of DO allocation, the TMDL allocation is defined by the following simple equation:

$$\text{TMDL} = \Sigma\ \text{WLA} + \Sigma\ \text{LA} + \text{MOS}$$

where,

WLA is waste load allocation for point (TPDES-regulated) source reductions,
LA is the load allocation for nonpoint source reductions, and
MOS is the margin of safety.

For DO exceedances, the pollutants most closely related to the impairment are CBOD and NH_3-N. When the minimum 24-hr DO criterion is also being exceeded as a result of diel DO 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 DO concentrations.

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. 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 (BMPs) 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.

6.2 WLA for Lower and Upper Reaches

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.

6.2.1 Input Data Requirements

For both the Lower and Upper Reaches, QUAL2K was applied using the existing segmentation and kinetic rates developed during the model validation process. Certain areas of model input, however, required updating to reflect the conditions under which the TMDL allocation for the point sources was performed. Applications of QUAL2K were made for low-flow conditions when minimum DO concentrations could occur in both reaches.

6.2.1.1 Headwater and Diffuse Sources Flow

For the Lower Reach headwater flows are 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 under which the DO criteria are applicable.

For unclassified streams, the critical low flow specification is based on Table 5 of the Texas Surface Water Quality Standards (TNRCC, 2000), which provides for determination of critical low flow based on designated aquatic life use and average stream bedslope.[7] Therefore Table 5 was used to determine the critical low flow for the tributaries to Segment 1245 that are represented in QUAL2K for the Lower and Upper Reaches (Table 6-1).

Critical low flow determination for 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 the absence of recent gauged streamflow records in Upper Oyster Creek. The hydrologic predictions from application of SWAT to Upper Oyster Creek watershed were evaluated to determine the critical low flows in the Upper Reach. As mentioned in Section 2, SWAT was applied to determine the daily streamflows needed to complete the bacteria TMDL (Hauck and Du, 2006; Section 4). To determine 7Q2 flow, the predicted daily flow data from SWAT for the period 1993 – 2004 were

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[7] The applicability of Table 5 can be confusing. Table 5 can be applied to Upper Oyster Creek (Segment 1245) for the DO assessment process as used in Section 3. However, Table 5 can not presently be applied to Segment 1245 (the mainstem) for TMDL or WLA purposes to define headwater flows, because the pertinent portion of the surface water quality standards is not approved by EPA. At the same time, Table 5 can be applied to unclassified segments, that is the tributaries, entering into Segment 1245 for headwater flow specification.

used as input to the TCEQ program 7Q2HM, which is a TCEQ program developed to compute 7Q2 and harmonic mean flows. SWAT results for the following two locations were used: (i) a location just below the Shannon Lift Station and (ii) 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 Pump Station was 0.009 cms and above the Second Lift Station was 0.117 cms.[8] 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 DO.

For the determination of low flows in the seasonal analysis, the 10th percentile flow (i.e., the flow that is exceeded 90 % 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 6-2). 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. The amount of the diffuse source for each month was calculated as follows:

Diffuse Source = Flow at Outlet (2nd Lift Station) – Flow at Headwater – Tributary Headwater Flows (Flewellen Creek + Red Gully, Table 6-1) – Average WWTF Discharges Used in SWAT

The diffuse sources computation ensures a water balance of each monthly critical low flow by taking into account mainstem and tributary headwater flow specifications in the model. Further, the computation corrects for the presence of WWTF discharges, which were incorporated into the SWAT modeling, by subtracting these discharges. As previously discussed, within QUAL2K each WWTF discharge is specified in the input, and therefore these discharges should not be incorporated into the computation of diffuse sources.

6.2.1.2 Stream Water Temperature

To perform the seasonal analysis, monthly water temperatures also need 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 data record included a predominance of temperature data for the Upper Reach, though some data were available for the Lower Reach. The data set was dominated by instantaneous temperature

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[8] The critical low flow at the outlet of the Upper Reach at Dam #3 is effectively zero; however, within the pool of Dam #3 is the intake for the Second Lift Station where the critical low flow is greater.

measurements, though 24-hr average water temperature data also populated the database, especially in recent years as a result of the DO assessment surveys discussed in Section 3. 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 process involves the following computations and decisions (also see Table 6-3):

- On a monthly basis determine average water temperature and standard deviation using available data.
- Use the average (avg), standard deviation (std), and the t-distribution tabular value (ν) in guidance provided by TCEQ to compute the 90th percentile temperature (T_{90} = Tavg + STD · ν). [For relatively small data sets as encountered for Segment 1245, TCEQ recommends using the computations described above to estimate the 90th percentile water temperature or finding a nearby USGS gauging station with a long record of water temperature data. Because the nearest USGS stations with temperature data were for systems that did not seem to represent the physical stream conditions found in Upper Oyster Creek, the decision was made to use the t-distribution method.] A monthly 90th percentile temperature is the temperature exceeded 10 percent of the time for the month being evaluated.
- Define the temperature for the three hottest months as the average of the average temperature for the months with the three hottest 90th percentile temperatures plus the average of the standard deviations of the same three months (for Segment 1245 the hottest months for water temperature were June, July, and August).
- For the remaining 9 months use the computed 90th percentile temperature.
- Within the first 6 months of the year, additional considerations are required for evaluating the higher DO criteria that are effective to protect during the spawning season when average water temperatures are between 17.2° C (63.0° F) and 22.8° C (73.0° F). First determine the month(s) with average water temperatures within the range provided above, which for this situation is only the month of March (Table 6-3). If the 90th percentile temperature for March is less than 22.8° C, then use that temperature to define water temperature for the applications of QUAL2K in evaluating spawning season DO criteria. Because the March 90th percentile temperature is 22.6° C, which meets the requirement, that temperature becomes the specified temperature for evaluating the spawning season DO criteria.

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. The temperature data collected during summer months in both reaches during the 24-hr DO assessment surveys was limited, but the data represented average water temperatures from 15-minute interval data (as opposed to just single daily instantaneous measurements) and were synoptic in nature so that for each survey the data from the Lower Reach (station 12074) were collected over a similar time period (give or take a couple of hours based on differences in time of multisonde deployment) as the data for the Upper Reach (stations 12079, 12082, 12083, 12086, 12087, and 12090). Comparison of these data indicated on average a 1.1º C lower temperature in the Lower Reach than in the Upper Reach (Table 6-4) during these three hottest months of June, July, and August. 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 6-3). 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 6-3 were considered appropriate for both reaches.

An additional complexity with temperature definition in the application of QUAL2K was that unlike QUALTX, where a water temperature can be user specified, QUAL2K predicts water temperature based on head budget equations and input of hourly air temperature, dew point, cloud cover, and wind speed data. Data obtained from the National Climatic Data Center website for Sugar Land for the years 2001 – 2005 were used to develop the required meteorological data input. For each month, the 90th percentile of 24-hr data was determined for air temperature and dew point temperature, and cloud cover and wind speed was based on median values of 24-hr data. During actual applications of QUAL2K, adjustments were made to the air temperature and dew point temperature input data until the average predicted water temperature was within a couple of a tenths of a degree C of the desired water temperature. Wind speed and cloud cover were not adjusted. This water temperature refinement was accomplished by adjusting the hourly air and dew point temperature data (increasing or decreasing) a constant amount and inspecting the predicted water temperatures along Upper Oyster Creek and its tributaries. Through adjustments to air temperature and dew point temperature, an average daily water temperature within a maximum of a couple of tenths of a degree C of the desired temperature could be readily obtained after typically three or four simulations.

6.2.1.3 Water Quality Specification for Headwaters

Headwater water quality input data for the mainstem and tributaries of the Lower and Upper Reaches were obtained from various sources. For ultimate CBOD (CBODu), organic nitrogen, NH_3-N, NO_2+NO_3-N, DO (% saturation), and chlorophyll-α, the default background concentrations used in TCEQ waste load evaluations were specified unless adequate (i.e., more than a couple of data points) site specific information were available. Portions of the necessary headwater water quality data for the mainstem of the Upper Reach were obtained from monitoring stations in the Brazos River in proximity to the Shannon Lift Station. The Brazos River water quality data were obtained from the TCEQ Surface Water Quality Monitoring database. The default background concentration for total phosphorus of 0.02 mg/L was separated as required in QUAL2K into organic P and PO_4-P components based on ratios determined from the model validation survey data sets and water quality data for the Brazos River. The headwater water quality input for QUAL2K are summarized in Table 6-5, and it should be noted that Flewellen Creek and Stafford Run are not included in this table, because no headwater flow contribution is associated with these tributaries.

6.2.1.4 Point Source 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 DO (Table 2-3). TCEQ's default multiplier of 2.3 was employed to convert $CBOD_5$ to CBODu. Total-P in effluent was assumed to be 5 mg/L for all facilities, which is 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 % 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 NO_2+NO_3 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 has been evaluated by TCEQ staff to produce effluent from the ponds that is at background levels of CBODu and NH_3-N with DO 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 2-3. For modeling purposes, the effluent from facilities with polishing ponds was assigned background concentrations for CBODu and NH_3-N, organic-N of 1 mg/L, 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), and 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 DO criteria, reductions were made in NH_3-N and $CBOD_5$ limits using the TCEQ domestic effluent set hierarchy as guidance until the DO criteria were met. DO limits were also increased, if necessary, applying the same hierarchical guidance.

6.2.1.5 Definition of Other Inputs

As developed in Section 5 (Selection and Validation of the Dissolved Oxygen Model), external factors to the model necessitated adjustments of one different input factor for the Lower and Upper Reaches. For the Lower Reach, the definition of the chlorophyll-α flux term from the pond system on Stafford Run required separate adjustment for the calibration and verification simulations. This flux term had significant effects on the phytoplankton predictions in the Lower Reach, but only minor effects on average DO concentration and insignificant effects on minimum DO concentrations (Figure 5-20). The smaller of the two flux terms used in the model validation process (chlorophyll-α = 50,000 μg/L; see Section 5.3.2 - Model Validation for Lower Reach) was used in order to be conservative, since the sensitivity analysis indicated that higher values slightly increased average DO concentrations in Oyster Creek immediately below the confluence with Stafford Run. The chlorophyll-α flux term was further restricted to a value of 20,000 μg/L for simulations evolving the months of November – March when algal growth would be anticipated to be less than in the months of warmer water temperatures and greater incident solar radiation.

For the Upper Reach, input of settling velocities for inorganic solids along the mainstem required different values for the calibration and verification periods, which are also discussed in Section 5. The sensitivity analysis indicated that higher settling velocities resulted in increased average DO concentrations in the lower portions of the reach, but only insignificant effects on minimum DO (Figure 5-35). To be conservative, the lower of the settling velocities specified for any location in the model segmentation in the calibration and verification input data sets were used in the model applications in this section.

6.2.2 Applications of QUAL2K

The validated QUAL2K models of the Lower and Upper Reaches were applied to determine allowable loadings from municipal WWTFs using the same input data as determined during the model validation process except for the input discussed above, which is needed to reflect conditions for assessing DO under critical conditions of temperature and flow. 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 DO criteria were not met, and the permit limits were adjusted until the criteria were not exceeded.

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

- Of the two assessment stations (12074 and 12077), data for station 12077 had twice as many exceedances as station 12074 (Table 3-3), yet station 12077 is upstream of any WWTFs in the Lower Reach, indicating DO 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 DO criterion in the mainstem 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 DO 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 (Table 5-1) and Discharge Monitoring Reports. The evaluation of the response of instream 24-hr average DO concentrations to full permits limits of WWTFs was performed under the modeling discussed herein.

Certain limitations on interpretations of the applications of QUAL2K to the variable of pH are necessary to individuals who may operate the models developed for this DO TMDL and closely evaluate model predictions. The user does not have the discretion as to whether or not to include pH in simulations—the model will always provide predictions of pH. No results have been provided within this report for pH, because pH levels are not a concern in Segment 1245 and no effort was made to calibrate and verify this parameter. Also, the necessary input data (e.g., alkalinity) were not collected to allow model calibration and verification of pH, and therefore little confidence can be placed in model predictions of pH. As a strong caution, the pH concentrations predicted by QUAL2K for these applications should not be considered meaningful or accurate.

Another qualification on QUAL2K results for individuals who may operate the models developed for this DO TMDL and closely evaluate model predictions concerns NO_2+NO_3-N predictions. Under full permit limits for WWTFs as evaluated for this TMDL, the model predicts NO_2+NO_3-N concentrations in the Lower Reach that exceed the primary drinking water criterion of 10 mg/L for nitrate as nitrogen in domestic water supplies. Upper Oyster Creek (Segment 1245) does have a designated use for domestic water supply; however, recent water rights information indicates that there were no domestic water rights or intakes on the Lower Reach for drinking water purposes based on existing water rights information provided in 2006 by Ms. Marian Chervenka, TCEQ Water Rights Permitting. The Texas Surface Water Quality Standards do not make a geographic distinction for Segment 1245 regarding the designated use for domestic water supply between the Upper Reach where domestic water rights do exist and the Lower Reach where they do not presently exist.

6.2.2.1 Margin of Safety

A margin of safety (MOS) is required in the determination of maximum allowable pollutant loadings under the TMDL process. The MOS may be either implicit through use of conservative model assumptions to develop the allocations or explicit through assigning a portion of the total TMDL as the MOS and using the remainder for allocations. An implicit MOS, based on conservative model assumptions, is used in this TMDL that include. 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 DO concentrations.

6.2.2.2 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 (0.00283 cms for headwater and Table 6-1 for tributaries) to determine maximum allowable loadings. The predicted average DO for the mainstem, Stafford Run, Steep Bank Creek, and Remnant of Flat Bank Creek under the existing WWTF permit limits condition and the allowable WWTF loading condition that reduces loadings sufficiently to meet the average DO criterion are provided in Figure 6-1. Under existing loadings the average DO is not maintained above the criterion in the mainstem and Steep Bank Creek. The average DO is acceptable for the Remnant of Flat Bank Creek and Stafford Run. However, predicted DO concentrations along the mainstem drop sharply immediately after Stafford Run enters, indicating negative impacts from Stafford Run on Oyster Creek. The maximum allowable loadings from WWTFs that do not result in exceedances of the average DO criterion and associated percent reduction in loadings are provided in Table 6-

6. It should be further noted that under this model scenario all WWTFs had a DO limit of 6.0 mg/L, representing an increase from 5.0 mg/L for some facilities (see present DO permit limits in Table 2-3).

The second set of model applications were performed under existing permit limits for WWTFs and to determine maximum allowable daily loadings in order to evaluate average DO for conditions protective of the spawning season, which for Segment 1245 occurs in March. The DO criterion is 1 mg/L higher to protect spawning except in Stafford Run with a no significant aquatic life use designation (Table 6-1). The 90th percentile water temperature for March is 22.6° C (Table 6-3). The predicted average DO for the mainstem, Stafford Run, Steep Bank Creek, and Remnant of Flat Bank Creek under the existing WWTF permit limits condition and under the allowable WWTF loading condition that reduces loadings sufficiently to meet the average DO criterion are provided in Figure 6-2. As for the summer condition, the existing permit loadings result in exceedances of the DO criterion, though the exceedances were less for the spawning season and are restricted to the mainstem. The maximum allowable loadings that do not result in exceedances of the average DO criterion and the necessary percent reductions in exiting loadings to achieve the allowable loadings are provided in Table 6-6. It should again be noted that under this model scenario all WWTFs had a DO limit of 6.0 mg/L, representing an increase from 5.0 mg/L for some facilities.

The third model application was made to investigate potential benefits of seasonal permit limits to be effective from November through February that account for the fact that fall and winter water temperatures are cooler than summer temperatures so that kinetic rates are reduced and DO saturation concentrations are increased. As an existing example, the Quail Valley Utility District WWTF presently operates under seasonal permits (Table 2-3). QUAL2K was applied with the existing permit limits for WWTFs and 90th percentile November water temperature (23.3° C; Table 6-3). Under this condition, the average DO criterion is met without the need for any load reductions and with DO limits as specified in existing permits (Figure 6-3). Since 90th percentile temperatures are lower in the months from December through February than November (Table 6-3), the DO criterion will also be met for these months. The water temperature for March is also lower than that of November; however, the higher DO criterion to protect spawning is effective for that month. As presented in Figure 6-2, this higher criterion can not be met under existing permit limits.

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

- November – February:
  Permit loadings for November conditions (from Table 6-6)
- March – October:
  Permit loadings for June-August conditions (from Table 6-6).

Because the summer condition allowable permit loadings are less than those required to protect spawning in March, the summer loadings will more than suffice to maintain DO concentrations during the spawning season. For the Lower Reach the maximum allowable loadings by individual WWTF are provided in Appendix C for the two seasonal conditions of March–October and November–February.

As the final model applications, various permit limits on total-P were considered for the WWTFs in the Lower Reach to investigate effectiveness of nutrient reduction to reduce aquatic vegetation and to both reduce diel DO fluctuations and increase minimum DO 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 also considered under the June-August flow and temperature conditions. Even results with permit limits of 0.2 mg/L total-P indicated unresponsiveness of the minimum DO to imposition of phosphorus control on WWTFs, though phytoplankton levels were reduced slightly (Figure 6-4). 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, which 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 6-4). Even if QUAL2K had predicted positive responsiveness in 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 with capabilities to obtain nutrients through roots and are therefore likely to be unresponsive to reductions in water column phosphorus concentrations (e.g., USDA-NRCS, 1999). It is concluded that based on lack of responsiveness of predicted minimum DOs in the model simulations of P reduction scenarios and the prevalence of rooted macrophytes throughout much of Stafford Run and Upper Oyster Creek, that imposition of P limits on WWTFs has limited to no potential of substantively improving 24-hr minimum DO concentrations in the Lower Reach.

6.2.2.3 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 (Table 6-2). The DO results for March were evaluated against the 24-hr average DO criterion to protect spawning whereas results for all other months were evaluated against the general DO criterion. The minimum 24-hr average DO predicted for the mainstem, Flewellen Creek, and Red Gully are provided in Table 6-7 for each condition. These model predictions indicate that potential exceedances of the 24-hr average DO criterion occurred during the March, September, October, and November scenarios.

As shown in Figure 6-5 for the March spawning scenario, the DO 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. This DO exceedance is attributable to the small amount of inflow entering the headwater and the relatively high SOD throughout the mainstem. The March DO 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 DO 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.

For the September scenario, predicted average DO was slightly below the criterion in Red Gully and barely meeting the criterion on Oyster Creek near the confluence with Red Gully (Figure 6-6). Slight reductions in allowable loading of NH_3-N from one of the facilities discharging into Red Gully were sufficient to provide predicted DO that met the DO criterion in Red Gully under September conditions (Table 6-8). The June-August scenario, representing the critical summer conditions of temperature (Table 6-3) and the June headwater flow (Table 6-2), which is the lowest flow for the three month of June, July, and August, was not indicated to result in any DO exceedances (Figure 6-7).

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 from WWTFs result in the pertinent average DO criteria being meet for the Upper Reach of Upper Oyster Creek and its major tributaries:

- November – February:
  Existing permit loadings (from Table 6-8)
- March – October:
  Permit loadings for September conditions (from Table 6-8).

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

In the Upper Reach, model applications were not performed to investigate potential effectiveness of reduced WWTF total-P discharges in lessening aquatic vegetation and increasing 24-hr minimum DO concentrations. The model applications were 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.

6.3 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 6-2). 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 6-9).

6.4 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 also 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 $CBOD_5$ are provided in Tables 6-10 and 6-11 for the March – October period and in Tables 6-12 and 6-13 for the November – February period. Correspondingly, for the Upper Reach the TMDL allocations for NH_3-N and $CBOD_5$ are provided in Tables 6-14 and 6-15 for the March – October period and in Tables 6-16 and 6-17 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 BMPs 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.

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 6-7), 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.

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.

Section 6

Tables

Table 6-1 Tributaries, reach location, designated aquatic life use, bedslope, critical low flow, and DO criteria

Tributary Name	Location	Designated Aquatic Life Use	Bedslope (m/km)	Critical Low Flow (cms)	General 24-hr Average/Minimum DO Criteria (mg/L)	Spawning-Season 24-hr Average/Minimum DO Criteria (mg/L)
Stafford Run	Lower Reach	No Significant	0.7	0.00000	2 / 2	2 / 2
Steep Bank Cr.	Lower Reach	Limited	0.4	0.00283	3 / 2	4 / 3
Remnant Flat Bank Cr.	Lower Reach	Intermediate	2.5	0.00283	4 / 3	5 / 4
Flewellen Cr.	Upper Reach	No Significant	1.1	0.00000	2 / 2	2 / 2
Red Gully	Upper Reach	Intermediate	0.1[a]	0.08496	4 / 3	5 / 4

[a] The bedslope of 0.1 m/km used for Red Gully to determine the critical low flow from Table 5 of TNRCC (2000) is not the actual average bedslope of the creek, but rather reflects the constant backwater effects from Oyster Creek that greatly reduces the effective slope of the lower portion of Red Gully where DO minimums occur. This approach represents the same manner in which TCEQ has accounted for the backwater effect on Red Gully in waste load evaluations.

Table 6-2 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 equation 1	-0.026	-0.037	-0.028	0.390	0.524	0.739	0.014	-0.246	0.807	-0.020	-0.016	-0.018

[a] The Second 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

Table 6-3 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 http://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.

Table 6-4 Summer season water temperature difference (°C) between Upper and Lower Reaches

Date	Lower Station 12074	Upper Stations						
		12079	12082	12083	12086	12087	12090	Avg
6/17/2003	27.5				29.4			29.4
7/15/2003	26.7				27.3			27.3
8/11/2003	28.3	30.9	30.8	30.2	29.7	29.9	30.1	30.3
8/2/2004	30.8	32.4	32.3	31.9	32.3	32.6	32.7	32.3
8/30/2004	29.2	29.5	29.5	28.7	29.2	29.3	29.7	29.3
7/13/2005	30.5	31.4	31.4	31.3	30.7		31.0	31.2
8/17/2005	28.7	30.5	29.6	29.7	29.0	29.0	28.5	29.4
Avg [a]	28.8							29.9

[a] A null hypothesis of no difference between the means is rejected due to p=0.004 at the 0.5 level. That is, the mean difference of 1.1º C between the water temperatures of Upper Reach and Lower Reach is statistically significant.

Table 6-5 Headwater water quality input to QUAL2K for mainstem, tributaries, and diffuse sources. [Note: Flewellen Creek and Stafford Run have no headwater flow (see Table 6-1) and are not included in this table.]

Constituent	Lower Reach Headwater	Steep Bank Creek	Remnant Flat Bank Creek	Upper Reach Headwater	Red Gully	Diffuse Sources (Upper Reach)
Inorganic Solids (mg/L)	11.6	11.6	11.6	85	68	68
DO (% sat.)	80	80	80	80	80	80
Fast CBODu (mg/L)	3.0	3.0	3.0	3.0	3.0	3.0
Organic-N (mg/L)	0.5	0.5	0.5	0.5	0.5	0.5
NH_3-N (mg/L)	0.05	0.05	0.05	0.05	0.05	0.05
NO_2+NO_3-N (mg/L)	0.200	0.200	0.200	0.585	0.200	0.200
Organic-P (mg/L)	0.008	0.008	0.008	0.021	0.019	0.019
PO4-P (mg/L)	0.012	0.012	0.012	0.025	0.001	0.001
Chla (µg/L)	2	2	2	2 / 8.7 [a]	2	2

[a] The chlorophyll-α data for the Brazos River in the vicinity of the Shannon Pump Station showed a seasonal component, though no other input parameters exhibited this characteristic for the Brazos River. Based on analysis of these data, a concentration of 2 µg/L of chlorophyll-α was used for the months of November through April and a concentration of 8.7 µg/L for May through October.

Table 6-6 Existing, maximum allowable loadings, and percent reductions for WWTFs (or WLA) in Lower Reach

Condition	Discharge (cms)	$CBOD_5$ (kg/d)	Ammonia N (kg/d)
Existing Permit Loading	1.078	931.3	253.27[b]
Allowable Loading (June-August Condition)[a]	1.078	482.7	186.26
Percent Reduction (June-August Condition)	0 %	48 %	26 %
Allowable Loading (Spawning Season, March)[a]	1.078	662.1	186.26
Percent Reduction (Spawning Season, March)	0 %	29 %	26 %
Allowable Loading (November)	1.078	931.3	268.41[b]
Percent Reduction (November)	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 2-3).

Table 6-7 Simulated minimum 24-hr average DO concentrations 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
Mainstem	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

Table 6-8 Existing, maximum allowable loadings, and percent reductions for WWTFs (or WLA) in Upper Reach

Condition	Discharge (cms)	$CBOD_5$ (kg/d)	Ammonia 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%

Table 6-9 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) Background $CBOD_5$ Load (kg/d)	0.04 1.0
Upper Reach:	
Critical low flow (cms) * Background NH_3-N Load (kg/d) Background $CBOD_5$ Load (kg/d)	0.9640 4.17 108.3

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

Table 6-10 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 6-11 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 6-12 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 6-13 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 6-14 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 6-15 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 6-16 TMDL summary for Upper Reach NH_3-N, critical low-flow condition, and the November – February period

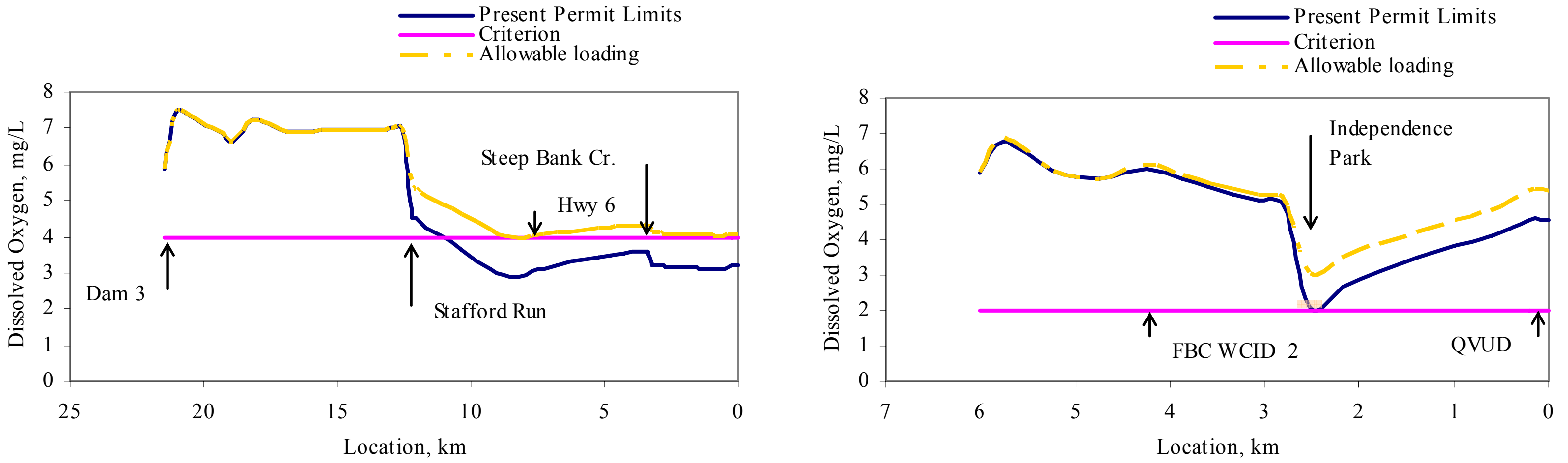
Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	26.86	26.86	0
Load Allocation	4.17	4.17	0
Total Loading	31.03	31.03	0

Table 6-17 TMDL summary for Upper Reach $CBOD_5$, critical low-flow condition, and the November - February period

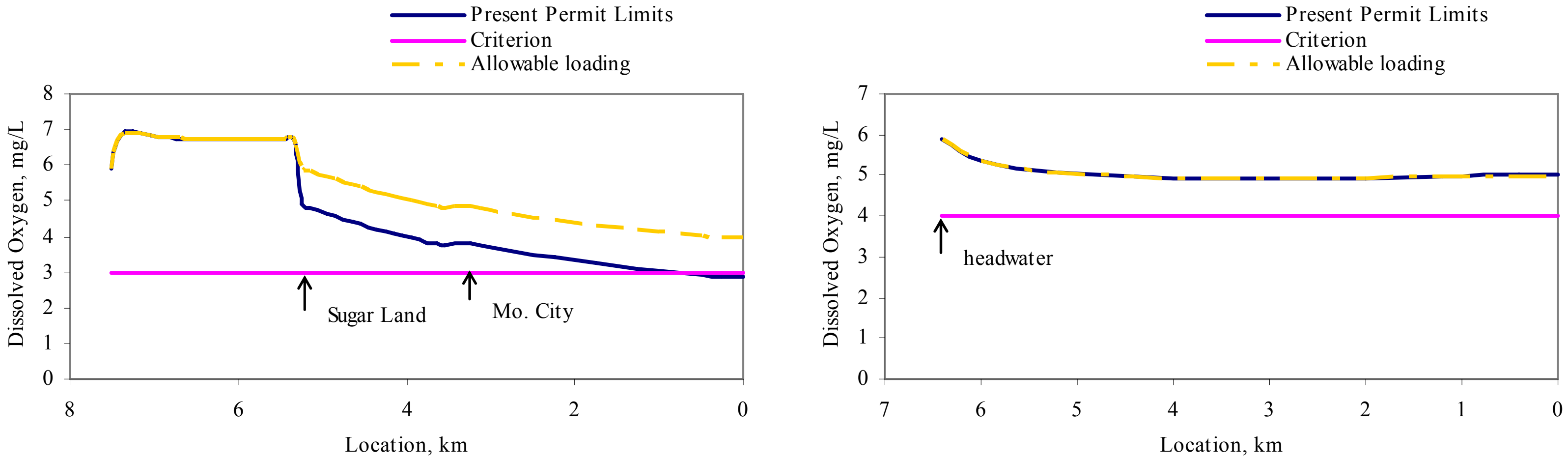
Source Category	Existing Loading (kg/d)	Allowable Loading (kg/d)	Percent Reduction (%)
Waste Load Allocation	114.2	114.2	0
Load Allocation	108.3	108.3	0
Total Loading	222.5	222.5	0

SECTION 6

FIGURES

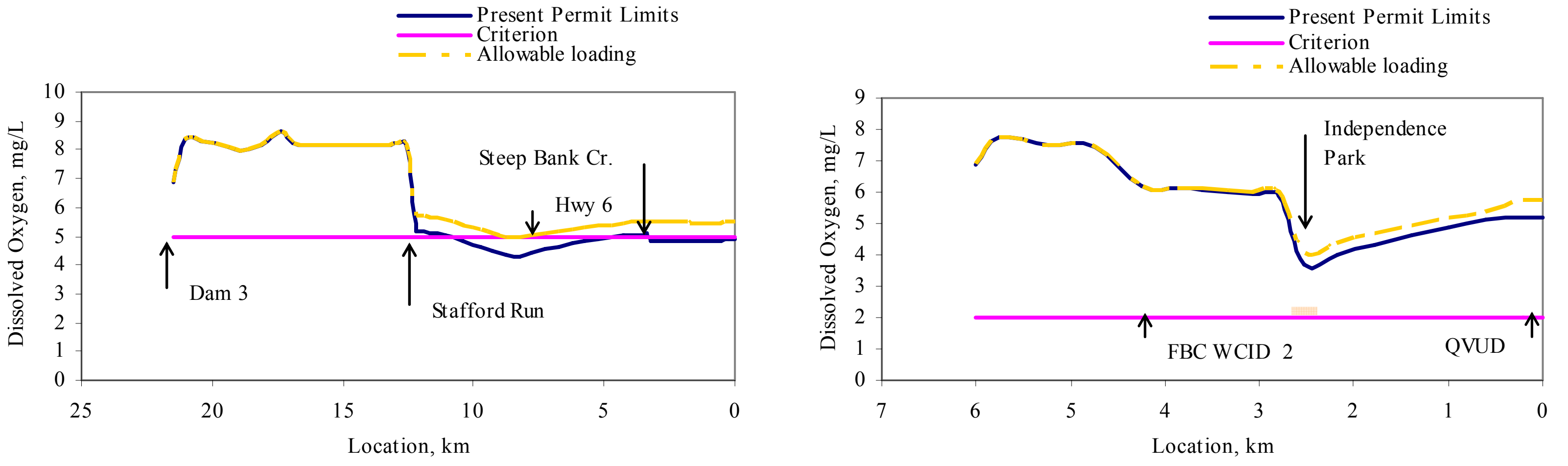


a) Lower Reach main stem **b) Stafford Run**

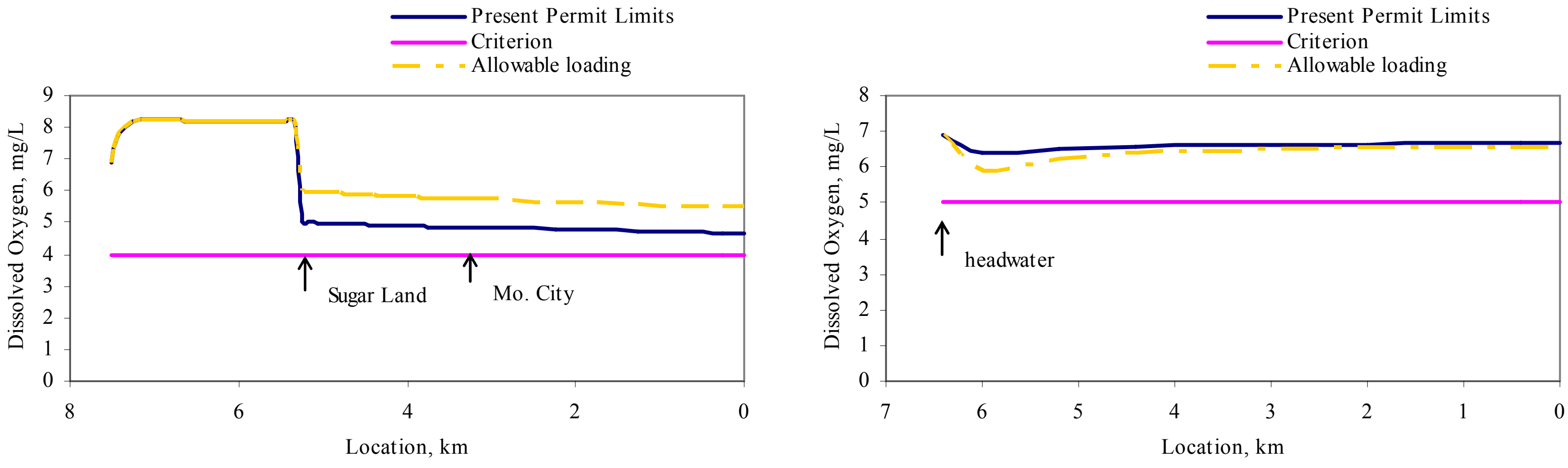


c) Steep Bank Cr. **d) Remnant Flat Bank Cr.**

Figure 6-1 QUAL2K average dissolved oxygen predictions for Lower Reach during critical summer conditions

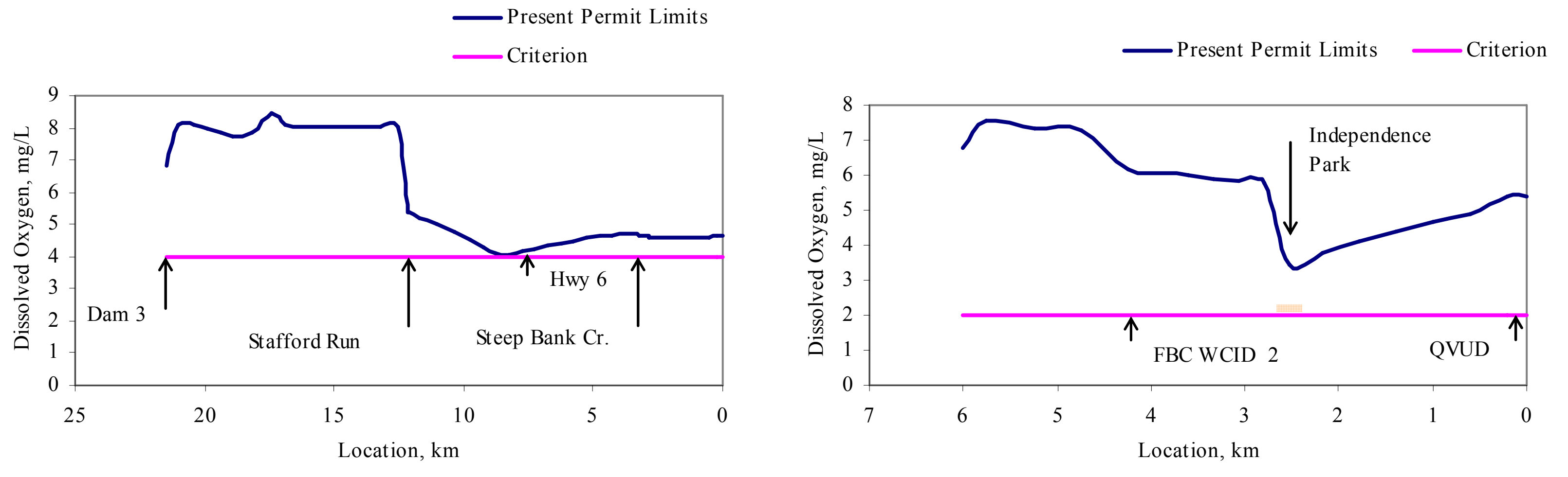


a) Lower Reach main stem **b) Stafford Run**



c) Steep Bank Cr. **d) Remnant Flat Bank Cr.**

Figure 6-2 QUAL2K average dissolved oxygen predictions for Lower Reach during spawning conditions (March)



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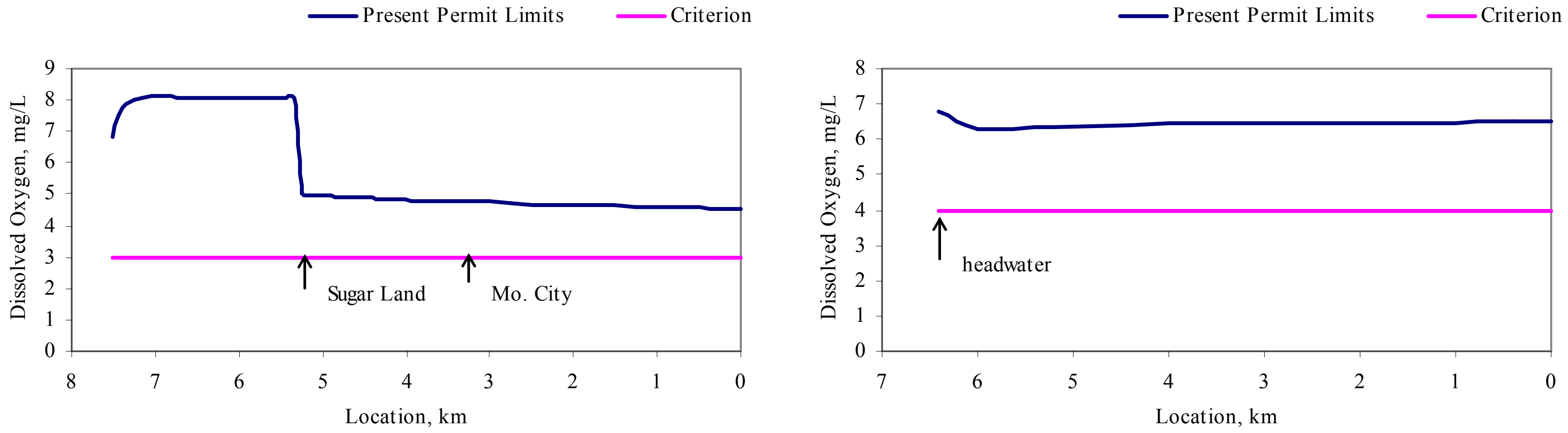
a) Lower Reach main stem **b) Stafford Run**



c) Steep Bank Cr. **d) Remnant Flat Bank Cr.**

Figure 6-3 QUAL2K average dissolved oxygen predictions for Lower Reach during winter conditions (Nov-Feb)

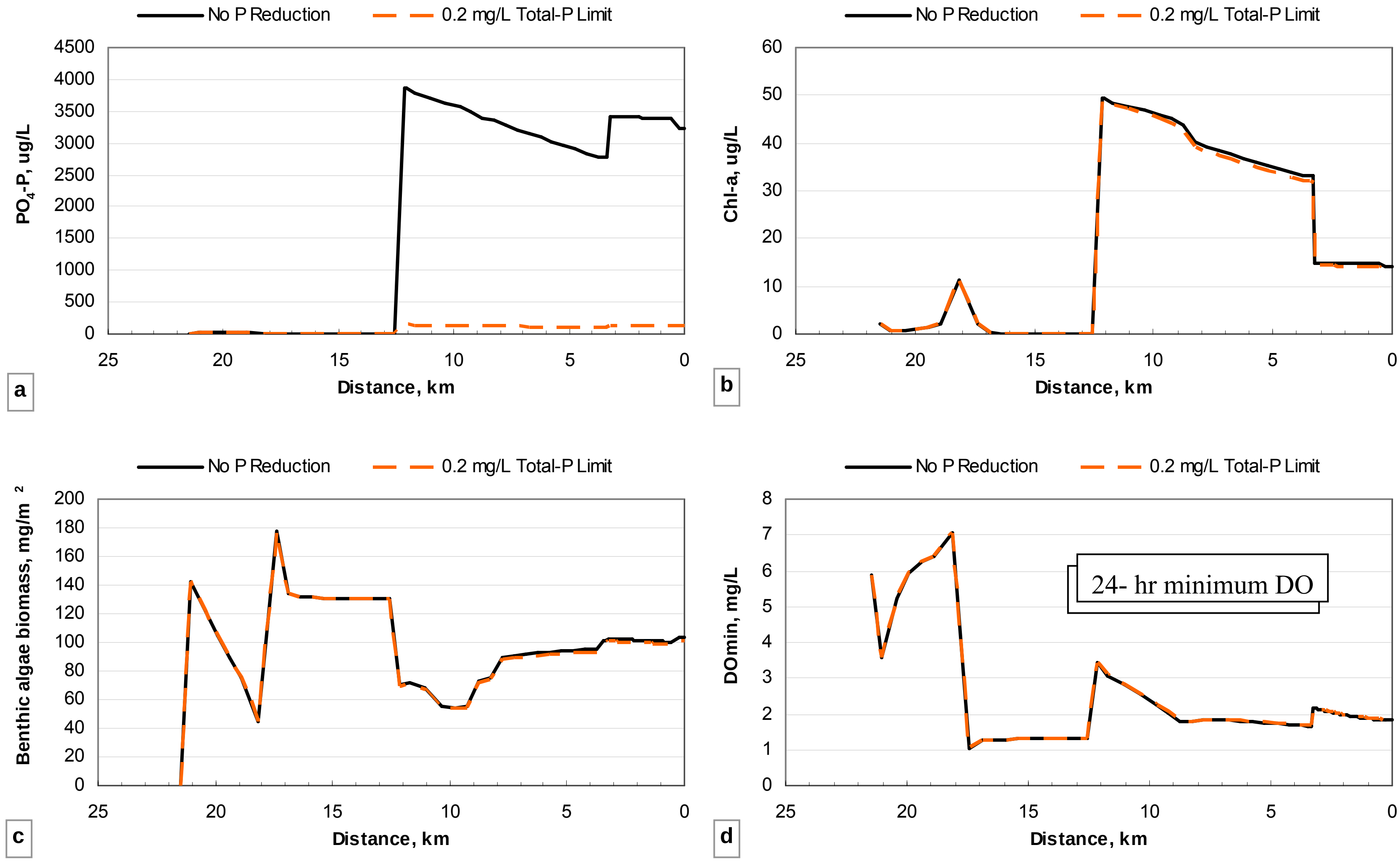
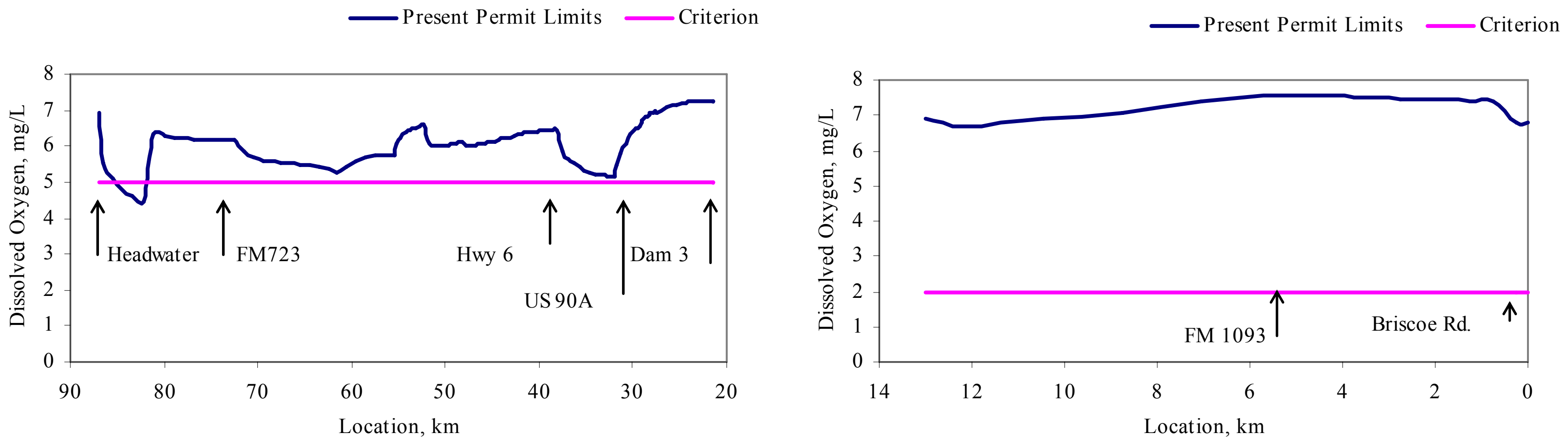
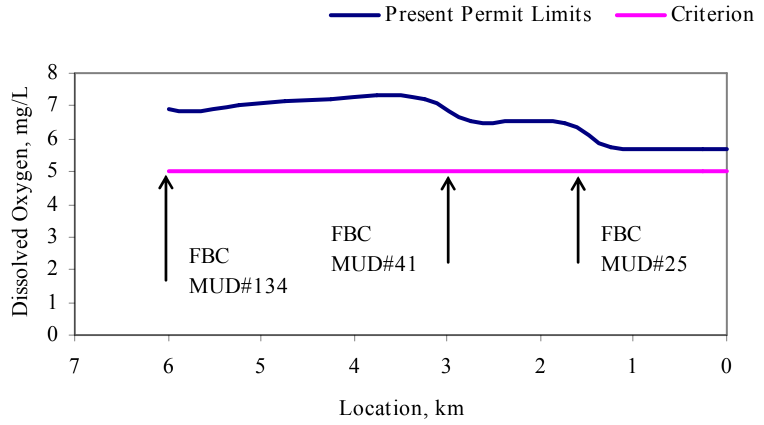


Figure 6-4 QUAL2K predictions with and without WWTFs Total-P limits during critical summer conditions. Main stem predictions of: a) PO_4-P, b) chlorophyll-α, c) benthic algae biomass, and d) dissolved oxygen

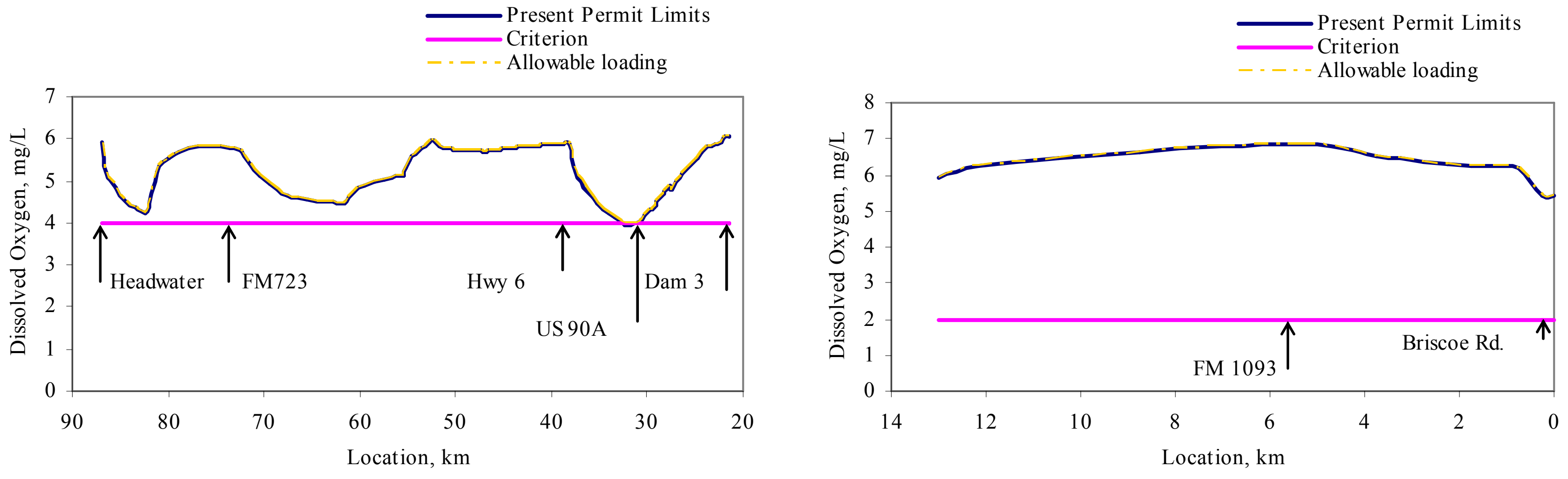


a) Upper Reach main stem **b) Flewellen Cr.**

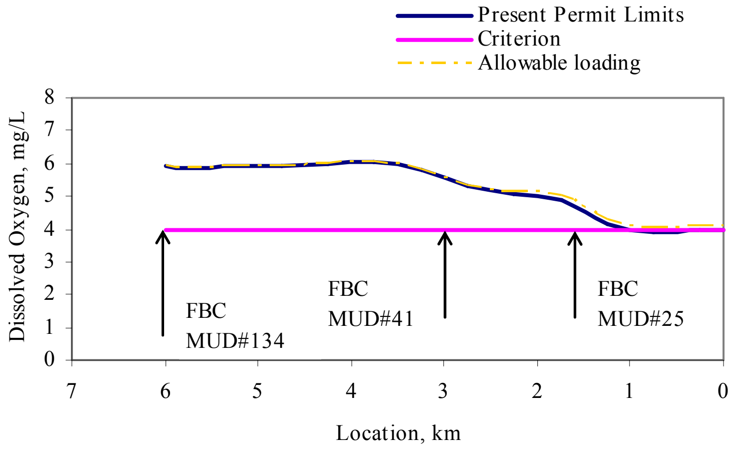


c) Red Gully

Figure 6-5 QUAL2K average dissolved oxygen predictions for Upper Reach during spawning conditions (March)

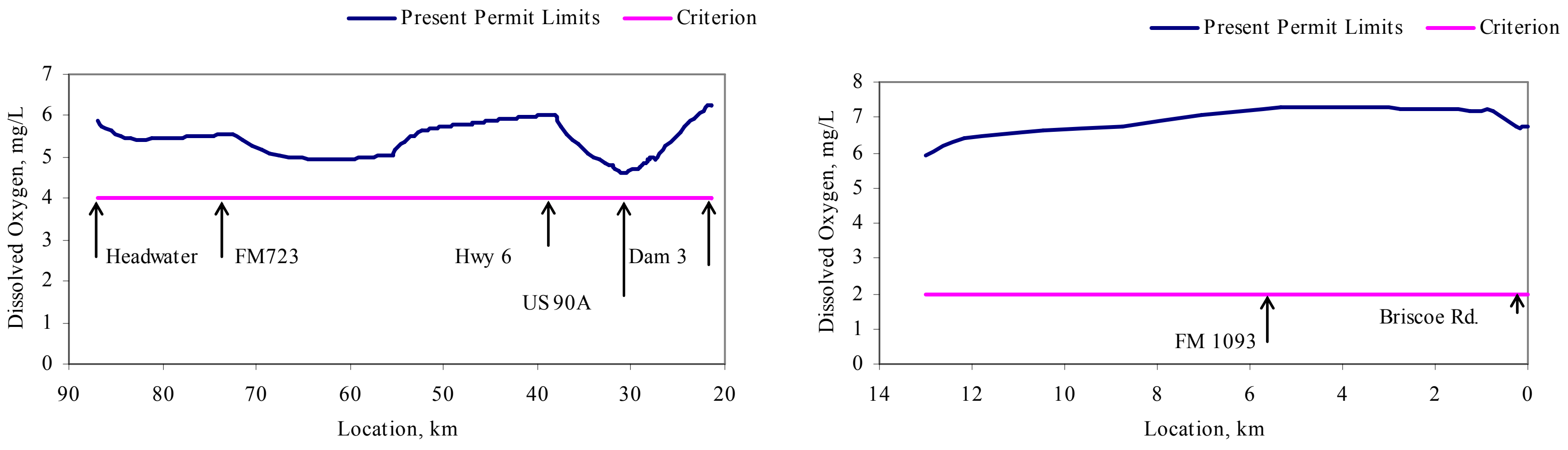


a) Upper Reach main stem **b) Flewellen Cr.**



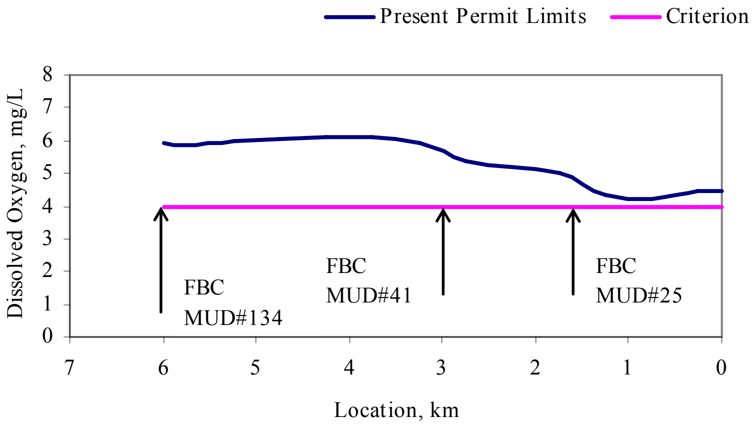
c) Red Gully

Figure 6-6 QUAL2K average dissolved oxygen predictions for Upper Reach during September conditions



a) Upper Reach main stem

b) Flewellen Cr.



c) Red Gully

Figure 6-7 QUAL2K average dissolved oxygen predictions for Upper Reach during June-August low flow and high temperature conditions

SECTION 7

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APPENDIX A

Variables Used in Regression Analysis

Table A-1 The 2003-2005 nutrients, TSS and chlorophyll-a data for Stations 12090, 12086, 12087, 12079, 12082, 12083, 12077 and 12074 of UOC

ID	Station	Deployment Start Date	Deployment End Date	NO_2+NO_3 (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TKN (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	Chla (µg/L)
1	12074	5/19/2003	5/20/2003	3.710	0.100	0.450	0.910	0.430	28	3.7	31.60
2	12074	6/17/2003	6/18/2003	1.610	0.380	0.520	0.820	1.020	41	2.5	15.00
3	12074	7/15/2003	7/16/2003	2.580	0.250	0.346	0.670	0.830	51	<2	10.70
4	12074	8/11/2003	8/12/2003	0.268	0.085	-	0.856	0.770	37	<2	19.10
5	12074	9/9/2003	9/10/2003	2.830	0.206	0.405	0.742	1.100	70	<2	11.30
6	12074	3/23/2004	3/24/2004	5.145	0.234	0.236	0.528	0.927	41	<2	30.26
7	12074	4/20/2004	4/21/2004	5.020	0.121	0.200	0.517	1.460	43	<2	38.70
8	12074	5/27/2004	5/28/2004	4.080	0.584	0.170	0.594	2.140	46	3.9	22.00
9	12074	8/2/2004	8/3/2004	1.750	0.210	0.170	0.399	0.890	64	<2	14.70
10	12074	8/30/2004	8/31/2004	2.823	0.255	0.229	0.366	0.938	66	<2	26.70
11	12074	9/29/2004	9/30/2004	6.402	0.196	0.499	0.847	0.932	39	<2	22.16
12	12074	5/3/2005	5/4/2005	7.340	0.010	0.487	0.850	1.140	47	5.5	62.60
13	12074	6/9/2005	6/10/2005	5.090	0.198	0.445	0.729	0.850	39	<2	28.10
14	12074	7/13/2005	7/14/2005	3.475	0.180	0.512	0.773	0.642	44	<2	18.40
15	12074	8/17/2005	8/18/2005	3.540	0.207	0.579	0.925	0.955	36	<2	8.29
16	12074	9/20/2005	9/21/2005	4.350	0.451	1.060	1.420	1.080	14	<2	11.80
17	12077	5/20/2003	5/21/2003	-	-	-	-	-	-	-	-
18	12077	6/17/2003	6/18/2003	-	-	-	-	-	-	-	-
19	12077	7/14/2003	7/15/2003	-	-	-	-	-	-	-	-
20	12077	8/11/2003	8/12/2003	-	-	-	-	-	-	-	-
21	12077	9/9/2003	9/10/2003	0.028	0.134	0.139	0.201	0.340	13	<2	3.56
22	12077	3/23/2004	3/24/2004	0.088	0.093	0.047	0.083	0.042	4	<2	1.31
23	12077	4/20/2004	4/21/2004	0.030	0.097	0.050	0.127	0.120	24	<2	2.23
24	12077	5/27/2004	5/28/2004	0.081	0.048	0.040	0.188	0.410	10	<2	3.20
25	12077	8/2/2004	8/3/2004	0.112	0.184	0.090	0.173	0.660	31	<2	4.67
26	12077	8/30/2004	8/31/2004	0.138	0.069	0.146	0.204	0.491	12	<2	3.78
27	12077	9/29/2004	9/30/2004	0.031	0.097	0.079	0.117	0.561	7	<2	1.04
28	12077	5/3/2005	5/4/2005	0.020	0.010	0.055	0.063	0.306	4	<2	2.50
29	12077	6/8/2005	6/9/2005	0.020	0.024	0.083	0.114	0.402	8	<2	2.50
30	12077	7/13/2005	7/14/2005	0.033	0.056	0.109	0.113	0.575	7	<2	12.00
31	12077	8/17/2005	8/18/2005	0.006	0.034	0.098	0.239	0.475	14	<2	3.56

Table A-1 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	NO_2+NO_3 (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TKN (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	Chla (µg/L)
32	12077	9/20/2005	9/21/2005	0.006	0.008	0.081	0.107	0.276	6	<2	1.60
33	12079	5/19/2003	5/20/2003	0.028	0.030	0.099	0.200	0.370	4	<2	5.45
34	12079	6/16/2003	6/17/2003	0.220	0.130	0.297	0.210	0.160	4	<2	7.05
35	12079	7/14/2003	7/15/2003	0.090	0.080	0.119	0.200	0.570	8	<2	5.93
36	12079	8/11/2003	8/12/2003	0.109	0.095	0.117	0.208	0.380	6	<2	3.31
37	12079	9/9/2003	9/10/2003	0.523	0.074	0.131	0.249	0.330	6	<2	3.31
38	12079	12/10/2003	12/11/2003	0.627	0.019	0.110	0.150	0.900	8	<2	13.60
39	12079	1/13/2004	1/14/2004	0.582	0.152	0.090	0.089	0.320	4	<2	3.20
40	12079	2/2/2004	2/3/2004	0.656	0.183	0.226	0.340	0.775	4	<2	1.44
41	12079	3/23/2004	3/24/2004	0.797	0.193	0.118	0.212	0.915	14	<2	2.46
42	12079	4/20/2004	4/21/2004	0.757	0.128	0.120	0.219	1.310	14	<2	3.17
43	12079	5/27/2004	5/28/2004	0.493	0.127	0.150	0.323	0.910	11	<2	3.47
44	12079	7/1/2004	7/2/2004	0.196	0.131	0.240	0.257	0.720	19	<2	3.34
45	12079	8/2/2004	8/3/2004	0.185	0.076	0.100	0.156	0.530	11	<2	6.34
46	12079	8/30/2004	8/31/2004	0.331	0.110	0.131	0.192	0.570	16	<2	5.70
47	12079	5/3/2005	5/4/2005	0.976	0.024	0.077	0.174	0.346	8	<2	7.17
48	12079	6/8/2005	6/9/2005	0.182	0.039	0.089	0.167	0.812	20	2.3	52.50
49	12079	7/13/2005	7/14/2005	0.056	0.044	0.104	0.074	0.636	20	<2	7.34
50	12079	8/17/2005	8/18/2005	0.449	0.050	0.096	0.260	0.644	22	<2	13.70
51	12079	9/20/2005	9/21/2005	0.006	0.008	0.098	0.148	0.339	12	<2	7.44
52	12082	5/19/2003	5/20/2003	0.150	0.030	0.085	0.210	0.330	7	<2	10.00
53	12082	6/16/2003	6/17/2003	0.540	0.050	0.105	4.140	3.980	10	3.5	8.66
54	12082	7/14/2003	7/15/2003	0.110	0.070	0.106	0.190	0.450	10	<2	6.87
55	12082	8/11/2003	8/12/2003	0.312	0.053	0.144	0.257	0.510	11	<2	5.45
56	12082	9/9/2003	9/10/2003	0.662	0.089	0.142	0.211	0.380	4	<2	6.28
57	12082	12/10/2003	12/11/2003	0.740	0.024	0.121	0.186	0.350	11	<2	14.10
58	12082	1/13/2004	1/14/2004	1.050	0.143	0.071	0.205	0.260	7	<2	5.01
59	12082	2/2/2004	2/3/2004	0.609	0.200	0.240	0.321	0.042	10	<2	0.58
60	12082	3/23/2004	3/24/2004	0.834	0.161	0.118	0.198	1.177	36	<2	3.96
61	12082	4/20/2004	4/21/2004	1.220	0.095	0.100	0.202	1.030	37	<2	2.05
62	12082	5/27/2004	5/28/2004	0.571	0.120	0.120	0.270	0.960	13	<2	3.77
63	12082	7/1/2004	7/2/2004	0.175	0.142	0.240		0.870	25	<2	3.29

Table A-1 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	NO_2+NO_3 (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TKN (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	Chla (µg/L)
64	12082	8/2/2004	8/3/2004	0.209	0.103	0.110	0.164	0.520	19	<2	5.47
65	12082	8/30/2004	8/31/2004	0.597	0.129	0.174	0.216	0.689	13	<2	3.86
66	12082	5/3/2005	5/4/2005	1.010	0.040	0.095	0.099	0.406	21	<2	7.63
67	12082	6/8/2005	6/9/2005	0.575	0.069	0.096	0.147	0.572	16	<2	22.50
68	12082	7/13/2005	7/14/2005	0.053	0.050	0.092	0.101	0.631	17	<2	23.70
69	12082	8/17/2005	8/18/2005	0.664	0.087	0.094	0.283	0.662	12	<2	9.02
70	12082	9/20/2005	9/21/2005	0.006	0.024	0.102	0.166	0.572	15	2.5	18.10
71	12083	5/19/2003	5/20/2003	0.150	0.060	0.082	0.210	0.400	13	2.6	5.54
72	12083	6/16/2003	6/17/2003	0.620	0.080	0.115	0.230	0.520	22	<2	6.18
73	12083	7/14/2003	7/15/2003	0.090	0.060	0.102	0.210	0.420	18	<2	5.04
74	12083	8/11/2003	8/12/2003	3.410	0.260		0.201	0.680	16	<2	2.46
75	12083	9/9/2003	9/10/2003	0.767	0.097	0.143	0.261	0.400	16	<2	2.46
76	12083	12/10/2003	12/11/2003	0.703	0.044	0.108	0.142	0.780	16	2.2	9.66
77	12083	1/13/2004	1/14/2004	0.697	0.133	0.069	0.194	0.340	20	<2	4.03
78	12083	2/2/2004	2/3/2004	0.587	0.264	0.201	0.290	1.466	11	<2	3.62
79	12083	3/23/2004	3/24/2004	0.957	0.147	0.116	0.227	0.997	42	<2	2.97
80	12083	4/20/2004	4/21/2004	1.280	0.084	0.100	0.242	1.220	56	<2	3.10
81	12083	5/27/2004	5/28/2004	0.519	0.100	0.100	0.298	1.040	44	<2	2.26
82	12083	7/1/2004	7/2/2004	0.191	0.142	0.280	0.261	0.840	42	<2	3.99
83	12083	8/2/2004	8/3/2004	0.201	0.093	0.110	0.171	0.540	27	<2	5.05
84	12083	8/30/2004	8/31/2004	0.662	0.249	0.177	0.255	1.249	20	<2	2.36
85	12083	5/3/2005	5/4/2005	0.642	0.043	0.062	0.030	0.571	29	<2	5.42
86	12083	6/8/2005	6/9/2005	0.756	0.081	0.089	0.167	0.686	37	<2	30.20
87	12083	7/13/2005	7/14/2005	0.081	0.048	0.084	0.136	0.493	33	<2	24.00
88	12083	8/17/2005	8/18/2005	0.634	0.087	0.094	0.313	0.801	16	<2	10.70
89	12083	9/20/2005	9/21/2005	0.035	0.083	0.145	0.190	0.628	15	<2	18.00
90	12086	2/10/2003	2/11/2003	1.860	0.270	0.306	0.560	1.110	20	<2	5.46
91	12086	5/20/2003	5/21/2003	-	-	-	-	-	-	-	-
92	12086	6/17/2003	6/18/2003	-	-	-	-	-	-	-	-
93	12086	7/15/2003	7/16/2003	-	-	-	-	-	-	-	-
94	12086	8/11/2003	8/12/2003	-	-	-	-	-	-	-	-

Table A-1 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	NO_2+NO_3 (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TKN (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	Chla (µg/L)
95	12086	9/9/2003	9/10/2003	0.687	0.076	0.130	0.284	0.370	28	<2	3.34
96	12086	12/10/2003	12/11/2003	0.644	0.040	0.086	0.183	0.360	27	<2	7.34
97	12086	1/13/2004	1/14/2004	0.580	0.118	0.059	0.189	0.890	46	<2	3.20
98	12086	2/2/2004	2/3/2004	1.096	0.351	0.276	0.381	0.289	11	<2	2.11
99	12086	3/23/2004	3/24/2004	1.536	0.138	0.110	0.241	0.781	82	<2	3.08
100	12086	4/20/2004	4/21/2004	1.290	0.084	0.090	0.274	1.090	133	<2	4.09
101	12086	5/25/2004	5/26/2004	0.520	0.116	0.090	0.373	1.290	126	<2	4.33
102	12086	7/1/2004	7/2/2004	0.300	0.151	0.270	0.336	1.010	41	3.8	2.58
103	12086	8/2/2004	8/3/2004	0.398	0.074	0.110	0.174	0.520	23	<2	4.90
104	12086	8/30/2004	8/31/2004	0.753	0.068	0.137	0.287	0.717	65	<2	7.19
105	12086	5/4/2005	5/5/2005	0.551	0.044	0.047	0.171	0.799	97	<2	8.61
106	12086	6/8/2005	6/9/2005	1.750	0.078	0.062	0.168	0.983	86	<2	17.80
107	12086	7/13/2005	7/14/2005	0.314	0.047	0.104	0.147	0.513	34	<2	23.40
108	12086	8/17/2005	8/18/2005	0.678	0.055	0.098	0.347	1.050	54	<2	7.26
109	12086	9/20/2005	9/21/2005	1.140	0.089	0.337	0.383	0.725	18	<2	19.50
110	12087	2/10/2003	2/11/2003	0.450	0.180	0.088	0.420	1.050	74	<2	3.61
111	12087	5/19/2003	5/20/2003	0.028	0.020	0.035	0.200	0.950	44	2.3	27.60
112	12087	6/16/2003	6/17/2003	0.800	0.090	0.059	0.140	0.690	42	2.2	5.34
113	12087	7/14/2003	7/15/2003	0.100	0.040	0.065	0.180	0.430	35	<2	7.87
114	12087	8/11/2003	8/12/2003	0.141	0.066	0.058	0.174	0.590	38	<2	5.56
115	12087	9/9/2003	9/10/2003	0.623	0.095	0.113	0.267	0.390	36	<2	5.56
116	12087	3/23/2004	3/24/2004	1.334	0.116	0.090	0.189	1.004	72	<2	3.08
117	12087	4/20/2004	4/21/2004	1.150	0.098	0.070	0.228	0.960	144	<2	1.30
118	12087	5/25/2004	5/26/2004	0.493	0.093	0.080	0.316	1.080	97	<2	3.56
119	12087	7/1/2004	7/2/2004	0.273	0.109	0.230	0.321	0.930	47	<2	3.24
120	12087	8/2/2004	8/3/2004	0.422	0.067	0.080	0.158	0.530	38	<2	8.90
121	12087	8/30/2004	8/31/2004	0.954	0.084	0.097	0.257	1.135	94	<2	3.56
122	12087	5/3/2005	5/4/2005	0.431	0.010	0.030	0.116	0.436	79	<2	14.00
123	12087	6/8/2005	6/9/2005	2.240	0.071	0.054	0.145	0.620	76	<2	17.30
124	12087	7/14/2005	7/15/2005	0.724	0.063	0.058	0.117	0.600	56	<2	17.40
125	12087	8/17/2005	8/18/2005	0.609	0.043	0.074	0.305	0.816	58	<2	4.05
126	12087	9/20/2005	9/21/2005	0.266	0.008	0.086	0.177	0.810	28	2.4	50.20

Table A-1 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	NO_2+NO_3 (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TKN (mg/L)	TSS (mg/L)	$CBOD_5$ (mg/L)	Chla (µg/L)
127	12090	2/10/2003	2/11/2003	14.800	0.620	0.369	0.600	1.160	12	<2	2.83
128	12090	5/19/2003	5/20/2003	0.028	0.050	0.004	0.140	1.100	22	4.5	25.30
129	12090	6/16/2003	6/17/2003	0.920	0.160	0.054	0.130	0.850	73	<2	4.60
130	12090	8/11/2003	8/12/2003	0.064	0.084	0.024	0.121	0.550	38	<2	4.15
131	12090	9/9/2003	9/10/2003	0.498	0.121	0.094	0.237	0.350	53	<2	3.96
132	12090	3/23/2004	3/24/2004	0.918	0.117	0.066	0.184	1.063	104	<2	2.14
133	12090	4/20/2004	4/21/2004	1.030	0.108	0.060	0.258	1.450	182	<2	1.83
134	12090	5/25/2004	5/26/2004	0.545	0.177	0.050	0.348	1.140	224	<2	9.29
135	12090	7/1/2004	7/2/2004	0.333	0.125	0.170	0.235	1.460	48	<2	4.31
136	12090	8/2/2004	8/3/2004	0.104	0.128	0.040	0.123	0.520	48	<2	11.20
137	12090	8/30/2004	8/31/2004	0.684	0.077	0.061	0.114	0.592	321	<2	2.58
138	12090	9/29/2004	9/30/2004	0.124	0.127	0.023	0.099	0.633	56	<2	3.99
139	12090	5/3/2005	5/4/2005	0.202	0.010	0.003	0.060	0.913	100	<2	62.10
140	12090	6/8/2005	6/9/2005	2.180	0.073	0.047	0.186	0.458	148	<2	15.60
141	12090	7/13/2005	7/14/2005	3.800	0.205	0.098	0.103	0.621	12	<2	8.05
142	12090	8/17/2005	8/18/2005	0.589	0.072	0.089	0.490	1.220	306	<2	4.85
143	12090	9/20/2005	9/21/2005	0.210	0.172	0.023	0.078	0.723	12	<2	3.38
	max			14.800	0.620	1.060	4.140	3.980	321	5.5	62.60
	min			0.006	0.008	0.003	0.030	0.042	4	2.2	0.58
	mean			1.060	0.115	0.145	0.305	0.749	41	3.1	10.02
	std			1.780	0.096	0.138	0.396	0.439	49	1.0	11.32

Table A-2. The 2003-2005 DO, water temperature data and DO exceedance for Stations 12090, 12086, 12087, 12079, 12082, 12083, 12077 and 12074 of UOC

ID	Station	Deployment Start Date	Deployment End Date	DOavg (mg/L)	DOmin (mg/L)	DOmax (mg/L)	Avg Temp (°C)	DO_Sat (mg/L)	DOavg_ %sat (%)	DOmin_ %sat (%)	DOavg_ Criteria	DOmin_ Criteria
1	12074	5/19/2003	5/20/2003	6.593	4.130	9.230	28.9	7.707	86	54	pass	pass
2	12074	6/17/2003	6/18/2003	4.343	2.940	5.810	27.5	7.895	55	37	pass	exceed.
3	12074	7/15/2003	7/16/2003	5.029	3.770	6.710	26.7	8.012	63	47	pass	pass
4	12074	8/11/2003	8/12/2003	4.371	2.820	6.350	28.3	7.786	56	36	pass	exceed.
5	12074	9/9/2003	9/10/2003	4.053	2.530	5.660	28.3	7.786	52	32	pass	exceed.
6	12074	3/23/2004	3/24/2004	7.115	6.130	8.220	21.4	8.848	80	69	pass	pass
7	12074	4/20/2004	4/21/2004	6.651	5.320	8.350	24.2	8.383	79	63	pass	pass
8	12074	5/27/2004	5/28/2004	4.903	3.390	6.550	27.5	7.900	62	43	pass	pass
9	12074	8/2/2004	8/3/2004	3.559	1.720	4.740	30.8	7.453	48	23	exceed.	exceed.
10	12074	8/30/2004	8/31/2004	5.578	3.800	7.140	29.2	7.670	73	50	pass	pass
11	12074	9/29/2004	9/30/2004	6.890	5.300	9.030	26.8	7.997	86	66	pass	pass
12	12074	5/3/2005	5/4/2005	9.186	7.030	13.330	23.6	8.477	108	83	pass	pass
13	12074	6/9/2005	6/10/2005	6.269	4.160	9.500	29.8	7.588	83	55	pass	pass
14	12074	7/13/2005	7/14/2005	4.820	3.320	6.740	30.5	7.492	64	44	pass	pass
15	12074	8/17/2005	8/18/2005	3.956	2.980	4.950	28.7	7.725	51	39	pass	pass
16	12074	9/20/2005	9/21/2005	3.264	1.800	4.480	29.2	7.662	43	23	exceed.	exceed.
17	12077	5/20/2003	5/21/2003	6.987	0.440	17.090	28.1	7.815	89	6	pass	exceed.
18	12077	6/17/2003	6/18/2003	6.159	3.990	11.660	28.9	7.704	80	52	pass	pass
19	12077	7/14/2003	7/15/2003	6.755	2.940	13.820	29.0	7.691	88	38	pass	exceed.
20	12077	8/11/2003	8/12/2003	6.861	2.340	17.010	28.4	7.773	88	30	pass	exceed.
21	12077	9/9/2003	9/10/2003	7.564	2.150	16.760	29.2	7.665	99	28	pass	exceed.
22	12077	3/23/2004	3/24/2004	9.694	4.130	17.990	20.5	9.002	108	46	pass	pass
23	12077	4/20/2004	4/21/2004	8.271	1.860	15.230	23.3	8.534	97	22	pass	exceed.
24	12077	5/27/2004	5/28/2004	8.259	2.540	15.430	28.3	7.782	106	33	pass	exceed.
25	12077	8/2/2004	8/3/2004	5.000	3.410	7.060	31.5	7.370	68	46	pass	pass
26	12077	8/30/2004	8/31/2004	7.399	3.500	12.970	30.5	7.500	99	47	pass	pass
27	12077	9/29/2004	9/30/2004	9.000	1.390	20.000	28.1	7.814	115	18	pass	exceed.
28	12077	5/3/2005	5/4/2005	7.770	1.960	15.550	24.2	8.380	93	23	pass	exceed.
29	12077	6/8/2005	6/9/2005	7.108	1.170	15.200	31.0	7.434	96	16	pass	exceed.
30	12077	7/13/2005	7/14/2005	5.375	0.860	16.070	31.1	7.418	72	12	pass	exceed.
31	12077	8/17/2005	8/18/2005	8.229	1.310	16.260	31.1	7.421	111	18	pass	exceed.

Table A-2 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	DOavg (mg/L)	DOmin (mg/L)	DOmax (mg/L)	Avg Temp (°C)	DO_Sat (mg/L)	DOavg_ %sat (%)	DOmin_ %sat (%)	DOavg_ Criteria	DOmin_ Criteria
32	12077	9/20/2005	9/21/2005	7.762	0.630	17.180	30.9	7.445	104	8	pass	exceed.
33	12079	5/19/2003	5/20/2003	7.239	5.970	8.940	30.2	7.532	96	79	pass	pass
34	12079	6/16/2003	6/17/2003	4.675	3.760	6.850	29.4	7.640	61	49	pass	pass
35	12079	7/14/2003	7/15/2003	6.220	4.890	9.090	30.6	7.481	83	65	pass	pass
36	12079	8/11/2003	8/12/2003	4.181	3.440	5.420	30.9	7.443	56	46	pass	pass
37	12079	9/9/2003	9/10/2003	5.174	3.640	6.640	28.9	7.705	67	47	pass	pass
38	12079	12/10/2003	12/11/2003	9.490	9.190	10.130	13.4	10.447	91	88	pass	pass
39	12079	1/13/2004	1/14/2004	9.303	9.100	9.520	13.4	10.452	89	87	pass	pass
40	12079	2/2/2004	2/3/2004	7.223	6.910	7.660	13.9	10.338	70	67	pass	pass
41	12079	3/23/2004	3/24/2004	5.620	5.310	6.210	21.3	8.866	63	60	pass	pass
42	12079	4/20/2004	4/21/2004	6.025	5.690	6.410	23.5	8.497	71	67	pass	pass
43	12079	5/27/2004	5/28/2004	5.402	4.690	6.250	28.8	7.717	70	61	pass	pass
44	12079	7/1/2004	7/2/2004	3.228	2.360	5.140	28.0	7.829	41	30	exceed.	exceed.
45	12079	8/2/2004	8/3/2004	4.686	3.150	6.850	32.4	7.262	65	43	pass	pass
46	12079	8/30/2004	8/31/2004	4.497	3.410	6.070	29.5	7.621	59	45	pass	pass
47	12079	5/3/2005	5/4/2005	7.516	6.860	8.970	23.1	8.566	88	80	pass	pass
48	12079	6/8/2005	6/9/2005	6.281	3.360	9.470	31.0	7.432	85	45	pass	pass
49	12079	7/13/2005	7/14/2005	4.696	2.860	7.070	31.4	7.385	64	39	pass	exceed.
50	12079	8/17/2005	8/18/2005	4.715	2.870	7.340	30.5	7.489	63	38	pass	exceed.
51	12079	9/20/2005	9/21/2005	5.426	4.110	6.540	31.5	7.366	74	56	pass	pass
52	12082	5/19/2003	5/20/2003	6.549	5.350	8.660	30.6	7.476	88	72	pass	pass
53	12082	6/16/2003	6/17/2003	4.373	3.410	6.140	29.2	7.660	57	45	pass	pass
54	12082	7/14/2003	7/15/2003	6.146	3.880	9.570	31.0	7.430	83	52	pass	pass
55	12082	8/11/2003	8/12/2003	3.556	2.480	6.460	30.8	7.456	48	33	exceed.	exceed.
56	12082	9/9/2003	9/10/2003	4.444	3.500	5.310	28.3	7.786	57	45	pass	pass
57	12082	12/10/2003	12/11/2003	9.601	9.030	10.230	13.2	10.497	91	86	pass	pass
58	12082	1/13/2004	1/14/2004	9.888	8.700	10.980	13.8	10.355	95	84	pass	pass
59	12082	2/2/2004	2/3/2004	6.718	6.510	6.980	13.8	10.344	65	63	pass	pass
60	12082	3/23/2004	3/24/2004	6.366	5.890	6.930	20.9	8.925	71	66	pass	pass
61	12082	4/20/2004	4/21/2004	5.600	5.310	5.990	24.0	8.423	66	63	pass	pass
62	12082	5/27/2004	5/28/2004	4.815	4.430	5.200	29.0	7.692	63	58	pass	pass
63	12082	7/1/2004	7/2/2004	2.419	1.880	3.290	28.0	7.827	31	24	exceed.	exceed.

Table A-2 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	DOavg (mg/L)	DOmin (mg/L)	DOmax (mg/L)	Avg Temp (°C)	DO_Sat (mg/L)	DOavg_ %sat (%)	DOmin_ %sat (%)	DOavg_ Criteria	DOmin_ Criteria
64	12082	8/2/2004	8/3/2004	3.504	2.100	5.000	32.3	7.272	48	29	exceed.	exceed.
65	12082	8/30/2004	8/31/2004	2.774	1.980	4.150	29.5	7.631	36	26	exceed.	exceed.
66	12082	5/3/2005	5/4/2005	6.670	5.850	7.670	23.2	8.538	78	69	pass	pass
67	12082	6/8/2005	6/9/2005	5.936	3.900	9.300	30.6	7.486	79	52	pass	pass
68	12082	7/13/2005	7/14/2005	5.810	3.890	8.240	31.4	7.380	79	53	pass	pass
69	12082	8/17/2005	8/18/2005	3.148	1.790	3.970	29.6	7.614	41	24	exceed.	exceed.
70	12082	9/20/2005	9/21/2005	7.317	4.790	10.660	31.7	7.339	100	65	pass	pass
71	12083	5/19/2003	5/20/2003	5.904	4.830	7.010	30.7	7.467	79	65	pass	pass
72	12083	6/16/2003	6/17/2003	4.109	3.390	4.630	28.7	7.733	53	44	pass	pass
73	12083	7/14/2003	7/15/2003	5.791	4.770	8.450	31.2	7.405	78	64	pass	pass
74	12083	8/11/2003	8/12/2003	3.453	2.890	4.140	30.2	7.533	46	38	exceed.	exceed.
75	12083	9/9/2003	9/10/2003	4.537	4.280	5.020	28.6	7.745	59	55	pass	pass
76	12083	12/10/2003	12/11/2003	9.161	8.960	9.670	13.0	10.539	87	85	pass	pass
77	12083	1/13/2004	1/14/2004	8.996	8.700	9.570	13.8	10.350	87	84	pass	pass
78	12083	2/2/2004	2/3/2004	6.303	6.020	6.760	14.4	10.220	62	59	pass	pass
79	12083	3/23/2004	3/24/2004	6.444	6.190	6.740	20.8	8.949	72	69	pass	pass
80	12083	4/20/2004	4/21/2004	5.777	5.510	6.050	23.8	8.450	68	65	pass	pass
81	12083	5/27/2004	5/28/2004	4.807	4.150	6.070	29.0	7.692	62	54	pass	pass
82	12083	7/1/2004	7/2/2004	1.757	1.230	2.380	28.1	7.813	22	16	exceed.	exceed.
83	12083	8/2/2004	8/3/2004	2.681	2.090	3.400	31.9	7.320	37	29	exceed.	exceed.
84	12083	8/30/2004	8/31/2004	1.831	1.350	2.190	28.7	7.733	24	17	exceed.	exceed.
85	12083	5/3/2005	5/4/2005	6.558	5.400	7.570	23.2	8.550	77	63	pass	pass
86	12083	6/8/2005	6/9/2005	4.181	2.400	5.320	31.1	7.421	56	32	pass	exceed.
87	12083	7/13/2005	7/14/2005	4.724	3.360	7.760	31.3	7.391	64	45	pass	pass
88	12083	8/17/2005	8/18/2005	3.282	2.980	4.060	29.7	7.594	43	39	exceed.	pass
89	12083	9/20/2005	9/21/2005	7.060	3.030	12.570	31.2	7.400	95	41	pass	pass
90	12086	2/10/2003	2/11/2003	8.624	8.180	9.290	11.5	10.912	79	75	pass	pass
91	12086	5/20/2003	5/21/2003	6.561	5.150	7.760	29.5	7.627	86	68	pass	pass
92	12086	6/17/2003	6/18/2003	4.958	4.700	5.670	29.4	7.635	65	62	pass	pass
93	12086	7/15/2003	7/16/2003	5.411	4.730	6.140	27.3	7.926	68	60	pass	pass
94	12086	8/11/2003	8/12/2003	4.243	3.960	4.790	29.7	7.598	56	52	pass	pass
95	12086	9/9/2003	9/10/2003	5.673	5.410	6.020	28.6	7.745	73	70	pass	pass

Table A-2 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	DOavg (mg/L)	DOmin (mg/L)	DOmax (mg/L)	Avg Temp (°C)	DO_Sat (mg/L)	DOavg_ %sat (%)	DOmin_ %sat (%)	DOavg_ Criteria	DOmin_ Criteria
96	12086	12/10/2003	12/11/2003	9.934	9.710	10.340	12.4	10.682	93	91	pass	pass
97	12086	1/13/2004	1/14/2004	9.357	9.140	9.750	13.8	10.361	90	88	pass	Pass
98	12086	2/2/2004	2/3/2004	6.154	6.020	6.450	14.6	10.180	60	59	pass	pass
99	12086	3/23/2004	3/24/2004	7.023	6.900	7.200	20.6	8.978	78	77	pass	pass
100	12086	4/20/2004	4/21/2004	6.366	6.270	6.470	23.2	8.545	74	73	pass	pass
101	12086	5/25/2004	5/26/2004	4.491	4.330	4.630	28.4	7.779	58	56	pass	pass
102	12086	7/1/2004	7/2/2004	2.505	2.420	2.580	28.3	7.787	32	31	exceed.	exceed.
103	12086	8/2/2004	8/3/2004	3.858	3.550	4.380	32.3	7.273	53	49	exceed.	pass
104	12086	8/30/2004	8/31/2004	3.477	2.780	3.950	29.2	7.665	45	36	exceed.	exceed.
105	12086	5/4/2005	5/5/2005	7.378	7.150	8.850	23.3	8.527	87	84	pass	pass
106	12086	6/8/2005	6/9/2005	4.441	4.180	4.640	30.7	7.469	59	56	pass	pass
107	12086	7/13/2005	7/14/2005	5.221	4.610	6.470	30.7	7.471	70	62	pass	pass
108	12086	8/17/2005	8/18/2005	3.871	3.700	3.980	29.0	7.688	50	48	exceed.	pass
109	12086	9/20/2005	9/21/2005	4.969	3.070	6.940	30.0	7.559	66	41	pass	pass
110	12087	2/10/2003	2/11/2003	9.805	8.800	10.590	12.7	10.606	92	83	pass	pass
111	12087	5/19/2003	5/20/2003	5.672	4.920	7.290	30.2	7.534	75	65	pass	pass
112	12087	6/16/2003	6/17/2003	4.639	4.190	5.340	28.6	7.742	60	54	pass	pass
113	12087	7/14/2003	7/15/2003	6.152	5.890	6.990	30.8	7.456	83	79	pass	pass
114	12087	8/11/2003	8/12/2003	4.642	4.050	5.480	29.9	7.572	61	53	pass	pass
115	12087	9/9/2003	9/10/2003	5.829	5.360	6.180	28.8	7.718	76	69	pass	pass
116	12087	3/23/2004	3/24/2004	7.490	7.340	7.710	20.6	8.978	83	82	pass	pass
117	12087	4/20/2004	4/21/2004	6.714	6.480	6.940	23.3	8.524	79	76	pass	pass
118	12087	5/25/2004	5/26/2004	4.962	4.640	5.230	28.3	7.785	64	60	pass	pass
119	12087	7/1/2004	7/2/2004	2.986	2.720	3.670	28.5	7.754	39	35	exceed.	exceed.
120	12087	8/2/2004	8/3/2004	4.639	3.920	5.380	32.6	7.227	64	54	pass	pass
121	12087	8/30/2004	8/31/2004	4.765	4.280	5.310	29.3	7.650	62	56	pass	pass
122	12087	5/3/2005	5/4/2005	7.506	6.950	7.950	22.7	8.629	87	81	pass	pass
123	12087	6/8/2005	6/9/2005	4.829	4.100	5.790	30.8	7.452	65	55	pass	pass
124	12087	7/14/2005	7/15/2005	4.972	3.420	6.050	30.2	7.534	66	45	pass	pass
125	12087	8/17/2005	8/18/2005	4.177	3.960	4.340	29.0	7.685	54	52	pass	pass
126	12087	9/20/2005	9/21/2005	8.646	6.820	10.310	30.5	7.491	115	91	pass	pass
127	12090	2/10/2003	2/11/2003	8.068	7.070	8.900	10.7	11.098	73	64	pass	pass

Table A-2 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	DOavg (mg/L)	DOmin (mg/L)	DOmax (mg/L)	Avg Temp (°C)	DO_Sat (mg/L)	DOavg_ %sat (%)	DOmin_ %sat (%)	DOavg_ Criteria	DOmin_ Criteria
128	12090	5/19/2003	5/20/2003	3.396	2.020	5.310	30.0	7.555	45	27	exceed.	exceed.
129	12090	6/16/2003	6/17/2003	3.913	3.000	4.780	28.1	7.812	50	38	exceed.	pass
130	12090	8/11/2003	8/12/2003	4.963	4.540	5.470	30.1	7.546	66	60	pass	pass
131	12090	9/9/2003	9/10/2003	5.622	5.320	5.950	29.0	7.691	73	69	pass	pass
132	12090	3/23/2004	3/24/2004	7.581	7.430	7.690	20.4	9.017	84	82	pass	pass
133	12090	4/20/2004	4/21/2004	6.773	6.550	7.010	22.5	8.664	78	76	pass	pass
134	12090	5/25/2004	5/26/2004	4.871	4.570	5.000	27.8	7.861	62	58	pass	pass
135	12090	7/1/2004	7/2/2004	3.193	2.810	3.830	28.7	7.736	41	36	exceed.	exceed.
136	12090	8/2/2004	8/3/2004	4.608	2.750	6.840	32.7	7.226	64	38	pass	exceed.
137	12090	8/30/2004	8/31/2004	5.415	5.200	5.700	29.7	7.605	71	68	pass	pass
138	12090	9/29/2004	9/30/2004	6.260	6.000	6.890	27.2	7.940	79	76	pass	pass
139	12090	5/3/2005	5/4/2005	7.946	6.860	9.020	22.8	8.615	92	80	pass	pass
140	12090	6/8/2005	6/9/2005	5.047	4.880	5.250	30.5	7.489	67	65	pass	pass
141	12090	7/13/2005	7/14/2005	3.414	1.280	5.590	31.0	7.425	46	17	exceed.	exceed.
142	12090	8/17/2005	8/18/2005	4.586	4.190	4.950	28.5	7.753	59	54	pass	pass
143	12090	9/20/2005	9/21/2005	3.449	1.670	5.730	30.5	7.494	46	22	exceed.	exceed.
	max			9.934	9.710	20.000	32.650	11.098	115	91		
	min			1.757	0.440	2.190	10.726	7.226	22	6		
	mean			5.744	4.360	7.675	26.762	8.083	70	53		
	std			1.856	2.043	3.494	5.518	0.936	19	20		

Table A-3 The 2003-2005 precipitations in 1, 2, 3, 4, 5, and 6 days prior to the day of DO measurement for Stations 12090, 12086, 12087, 12079, 12082, 12083, 12077 and 12074 of UOC

ID	Station	Deployment Start Date	Deployment End Date	1-day rain (mm)	2-day rain (mm)	3-day rain (mm)	4-day rain (mm)	5-day rain (mm)	6-day rain (mm)
1	12074	5/19/2003	5/20/2003	0.0	0.0	0.0	0.0	0.0	0.0
2	12074	6/17/2003	6/18/2003	2.5	12.4	18.8	21.6	24.9	24.9
3	12074	7/15/2003	7/16/2003	18.3	20.8	20.8	20.8	21.1	21.3
4	12074	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
5	12074	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5
6	12074	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
7	12074	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
8	12074	5/27/2004	5/28/2004	0.0	0.0	0.0	0.0	0.0	0.0
9	12074	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
10	12074	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
11	12074	9/29/2004	9/30/2004	0.0	0.0	0.0	0.0	9.7	9.7
12	12074	5/3/2005	5/4/2005	4.1	4.1	4.1	4.1	4.1	4.1
13	12074	6/9/2005	6/10/2005	0.0	0.0	0.0	0.0	0.0	0.0
14	12074	7/13/2005	7/14/2005	26.4	44.2	44.2	44.2	44.2	44.2
15	12074	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5
16	12074	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
17	12077	5/20/2003	5/21/2003	0.0	0.0	0.0	0.0	0.0	0.0
18	12077	6/17/2003	6/18/2003	2.5	12.4	18.8	21.6	24.9	24.9
19	12077	7/14/2003	7/15/2003	2.5	2.5	2.5	2.8	3.0	9.9
20	12077	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
21	12077	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5
22	12077	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
23	12077	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
24	12077	5/27/2004	5/28/2004	0.0	0.0	0.0	0.0	0.0	0.0
25	12077	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
26	12077	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
27	12077	9/29/2004	9/30/2004	0.0	0.0	0.0	0.0	9.7	9.7
28	12077	5/3/2005	5/4/2005	4.1	4.1	4.1	4.1	4.1	4.1
29	12077	6/8/2005	6/9/2005	0.0	0.0	0.0	0.0	0.0	0.0
30	12077	7/13/2005	7/14/2005	26.4	44.2	44.2	44.2	44.2	44.2
31	12077	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5

Table A-3 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	1-day rain (mm)	2-day rain (mm)	3-day rain (mm)	4-day rain (mm)	5-day rain (mm)	6-day rain (mm)
32	12077	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
33	12079	5/19/2003	5/20/2003	0.0	0.0	0.0	0.0	0.0	0.0
34	12079	6/16/2003	6/17/2003	9.9	16.3	19.1	22.4	22.4	22.4
35	12079	7/14/2003	7/15/2003	2.5	2.5	2.5	2.8	3.0	9.9
36	12079	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
37	12079	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5
38	12079	12/10/2003	12/11/2003	0.0	10.9	10.9	10.9	10.9	10.9
39	12079	1/13/2004	1/14/2004	0.3	0.3	0.3	0.3	0.3	16.8
40	12079	2/2/2004	2/3/2004	1.0	6.9	6.9	8.1	36.6	36.6
41	12079	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
42	12079	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
43	12079	5/27/2004	5/28/2004	0.0	0.0	0.0	0.0	0.0	0.0
44	12079	7/1/2004	7/2/2004	0.3	0.8	59.2	60.7	60.7	61.5
45	12079	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
46	12079	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
47	12079	5/3/2005	5/4/2005	4.1	4.1	4.1	4.1	4.1	4.1
48	12079	6/8/2005	6/9/2005	0.0	0.0	0.0	0.0	0.0	0.0
49	12079	7/13/2005	7/14/2005	26.4	44.2	44.2	44.2	44.2	44.2
50	12079	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5
51	12079	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
52	12082	5/19/2003	5/20/2003	0.0	0.0	0.0	0.0	0.0	0.0
53	12082	6/16/2003	6/17/2003	9.9	16.3	19.1	22.4	22.4	22.4
54	12082	7/14/2003	7/15/2003	2.5	2.5	2.5	2.8	3.0	9.9
55	12082	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
56	12082	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5
57	12082	12/10/2003	12/11/2003	0.0	10.9	10.9	10.9	10.9	10.9
58	12082	1/13/2004	1/14/2004	0.3	0.3	0.3	0.3	0.3	16.8
59	12082	2/2/2004	2/3/2004	1.0	6.9	6.9	8.1	36.6	36.6
60	12082	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
61	12082	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
62	12082	5/27/2004	5/28/2004	0.0	0.0	0.0	0.0	0.0	0.0
63	12082	7/1/2004	7/2/2004	0.3	0.8	59.2	60.7	60.7	61.5

Table A-3 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	1-day rain (mm)	2-day rain (mm)	3-day rain (mm)	4-day rain (mm)	5-day rain (mm)	6-day rain (mm)
64	12082	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
65	12082	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
66	12082	5/3/2005	5/4/2005	4.1	4.1	4.1	4.1	4.1	4.1
67	12082	6/8/2005	6/9/2005	0.0	0.0	0.0	0.0	0.0	0.0
68	12082	7/13/2005	7/14/2005	26.4	44.2	44.2	44.2	44.2	44.2
69	12082	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5
70	12082	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
71	12083	5/19/2003	5/20/2003	0.0	0.0	0.0	0.0	0.0	0.0
72	12083	6/16/2003	6/17/2003	9.9	16.3	19.1	22.4	22.4	22.4
73	12083	7/14/2003	7/15/2003	2.5	2.5	2.5	2.8	3.0	9.9
74	12083	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
75	12083	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5
76	12083	12/10/2003	12/11/2003	0.0	10.9	10.9	10.9	10.9	10.9
77	12083	1/13/2004	1/14/2004	0.3	0.3	0.3	0.3	0.3	16.8
78	12083	2/2/2004	2/3/2004	1.0	6.9	6.9	8.1	36.6	36.6
79	12083	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
80	12083	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
81	12083	5/27/2004	5/28/2004	0.0	0.0	0.0	0.0	0.0	0.0
82	12083	7/1/2004	7/2/2004	0.3	0.8	59.2	60.7	60.7	61.5
83	12083	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
84	12083	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
85	12083	5/3/2005	5/4/2005	4.1	4.1	4.1	4.1	4.1	4.1
86	12083	6/8/2005	6/9/2005	0.0	0.0	0.0	0.0	0.0	0.0
87	12083	7/13/2005	7/14/2005	26.4	44.2	44.2	44.2	44.2	44.2
88	12083	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5
89	12083	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
90	12086	2/10/2003	2/11/2003	0.0	8.6	9.7	9.7	23.9	23.9
91	12086	5/20/2003	5/21/2003	0.0	0.0	0.0	0.0	0.0	0.0
92	12086	6/17/2003	6/18/2003	2.5	12.4	18.8	21.6	24.9	24.9
93	12086	7/15/2003	7/16/2003	18.3	20.8	20.8	20.8	21.1	21.3
94	12086	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
95	12086	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5

Table A-3 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	1-day rain (mm)	2-day rain (mm)	3-day rain (mm)	4-day rain (mm)	5-day rain (mm)	6-day rain (mm)
96	12086	12/10/2003	12/11/2003	0.0	10.9	10.9	10.9	10.9	10.9
97	12086	1/13/2004	1/14/2004	0.3	0.3	0.3	0.3	0.3	16.8
98	12086	2/2/2004	2/3/2004	1.0	6.9	6.9	8.1	36.6	36.6
99	12086	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
100	12086	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
101	12086	5/25/2004	5/26/2004	0.0	0.0	0.0	0.0	0.0	0.0
102	12086	7/1/2004	7/2/2004	0.3	0.8	59.2	60.7	60.7	61.5
103	12086	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
104	12086	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
105	12086	5/4/2005	5/5/2005	0.0	4.1	4.1	4.1	4.1	4.1
106	12086	6/8/2005	6/9/2005	0.0	0.0	0.0	0.0	0.0	0.0
107	12086	7/13/2005	7/14/2005	26.4	44.2	44.2	44.2	44.2	44.2
108	12086	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5
109	12086	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
110	12087	2/10/2003	2/11/2003	0.0	8.6	9.7	9.7	23.9	23.9
111	12087	5/19/2003	5/20/2003	0.0	0.0	0.0	0.0	0.0	0.0
112	12087	6/16/2003	6/17/2003	9.9	16.3	19.1	22.4	22.4	22.4
113	12087	7/14/2003	7/15/2003	2.5	2.5	2.5	2.8	3.0	9.9
114	12087	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
115	12087	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5
116	12087	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
117	12087	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
118	12087	5/25/2004	5/26/2004	0.0	0.0	0.0	0.0	0.0	0.0
119	12087	7/1/2004	7/2/2004	0.3	0.8	59.2	60.7	60.7	61.5
120	12087	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
121	12087	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
122	12087	5/3/2005	5/4/2005	4.1	4.1	4.1	4.1	4.1	4.1
123	12087	6/8/2005	6/9/2005	0.0	0.0	0.0	0.0	0.0	0.0
124	12087	7/14/2005	7/15/2005	29.2	55.6	73.4	73.4	73.4	73.4
125	12087	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5
126	12087	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
127	12090	2/10/2003	2/11/2003	0.0	8.6	9.7	9.7	23.9	23.9

Table A-3 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	1-day rain (mm)	2-day rain (mm)	3-day rain (mm)	4-day rain (mm)	5-day rain (mm)	6-day rain (mm)
128	12090	5/19/2003	5/20/2003	0.0	0.0	0.0	0.0	0.0	0.0
129	12090	6/16/2003	6/17/2003	9.9	16.3	19.1	22.4	22.4	22.4
130	12090	8/11/2003	8/12/2003	3.3	25.1	25.6	28.7	28.7	28.7
131	12090	9/9/2003	9/10/2003	1.0	1.0	1.3	1.3	1.3	13.5
132	12090	3/23/2004	3/24/2004	0.0	0.0	3.3	3.3	3.3	3.3
133	12090	4/20/2004	4/21/2004	0.0	0.0	0.0	0.0	0.0	0.0
134	12090	5/25/2004	5/26/2004	0.0	0.0	0.0	0.0	0.0	0.0
135	12090	7/1/2004	7/2/2004	0.3	0.8	59.2	60.7	60.7	61.5
136	12090	8/2/2004	8/3/2004	8.9	22.9	22.9	22.9	23.6	58.7
137	12090	8/30/2004	8/31/2004	0.0	0.0	54.9	54.9	54.9	54.9
138	12090	9/29/2004	9/30/2004	0.0	0.0	0.0	0.0	9.7	9.7
139	12090	5/3/2005	5/4/2005	4.1	4.1	4.1	4.1	4.1	4.1
140	12090	6/8/2005	6/9/2005	0.0	0.0	0.0	0.0	0.0	0.0
141	12090	7/13/2005	7/14/2005	26.4	44.2	44.2	44.2	44.2	44.2
142	12090	8/17/2005	8/18/2005	0.0	1.5	3.0	5.5	5.5	5.5
143	12090	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0
	max			29.2	55.6	73.4	73.4	73.4	73.4
	min			0.0	0.0	0.0	0.0	0.0	0.0
	mean			3.2	7.5	13.7	14.3	15.8	19.1
	std			6.7	12.3	19.1	19.3	19.6	21.3

Table A-4 The 2003-2005 water pumping data in 1, 2, 3, 4, 5, and 6 days prior to the day of DO measurement for both Shannon Station and 2nd Lift Station

		Deployment Start Date	Deployment End Date	Water pumping at Shannon Station (acre-ft)						Water pumping at 2nd Lift Station (acre-ft)					
ID	**Station**			**1-day**	**2-day**	**3-day**	**4-day**	**5-day**	**6-day**	**1-day**	**2-day**	**3-day**	**4-day**	**5-day**	**6-day**
1	12074	5/19/2003	5/20/2003	401.1	802.2	1124.4	1336.2	1548.0	1759.8	190.0	380.0	538.3	728.3	870.8	1060.8
2	12074	6/17/2003	6/18/2003	136.6	348.4	516.8	711.1	990.4	1326.9	256.0	512.0	768.0	1024.0	1280.0	1536.0
3	12074	7/15/2003	7/16/2003	0.0	61.8	273.6	485.4	681.0	853.0	174.2	364.2	554.2	744.2	934.2	1124.2
4	12074	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
5	12074	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0
6	12074	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
7	12074	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
8	12074	5/27/2004	5/28/2004	211.8	429.4	647.0	868.4	1099.1	1334.7	190.0	380.0	570.0	760.0	950.0	1140.0
9	12074	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
10	12074	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
11	12074	9/29/2004	9/30/2004	207.3	414.6	621.9	829.2	1036.5	1248.3	190.0	380.0	570.0	760.0	950.0	1140.0
12	12074	5/3/2005	5/4/2005	366.8	660.6	850.4	1062.3	1274.2	1486.1	245.0	435.0	625.0	815.0	1005.0	1195.0
13	12074	6/9/2005	6/10/2005	0.0	204.4	507.1	714.4	921.7	1129.0	190.0	380.0	570.0	760.0	950.0	1140.0
14	12074	7/13/2005	7/14/2005	77.8	207.4	414.9	622.2	829.5	1122.7	190.0	380.0	570.0	760.0	950.0	1140.0
15	12074	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1
16	12074	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
17	12077	5/20/2003	5/21/2003	276.5	677.6	1078.7	1400.9	1612.7	1824.5	239.5	429.5	619.5	777.8	967.8	1110.3
18	12077	6/17/2003	6/18/2003	136.6	348.4	516.8	711.1	990.4	1326.9	256.0	512.0	768.0	1024.0	1280.0	1536.0
19	12077	7/14/2003	7/15/2003	61.8	273.6	485.4	681.0	853.0	1029.3	190.0	380.0	570.0	760.0	950.0	1140.0
20	12077	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
21	12077	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0
22	12077	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
23	12077	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
24	12077	5/27/2004	5/28/2004	211.8	429.4	647.0	868.4	1099.1	1334.7	190.0	380.0	570.0	760.0	950.0	1140.0
25	12077	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
26	12077	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
27	12077	9/29/2004	9/30/2004	207.3	414.6	621.9	829.2	1036.5	1248.3	190.0	380.0	570.0	760.0	950.0	1140.0
28	12077	5/3/2005	5/4/2005	366.8	660.6	850.4	1062.3	1274.2	1486.1	245.0	435.0	625.0	815.0	1005.0	1195.0
29	12077	6/8/2005	6/9/2005	204.4	507.1	714.4	921.7	1129.0	1336.3	190.0	380.0	570.0	760.0	950.0	1140.0
30	12077	7/13/2005	7/14/2005	77.8	207.4	414.9	622.2	829.5	1122.7	190.0	380.0	570.0	760.0	950.0	1140.0
31	12077	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1

Table A-4 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	Water pumping at Shannon Station (acre-ft)						Water pumping at 2nd Lift Station (acre-ft)					
				1-day	2-day	3-day	4-day	5-day	6-day	1-day	2-day	3-day	4-day	5-day	6-day
32	12077	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
33	12079	5/19/2003	5/20/2003	401.1	802.2	1124.4	1336.2	1548.0	1759.8	190.0	380.0	538.3	728.3	870.8	1060.8
34	12079	6/16/2003	6/17/2003	211.8	380.2	574.5	853.8	1190.3	1457.8	256.0	512.0	768.0	1024.0	1280.0	1536.0
35	12079	7/14/2003	7/15/2003	61.8	273.6	485.4	681.0	853.0	1029.3	190.0	380.0	570.0	760.0	950.0	1140.0
36	12079	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
37	12079	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0
38	12079	12/10/2003	12/11/2003	207.3	414.6	621.9	829.2	1036.5	1243.8	190.0	380.0	570.0	760.0	950.0	1140.0
39	12079	1/13/2004	1/14/2004	207.3	414.6	621.9	815.9	987.9	1071.8	190.0	380.0	570.0	760.0	950.0	1140.0
40	12079	2/2/2004	2/3/2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	12079	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
42	12079	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
43	12079	5/27/2004	5/28/2004	211.8	429.4	647.0	868.4	1099.1	1334.7	190.0	380.0	570.0	760.0	950.0	1140.0
44	12079	7/1/2004	7/2/2004	0.0	0.0	0.0	0.0	0.0	0.0	190.0	380.0	570.0	752.1	878.7	910.4
45	12079	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
46	12079	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
47	12079	5/3/2005	5/4/2005	366.8	660.6	850.4	1062.3	1274.2	1486.1	245.0	435.0	625.0	815.0	1005.0	1195.0
48	12079	6/8/2005	6/9/2005	204.4	507.1	714.4	921.7	1129.0	1336.3	190.0	380.0	570.0	760.0	950.0	1140.0
49	12079	7/13/2005	7/14/2005	77.8	207.4	414.9	622.2	829.5	1122.7	190.0	380.0	570.0	760.0	950.0	1140.0
50	12079	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1
51	12079	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
52	12082	5/19/2003	5/20/2003	401.1	802.2	1124.4	1336.2	1548.0	1759.8	190.0	380.0	538.3	728.3	870.8	1060.8
53	12082	6/16/2003	6/17/2003	211.8	380.2	574.5	853.8	1190.3	1457.8	256.0	512.0	768.0	1024.0	1280.0	1536.0
54	12082	7/14/2003	7/15/2003	61.8	273.6	485.4	681.0	853.0	1029.3	190.0	380.0	570.0	760.0	950.0	1140.0
55	12082	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
56	12082	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0
57	12082	12/10/2003	12/11/2003	207.3	414.6	621.9	829.2	1036.5	1243.8	190.0	380.0	570.0	760.0	950.0	1140.0
58	12082	1/13/2004	1/14/2004	207.3	414.6	621.9	815.9	987.9	1071.8	190.0	380.0	570.0	760.0	950.0	1140.0
59	12082	2/2/2004	2/3/2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	12082	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
61	12082	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
62	12082	5/27/2004	5/28/2004	211.8	429.4	647.0	868.4	1099.1	1334.7	190.0	380.0	570.0	760.0	950.0	1140.0
63	12082	7/1/2004	7/2/2004	0.0	0.0	0.0	0.0	0.0	0.0	190.0	380.0	570.0	752.1	878.7	910.4

Table A-4 (cont.)

ID	Station	Deployment Start Date	Deployment End Date	Water pumping at Shannon Station (acre-ft)						Water pumping at 2nd Lift Station (acre-ft)					
				1-day	2-day	3-day	4-day	5-day	6-day	1-day	2-day	3-day	4-day	5-day	6-day
64	12082	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
65	12082	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
66	12082	5/3/2005	5/4/2005	366.8	660.6	850.4	1062.3	1274.2	1486.1	245.0	435.0	625.0	815.0	1005.0	1195.0
67	12082	6/8/2005	6/9/2005	204.4	507.1	714.4	921.7	1129.0	1336.3	190.0	380.0	570.0	760.0	950.0	1140.0
68	12082	7/13/2005	7/14/2005	77.8	207.4	414.9	622.2	829.5	1122.7	190.0	380.0	570.0	760.0	950.0	1140.0
69	12082	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1
70	12082	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
71	12083	5/19/2003	5/20/2003	401.1	802.2	1124.4	1336.2	1548.0	1759.8	190.0	380.0	538.3	728.3	870.8	1060.8
72	12083	6/16/2003	6/17/2003	211.8	380.2	574.5	853.8	1190.3	1457.8	256.0	512.0	768.0	1024.0	1280.0	1536.0
73	12083	7/14/2003	7/15/2003	61.8	273.6	485.4	681.0	853.0	1029.3	190.0	380.0	570.0	760.0	950.0	1140.0
74	12083	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
75	12083	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0
76	12083	12/10/2003	12/11/2003	207.3	414.6	621.9	829.2	1036.5	1243.8	190.0	380.0	570.0	760.0	950.0	1140.0
77	12083	1/13/2004	1/14/2004	207.3	414.6	621.9	815.9	987.9	1071.8	190.0	380.0	570.0	760.0	950.0	1140.0
78	12083	2/2/2004	2/3/2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
79	12083	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
80	12083	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
81	12083	5/27/2004	5/28/2004	211.8	429.4	647.0	868.4	1099.1	1334.7	190.0	380.0	570.0	760.0	950.0	1140.0
82	12083	7/1/2004	7/2/2004	0.0	0.0	0.0	0.0	0.0	0.0	190.0	380.0	570.0	752.1	878.7	910.4
83	12083	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
84	12083	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
85	12083	5/3/2005	5/4/2005	366.8	660.6	850.4	1062.3	1274.2	1486.1	245.0	435.0	625.0	815.0	1005.0	1195.0
86	12083	6/8/2005	6/9/2005	204.4	507.1	714.4	921.7	1129.0	1336.3	190.0	380.0	570.0	760.0	950.0	1140.0
87	12083	7/13/2005	7/14/2005	77.8	207.4	414.9	622.2	829.5	1122.7	190.0	380.0	570.0	760.0	950.0	1140.0
88	12083	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1
89	12083	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
90	12086	2/10/2003	2/11/2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.7	79.2	142.5	221.7
91	12086	5/20/2003	5/21/2003	276.5	677.6	1078.7	1400.9	1612.7	1824.5	239.5	429.5	619.5	777.8	967.8	1110.3
92	12086	6/17/2003	6/18/2003	136.6	348.4	516.8	711.1	990.4	1326.9	256.0	512.0	768.0	1024.0	1280.0	1536.0
93	12086	7/15/2003	7/16/2003	0.0	61.8	273.6	485.4	681.0	853.0	174.2	364.2	554.2	744.2	934.2	1124.2
94	12086	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
95	12086	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0

Table A-4 (cont.)

				Water pumping at Shannon Station (acre-ft)						Water pumping at 2nd Lift Station (acre-ft)					
ID	**Station**	**Deployment Start Date**	**Deployment End Date**	**1-day**	**2-day**	**3-day**	**4-day**	**5-day**	**6-day**	**1-day**	**2-day**	**3-day**	**4-day**	**5-day**	**6-day**
96	12086	12/10/2003	12/11/2003	207.3	414.6	621.9	829.2	1036.5	1243.8	190.0	380.0	570.0	760.0	950.0	1140.0
97	12086	1/13/2004	1/14/2004	207.3	414.6	621.9	815.9	987.9	1071.8	190.0	380.0	570.0	760.0	950.0	1140.0
98	12086	2/2/2004	2/3/2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99	12086	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
100	12086	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
101	12086	5/25/2004	5/26/2004	217.6	439.0	669.7	905.3	1145.7	1298.9	190.0	380.0	570.0	760.0	950.0	1140.0
102	12086	7/1/2004	7/2/2004	0.0	0.0	0.0	0.0	0.0	0.0	190.0	380.0	570.0	752.1	878.7	910.4
103	12086	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
104	12086	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
105	12086	5/4/2005	5/5/2005	361.2	728.0	1021.8	1211.6	1423.5	1635.4	284.2	529.2	719.2	909.2	1099.2	1289.2
106	12086	6/8/2005	6/9/2005	204.4	507.1	714.4	921.7	1129.0	1336.3	190.0	380.0	570.0	760.0	950.0	1140.0
107	12086	7/13/2005	7/14/2005	77.8	207.4	414.9	622.2	829.5	1122.7	190.0	380.0	570.0	760.0	950.0	1140.0
108	12086	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1
109	12086	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
110	12087	2/10/2003	2/11/2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.7	79.2	142.5	221.7
111	12087	5/19/2003	5/20/2003	401.1	802.2	1124.4	1336.2	1548.0	1759.8	190.0	380.0	538.3	728.3	870.8	1060.8
112	12087	6/16/2003	6/17/2003	211.8	380.2	574.5	853.8	1190.3	1457.8	256.0	512.0	768.0	1024.0	1280.0	1536.0
113	12087	7/14/2003	7/15/2003	61.8	273.6	485.4	681.0	853.0	1029.3	190.0	380.0	570.0	760.0	950.0	1140.0
114	12087	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
115	12087	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0
116	12087	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
117	12087	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
118	12087	5/25/2004	5/26/2004	217.6	439.0	669.7	905.3	1145.7	1298.9	190.0	380.0	570.0	760.0	950.0	1140.0
119	12087	7/1/2004	7/2/2004	0.0	0.0	0.0	0.0	0.0	0.0	190.0	380.0	570.0	752.1	878.7	910.4
120	12087	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
121	12087	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
122	12087	5/3/2005	5/4/2005	366.8	660.6	850.4	1062.3	1274.2	1486.1	245.0	435.0	625.0	815.0	1005.0	1195.0
123	12087	6/8/2005	6/9/2005	204.4	507.1	714.4	921.7	1129.0	1336.3	190.0	380.0	570.0	760.0	950.0	1140.0
124	12087	7/14/2005	7/15/2005	56.2	134.0	263.6	471.1	678.4	885.7	190.0	380.0	570.0	760.0	950.0	1140.0
125	12087	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1
126	12087	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5

Table A-4 (cont.)

		Deployment Start Date	Deployment End Date	Water pumping at Shannon Station (acre-ft)						Water pumping at 2nd Lift Station (acre-ft)					
ID	**Station**			**1-day**	**2-day**	**3-day**	**4-day**	**5-day**	**6-day**	**1-day**	**2-day**	**3-day**	**4-day**	**5-day**	**6-day**
127	12090	2/10/2003	2/11/2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.7	79.2	142.5	221.7
128	12090	5/19/2003	5/20/2003	401.1	802.2	1124.4	1336.2	1548.0	1759.8	190.0	380.0	538.3	728.3	870.8	1060.8
129	12090	6/16/2003	6/17/2003	211.8	380.2	574.5	853.8	1190.3	1457.8	256.0	512.0	768.0	1024.0	1280.0	1536.0
130	12090	8/11/2003	8/12/2003	207.3	414.6	621.9	816.2	1028.0	1239.8	190.0	314.2	438.4	628.4	786.7	944.7
131	12090	9/9/2003	9/10/2003	207.3	414.6	617.5	829.3	1032.3	1244.1	190.0	380.0	570.0	760.0	950.0	1140.0
132	12090	3/23/2004	3/24/2004	189.6	401.4	596.6	761.4	933.4	1101.2	190.0	348.3	538.3	728.3	918.3	1108.3
133	12090	4/20/2004	4/21/2004	211.4	422.9	634.3	851.9	1055.9	1155.6	190.0	380.0	570.0	760.0	950.0	1140.0
134	12090	5/25/2004	5/26/2004	217.6	439.0	669.7	905.3	1145.7	1298.9	190.0	380.0	570.0	760.0	950.0	1140.0
135	12090	7/1/2004	7/2/2004	0.0	0.0	0.0	0.0	0.0	0.0	190.0	380.0	570.0	752.1	878.7	910.4
136	12090	8/2/2004	8/3/2004	280.7	527.1	776.4	1068.0	1474.8	1881.6	245.3	501.3	757.3	1013.3	1252.8	1442.8
137	12090	8/30/2004	8/31/2004	333.5	554.7	628.5	831.1	1048.7	1327.4	284.2	568.4	852.6	1136.8	1421.0	1705.2
138	12090	9/29/2004	9/30/2004	207.3	414.6	621.9	829.2	1036.5	1248.3	190.0	380.0	570.0	760.0	950.0	1140.0
139	12090	5/3/2005	5/4/2005	366.8	660.6	850.4	1062.3	1274.2	1486.1	245.0	435.0	625.0	815.0	1005.0	1195.0
140	12090	6/8/2005	6/9/2005	204.4	507.1	714.4	921.7	1129.0	1336.3	190.0	380.0	570.0	760.0	950.0	1140.0
141	12090	7/13/2005	7/14/2005	77.8	207.4	414.9	622.2	829.5	1122.7	190.0	380.0	570.0	760.0	950.0	1140.0
142	12090	8/17/2005	8/18/2005	221.4	442.8	683.2	948.0	1212.8	1438.8	190.0	380.0	570.0	760.0	942.1	1132.1
143	12090	9/20/2005	9/21/2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
	max			401.1	802.2	1124.4	1400.9	1612.7	1881.6	284.2	568.4	852.6	1136.8	1421.0	1705.2
	min			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	mean			188.1	382.8	563.0	749.7	945.1	1134.8	185.9	363.6	542.0	724.9	901.2	1075.4
	std			114.2	208.1	280.9	353.9	437.1	522.2	70.5	139.4	207.1	272.6	337.3	393.1

APPENDIX B

Correlation Coefficients Among Nutrients, TSS, and Chlorophyll-a

Correlation coefficients among nutrients, TSS and chlorophyll-a

12090	NH3	PO4-P	Total-P	TKN	TSS	Chla	
	0.39	0.31	-0.03	-0.17	-0.01	-0.12	NO2+NO3
		0.34	0.00	-0.08	-0.27	-0.60	NH3
			0.45	0.31	0.11	-0.45	PO4-P
				0.50	0.60	-0.30	Total-P
					0.26	0.02	TKN
						-0.11	TSS
12086.12087	0.38	0.20	0.18	0.18	0.26	-0.12	NO2+NO3
		0.65	0.67	0.12	-0.15	-0.44	NH3
			0.72	0.04	-0.43	-0.14	PO4-P
				0.43	-0.06	-0.34	Total-P
					0.58	-0.10	TKN
						-0.24	TSS
12079.12082.12083	0.45	-0.14	0.10	0.22	0.17	-0.22	NO2+NO3
		0.56	0.47	0.40	0.04	-0.44	NH3
			0.50	0.11	-0.07	-0.29	PO4-P
				0.27	-0.03	-0.34	Total-P
					0.49	-0.05	TKN
						0.07	TSS
Upper Reach	0.39	0.02	0.10	0.14	0.16	-0.14	NO2+NO3
		0.49	0.42	0.24	-0.05	-0.44	NH3
			0.56	0.00	-0.30	-0.25	PO4-P
				0.35	0.18	-0.31	Total-P
					0.39	-0.02	TKN
						-0.03	TSS
12077	0.49	0.15	0.26	0.19	0.31	0.05	NO2+NO3
		0.21	0.28	0.21	0.70	0.06	NH3
			0.53	0.49	0.09	0.39	PO4-P
				0.42	0.45	0.11	Total-P
					0.25	0.49	TKN
						0.07	TSS
12074	-0.15	0.15	0.13	0.22	-0.24	0.65	NO2+NO3
		0.13	0.11	0.59	-0.12	-0.49	NH3
			0.96	-0.27	-0.69	-0.22	PO4-P
				-0.18	-0.77	-0.17	Total-P
					0.13	0.12	TKN
						-0.02	TSS

APPENDIX C

Lower Reach WLA by Individual WWTF

Table C-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 C-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 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.