Investigation into the Occurrences of Low Dissolved Oxygen in Johnson Lake Jack County, Texas

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INVESTIGATION INTO THE OCCURRENCES OF LOW DISSOLVED OXYGEN IN JOHNSON LAKE JACK COUNTY, TEXAS

Prepared by:

PBS&J
6504 Bridge Point Parkway
Suite 200
Austin, Texas 78730

Prepared for:

Trinity River Authority of Texas
Clean Rivers Program
5300 South Collins
P.O. Box 60
Arlington, Texas 76004

STATE OF TEXAS
PAUL A. JENSEN
48917
REGISTERED
PROFESSIONAL ENGINEER

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Acronyms and Abbreviations

ac-ft/yr	acre feet per year
$CBOD_5$	Carbonaceous Biochemical Oxygen Demand
DO	dissolved oxygen
gpm	gallons per minute
km	kilometers
LCC	Little Cleveland Creek
mg/L	milligrams per liter
MGD	million gallons per day
NH_3-N	Ammonia-Nitrogen
QAPP	Quality Assurance Project Plan
TCEQ	Texas Commission on Environmental Quality
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
WWTP	wastewater treatment plant

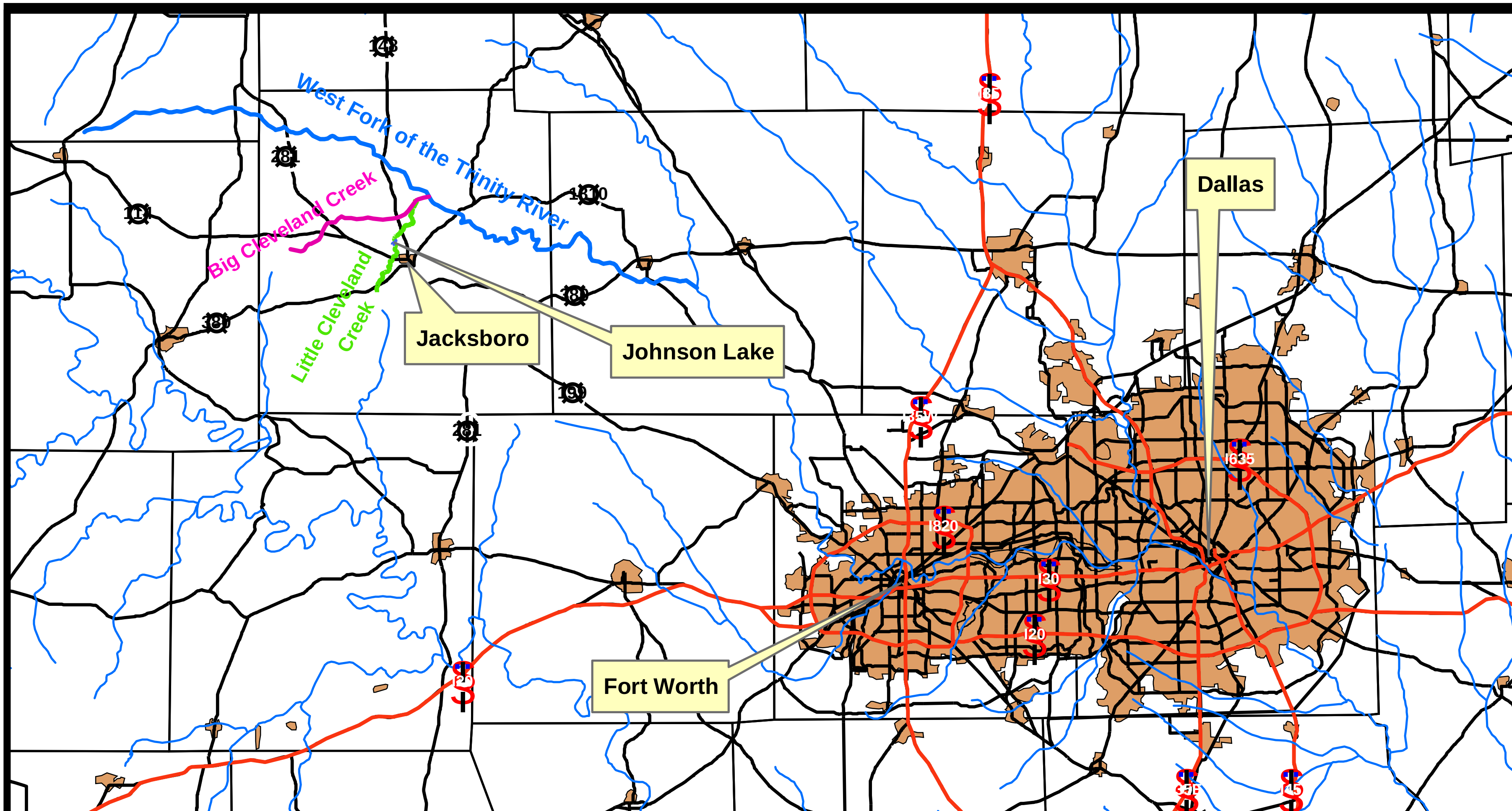
1.0 INTRODUCTION AND OVERVIEW

The City of Jacksboro collects and treats domestic wastewater from the community. Their present wastewater treatment plant (WWTP) was permitted (Permit #10944) in 1998. Because of a complex series of legal and regulatory events, the permit expired in 2000 and, under current Texas Commission on Environmental Quality (TCEQ) procedures, cannot be renewed. This document presents an approach to untangle the situation that will allow the permit to be renewed.

Figure 1-1 shows the overall area. The City of Jacksboro is located northwest of Fort Worth and the discharge from the WWTP eventually goes to the West Fork of the Trinity River, segment 0812. Figure 1-2 shows an aerial view of the study area in more detail, taken in 1996 before the new WWTP was constructed. The new plant was built to the east of the lagoons, which are now empty. Wastewater is discharged into Little Cleveland Creek (LCC), an intermittent stream, at the location shown. Just downstream from the WWTP discharge point is a permitted diversion from LCC (Certificate of Adjudication 08-3313). The diversion (200 acre feet per year [ac-ft/yr]) is permitted by the TCEQ for irrigation use at a golf course located about 1.2 miles to the east. The maximum authorized diversion rate is 1,200 gallons per minute (gpm), considerably larger than the wastewater discharge flow. LCC continues for approximately 2 kilometers (km) before it enters a flood control reservoir, Johnson Lake. It then flows into Cleveland Creek and on to segment 0812.

The reach between the WWTP and Johnson Lake is the focus of this study. The primary land use in the watershed is cattle grazing, with some hay cultivation. Along the creek the soil is sandy which limits runoff when rains occur.

This report includes a discussion and background on the wastewater permit issue presented in Section 2.0. The field work, including an intensive survey conducted as part of the project is described in Section 3.0. This section also references a summary of data obtained in prior studies. Section 4.0 describes a lake elevation model of Johnson Lake, and how this fits with the QUAL-TX model of the stream. It includes both a calibration and long-term simulation of lake levels. Calibration of the QUAL-TX model of the stream is described in Section 5, along with application to the system, considering the results of the lake level model. Alternatives are presented that appear to meet the requirements for the TCEQ to issue a new permit for the facility. Section 6.0 summarizes the findings and presents a proposal for a broader solution to the underlying problem.



Legend

- Interstate Highways
- State Highways
- Urban Areas
- Counties

0 5 10 20 30 40 Miles

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Austin, Texas 78730
Phone: (512) 329-8342 Fax: (512) 327-2453

Fig. 1-1
Location of Study Area

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0 0.2 0.4 0.8 1.2 Miles

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Fig. 1-2

Study Area

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2.0 BACKGROUND ON CITY OF JACKSBORO WASTEWATER PERMIT

This section reviews the background of the wastewater permit issue and concludes with a status discussion and a brief description of the approach taken to resolve the issue.

The City of Jacksboro has operated a WWTP at this location since 1950. Initially the plant employed an Imhoff tank and a series of ponds for treatment. Through a series of modifications over the years, these served the City until the early 1990s when a combination of operational problems and increasing environmental expectations led the City to begin planning a new WWTP. During the permit application review process for the new plant, the City coordinated with the predecessor agency (TNRCC) and decided to design and build a new advanced secondary WWTP. The City requested that their permitted monthly average flow be increased from 0.65 Million Gallons per Day (MGD) to 0.7 MGD. In October, 1994, the TNRCC modeling staff reviewing their permit application recommended permit limits of 10/3/4 ($CBOD_5$/Ammonia-N/Dissolved Oxygen [DO]).

When the new draft permit was published, a downstream landowner whose land includes the lower part of LCC and Johnson Lake, protested the permit and asked for an evidentiary hearing on the merits. After the hearing the Commission determined that the proposed permit limits were appropriate and issued the permit.

This did not resolve the matter. In summer 1997 the downstream landowners took their case to State District Court. The court affirmed the Commission’s decision to issue the permit. In January 1998 the City requested a minor amendment to relocate the outfall a short distance. This was evaluated by TNRCC modeling staff and 10/3/4 permit limits were again recommended. The permit was subsequently approved by the Commission. In August of 1998 a motion for reconsideration of the minor amendment was made by the landowner and overruled by the Commission.

In October 1998 the City of Jacksboro commenced discharge from their new WWTP. Where the old plant had been having trouble meeting a 30 mg/L BOD limit, the new plant performed better than the new lower permit limits. For example, November 2003 is a typical month that had an average flow of .243 MGD. For that month the average $CBOD_5$ was 2.5 mg/L while the permit limit is 10 mg/L. The NH_3-N averaged 0.203 mg/L relative to a permit limit of 3 mg/L. The effluent DO level also exceeded the permit minimum by a substantial margin.

In fall 1998 the new plant was operating and producing a good quality effluent, but the issue was still not resolved. In response to low DO issues at the mouth of the creek raised during the hearing process, the TNRCC staff constructed a new model of Little Cleveland Creek and a portion of Johnson Reservoir using data provided by consultants representing the downstream landowner. The new TNRCC model predicted that NO effluent set could be recommended that would attain water quality criteria for dissolved oxygen selected for the lower, impounded portion of the creek.

This new development posed significant problems. In November and December 1998, TNRCC staff met with City representatives and representatives of the downstream landowner to discuss results from the revised model. The City provided comments on the TNRCC model and proposed to gather more information on water quality downstream from their plant. A general study plan was submitted.

Between February 1999 and April 2000, The City of Jacksboro collected periodic DO measurements at various locations downstream of its WWTP. The data indicated relatively persistent depressed DO in the upper end of Johnson Reservoir.

In 2000 the City filed an application to renew their permit. Normal procedure at the agency for each new or renewed wastewater discharge permit is to have the water quality modeling staff determine that applicable water quality criteria in the receiving stream will be attained if the permit is issued with the proposed effluent limits. In September 2000 the renewal application was reviewed by TNRCC modeling staff using the new model. As before, the model indicated that no effluent set could be recommended that would attain the dissolved oxygen criteria used in the lower, impounded portion of the creek. With that result, commission rules do not allow it to issue a renewed permit. The renewal of the permit is now frozen, and the City continues to operate the plant under their 1998 permit. This is still the situation in July 2005.

A meeting was held in Jacksboro in March 2003 involving representatives of the TCEQ and City of Jacksboro. At the meeting the history of the problem was reviewed and several alternatives were discussed including piping the effluent directly to or past the lake, avoiding the Gordian model knots. The commission staff indicated a willingness to enlist the Clean Rivers Program if a special study were needed to resolve the issues.

Following the meeting PBS&J staff met several times with commission modeling staff to formulate a plan. The modeling staff indicated that perhaps the biggest problem was the arm of Johnson Lake that was included in the new modeled portion of Little Cleveland Creek. The default DO criterion for the lake is 5 mg/L, but the model and available field data show much lower levels in the portion of the creek that is impounded in the lake. Staff indicated that if this 5 DO criterion problem could not be solved, there was essentially no hope of getting the model to show criteria attainment under any wastewater discharge scenario, including zero discharge.

Another piece of background information on the system is the water rights permit held by the Jacksboro Country Club. The Certificate of Adjudication 08-3313 authorizes up to 200 ac-ft of sewage effluent per year from the City of Jacksboro to be diverted for irrigation use on a nearby golf course. The maximum diversion rate allowed is 2.67 cubic feet per second (cfs) (1,200 gpm). During dry periods in the summer, the authorized diversion rate (1.72 MGD) is much larger than the entire wastewater flow (typically 0.3

MGD). The actual maximum diversion rate is lower than the authorized rate, but it is still capable of taking essentially all of the wastewater flow from the LCC.

At this point there appears to be a reasonable approximation to the "perfect regulatory storm" arising from the unfortunate combination of the following elements:

- **Relatively low DO levels in the LCC**. These exist because LCC is now a shaded and low gradient stream similar to those of east Texas, where DO levels are often low while still supporting a diverse aquatic life community. This is not a natural condition in the Jacksboro area, but rather one that is created by the discharge of relatively high quality effluent into a low-gradient stream that is further slowed by beaver dams and the lake backwater. The existence of natural low DO levels in east Texas streams while still supporting good aquatic life uses is a long-standing regulatory (standards) problem.

- **Problems in addressing water diversions**. This is sometimes a problem in defining what is a critical condition for a wastewater permit. The critical condition is usually one where the upstream flow and available dilution is at a minimum. That really isn't an issue here since the upstream flow is zero almost all of the time. However, if the full diversion were considered, as would likely be the case in hot, dry, conditions normally used for wastewater permit analysis, there would not be a criteria attainment concern in LCC (the creek would be dry), but there still might be in the arm of the lake. The effect of the diversion is also significant for the lake level analysis.

- **Lake arm criteria attainment problems**. This regulatory problem is widespread in Texas. It derives from there not being a suitable and clear definition for the boundary between areas where different DO criteria apply. In this case it is the boundary between application of DO criteria intended for open lakes and for tributary streams. Applying a criterion intended for an open lake to a shaded and quiescent arm or backwater of a lake frequently results in non-attainment.

- **Effect of evidentiary hearings**. A hearing is an adversarial process that sometimes results in new information and issues. In this case the lake arm issue was not a factor in the normal permit processing even though many discharges eventually flow into lake arms or backwater areas. But once the issue was introduced by the opposition in the hearing process, it had to be considered.

The unfortunate combination of these elements makes it difficult to resolve the permit issue. While DO levels in the LCC above the lake, the area where the permit analysis was originally performed, appear to be satisfactory, and the evidentiary hearing is no longer a concern (the current landowners have expressed no interest in further legal challenges and have cooperated in this study), decisions made in the hearing environment cannot be reversed without a technically valid reason.

This study develops a technical basis to resolve the issue. It is done through a combination of data collection, model calibration, analysis of lake levels associated with low flow conditions, and modeling using QUAL-TX. A proposal to resolve the lake arm issue is also discussed.

3.0 FIELD DATA COLLECTION

Field data are essential for water quality studies. One creek water quality survey was conducted in 1996 by consultants working for the downstream landowner, and the City conducted weekly DO and temperature monitoring during the 1999–2000 period. Copies of these data are included in Attachment A.

This section describes new field work conducted in support of the overall analysis. It includes data on the level variation of Johnson Lake and another set of water quality data in LCC under steady, low-flow conditions. The field work described here was defined in advance with a TCEQ-approved Quality Assurance Project Plan (QAPP).

3.1 LAKE LEVEL MONITORING

By summer 2004 a plan had been developed for the work, and one major component would be getting a better understanding of how the lake level varied. To do this a water level recording device (Global Water WL15 water level logger) was installed along the dam of Johnson Lake. The probe was set in PVC conduit down to a depth of roughly 12 feet, the bottom of the lake. Figure 3-1 is a plot of the record produced by the probe, along with the local rainfall records.

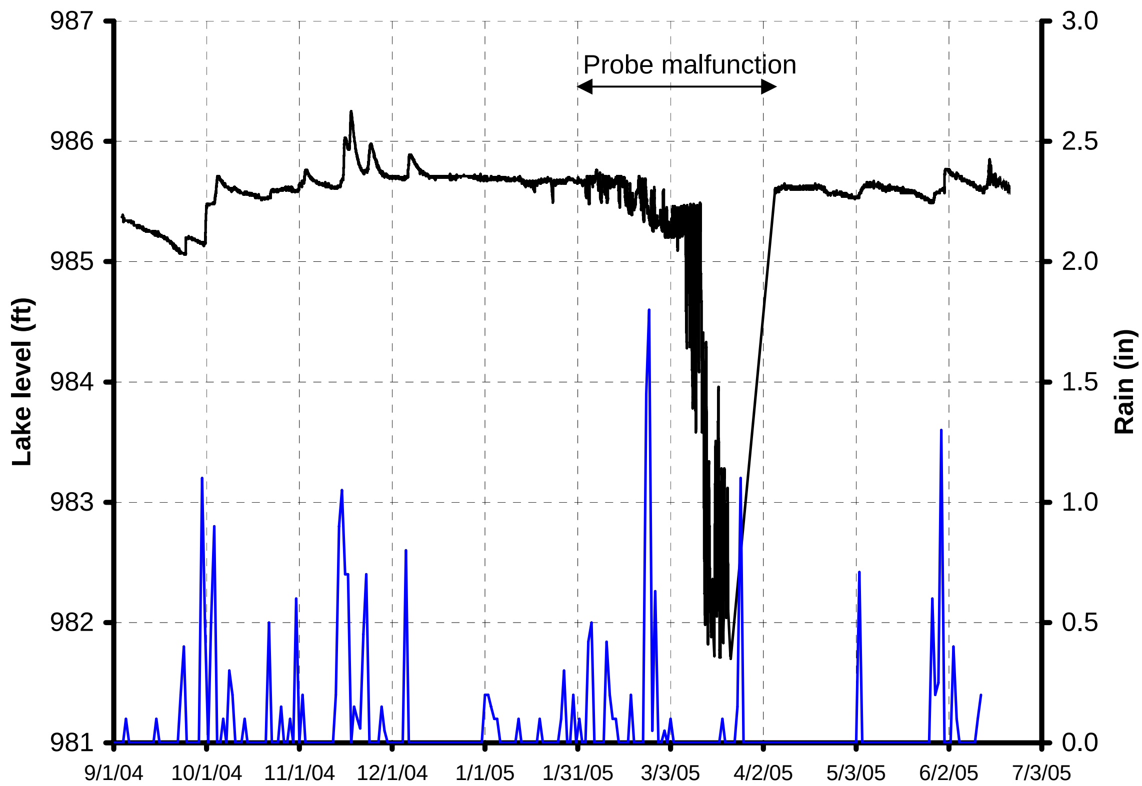
The period from February 1 to April 1 contained erroneous data produced by a bad battery in the unit. When the problem was discovered and corrected, normal elevation recording resumed.

From the figure it is clear that the reservoir elevation rises following local rains and declines in dry periods. If there were a dry period of any length, it most likely would have dropped further. The goal of this monitoring was to obtain data on the rate at which the water level rises and falls in response to local rains and dry periods that can be used to calibrate a model of the reservoir. Unfortunately, there were only short periods of dry weather in the available time for the study, so the record does not include much variation in water level. The use of these data in the lake model is described in Section 4.0.

3.2 INTENSIVE SURVEY, JUNE 13–15, 2005

This section describes the data collection efforts to support water quality modeling. QUAL-TX is the numerical model used by TCEQ for stream DO modeling and the setting of wastewater permit limits. It is a steady-state, 1-dimensional model that represents the major water quality variables and processes in a stream. As with all general numerical models, rates and coefficients need to be selected to represent the specific processes in the stream under consideration. This is done through the calibration process. In that process the model rates and coefficients are adjusted so that the model matches field data that are collected to represent an average, steady condition. The calibration process requires stream data that are collected under steady conditions, averaged over a 24-hour period. The TCEQ has evolved a procedure known as an Intensive Survey (IS) specifically to obtain the needed data for QUAL-TX calibration.

FIGURE 3-1
JOHNSON LAKE LEVEL AND LOCAL RAINFALL RECORD



The IS requires collecting data from each station at least four times over a 24-hour period. For probe observations (DO, temperature, conductivity, pH) the values are recorded and averaged. For water chemistry samples (in this case: $CBOD_5$, Total Kjeldahl Nitrogen (TKN), Ammonia-N, Nitrate-Nitrite-N, Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS), and Chlorophyll *a*) composite water samples are prepared by taking a sample late in the afternoon of the first day and adding three additional samples over the course of the next day. The end result is a set of composite samples for each station collected over a 24-hour period. These composite samples can be analyzed to yield average values that the model needs for each station.

Stations for the IS were defined in the QAPP (TRA 2004). Figure 3-2 shows the locations and a brief description of the stations.

3.2.1 Data Collection

The PBS&J and Trinity River Authority (TRA) crew traveled to the area on June 13 and performed a site reconnaissance on the morning of June 14. During the site reconnaissance, measurements of the channel width, depth, and velocity were made using a portable measuring rod laid across the stream, and a top-setting depth rod with a Marsh-McBirney Model 200 magnetic current meter attached. The process of doing station measurements is shown in figures 3-3 and 3-4. Table 3-1 presents the dimensions, velocities and calculated flows.

Table 3-1. Flow, Average Depth, and Velocity

Station	Time of measurement	Stream Km	Depth (m)	Velocity (m/s)	Q (m^3/s)
Outfall	6/14/2005 9:00	3.02	0.074	0.239	0.0117
6A	6/14/2005 9:30	2.81	0.071	0.062	0.0043
5	6/14/2005 9:40	2.24	0.089	0.094	0.0077
5B	6/14/2005 10:00	1.81	0.021	0.057	0.0030
4	6/14/2005 11:30	1.5	0.177	0.014	0.0052
3A	6/14/2005 11:15	1.13	0.136	0.073	0.0151

Later in the morning the sampling boat was launched into Johnson Lake to access stations at the lower end of the creek and the lake. Figure 3-5 shows the lake and sampling boat, with the picture taken from the dam near the location of the water level logger. During June 14 and 15 a number of trips around the lake were made with the depth indicator in operation. Figure 3-6 is a summary of approximate lake depths obtained from these observations.

Stations were selected in the open lake near the point where LCC entered (station 1) and as far up LCC as it was possible to go by boat (station 2). Making the trip to station 2, past or through numerous fallen trees, was a boat-handling challenge.

Legend

Sampling Station

0 500 1,000 2,000 3,000 4,000 Feet

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Fig. 3-2

Locations of Sampling Stations

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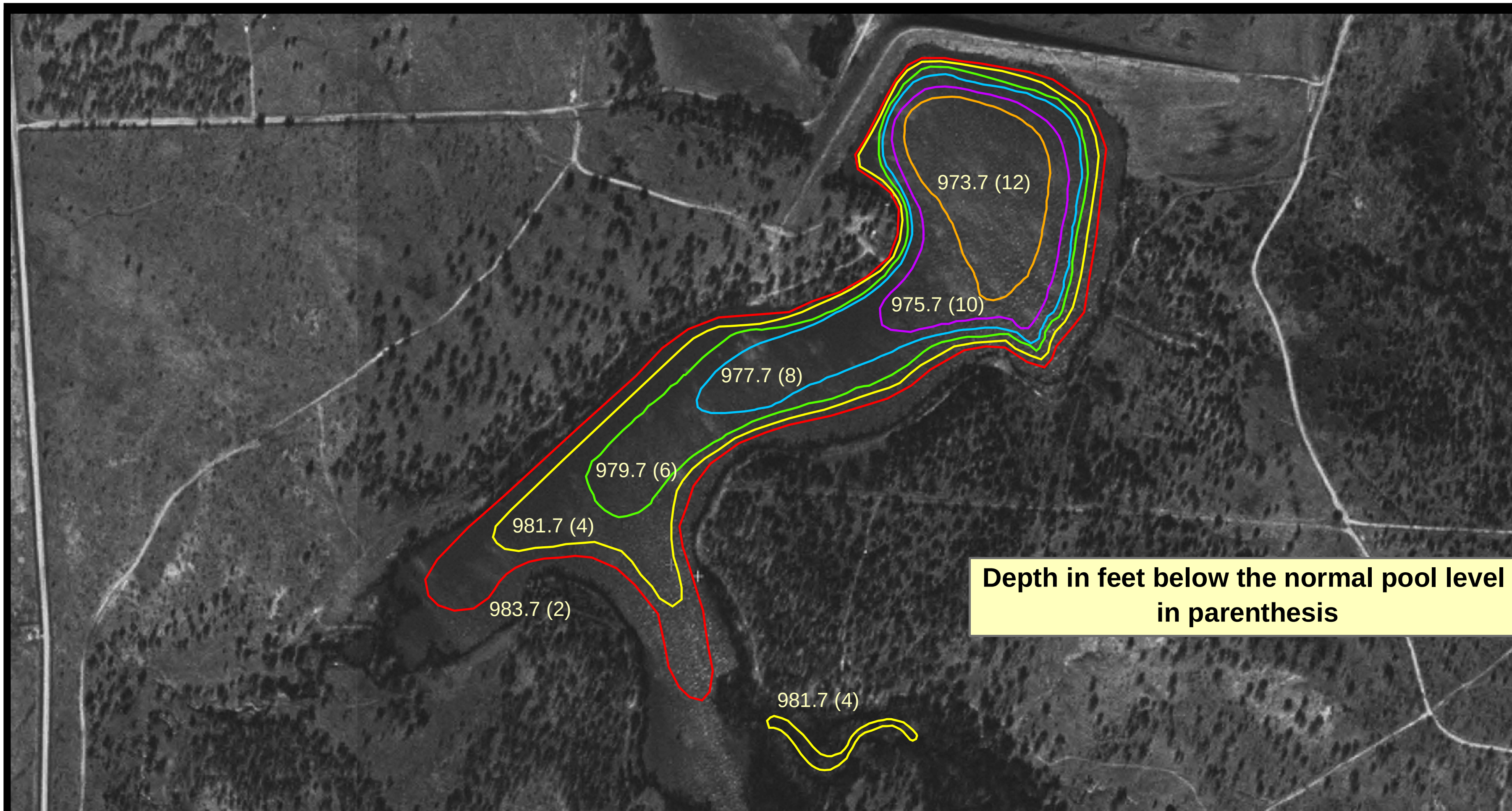
Figure 3-3. Stream flow measurements

Figure 3-4. Width and depth measurements at station 6A, below concrete dam

Figure 3-5, View of Johnson Lake from dam, facing southwest

The first set of observations was taken late in the afternoon of June 14. The water samples, that constituted one-fourth of the samples to be analyzed, were placed on ice for the evening. Figure 3-7 and 3-8 show the process of taking probe readings in the stream during the day. Figure 3-9 shows a beaver dam near station 5B.

Two datasondes, one from TRA and the other from PBS&J, were deployed to provide readings during the evening. One was deployed at station 1 in Johnson Lake and the other at station 6A, just downstream of the concrete dam (station 6). The probe at station 1, where the water in the lake was approximately 2 feet deep, was attached to a metal fence pole hammered into the lake bottom. This is shown in Figure 3-10.



Contours in feet

0 200 400 800 1,200 1,600
Feet

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Fig. 3-6
Johnson Lake Depth Contours

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The probe just downstream of station 6 was placed in the flowing streambed and secured with line to a tree.

Table 3-2 presents the average data obtained from each of the stations. The chemical parameters are values from composite samples while the probe parameters are the arithmetic averages of the probe readings. Figure 3-11 shows the DO data obtained at stations 6 and 1 during the 24-hour period, with the datasonde readings in the evenings included. Figure 3-12 plots the chemical and probe data plotted longitudinally along LCC.

Figure 3-7. Probe reading at station 6

Figure 3-8. Probe reading at station 5

Figure 3-9. Beaver dam at station 5B

Figure 3-10. Overnight deployment of sonde at station 1

3.2.2 Discussion of Data

As can be seen from Table 3-2 and Figure 3-12, the DO data are relatively constant until the lower part of the system. At station 2, which is shaded and covered with duckweed, the DO level is very low. Another interesting feature of the water at this station was its clarity. Below the duckweed, which typically is not a permanent feature, there was extensive submerged aquatic vegetation and the water was very clear. A

TABLE 3-2
SUMMARY OF INTENSIVE SURVEY DATA

Station	Stream Km	Temperature (deg C)	Conductivity (umhos/cm)	pH (SU)	DO (mg/L)	CBOD5 (mg/L)	Chlorophyll *a* (ug/L)	NH_3-N (mg/L)	NO_3+NO_2-N (mg/L)	TKN (mg/L)	TSS (mg/L)	VSS (mg/L)
6	2.84	26.3	624	7.1	2.77	3	1.3	1.11	1.09	3	12	6
6A	2.81	25.9	639	7.3	3.63							
5	2.24	25.6	639	7.3	3.94	1.5	3.2	2.97	1.93	4	7	<2
5A	1.96	24.3	639	7.3	3.81							
5B	1.81	24.6	635	7.4	4.17							
4	1.5	24.7	629	7.4	4.51	1.5	4.1	0.57	3.87	2	15	2
3A	1.13	24.4	617	7.4	4.58							
3	0.76	24.4	618	7.4	3.08	2	3.1	<0.02	3.84	1.4	4	<2
2	0.22	24.3	656	7.0	0.71	2	6.2	0.05	11.8	<0.2	9	7
1	-0.1	28.1	549	8.9	12.43	6	85	<0.02	2.98	2.1	44	31

Notes:
1. Values of probe parameters (temp, cond, pH, DO) are averages of 4 measurements, except that at Stations 5A and 6A values are averages of 3 and 2 measurements respectively.
2. Values of chemical parameters are from composite samples.

FIGURE 3-11
DISSOLVED OXYGEN DATA AT STATIONS 1 AND 6A

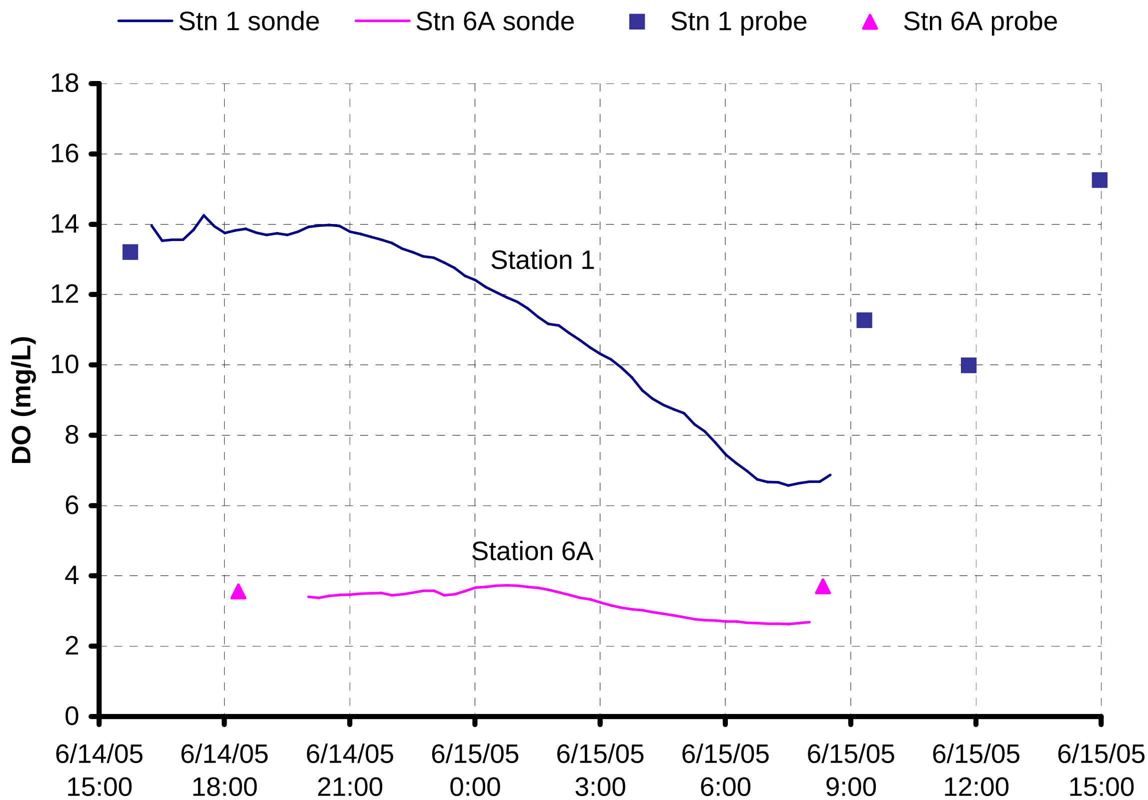
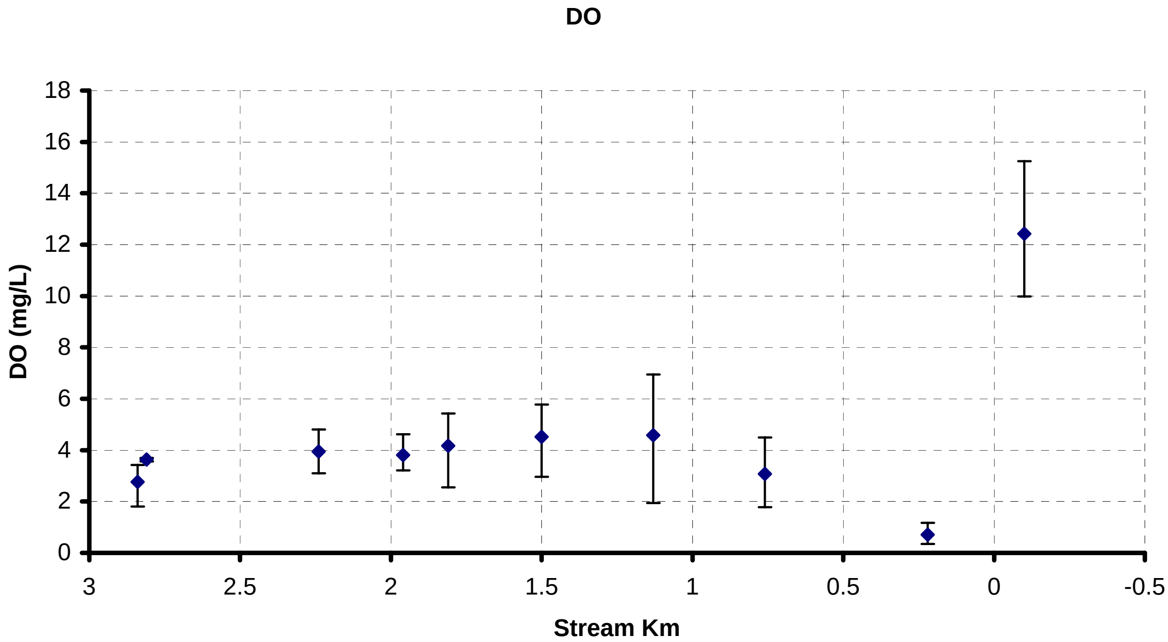


FIGURE 3-12
LONGITUDINAL PROFILES OF PROBE AND CHEMICAL DATA



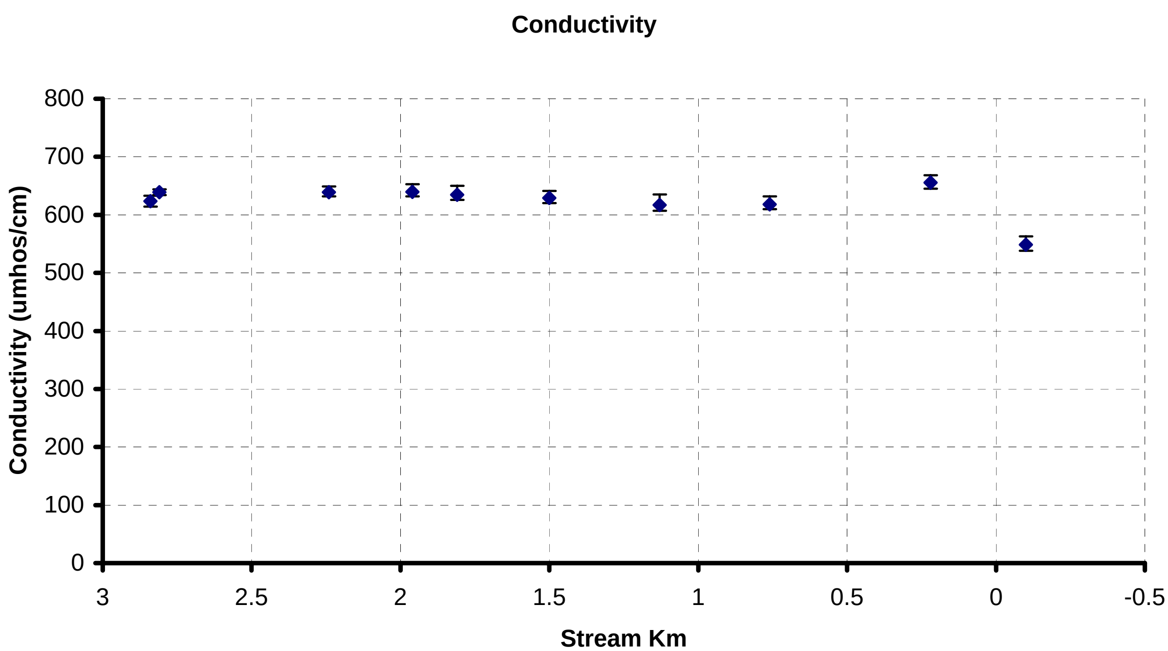
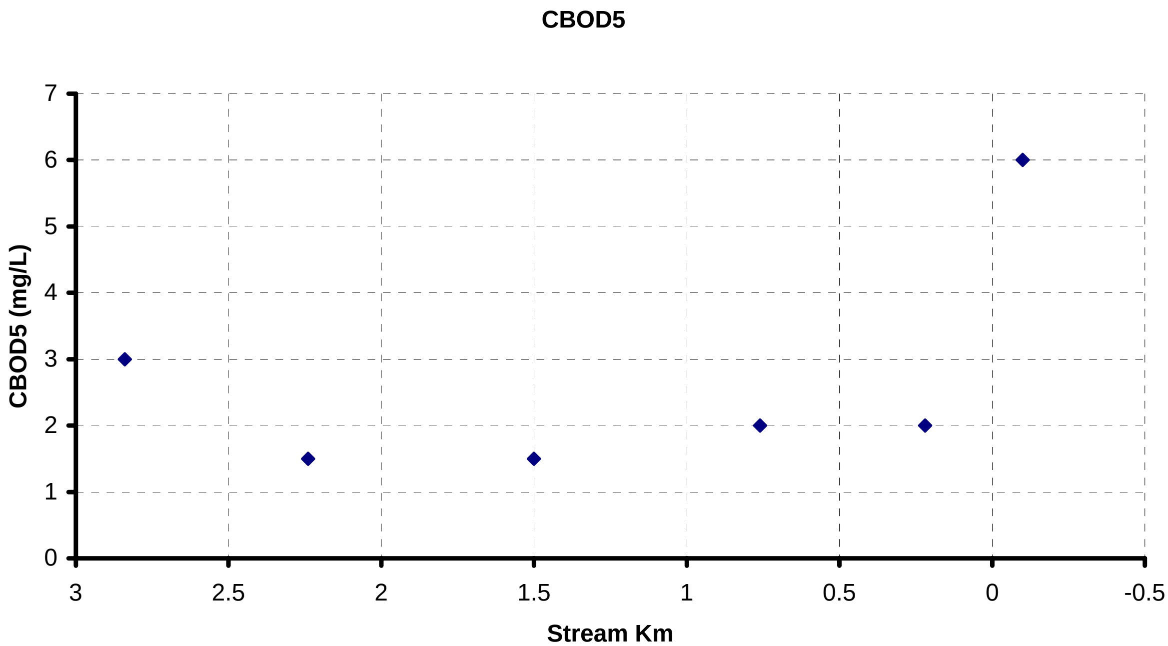


FIGURE 3-12 (cont'd)
LONGITUDINAL PROFILES OF PROBE AND CHEMICAL DATA



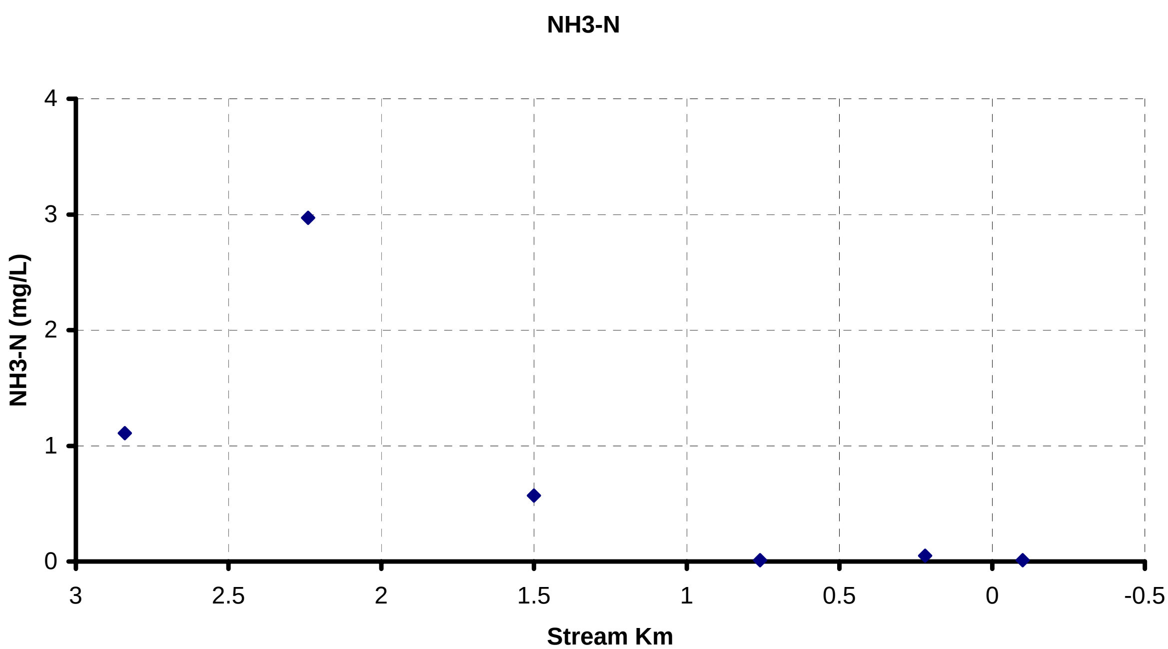
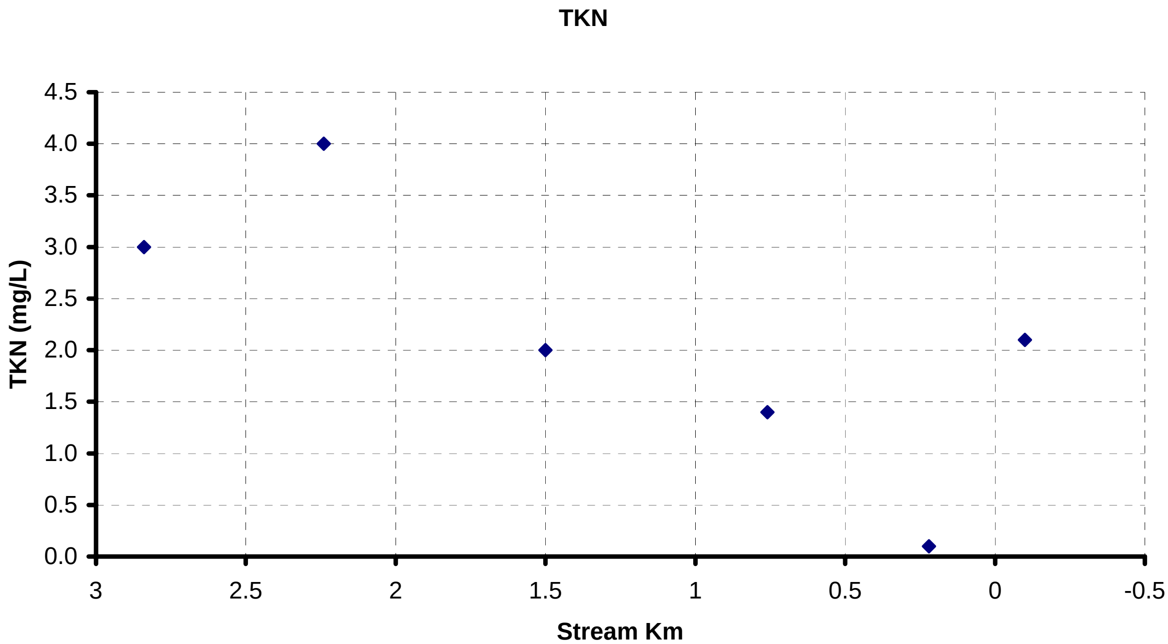


FIGURE 3-12 (cont'd)
LONGITUDINAL PROFILES OF PROBE AND CHEMICAL DATA



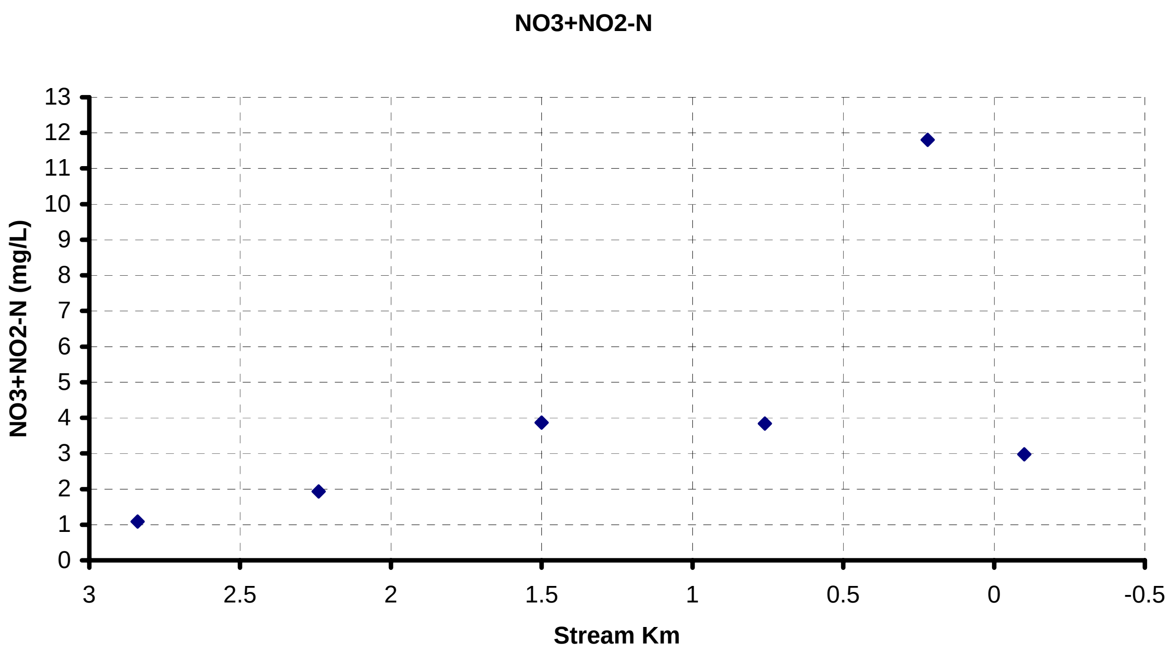
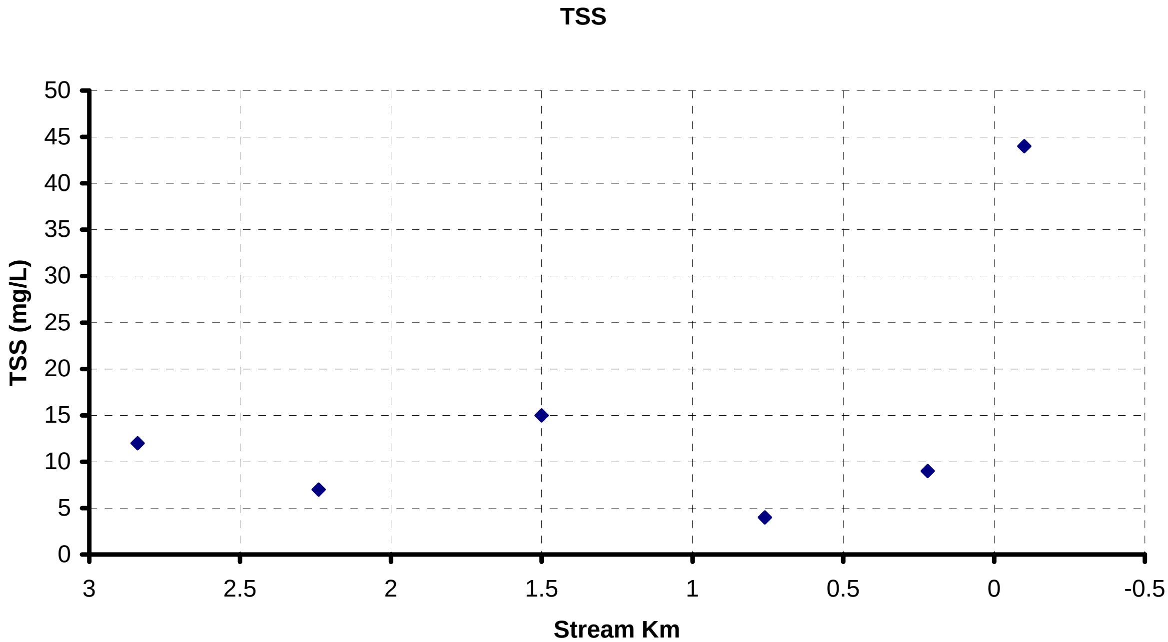


FIGURE 3-12 (cont'd)
LONGITUDINAL PROFILES OF PROBE AND CHEMICAL DATA



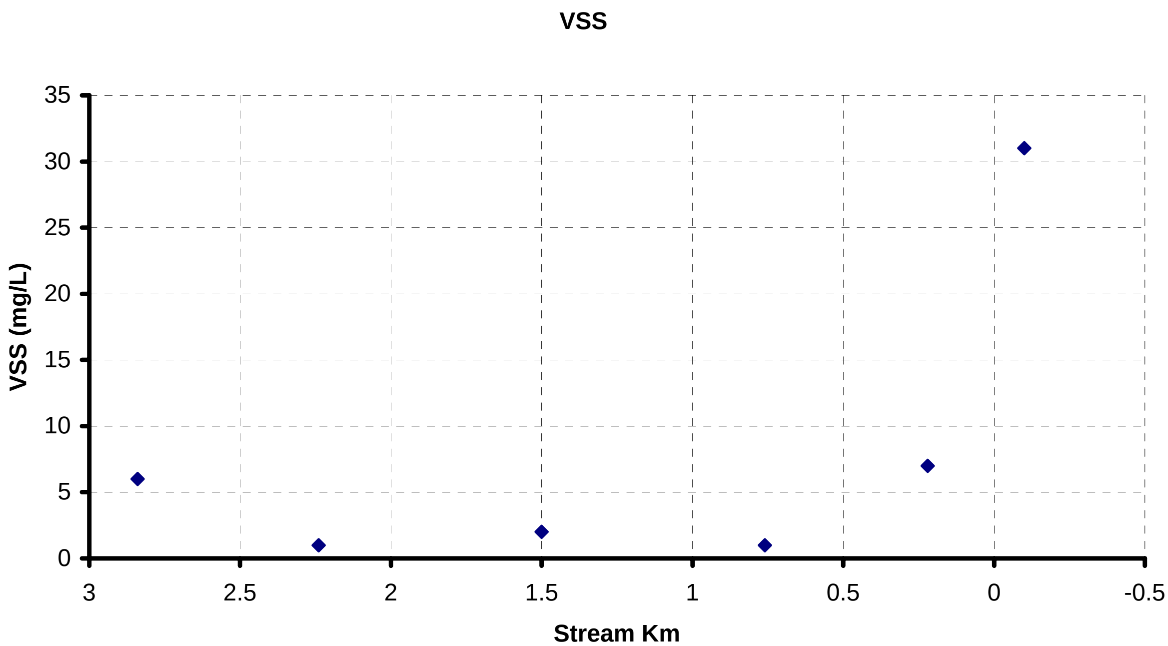
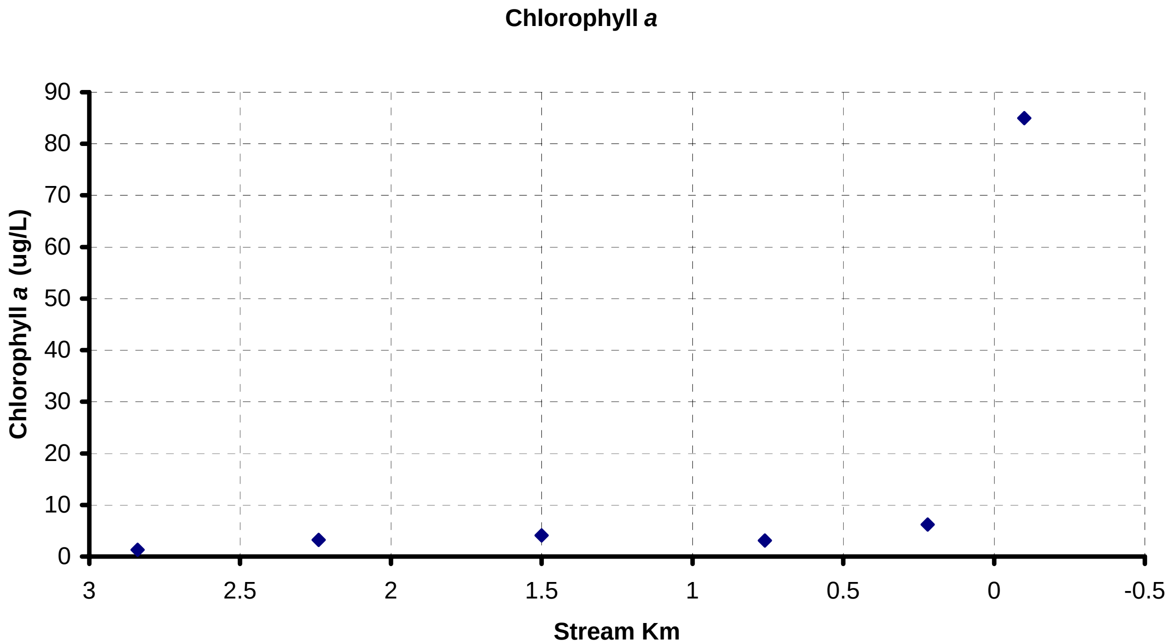


FIGURE 3-12 (cont'd)
LONGITUDINAL PROFILES OF PROBE AND CHEMICAL DATA



likely explanation for the low DO level at this station is respiration by the submerged plants with little opportunity of photosynthesis. Moving out to the lake (station 1), the DO level is quite elevated. This appears to be a response to the available sunlight, adequate nutrients, and high chlorophyll *a* concentrations.

$CBOD_5$ data are low throughout the system, except for station 1 in the lake. At that point the $CBOD_5$ data are somewhat elevated, probably due to the high chlorophyll *a* concentration at that station.

Ammonia-N concentrations are low throughout the system, except for station 5 in the upper reach of the stream. This station is a cattle crossing and watering location, and cattle were observed at this station during the sampling. It is possible that cattle could contribute to the ammonia-N concentration at this station. The TKN values appeared to track reasonably well with the ammonia-N concentration, as is often the case. TKN includes both ammonia-N and organic N, but not oxidized forms such as nitrate or nitrite-N.

Nitrate-N levels were relatively low near the discharge and increased slightly with distance downstream. The relatively low concentrations in the upper LCC, that is nearly pure wastewater, combined with a high concentration near station 2, in the impounded area of the creek, is hard to explain. A possible explanation or theory is that the small rain on the evening before the start of sampling may have inserted enough water into the creek to replace the volume behind the concrete dam, and send that water with its elevated nitrate-N levels downstream where it might have been measured at station 2. With that theory one would expect there to be a reduction in conductivity at station 6 where wastewater is replaced by runoff. However, there is no indication that this theory is supported by conductivity observations. The observed pattern for nitrate-N concentrations may have to remain a mystery.

The TSS and VSS data are low throughout the system. At station 1, in the open lake, there are very high chlorophyll *a* levels and the TSS-VSS data are also elevated. The relatively high proportion of the TSS represented by VSS at this station is consistent with high chlorophyll *a* levels.

4.0 JOHNSON LAKE WATER LEVEL SIMULATION

This section presents an analysis of water level variations in Johnson Lake in response to various inflows and outflows. The goal of the analysis is to be able to characterize the frequency distribution of Johnson Lake water levels.

A Microsoft Excel spreadsheet model was developed to simulate the system. The simulation is essentially a water balance calculation that accounts for inflow, outflow, and change in storage. The inflows include runoff and the wastewater treatment plant effluent minus the diversion for golf course irrigation. Outflow from the lake occurs when the water level is above the riser or drain structure, the top of which is at 985.7 feet. Figure 4-1 shows this structure. When the water level is above 1,000.7 feet, water will discharge through the 250-foot-wide spillway in addition to through the riser. In the simulation, direct precipitation on the lake, evaporation and seepage are also taken into account.

Figure 4-1. Top of riser

This section describes the data compilation of the data for the model, calibration of the model with the level records described in the previous section, and a long-term simulation. The results of the long-term simulation are then used to develop the frequency distribution of the water level of Johnson Lake. The calibration provided an estimate of the seepage rate of the reservoir. The calibration was also intended to provide estimates of coefficients in a runoff model. However, as explained below, this part of the calibration turned out to be unsatisfactory. In the long-term simulation, the flow record of a gage in a nearby watershed was used.

4.1 DATA COMPILATION

4.1.1 Precipitation Data

For calibration of the model, 15-minute precipitation data at Jacksboro (Cooperative Station ID# 414517) were downloaded from the National Climatic Data Center (NCDC 2005). At the time of this study, the data were only available up to January 2005 and there are also some missing data in the record. Therefore, the data were supplemented with rain data recorded at the water treatment plant (WTP). The WTP rain data are measured daily. The daily data were disaggregated into 15-minute data by assuming a series of 0.1-inch data spaced 1 hour apart and centered at noon.

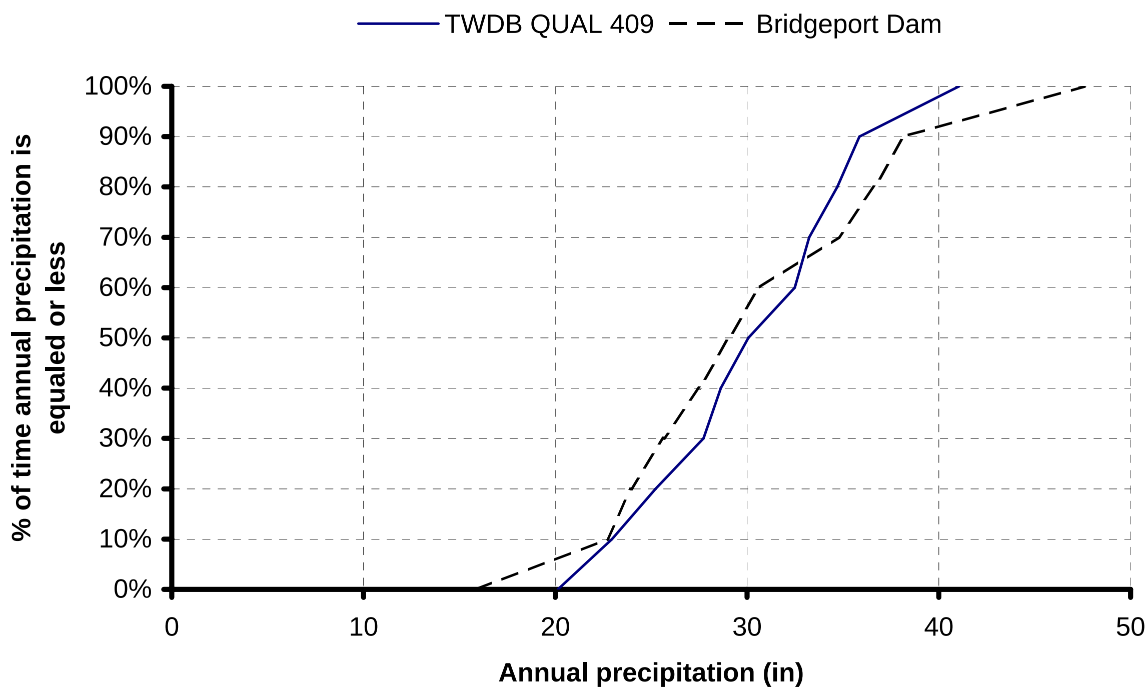
For the long-term simulation, one of the challenges was obtaining a good set of precipitation data. The Jacksboro Coop Station (#414517) does not have 15-minute or hourly precipitation data between 1978 and 2002. A nearby station, Jacksboro 1 NNE (#414520) has long-term 15-minute precipitation data. However, there are many missing periods in the record. The nearest station that has a reasonable long-term precipitation record is Lake Bridgeport Dam (#414972). The station is about 18 miles to the east of Jacksboro.

It is not uncommon for weather data to have missing values. The periods of missing data in the precipitation record at Lake Bridgeport Dam were reviewed. The annual rainfall amounts were compared with the TWDB QUAD 409 data. Years with significant missing data issue were identified and not used for the long-term water level simulation. As a result, from 1961 through 2002, 12 years of data were eliminated and 30 years of data were considered useful for simulation. Figure 4-2 shows the cumulative frequency plots of the TWDB QUAD 409 annual rainfall from 1961 through 2002 and the Lake Bridgeport Dam data for the same period but with the “bad data” years excluded. It appears that the Lake Bridgeport Dam data provides a reasonable representation of the Jacksboro area rainfall.

4.1.2 Evaporation

Monthly lake evaporation and precipitation rates for each one-degree quadrangle in Texas are available from the Texas Water Development Board (TWDB) web site (TWDB 2005). The periods of data for evaporation and precipitation are from 1954 through 2002 and 1940 through 2002, respectively. Johnson Lake is located in QUAD 409. Since the period of data does not include the calibration period, the evaporation rates for the calibration period have to be estimated. The following example illustrates the procedure. October 2005 has a rainfall amount of 3.75 inches. From the TWDB monthly precipitation data, the Octobers with similar rainfall amount were identified. The average of the corresponding evaporation rates of these months was used as the evaporation rate for October 2005. The rate was assumed to be constant throughout a month.

FIGURE 4-2
CUMULATIVE FREQUENCY PLOT OF ANNUAL PRECIPITATION



4.1.3 Runoff

HEC-HMS Version 2.2.2 developed by the Hydrologic Engineering Center was used to simulate runoff of the watershed. The watershed, along with the location of key features, is shown in Figure 4-3. To estimate the precipitation excess that results in runoff, the Deficit and Constant-rate Loss Model in HMS was used. It is a quasi-continuous model that continuously tracks the moisture deficit, computing it as the initial abstraction volume, less precipitation volume, plus recovery volume during precipitation-free periods. Initial values of model coefficients were estimated based on guidelines in the model manual and adjusted in the calibration process.

4.1.4 Seepage

The seepage rate was adjusted during the calibration process.

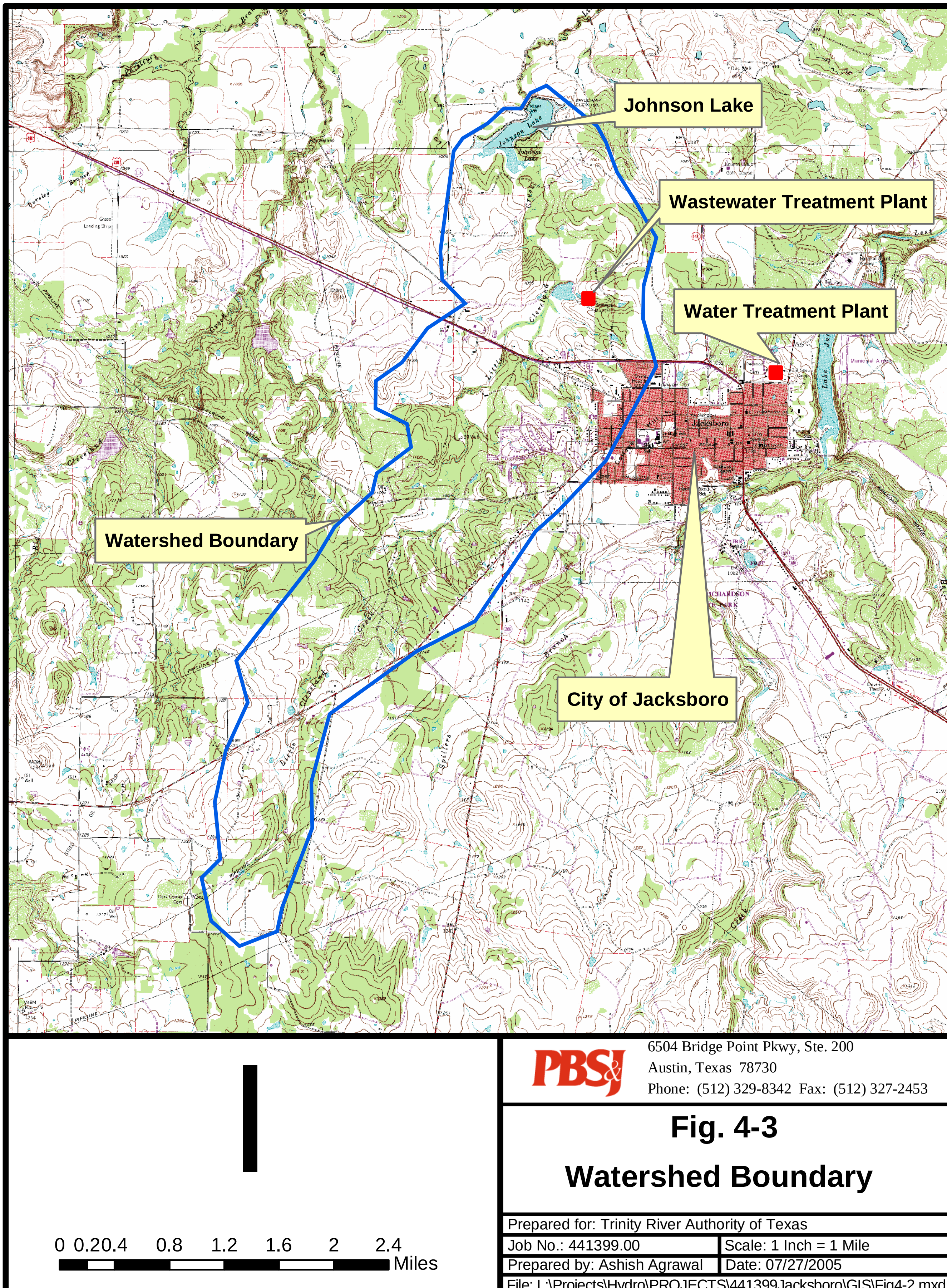
4.1.5 Plant Effluent and Diversion

Daily average effluent discharge data were available from the wastewater treatment plant for the calibration period. In the calibration, the discharge rate was assumed constant during the day. In the long-term simulation, monthly averages were calculated from the available data and applied in the spreadsheet model.

Monthly diversion data for golf course irrigation were available from TCEQ Surface Water Use Reports from 2002 to 2004. Because the diversion amounts are computed from monthly electric consumption records for pumping, the diversion was assumed to be constant throughout the month. The monthly average wastewater flow and diversion data employed are as follows:

Month	Discharge (mgd)	Diversion (mgd)
January	0.257	0.003
February	0.307	0.000
March	0.270	0.000
April	0.302	0.076
May	0.344	0.062
June	0.341	0.035
July	0.369	0.095
August	0.367	0.135
September	0.320	0.174
October	0.309	0.000
November	0.403	0.044
December	0.283	0.066

The discharge data are for July 2004 through June 2005. As this was a fairly wet year, the flows should be conservatively high. The diversion data are for 2002–2004.



PBSJ
6504 Bridge Point Pkwy, Ste. 200
Austin, Texas 78730
Phone: (512) 329-8342 Fax: (512) 327-2453

Fig. 4-3

Watershed Boundary

Prepared for: Trinity River Authority of Texas

Job No.: 441399.00	Scale: 1 Inch = 1 Mile
Prepared by: Ashish Agrawal	Date: 07/27/2005

File: L:\Projects\Hydro\PROJECTS\441399Jacksboro\GIS\Fig4-2.mxd

4.2 MODEL CALIBRATION

Figure 4-4 shows the comparison between model results and the observed water levels during the period of level recording. The model was calibrated by adjusting watershed runoff patterns and lake seepage to achieve the level of agreement. The sharp increases in the observed water levels correspond to runoff events. Since there is no gaged flow record in the LCC watershed, the runoff model was also calibrated based on the lake level record. It is noted that the period is relatively wet so that there is no significant drop in water level. Given the spatial variability in rainfall, limited data and other uncertainties in the input data, the model appears to simulate the recorded lake level fluctuation reasonably well. The seepage rate of the lake bottom was determined to be 0.1 inch per day (in/day) from this calibration.

Since the runoff model was calibrated to data representing a limited range of runoff conditions, a reality check was made by comparing the runoff calculated by the model with the flow record at the USGS gage 08042700 on North Creek at Hwy 281. The gage is about 10 miles to the northwest of Jacksboro. The flow record is available from August 1, 1956, through October 2, 1980. The gage has a contributing drainage area of 21.6 square miles, whereas the LCC watershed at Johnson Lake has a smaller area of 7.35 square miles. The North Creek gaged flow was adjusted by a factor of 0.34 (7.35/21.6) and the annual flow was compared with the LCC flow from the HEC-HMS model in Figure 4-5. It was found that on average, the modeled flow was about 75 percent higher than the area-adjusted gage flow. It appears that the model calibrated to the short relatively wet period produces too much runoff.

One approach would be to calibrate a runoff model for the North Creek watershed using the gaged flow, and then apply the model coefficients to the LCC watershed. It is noted that the goal of this study is not to produce a history of the Johnson Lake level, but to characterize the lake level frequency distribution. Since the North Creek gaged record represents flow in an intermittent stream in the general area of LCC, the area-adjusted flow of the North Creek gage appears to be a more representative input to the long-term simulation of Johnson Lake level.

4.3 LONG-TERM SIMULATIONS

Figure 4-6 shows the modeled Johnson Lake level in a long-term simulation without effluent discharge, using the area-adjusted gaged record for North Creek and records of local precipitation directly on the lake. The results for 1972 to 1975 are not used because of the serious data problem in the precipitation record in those years mentioned in Section 4.1.1. Figure 4-7 shows the frequency distribution of the water level. About 33 percent and 16 percent of the time the water level is 2 feet and 4 feet below the riser, respectively. The simulation indicates that in the absence of the effluent discharge, it would not be uncommon for the lower reach of Little Cleveland Creek to not be impounded. The definition on an intermittent stream is one that is dry for at least 1 week in most years. With 16 percent of the time (about 8 weeks/year) having an elevation lower than the deepest part of the creek, the lower part of LCC would clearly be considered intermittent in the absence of a wastewater discharge.

FIGURE 4-4
CALIBRATION OF JOHNSON LAKE WATER LEVEL SPREADSHEET MODEL

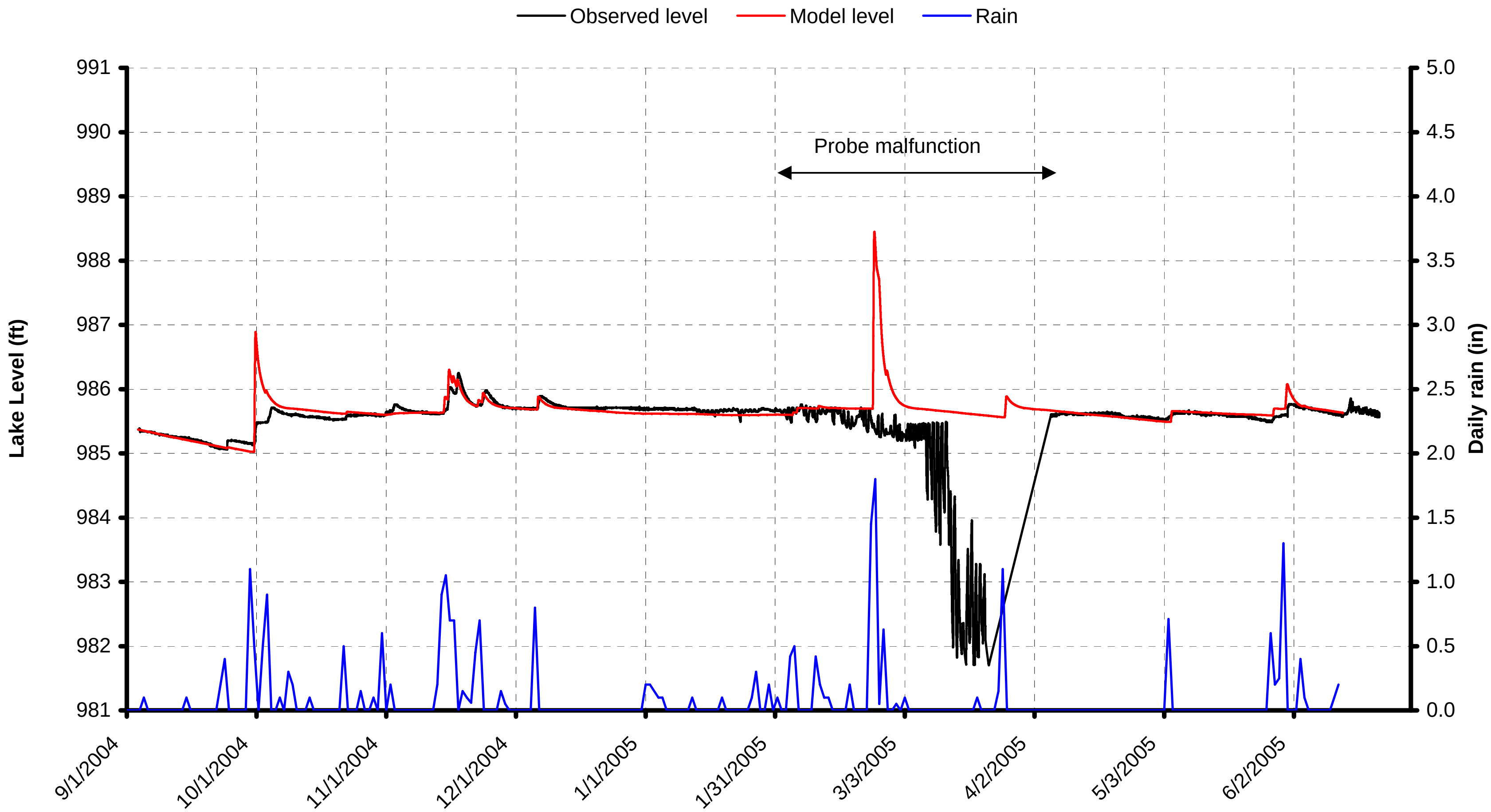


FIGURE 4-5
COMPARISON OF ANNUAL FLOWS AT
NORTH CREEK GAGE AND LCC RUNOFF MODEL

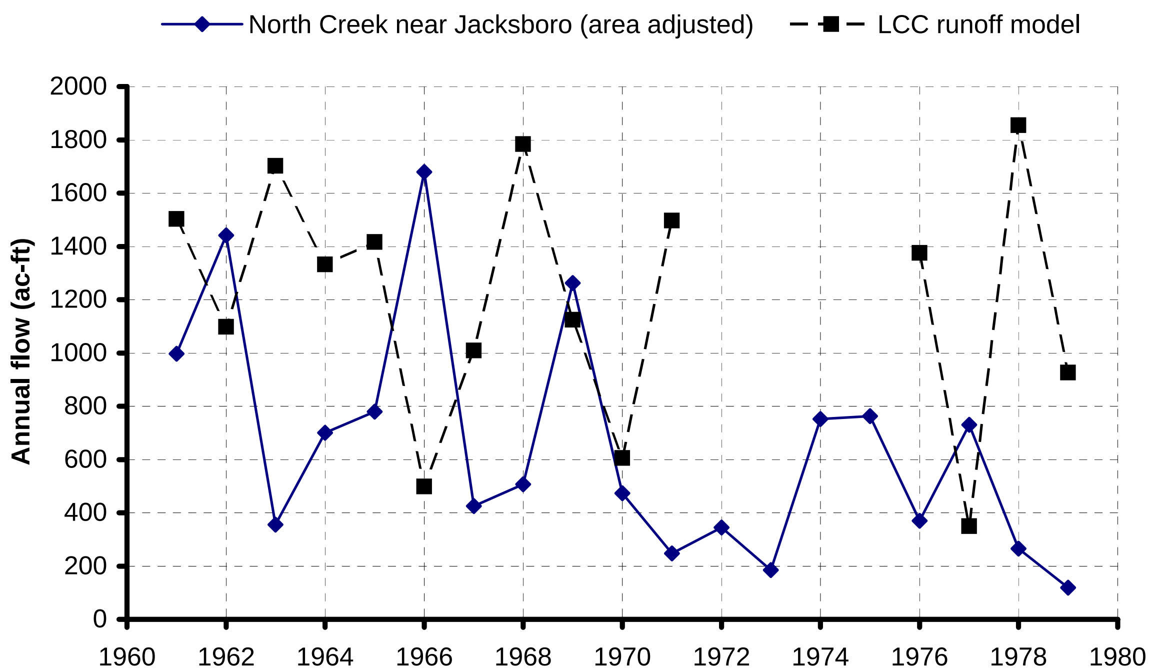


FIGURE 4-6
SIMULATION OF JOHNSON LAKE LEVEL WITHOUT EFFLUENT

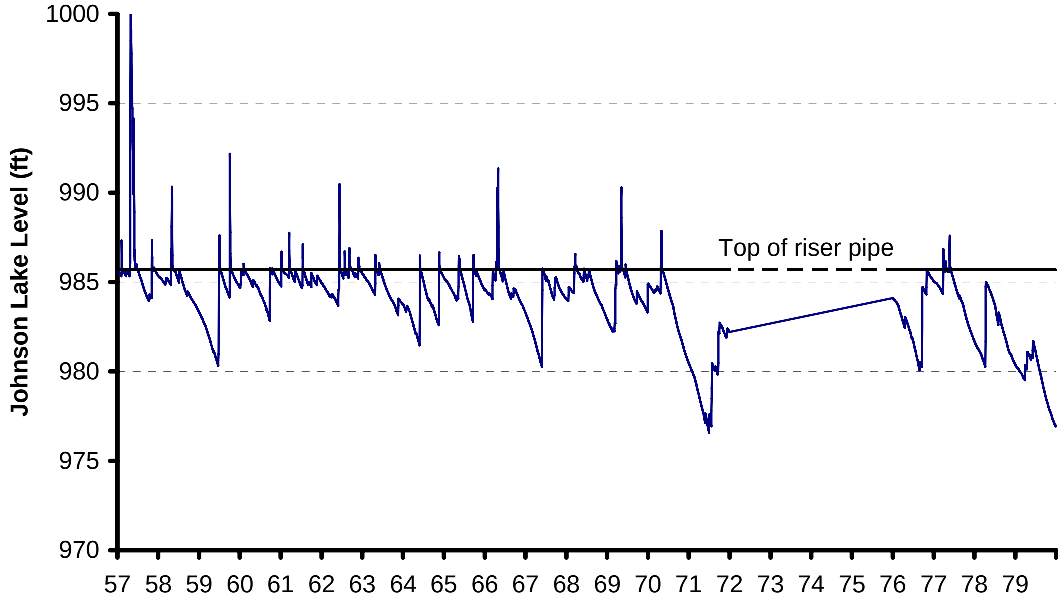
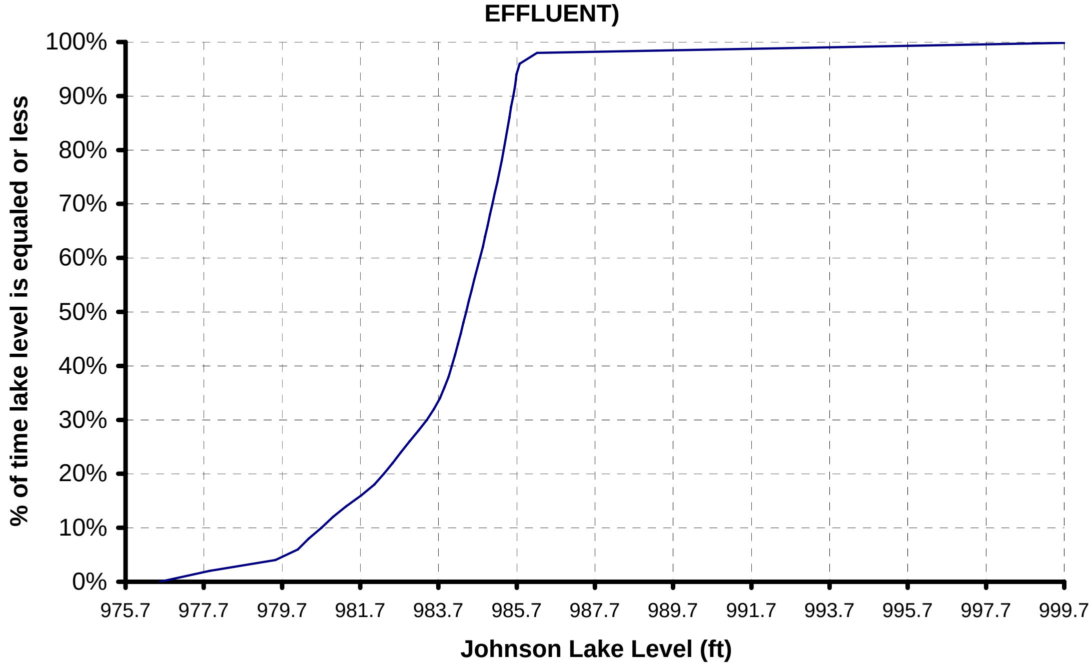


FIGURE 4-7
FREQUENCY DISTRIBUTION OF JOHNSON LAKE LEVEL (WITHOUT EFFLUENT)



A long-term simulation with effluent discharge minus diversion was also performed. Figure 4-8 shows the lake level and Figure 4-9 shows the frequency distribution of the water level. As expected, the water level is higher with the discharge in operation and the lowest level is 2 feet below the top of the riser pipe. In this case the lake at station 1 would be dry, but there would still be pools in the area around station 2.

FIGURE 4-8
SIMULATION OF JOHNSON LAKE LEVEL WITH EFFLUENT

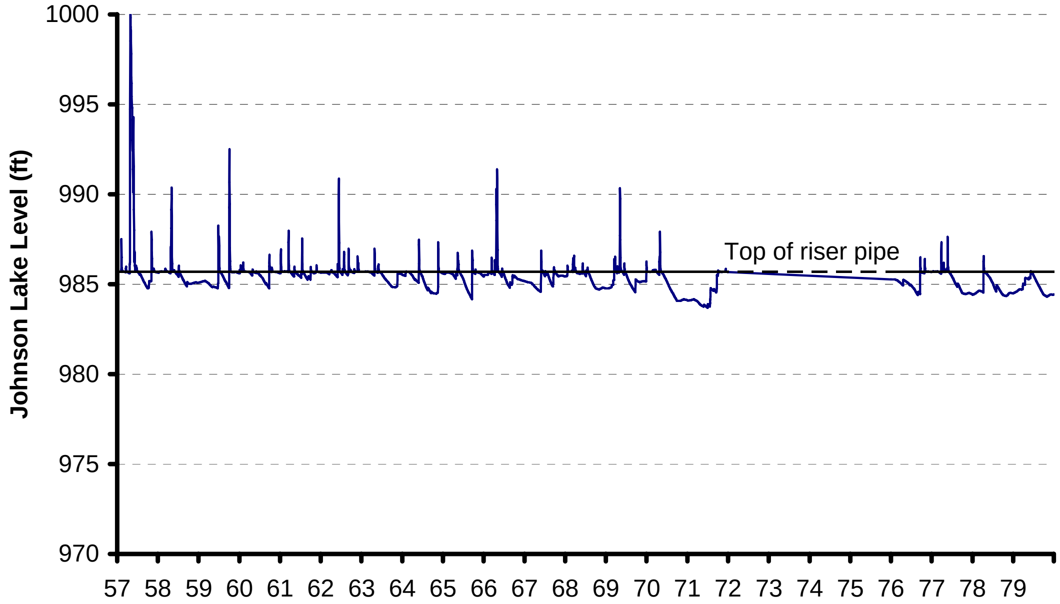
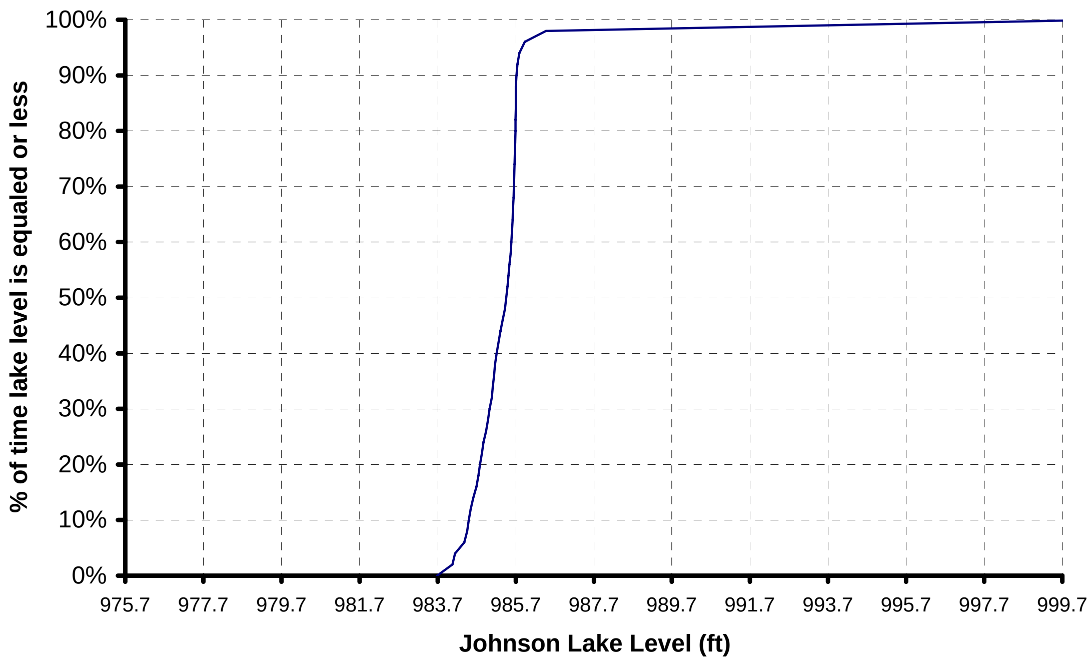


FIGURE 4-9
FREQUENCY DISTRIBUTION OF JOHNSON LAKE LEVEL (WITH EFFLUENT)



5.0 QUAL-TX MODEL

In 1998 the TCEQ developed a QUAL-TX model of Little Cleveland Creek (LCC) and Johnson Lake. That model was calibrated using data collected in September 1996, before the new WWTP began operations. In this study, the TCEQ model is updated with new data from the June 2005 intensive survey. This section first discusses the results obtained from TCEQ's model. Then the calibration effort and results are presented.

5.1 TCEQ'S 1998 MODEL

The model was originally developed from water surface elevation data, hydraulic data and chemical water quality monitoring data from the September 1996 intensive survey, performed by consultants working in opposition to the upgraded WWTP. In their calibration the TCEQ found that sediment oxygen demand (SOD) was one of the primary factors controlling dissolved oxygen in the model. The model predicts the DO concentration shown in Figure 5-1 under conditions of permitted wastewater flow and no wastewater flow. The DO criteria assigned by TCEQ are also shown in the figure.

The model shows that the criteria are not met. However, several limitations need to be recognized. In the no-discharge run the TCEQ assumed an upstream flow of 0.1 cfs. That is normal procedure, but it can be misleading since the flow, 0.06 MGD, is roughly 20 percent of the actual average wastewater flow. In reality, the stream is normally dry upstream of the discharge and if the wastewater were removed there would be no flow in the creek under normal conditions. The other limitations are with the criteria assigned. TCEQ Surface Water Quality Standards (307.4(h)(4) (TCEQ 2003) specifies that intermittent streams, when water is present, have a 24-hour mean of at least 2.0 mg/L and a minimum of 1.5 mg/L. The standards state that the appropriate criterion to apply in the LCC, when the discharge is putting water in the creek, is 2.0 mg/L.

Figure 5-2 shows a profile view of the creek and lake elevations obtained in prior surveys. It can be seen in this view that the portion of the creek between Km 0 and 1 is an impounded arm of the lake. A photograph is shown in Figure 5-3. Physically it is narrow, heavily shaded by trees, and has little aeration from wind because of the surrounding banks. If it were a lake it would have a presumed high aquatic life use and associated DO criterion (5 mg/L). However, it is not the kind of water that most professionals would consider a lake. Moreover, based on the analysis in the previous section where absent the discharge the water level would drop out of this area for about 8 weeks per year on average, much more than "at least 1 week during most years," it is technically intermittent rather than perennial. Under TCEQ Standards, when water is in an intermittent stream, the condition being modeled, a DO criterion of 2.0 mg/L is specified.

FIGURE 5-1
RESULTS OF TCEQ'S MODEL

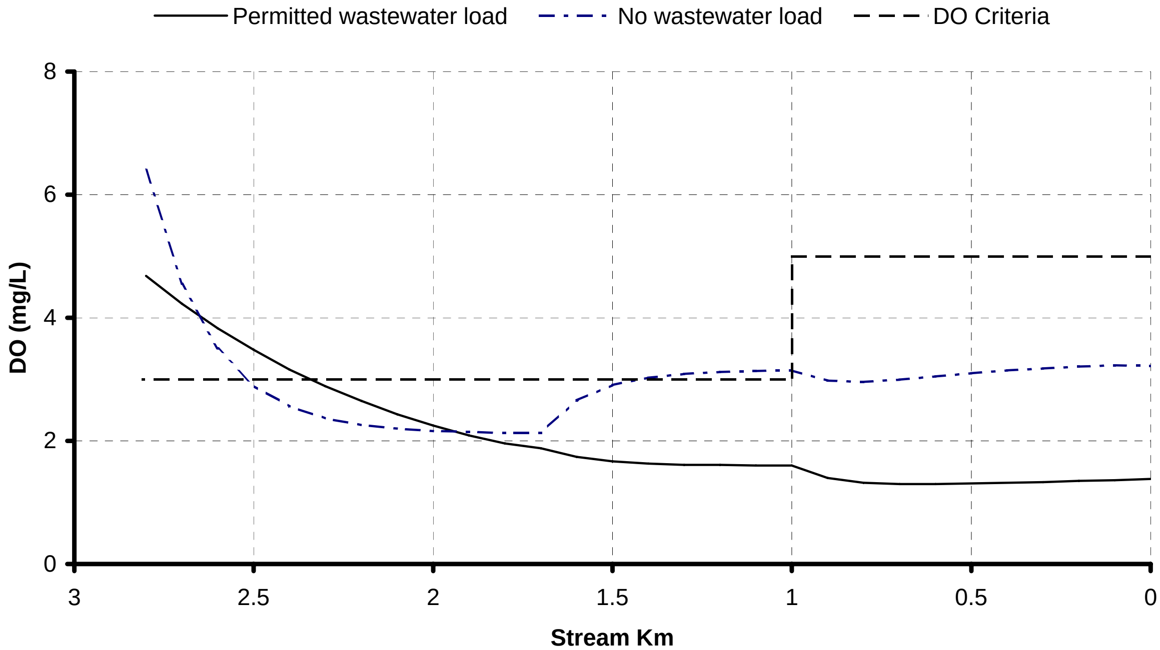


FIGURE 5-2
SURVEY RESULTS OF LITTLE CLEVELAND CREEK

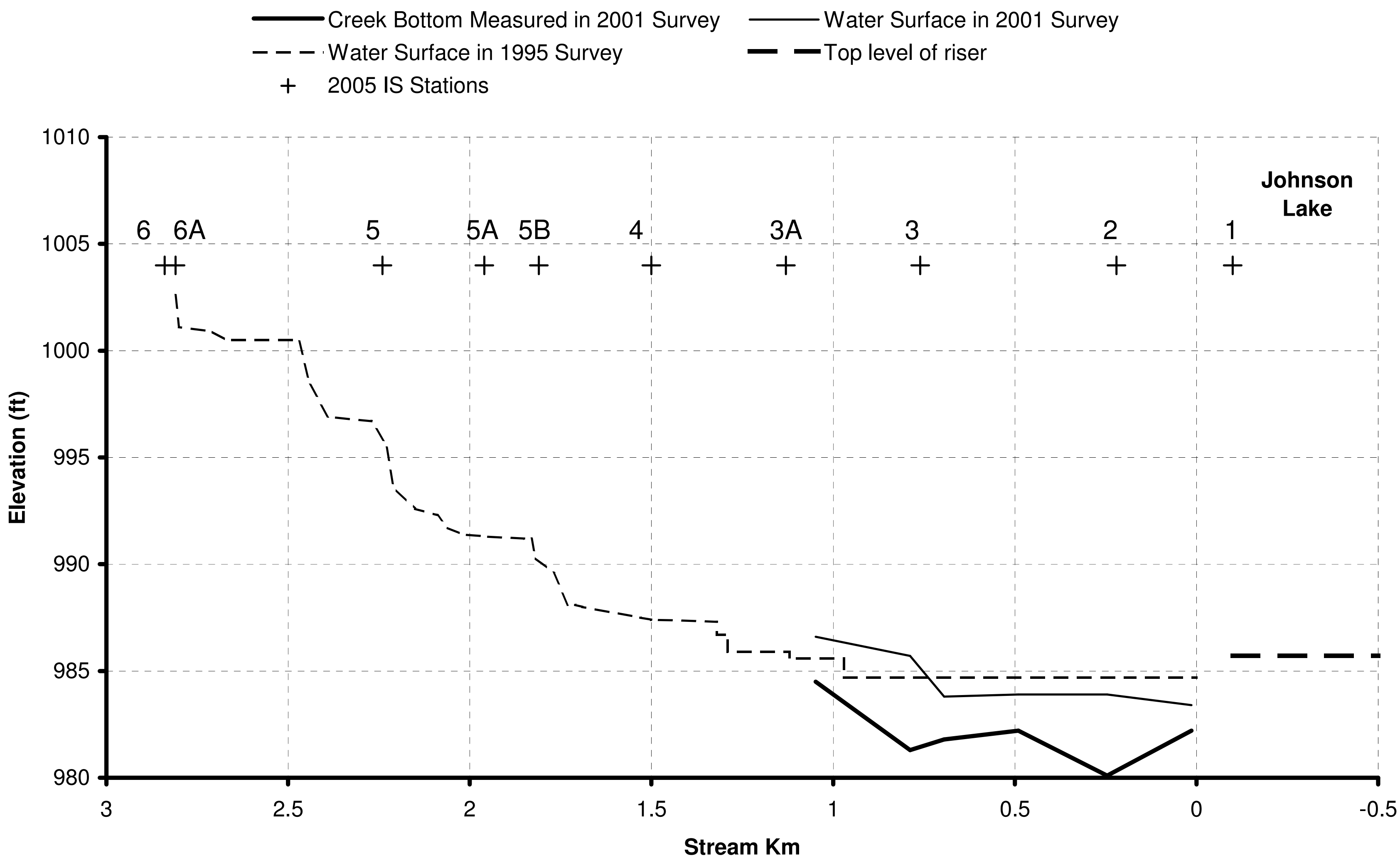


Figure 5-3. Lake arm near station 2

5.2 MODEL CALIBRATION

5.2.1 Hydraulic coefficients

Measurements of the channel width, depth, and velocity were made at six locations of the stream between 9:00 and 11:30 A.M. on June 14, 2005. The depth and velocity measurements were integrated across the width of the stream to obtain the flow and the cross-sectional average depth and velocity. The flows, average depths and average velocities are shown in Table 3-1. Because the stream is very small and shallow, there is considerable variation in the measured flows from station to station, ranging from 0.003 to 0.015 cubic meters per second (m^3/s). Part of the variation is due to subsurface flow in the sandy stream and part due to inability to measure flows in water a few centimeters deep. The effluent discharges on June 14 and June 15 are 0.307 and 0.332 MGD, respectively. There was no diversion for golf course irrigation on these days. The average discharge of the 2 days, 0.320 MGD (0.014 m^3/s), was used as the flow in the stream.

The TCEQ's model is divided into 4 reaches with the hydraulic coefficients shown in the following table:

Reach ID	Begin Reach Km	End Reach Km	Reach Description	a	b	c	d	e
1	2.81	2.80	Flowing	0.2022	0.5	1.065	0.4	0.0
2	2.80	1.70	Flowing	0.2022	0.5	1.065	0.4	0.0
3	1.70	1.00	Beaver Dams	0.4291	1.0	0.0	0.0	0.55
4	1.00	0.00	Backwater	0.2638	1.0	0.0	0.0	0.56

$V = aQ^b$, $D = cQ^d + e$, V is velocity (m/s), Q is flow (m^3/s), D is depth (m).

The coefficients for Reaches 1 and 2 were determined using results of a dye study. This appears to be a good set of measurements, and it was not considered necessary to revise the coefficients for Reaches 1 and 2.

Reach 3 consists of mainly pools. It was modeled with a constant-depth because of beaver dams. Coefficient “b” in the equation V = aQb was taken as 1 and “a” was estimated as 1/(depth x width). The coefficients in TCEQ’s model were estimated based on limited data. Therefore it was decided to revise these coefficients with the new measurements following the same approach.

Reach 4 was impounded by the lake and was also modeled with a constant depth. In the September 1996 survey the lake level was at 984.7 feet. There was no elevation measurement for this reach in the June 2005 survey. However, the lake level was observed to be at the top of the riser (985.7 feet). Therefore, 1 foot was added to the depth coefficient “e”. Previously the average width was 6.77 meters and it was assumed to be 10 meters in the 2005 survey.

In the updated model, two additional reaches were added to represent the lake beyond the mouth of the Little Cleveland Creek. The hydraulic coefficients in the updated model are shown in the following table:

Reach ID	Begin Reach Km	End Reach Km	Reach Description	a	b	c	d	e
1	2.81	2.80	Flowing	0.2022	0.5	1.065	0.4	0.0
2	2.80	1.70	Flowing	0.2022	0.5	1.065	0.4	0.0
3	1.70	1.00	Beaver Dams	3.415	1.0	0.0	0.0	0.16
4	1.00	0.00	Backwater	0.116	1.0	0.0	0.0	0.86
5	0.00	-0.10	Open lake	0.017	1.0	0.0	0.0	0.6
6	-0.10	-0.30	Open lake	0.0083	1.0	0.0	0.0	1.2

5.2.2 Reaction Rates

The reaction rates in TCEQ’s model were kept unchanged since the new data did not suggest that revision was necessary.

5.2.3 Reaeration Coefficients

The Texas Equation was used to estimate reaeration rates for Reaches 1 to 3. However, the Texas Equation when applied to Reaches 4 to 6 would result in values below the minimum allowable rates calculated from 0.6/D (TCEQ, 2003). The minimum allowable rates were used for these reaches.

5.2.4 Sediment Oxygen Demand

In TCEQ's model, the SOD rate was set at 1.9 g/m^2-day for Reaches 1 and 2, and 1.5 g/m^2-day for Reaches 3 and 4. In the current calibration, the SOD was adjusted so that the modeled DO agreed with the observed DO. In the updated model, the SOD is 1.5 g/m^2-day for Reaches 1 to 4 and the default of 0.35 g/m^2-day used for Reaches 5 and 6. Improved treatment that began in 1998 has reduced the organic loading in the discharge that can become an oxygen-demanding deposit in the stream bottom. Therefore, some reduction of SOD in Reaches 1 and 2 seems reasonable. Nevertheless, the SOD is still high in the studied reaches.

5.2.5 Calibration Results

Figure 5-4 shows the calibration results. Note that the most upstream data point in the figure is measurement at the outfall pool behind the dam and represents condition of the effluent. As mentioned in Section 5.1, the average effluent discharge during the intensive survey was 0.320 MGD. This flow was input at the upstream end of the model. As shown in Figure 5-4a, the conductivity data show a slight dip between Km 1.5 and 0.5 but is higher further downstream. Other than that the conductivity was essentially constant along the stream during the survey, suggesting that there was little or no inflow between the effluent discharge point and the lake. The modeled conductivity drops slightly at the downstream end of the model, apparently due to a default boundary condition not controlled by the user.

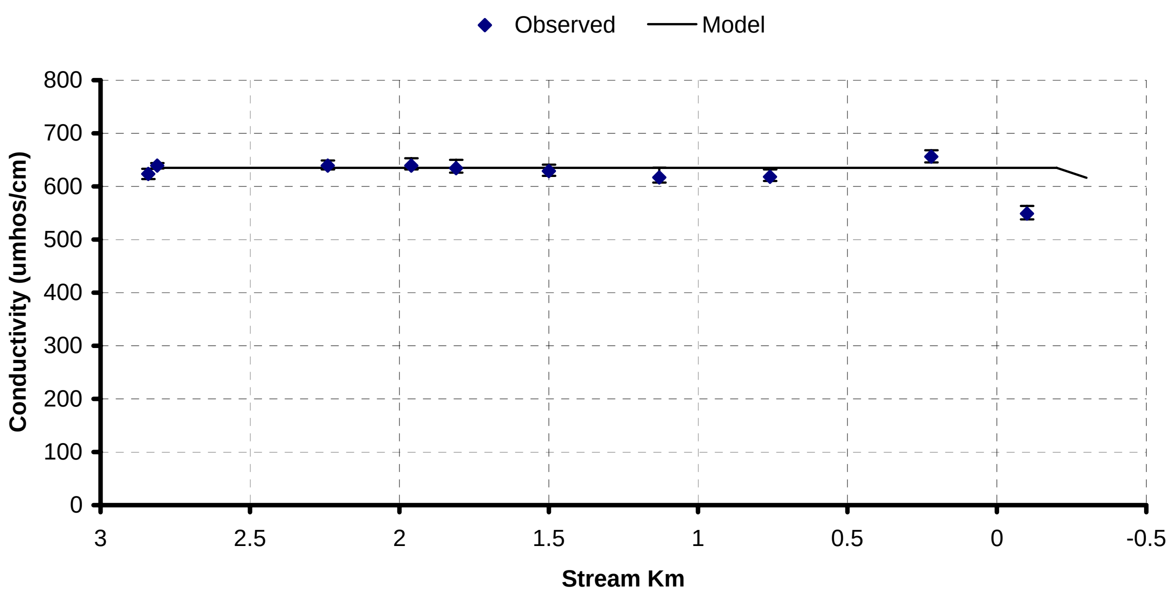
Figure 5-4b shows that the modeled DO matches the data reasonably well. With high chlorophyll *a* level, supersaturation occurred in the lake (station 1). With heavy shading and limited reaeration, DO levels were low in the lake arm (station 2). Chlorophyll *a* was not simulated in the model. However, the chlorophyll *a* concentrations measured were input to simulate oxygen production due to photosynthesis.

In Figure 5-4c, the model results of $CBOD_5$ show a significant decrease in Reaches 4 to 6 because of higher residence times in these reaches allowing more decay to occur. Nevertheless, the $CBOD_5$ level was low in the stream and did not have much effect on the DO.

Figure 5-4d to 5-4f show the simulation of nitrogen species. As explained in Section 3, the higher values of NH_3-N at about Km 2 might be due to the cattle crossing. The model is not set up to simulate plant uptake and may be the reason that the model results are higher than the data. Organic nitrogen is low in the stream. As mentioned in Section 3, the observed pattern of NO3+NO2-N is hard to explain and no attempt was made to match model results with data. This part of the model does not have a significant impact on the DO simulation.

FIGURE 5-4
QUAL-TX CALIBRATION RESULTS

a. Conductivity



b. DO

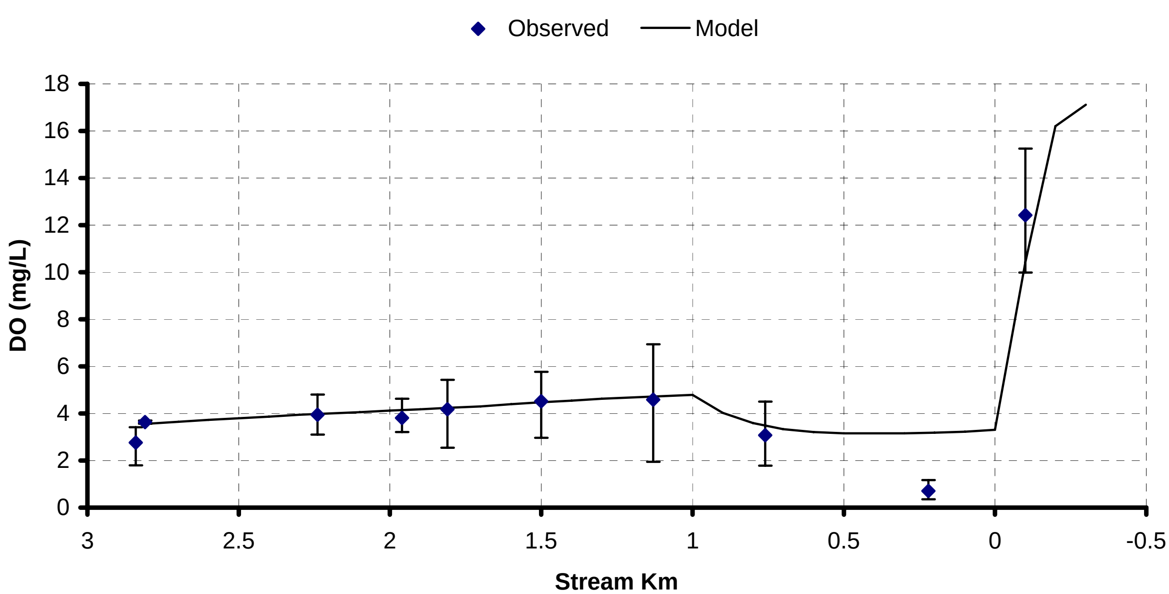
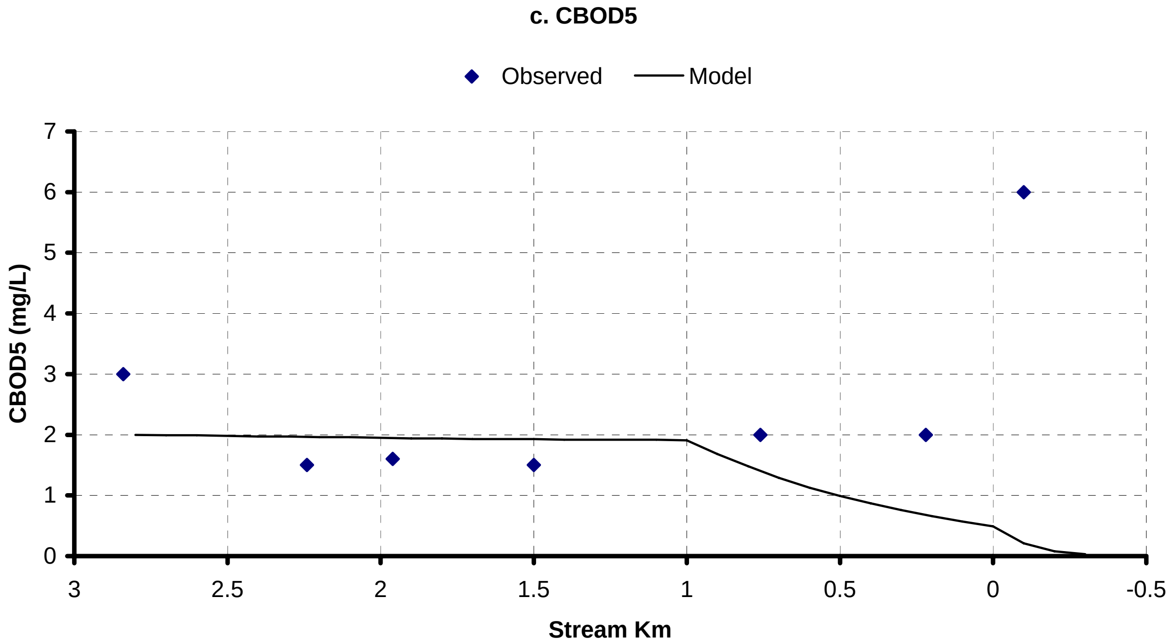


FIGURE 5-4 (cont'd)
QUAL-TX CALIBRATION RESULTS



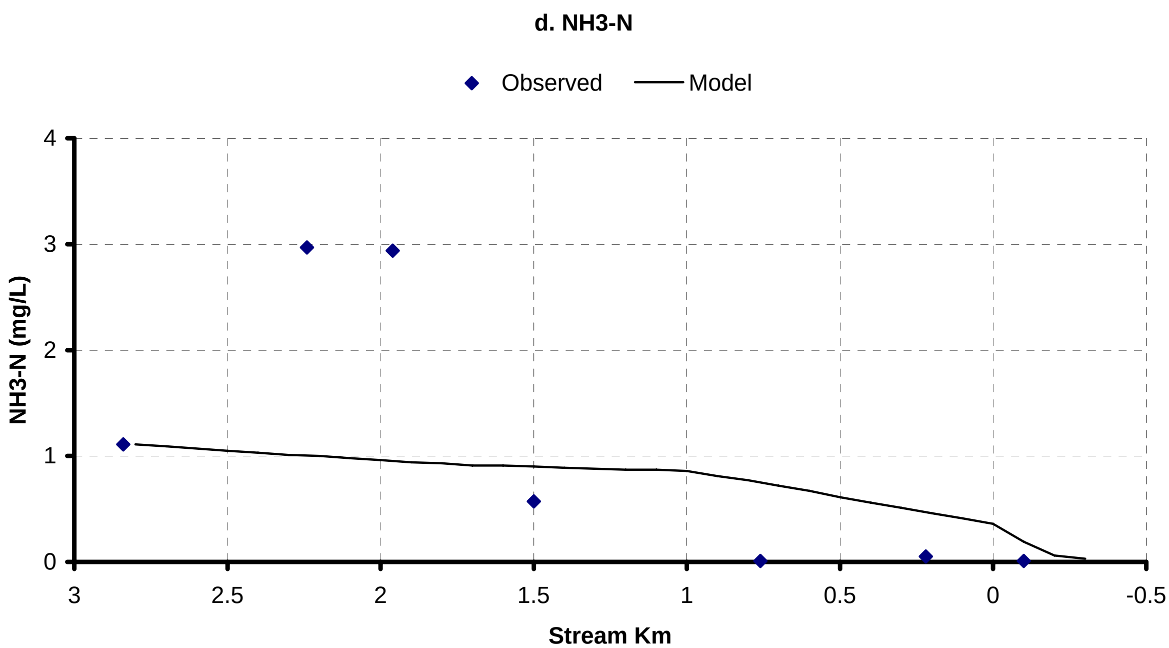
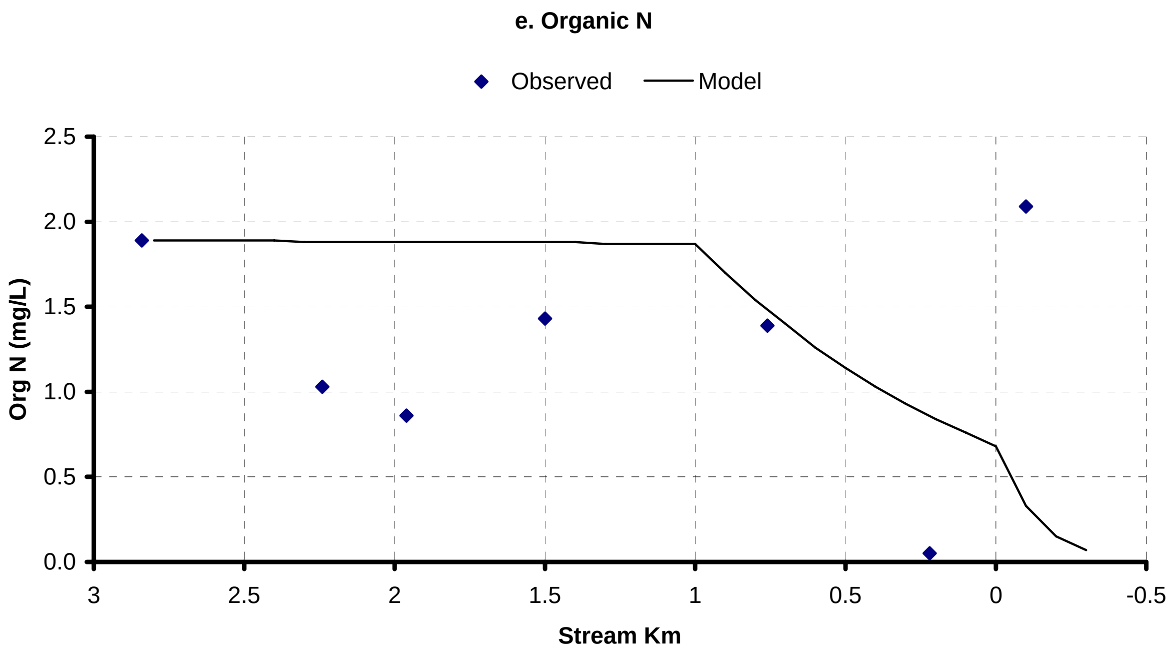
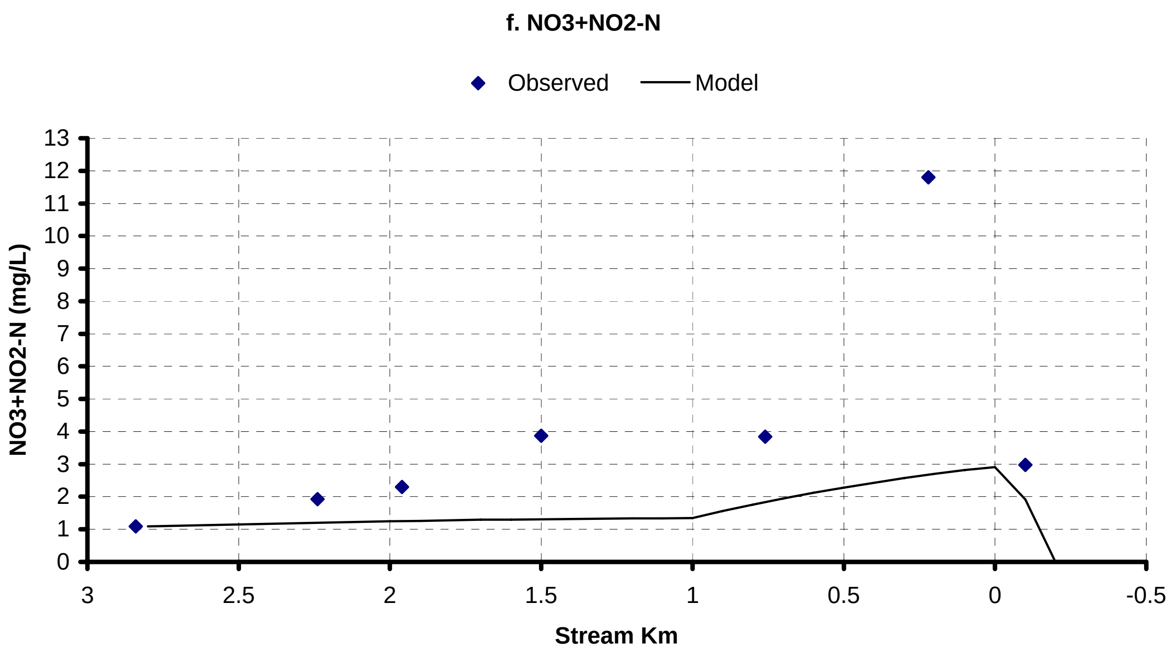


FIGURE 5-4 (cont'd)
QUAL-TX CALIBRATION RESULTS





5.3 MODELING WITH PERMITTED WASTEWATER FLOW AND LOAD

The next step was to apply the calibrated model to critical conditions with the permitted wastewater flow and load. The permitted flow is 0.7 MGD and the effluent concentrations for $CBOD_5$, NH_3-N and DO are 10 mg/L, 3 mg/L and 4 mg/L respectively. The critical conditions are low flow with summer temperatures. Figure 5-5 shows the DO profile with the permitted wastewater flow and load as input to the calibrated model. Note that no chlorophyll is included in this model. Upstream of Km 1, a DO criterion of 2 mg/L for intermittent stream is shown. Downstream of Km 1, the lake criterion of 5 mg/L is shown since that part is impounded in the calibrated model. With the high residence time in the impounded reach and high SOD, the DO level is well below the criterion. The DO level increases beyond Km 0 because of the lower SOD.

For LCC, without the effluent discharge the stream would be dry under almost all conditions, including critical conditions. Moreover, under critical conditions the lake level would likely be low and none of the reaches in the model would be impounded. This is supported by the Johnson Lake level simulation described in Section 4. Therefore, for evaluation of criteria attainment, it is more appropriate to treat the lower reach as not impounded. Since no data were available to develop model coefficients for Reaches 4 to 6 when they were not impounded, they were assumed to have similar characteristics as Reach 3. Therefore, the model coefficients for Reach 3 were repeated for Reaches 4 to 6. The resulting DO profile is shown in Figure 5-6. Again no chlorophyll is included in this model. The DO is above the criterion for an intermittent stream (2 mg/L) everywhere along the stream.

The hydraulic coefficients of Reach 3 are based on measurements at two locations in that reach. There may be some areas of the pools that are deeper than the measured depths. A sensitivity run was made with the depth doubled and velocity halved for Reaches 3 to 6. The DO profile is shown in Figure 5-7. The DO is still above 2 mg/L everywhere along the stream.

FIGURE 5-5
DO PROFILE UNDER CRITICAL CONDITIONS AND IMPOUNDED LAKE ARM
(WITH CALIBRATION COEFFICIENTS)

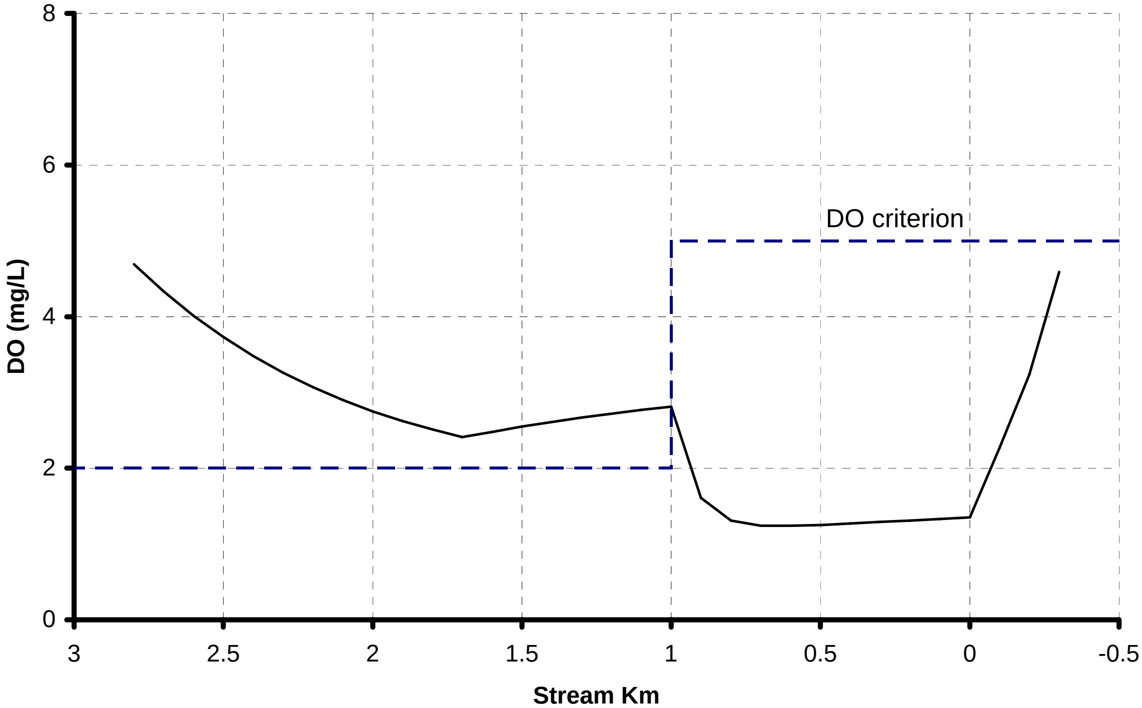


FIGURE 5-6
DO PROFILE UNDER CRITICAL CONDITIONS (NO IMPOUNDED REACHES)

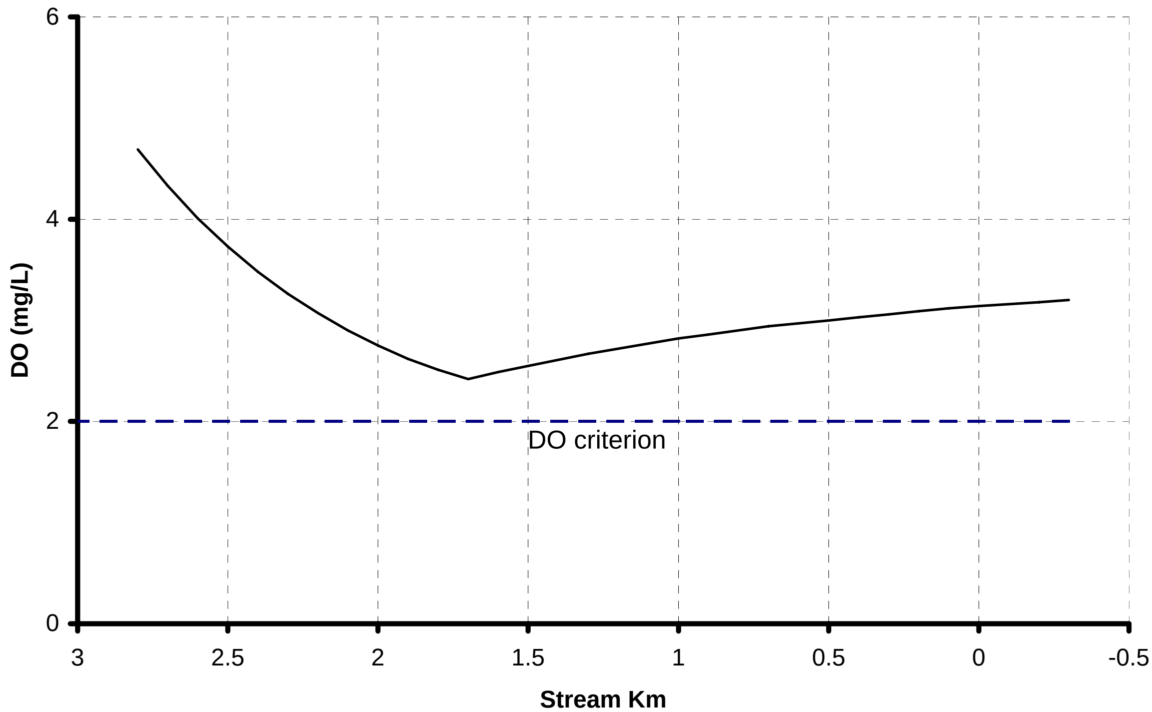
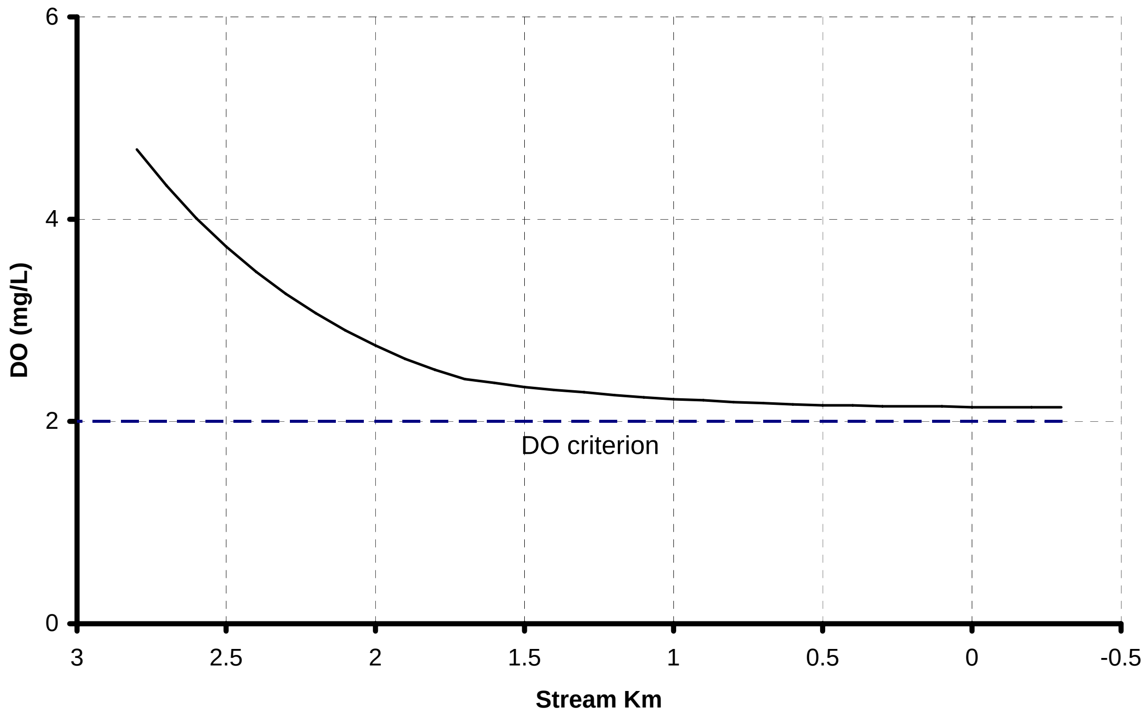


FIGURE 5-7
DO PROFILE UNDER CRITICAL CONDITIONS (SENSITIVITY RUN)



6.0 DISCUSSION AND CONCLUSIONS

As discussed in Section 2.0, Background on City of Jacksboro Wastewater Permit, there is a complex regulatory tangle that has kept the City of Jacksboro TPDES wastewater discharge permit in stasis for the past 5 years. Stated simply, the situation had evolved to the point where the TCEQ's official water quality model of the system indicates that no set of wastewater effluent limits, including higher treatment levels or complete removal of the wastewater source, could meet the existing interpretation of water quality standards. With this situation, the permit has been held between application and issuance since 2000. The objective of this study is to find a way to untangle the regulatory backlash and allow normal permit processing to proceed.

The major elements of the study include historical analysis, collection of new data, analysis of system hydraulics and lake levels, a careful review of the existing Surface Water Quality Standards, and new modeling of the system. At the end of the process a water quality model has been produced that follows TCEQ procedures and Standards, and that indicates the existing (and previously recommended by TCEQ) wastewater permit limits are appropriate.

The underlying reason this relatively unusual situation evolved was the problem of the lake arm. These are the backwater areas of reservoirs that receive inflow from a tributary and are impounded by the reservoir. They are typically narrow, tree lined, shielded from the wind, and may be somewhat deeper than a corresponding location further downstream, where sediment deposition occurs. These are all factors that are conducive to low DO levels. Attachment B presents a sensitivity analysis for these parameters in backwater areas. When a tributary also receives a wastewater discharge there is more of a supply of nutrients and the amount of biological activity is greater. In shaded and quiescent conditions, this can further depress DO levels, as has been shown to be the case in LCC. In general, lake arms are not at all representative of the lake that has a presumed "high" aquatic life use and a DO criterion of 5.0 mg/L. Applying this DO criterion to lake arms will (and has) produce many examples of non-attainment. Most have not had the impact of this particular situation, but all have the potential to produce regulatory problems. It is important to emphasize that while these are regulatory problems, they are not water quality problems. While lake arms will have lower DO than the adjacent lake, they still support aquatic life that appear to be characterized by large numbers and high diversity. The sheltered conditions and heavy vegetation provide important habitat for lake fisheries.

There is a simple solution available that involves nothing more than a modification of TCEQ procedures. That is to administratively define lake stations as those that are at least 50 feet (or some appropriate distance) from the bank. The uses and criteria for tributary streams would apply moving downstream until the lake is encountered. This is effectively what was accomplished in this study by documenting the variation of the lake level and demonstrating that absent the artificial wastewater discharge, the creek would be intermittent all the way to the lake at station 1. The advantage of the administrative solution is that it deals in an effective manner with the problem while avoiding the cost and complexity of reservoir level analysis. In addition, there are reservoirs that have lake arms, but where the level analysis will not help because they are kept at near constant level.

The conclusions of this study are:

1. Little Cleveland Creek is an intermittent stream throughout the area of analysis. When an intermittent stream has water, in this case due to the wastewater discharge, the Standards state that the appropriate DO criterion to apply is 2.0 mg/L.
2. When the QUAL-TX model is calibrated to new data using TCEQ procedures, it indicates that the effluent set previously recommended by TCEQ's predecessor agency (10 $CBOD_5$, 3 NH_3-N, and 4 DO) easily attains criteria.
3. With that finding, the TCEQ will be able to issue the permit for the City of Jacksboro, ending half a decade of regulatory entanglement.
4. The lake arm issue that caused this problem and that has caused regulatory problems in many parts of the state, can be easily resolved by administratively defining a lake station to be at least 50 feet from the shoreline in all directions. Samples collected in narrow arms would not be far enough from shore to qualify as a lake station and would be considered a part of the tributary stream.

7.0 REFERENCES

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Texas Commission on Environmental Quality (TCEQ). 2003. Procedures to Implement the Texas Surface Water Quality Standards.

Trinity River Authority (TRA). 2004. Quality Assurance Project Plan.

Texas Water Development Board (TWDB). 2005. Lake evaporation and precipitation rates for each one-degree quadrangle in Texas. Available at http://hyper20.twdb.state.tx.us/Evaporation/evap.html

Attachment A

September 1996 Intensive Survey Data
and February 1999 to April 2000 Monitoring Data

TECHNICAL REPORT

WATER QUALITY AND HYDRAULIC SURVEYS AND WATER QUALITY MODELING OF LITTLE CLEVELAND CREEK BELOW THE CITY OF JACKSBORO WASTEWATER TREATMENT PLANT

prepared for

Booth Ahrens & Werkenthin, P. C.
Austin, Texas

Attorneys for

Mrs. Eva Hamman
Jacksboro, Texas

July 1998

prepared by

Bruce L. Wiland, P. E.
Austin, Texas

and

R. J. Brandes Company
Austin, Texas

STATE OF TEXAS
BRUCE L. WILAND
45700
REGISTERED
PROFESSIONAL ENGINEER

8/5/98

EXHIBIT B

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INTRODUCTION

This study has been undertaken to investigate the potential impacts of the discharge from the City of Jacksboro's (City) wastewater treatment plant (WWTP) on the water quality of Little Cleveland Creek and Johnson Lake. Effluent from the City's WWTP is discharged into Little Cleveland Creek northwest of downtown Jacksboro at a point approximately 3,000 feet north of U. S. Highway 281 and 5,500 feet west of State Highway 148. The effluent flows down the creek for approximately 0.8 miles (1.3 kilometers) to property owned by Mrs. Eva Hamman and then through the Hamman property for another 0.9 miles (1.5 kilometers) to the main body of Johnson Lake. Johnson Lake, which is a floodwater retarding structure constructed by the Soil Conservation Service around 1950, has a normal pool surface area of about 160 acres and is located entirely on the Hamman property. Below Johnson Lake, Little Cleveland Creek continues to flow through the Hamman property, ultimately discharging into Big Cleveland Creek and then into the West Fork of the Trinity River.

Above the City's WWTP discharge, the flow in Little Cleveland Creek is intermittent, occurring only in response to stormwater runoff during rainfall events. Downstream of the discharge, there is continuous flow in the creek as the effluent travels downstream to Johnson Lake. The Texas Natural Resource Conservation Commission (TNRCC) has established water quality standards and criteria for Little Cleveland Creek and Johnson Lake that are intended to protect existing uses of these waters and that must be satisfied with the effluent discharged into the creek. For dissolved oxygen, the adopted numerical standards are as follows:

Little Cleveland Creek	3.0 mg/L
Johnson Lake	5.0 mg/L

The extent to which these dissolved oxygen standards will be satisfied with the proposed increases in the pollutant loadings from the City's WWTP discharge is the subject of this investigation. To examine these impacts, field surveys involving stream channel geometry measurements and water quality sampling have been conducted, and a stream water quality model has been developed to simulate dissolved oxygen levels along the creek in response to existing channel geometry and hydraulic conditions and the pollutant loadings discharged from the City's WWTP.

WATER QUALITY AND HYDRAULIC SURVEYS

In October, 1995, a geometric field survey of Little Cleveland Creek from the City's WWTP to Johnson Lake was conducted by Clear Fork Surveying & Mapping Co., Inc. A copy of this survey is attached to this report. Information from this survey has been used to locate specific stream features, to establish water surface gradients based on measured elevations along the stream, and to calculate stream distances (kilometers) as shown on the location map in Figure 1.

Surveyed water surface elevations along Little Cleveland Creek and a summary of other stream geometry and hydraulic data at specific locations as measured and observed in the field are listed in Table 1. The water surface profile along Little Cleveland Creek based on these data is plotted on the graph in Figure 2. As can be seen from the water surface profile plot in Figure 2 and as has been confirmed visually in the field, Little Cleveland Creek between the City's discharge point and the main body of Johnson Lake generally is characterized by three hydraulically-different reaches. The upper reach from just below the Concrete Dam at Station A2 near the City's discharge point downstream to just above the Hamman fence line at Station B (Kilometer 1.69) is basically free-flowing and has an average water surface slope of 0.0041. The middle reach from Kilometer 1.69 downstream to Debris Dam #3 (Kilometer 0.97) is characterized by numerous pools and has a much lower water surface slope of 0.0010. Below Debris Dam #3, the creek hydraulics appear to be controlled by backwater from Johnson Lake, with the water surface slope essentially zero along this lower reach. In essence, this lower reach of Little Cleveland Creek as depicted on the water surface profile plot in Figure 2 actually is the upper end of Johnson Lake. Hence, the interface between the stream portion of Little Cleveland Creek and the headwaters of Johnson Lake is at Debris Dam #3 as shown on the map in Figure 1.

A hydraulic and water quality survey of Little Cleveland Creek was conducted on September 10-11, 1996. The purpose of the survey was to characterize stream channel cross-sections and velocities so that the hydraulics in the water quality model could be more accurately represented. Water quality samples and field measurements also were taken during this diurnal survey. Field measurements were taken at the following locations as depicted on the location map in Figure 1:

Station A	Outfall Pool on Little Cleveland Creek below Jacksboro WWTP Discharge and 2' above Concrete Dam (Kilometer 2.83+)
Station A2	Little Cleveland Creek 10' below Concrete Dam (Kilometer 2.83-)
Station A3	Upper Reach of Little Cleveland Creek (Kilometer 2.23)
Station B	Little Cleveland at Hamman Fence Line (Kilometer 1.50)
Station B2	Little Cleveland Creek at Pipeline Crossing (Kilometer 1.06)
Station C	Little Cleveland Creek at Iron Bridge (Kilometer 0.77)

Measurements of water temperature, pH, dissolved oxygen, specific conductivity, and oxidation-reduction potential at Stations A, A2, A3, B and C were taken approximately every three hours except for the 2-3 a.m. time period. Measurements were taken approximately every six hours at Station B2 due to the limited access. A tabulation of these measurements is presented in Table 2. Water quality analyses for 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), ammonia nitrogen (NH_3-N), Kjeldahl nitrogen as nitrogen (Kjeldahl-N), nitrites plus nitrates (NO_{2+3}-N), and total phosphorus (Total P) were conducted on composite samples taken at Stations A, B and C. The results from these analyses expressed in milligrams per liter (mg/L) are listed below:

	BOD_5	TSS	NH_3-N	Kjeldahl-N	NO_{2+3}-N	Total P
Station A	19	53.3	<0.01	6.35	<0.01	1.43
Station B	14	26.7	<0.01	1.72	0.288	1.14
Station C	10	49	1.12	3.74	0.101	1.11

As indicated by the data collected during the water quality survey, even though the oxygen demanding pollutants were moderate to low at the outfall pool (BOD_5 = 19 mg/L, NH_3-N =

<0.01 mg/L and Kjeldahl-N = 6.35 mg/L at Station A), the dissolved oxygen in the stream was severely depressed downstream, ranging between 1.1 mg/L and 2.3 mg/L at the Iron Bridge (Station C). A plot of the range of dissolved oxygen levels observed during the survey along the length of the sream is presented in Figure 3. As indicated, violations of the existing TNRCC dissolved oxygen standards for Little Cleveland Creek and Johnson Lake occurred.

Flow measurements also were made at Station A/A2 and at Station B on Little Cleveland Creek on both days of the survey. Flows at Station A/A2 were determined using a weir equation based on the depth of flow measured over the Concrete Dam. These calculated flows as observed at Station A/A2 are as follows:

Date	Time	Weir Depth inches	Flow cfs	Flow cu m/s
09/10/96	17:00	1.375	0.229	0.00649
09/10/96	20:13	1.000	0.137	0.00388
09/10/96	23:05	1.100	0.160	0.00453
09/11/96	05:13	1.200	0.185	0.00524
09/11/96	08:03	1.200	0.185	0.00524
09/11/96	14:14	1.250	0.202	0.00572
Average Flow			0.183	0.00518

Flows at Station B were determined by measuring velocities across a transect using a pygmy meter. The flows measured at Station B are as follows:

Date	Time	Flow cfs	Flow cu m/s
09/10/96	18:10	0.262	0.00742
09/11/96	14:33	0.246	0.00697
Average Flow		0.254	0.00719

Concurrently with the water quality study, a dye release was made in Little Cleveland Creek to determine the average velocity of the stream under the existing flow conditions. Rhodamine WT was injected into the stream on September 10 just below the Concrete Dam and allowed to travel downstream overnight. The peak of the dye plume was visually located the following morning. Several width measurements also were made at representative locations along the stream where the dye study was conducted. Data from the dye study are as follows:

	Date	Time	Location* kilometers	Location* feet
Dye Release	09/10/96	17:27	2.83	9,285
Dye Peak	09/11/96	07:57	1.97	6,464

TABLE 1 SUMMARY OF PHYSICAL MEASUREMENTS AND LOCATIONS

Stream Distance (km)	Stream Distance (feet)	Water Surface Elevation (feet MSL)	Water Surface Width (feet)	Water Depth (feet)	Location Description
2.83	9,285	-	-	-	WQ Station A (Above Concrete Dam)
2.83	9,285	-	-	-	Concrete Dam / Elev=1007.6 feet MSL
2.83	9,285	-	-	-	Dye Release (09/10/96 @ 17:27)
2.83	9,285	-	-	-	WQ Station A2 (Below Concrete Dam)
2.81	9,220	1002.6	-	-	
2.80	9,187	1001.1	-	-	
2.76	9,056	-	3.0	-	Width Measurement
2.71	8,892	1000.9	-	-	
2.67	8,760	1000.5	-	-	
2.47	8,104	1000.5	-	-	
2.44	8,006	998.4	-	-	
2.39	7,842	996.9	-	-	
2.27	7,448	996.7	-	-	
2.23	7,317	995.6	10.0	-	WQ Station A3
2.21	7,251	993.6	-	-	
2.15	7,054	992.6	-	-	
2.09	6,857	992.3	-	-	
2.06	6,759	991.7	-	-	
2.02	6,628	991.4	-	-	
1.97	6,464	-	-	-	Dye Peak (09/11/96 @ 0757)
1.96	6,431	991.3	-	-	
1.94	6,365	-	14.5	-	Width Measurement
1.90	6,234	-	-	-	Cow Crossing
1.85	6,070	991.2	-	-	
1.83	6,004	991.2	-	-	Debris Dam #1 (upstream)
1.82	5,971	990.3	-	-	Debris Dam #1 (downstream)
1.77	5,807	989.6	-	-	
1.73	5,676	988.1	-	-	
1.71	5,611	988.1	-	-	
1.69	5,545	988.0	-	-	
1.53	5,020	987.5	-	-	
1.50	4,922	987.4	-	-	Hamman Fenceline / WQ Station B
1.49	4,889	987.4	-	-	
1.32	4,331	987.3	-	-	Rock Outcrop #1 (upstream)
1.32	4,331	986.7	-	-	Rock Outcrop #1 (downstream)
1.31	4,298	-	14.3	1.4	Width RJB-8
1.29	4,232	986.7	-	-	Rock Outcrop #2 (upstream)
1.29	4,232	985.9	-	-	Rock Outcrop #2 (downstream)
1.12	3,675	985.9	-	-	Debris Dam #2 (upstream)

TABLE 1 SUMMARY OF PHYSICAL MEASUREMENTS AND LOCATIONS, cont'd.

Stream Distance (km)	Stream Distance (feet)	Water Surface Elevation (feet MSL)	Water Surface Width (feet)	Water Depth (feet)	Location Description
1.12	3,675	985.6	-	-	Debris Dam #2 (downstream)
1.06	3,478	-	13.5	2.1	Pipeline Crossing / WQ Station B2
1.06	3,478	-	13.5	2.1	Pipeline Crossing / Width RJB-7
0.97	3,183	985.6	19.9	3.4	Debris Dam #3 (upstream) / Width RJB-6
0.97	3,183	984.7	-	-	Debris Dam #3 (downstream)
0.95	3,117	-	19.0	1.3	Width RJB-5
0.87	2,854	-	24.0	1.8	Width RJB-4
0.77	2,526	-	-	-	Iron Bridge (Elev=988.5') / WQ Station C
0.75	2,461	-	18.8	1.0	Width RJB-3
0.62	2,034	-	26.2	2.0	Width RJB-2
0.47	1,542	-	25.4	1.6	Width RJB-1
0.18	591	984.7	-	-	
0.00	0	984.7	-	-	Mouth of creek at Johnson Lake

TABLE 2 FIELD MEASUREMENTS OF LITTLE CLEVELAND CREEK

Sampling Date: September 10-11, 1996

Sampling Station	Time	Water Temperature Degrees C	pH	Dissolved Oxygen mg/L	Specific Conductivity	Oxyidation Reduction Potential
A	1707	27.0	9.0	7.4	0.787	0.202
	2013	25.8	8.6	3.7	0.800	0.209
	2305	25.3	8.5	2.5	0.803	0.264
	0513	24.3	8.4	2.1	0.806	0.293
	0803	24.0	8.3	1.2	0.815	0.308
	1114	25.2	8.5	2.7	0.801	0.302
	1402	26.8	8.9	6.9	0.793	0.250
	Diurnal Avg	25.4	8.6	3.6	0.801	0.263
A2	1713	26.4	9.0	7.5	0.787	0.200
	2017	25.7	8.7	4.2	0.787	0.201
	2309	25.3	8.7	3.5	0.791	0.252
	0517	24.5	8.5	2.5	0.794	0.261
	0807	24.2	8.4	2.5	0.799	0.277
	1118	25.2	8.6	4.7	0.788	0.267
	1406	26.1	8.9	7.2	0.783	0.233
	Diurnal Avg	25.3	8.7	4.4	0.790	0.243
A3	1740	26.4	8.1	7.4	0.816	0.228
	2030	25.7	8.1	4.1	0.825	0.222
	2321	24.6	7.9	2.3	0.831	0.283
	0530	22.9	7.9	2.0	0.836	0.327
	0817	22.3	7.9	2.1	0.839	0.347
	1128	23.6	8.0	4.4	0.830	0.340
	1423	25.7	8.3	7.8	0.822	0.284
	Diurnal Avg	24.4	8.0	4.0	0.829	0.292
B	1751	24.7	7.9	6.6	0.815	0.257
	2043	24.4	7.9	5.2	0.825	0.234
	2336	24.0	7.8	3.5	0.829	0.300
	0550	22.7	7.7	2.2	0.817	0.285
	0828	22.3	7.8	2.0	0.831	0.360
	1142	23.0	7.9	3.4	0.832	0.363
	1433	24.0	8.0	5.9	0.828	0.326
	Diurnal Avg	23.6	7.8	4.0	0.825	0.302

TABLE 2 FIELD MEASUREMENTS OF LITTLE CLEVELAND CREEK, cont'd.

Sampling Station	Time	Water Temperature	pH	Dissolved Oxygen mg/L	Specific Conductivity	Oxyidation Reduction Potential
B2	1918	24.8	7.9	6.1	0.815	0.205
	0031	23.6	7.8	4.3	0.820	0.283
	0647	22.6	7.6	1.9	0.825	0.328
	1234	23.6	7.8	3.4	0.820	0.355
	Diurnal Avg	23.7	7.8	3.9	0.820	0.293
C	1901	25.2	7.5	2.3	0.805	0.213
	2122	24.8	7.7	1.7	0.808	0.229
	0016	24.1	7.5	1.5	0.812	0.237
	0632	22.6	7.5	1.1	0.818	0.266
	0903	22.3	7.7	1.2	0.820	0.354
	1223	23.6	7.7	1.8	0.818	0.383
	1526	24.0	7.8	2.2	0.822	0.361
	Diurnal Avg	23.7	7.6	1.6	0.815	0.287

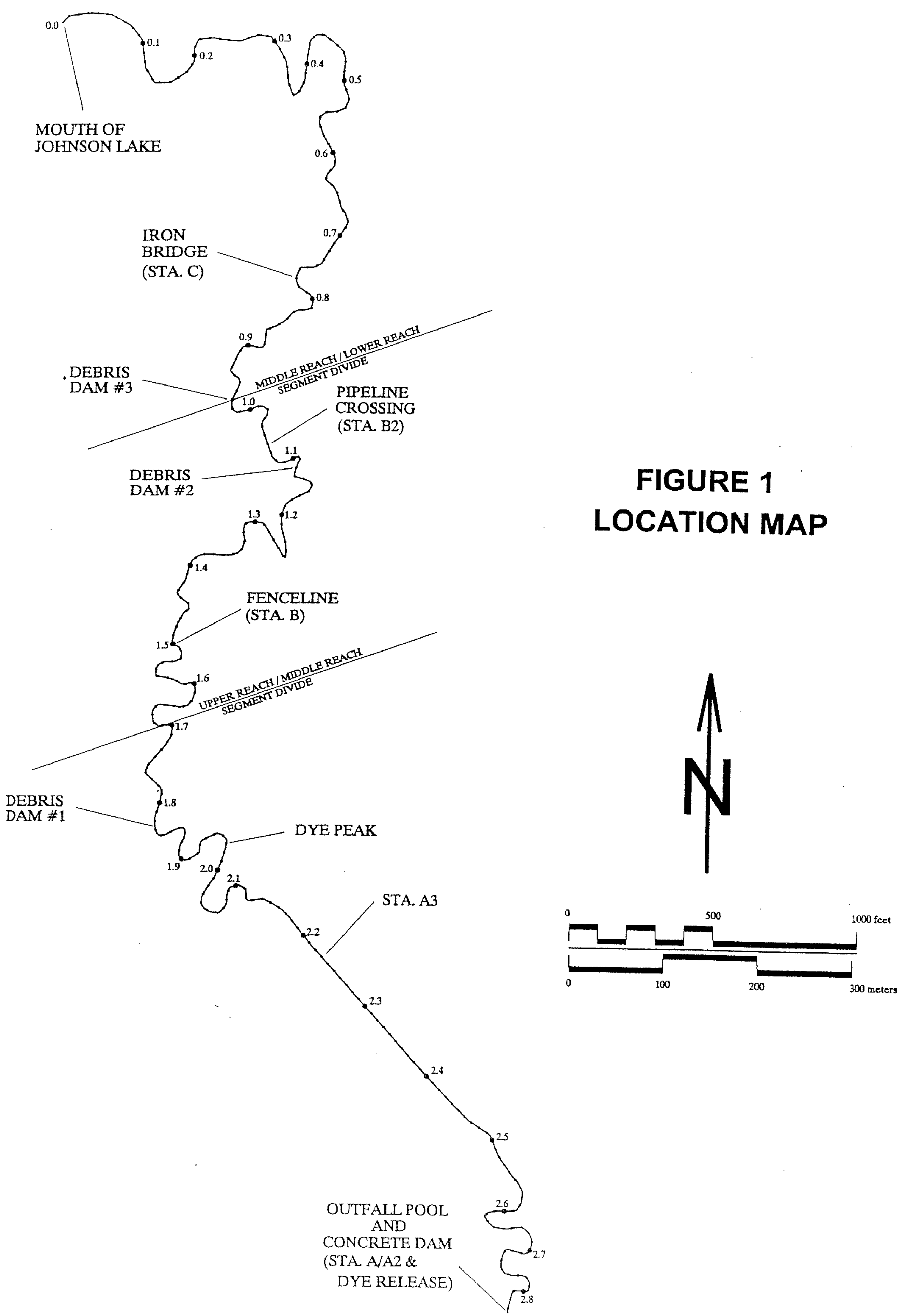
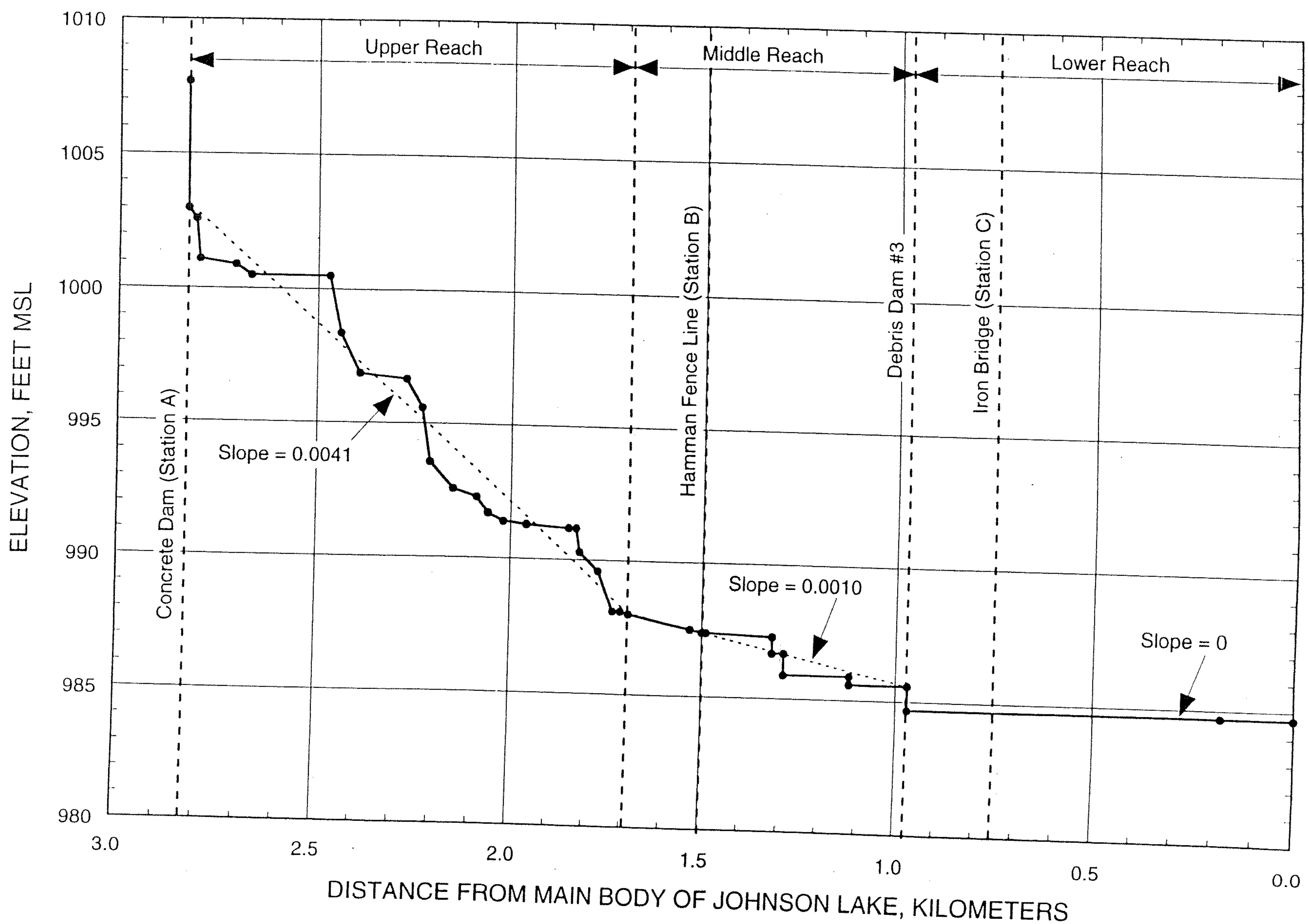


FIGURE 1
LOCATION MAP

FIGURE 2 WATER SURFACE PROFILE



	Location* kilometers	Width feet	Width meters
Width #1	2.76	3.0	0.91
Width #2	2.23	10.0	3.05
Width #3	1.94	14.5	4.42

* Location refers to distance upstream from the main body of Johnson Lake.

The dye plume was observed to travel approximately 2,800 feet in 14.5 hours resulting in an average velocity of 0.0540 fps or 0.0165 m/sec. The average width of the stream channel along the stream reach where the dye study was conducted was determined to be 9.2 feet or 2.8 meters. Based on the streamflow that was measured at the time of dye release (0.229 cfs or 0.00649 cu m/s), the average depth in the stream can be calculated by dividing the flow by the velocity and width. The average depth calculated in this manner is 0.46 feet or 0.14 meters.

Another dye release to determine the velocity in the stream between Station B and Johnson Lake was determined to be impractical for the scope of this study due to the length of time it would take for the dye to travel through this sluggish reach of the creek. Instead, numerous cross-sections were taken to determine the width and depth of the stream between Station B and Johnson Lake. By using the cross-sectional area computed from these measurements combined with the average flow of 0.254 cfs (0.00719 cu m/s) at Station B, the average velocity of the flow has been determined. The actual channel cross-sectional measurements are listed in Table 3 by station number. A summary of the measured channel widths and average depths and the calculated velocities for the middle reach and the lower reach of the creek is presented in the following table.

Station	Location kilometers	Width feet	Width meters	Depth feet	Depth meters	Velocity fps	Velocity m/s
Middle Reach							
RJB-8	1.31	14.3	4.36	1.4	0.43		
RJB-7	1.06	13.5	4.11	2.1	0.64		
Average		13.9	4.24	1.8	0.54	0.010	0.00314
Lower Reach							
RJB-6	0.97	19.9	6.07	3.4	1.04		
RJB-5	0.95	19.0	5.79	1.3	0.40		
RJB-4	0.87	24.0	7.32	1.8	0.55		
RJB-3	0.75	18.8	5.73	1.0	0.30		
RJB-2	0.62	26.2	7.99	2.0	0.61		
RJB-1	0.47	25.4	7.74	1.6	0.49		
Average		22.2	6.77	1.8	0.57	0.006	0.00186

The sluggishness of the flow in these reaches is apparent from the extremely low velocities indicated in the above table. The velocity in the lower reach is indicative of backwater conditions as influenced by Johnson Lake.

WATER QUALITY MODELING

A simple Streeter-Phelps dissolved oxygen model of Little Cleveland Creek has been developed to evaluate the impacts of various effluent levels discharged from the Jacksboro WWTP. In structuring this model, the stream has been divided into three segments based on visual observations and the field survey data. The upper segment extends from just below the Concrete Dam at Station A2 to just above the Hamman fence line at Station B (Kilometer 1.7). The middle segment extends from Kilometer 1.7 to Kilometer 1.0 near Debris Dam #3. The lower segment extends from Debris Dam #3 to the main body of Johnson Lake at Kilometer 0.0; however, as described above, this lower segment actually is influenced by backwater from Johnson Lake and, in fact, is part of the headwaters of Johnson Lake.

In the upper reach of the model, the exponential relationships between flow and depth and flow and velocity were calculated based on the average values of velocity, depth, and flow from the dye study. In the middle and lower reaches, the relationships were based on the measured depths and widths. Because only one flow condition was observed during the field survey, it was necessary to set the exponents and then solve for the coefficients. For the upper reach, the coefficients in these equations were developed using the typical TNRCC default exponents of 0.5 (velocity) and 0.4 (depth). In the middle reach, the velocity exponent was set to 0.8, and the depth exponent was set to 0.1 because of the numerous pools present and their effect on the hydraulics. For the lower reach where the hydraulics are controlled by backwater from Johnson Lake, the exponent for velocity was set to 1.0 and the exponent for depth was set to 0.0 since width and depth were assumed to remain constant at the flows being modeled. The resulting coefficients and exponents as specified in the model are listed below:

	Velocity Coefficient	Velocity Exponent	Depth Coefficient	Depth Exponent
Upper Reach	0.205	0.500	1.050	0.400
Middle Reach	0.163	0.800	0.885	0.100
Lower Reach	0.259	1.000	0.570	0.000

Because the Streeter-Phelps model allows only one exponential equation, the velocities and depths at the different flow conditions were calculated manually for the middle and lower reaches and then input to the model. The same biological coefficients used by the TNRCC in its previous water quality modeling of Little Cleveland Creek also were specified in the model developed and applied in this investigation.

Three different effluent conditions for the Jacksboro WWTP have been evaluated with the Street-Phelps model of Little Cleveland Creek. The first two correspond to the Interim and Final permit effluent limitations as approved by the TNRCC. The third is an assumed Advanced

Treatment effluent condition. Because the upper limit of the model corresponds to a point on the creek just below the Concrete Dam near the WWTP outfall, an increase of 0.8 mg/L has been added to the effluent dissolved oxygen concentration in the model to account for the reaeration that occurs as the flow passes over the dam as observed during the sampling survey. The three different effluent sets evaluated are summarized in the following table.

Effluent Set	Flow (MGD)	Effluent BOD_5 (mg/L)	Effluent NH_3-N (mg/L)	Effluent Dissolved Oxygen (mg/L)	Headwater Dissolved Oxygen (mg/L)
Interim	0.65	30	5	4	4.8
Final	0.70	10	3	4	4.8
Advanced Treatment	0.70	5	2	6	6.8

Tables 4, 5 and 6 present the printout of the results from the model simulations corresponding to the Interim, Final and Advanced Treatment effluent sets, respectively. Listed below are the minimum values of the simulated dissolved oxygen concentration for each of the three effluent sets for different reaches of the creek. In this table, the upper and middle reaches of the creek as defined in this investigation and in the model represent true stream reaches, whereas the lower reach actually is part of Johnson Lake since it is in the backwater of the reservoir. Comparison of these simulated minimum dissolved oxygen levels with the TNRCC dissolved oxygen standards for Little Cleveland Creek and Johnson Lake indicates violations of the standards for all reaches under the Interim and Final effluent sets and for the lower reach under the Advanced Treatment effluent set assuming this lower reach is subject to the Johnson Lake criteria.

Effluent Set	Simulated Minimum Dissolved Oxygen Concentrations	
	Upper & Middle Reaches Above Km 1.0 (mg/L)	Lower Reach Below Km 1.0 (mg/L)
Interim	0.00	0.00
Final	1.48	1.39
Advanced Treatment	4.01	3.94

Water Body	Dissolved Oxygen Standards Adopted by TNRCC	
	Upper & Middle Reaches Above Km 1.0 (mg/L)	Lower Reach Below Km 1.0 (mg/L)
Little Cleveland Creek	3.0	3.0
Johnson Lake	n. a.	5.0

FIGURE 3 PLOT OF DISSOLVED OXYGEN MEASUREMENTS

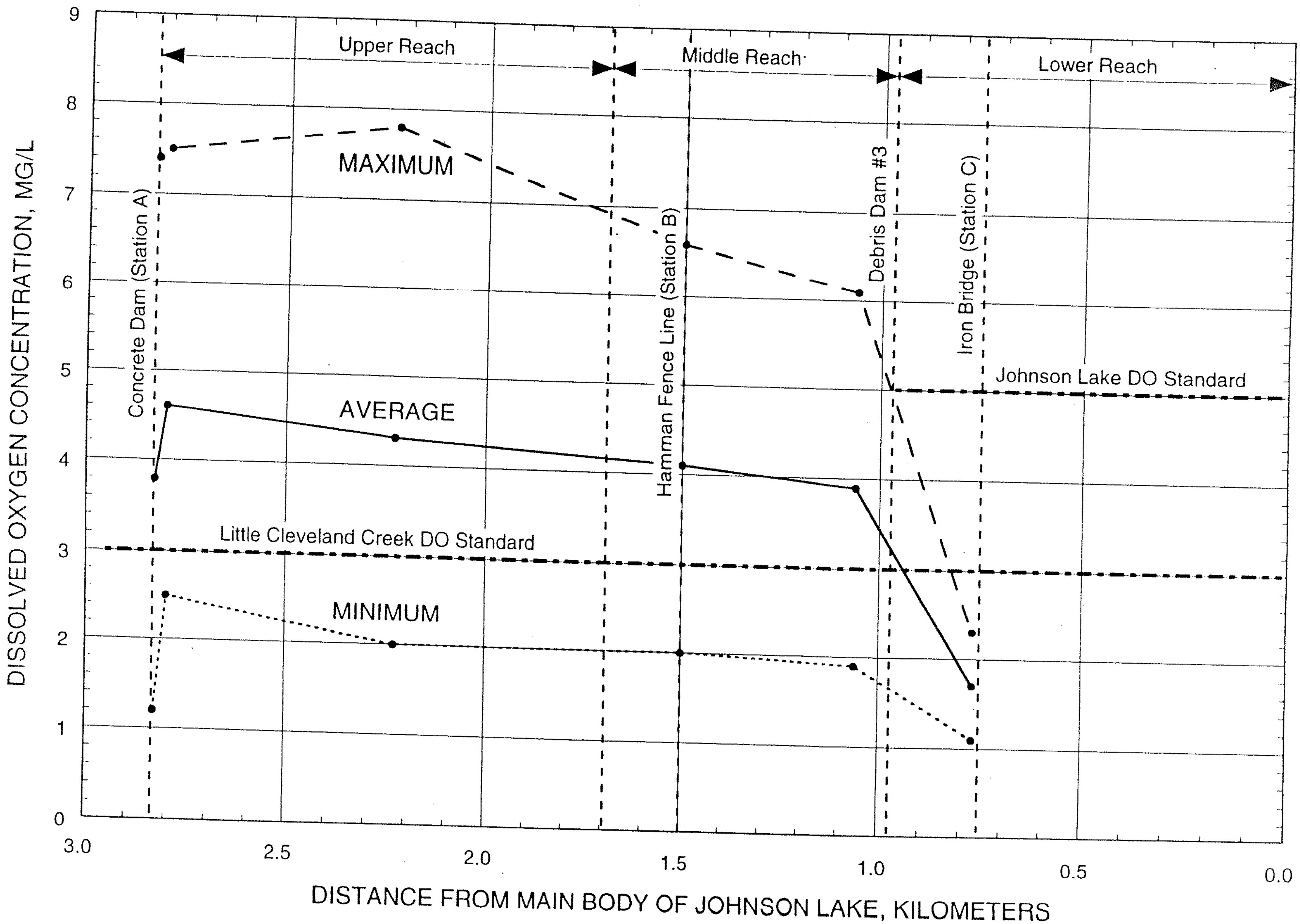


TABLE 3 CROSS-SECTION MEASUREMENTS OF LITTLE CLEVELAND CREEK

Sampling Date: September 10-11, 1996

Station																
RJB-8	Distance	2.0	3.0	4.0	6.0	8.0	10.0	12.0	14.0	15.0	16.0	16.3				
	Depth	0.0	0.9	1.7	1.9	1.7	1.7	1.3	1.4	1.1	0.9	0.8				
RJB-7	Distance	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	16.5
	Depth	0.0	2.4	2.6	2.6	2.7	2.6	2.6	2.5	2.4	2.0	1.9	1.7	1.3	1.3	0.0
RJB-6	Distance	3.6	5.0	7.0	9.0	11.0	13.0	15.0	17.0	19.0	21.0	23.0	23.5			
	Depth	1.6	2.0	2.6	4.6	5.1	5.0	4.7	4.0	3.2	1.7	0.5	0.0			
RJB-5	Distance	5.5	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	23.8	24.5				
	Depth	0.3	0.7	1.1	1.3	1.3	1.7	1.7	1.7	1.6	0.8	0.8				
RJB-4	Distance	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	25.0	27.0	28.0	
	Depth	0.6	0.6	0.9	1.2	1.8	2.0	2.2	2.4	2.6	2.5	2.3	2.3	1.8	1.7	
RJB-3	Distance	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	22.8				
	Depth	0.6	1.3	1.6	1.5	1.2	0.9	0.6	0.7	0.7	0.3	0.0				
RJB-2	Distance	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	39.2	40.2
	Depth	0.2	1.9	2.4	2.6	2.9	3.0	3.0	2.6	2.3	1.9	1.7	0.9	0.7	0.8	0.0
RJB-1	Distance	3.8	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	29.2	
	Depth	0.0	1.0	0.7	1.7	2.0	2.5	3.0	2.6	2.3	1.9	1.5	0.8	0.3	0.4	

Note: Distances and depths are in feet. The first distance measurement is the edge of water at the left bank looking downstream (west bank).

TABLE 4
MODEL OUTPUT FROM INTERIM EFFLUENT SET SIMULATION

TEXAS WATER COMMISSION
SIMPLIFIED STREETER-PHELPS STREAM MODEL

LITTLE CLEVELAND CREEK
JACKSBORO WWTP AT 0.65 MGD / 30 BOD5 / 5 NH3 / 4 DO INTERIM.DAT

METRIC UNITS
NO. OF STREAM SEGMENTS = 3
STEP SIZE = .10 KILOMETERS
MODEL ANALYSIS CEASES AT STREAM DISTANCE .00 KILOMETERS
K2 CALCULATED BY THE TEXAS REAERATION EQUATION
HYDRAULICS CALCULATED BY EQUATIONS V= .205*Q** .500 D= 1.050*Q** .400

DIST KM	KD 1/DA	KS 1/DA	KN 1/DA	DEPTH M	WIDTH M	VELO M/S	TEMP DEG C	FLOW CMS	BOD MG/L	NH3 MG/L	DO MG/L
2.80	.10	.00	.30	.25	3.25	.03	30.00	.02848	69.00	5.00	4.80
1.70	.10	.00	.30	.62	4.86	.01	30.00	.00000	.00	.00	.00
1.00	.10	.00	.30	.57	6.77	.01	30.00	.00000	.00	.00	.00

DIST KM	DO MG/L	BOD MG/L	NH3 MG/L	FLOW CMS	DOSAT MG/L	K2 1/DA	KD 1/DA	KS 1/DA	KN 1/DA
2.80	4.80	69.00	5.00	.02848	7.54	3.16	.16	.00	.67
2.70	4.28	68.64	4.89	.02848	7.54	3.16	.16	.00	.67
2.60	3.82	68.27	4.78	.02848	7.54	3.16	.16	.00	.67
2.50	3.41	67.91	4.68	.02848	7.54	3.16	.16	.00	.67
2.40	3.06	67.55	4.57	.02848	7.54	3.16	.16	.00	.67
2.30	2.76	67.20	4.47	.02848	7.54	3.16	.16	.00	.67
2.20	2.50	66.84	4.37	.02848	7.54	3.16	.16	.00	.67
2.10	2.27	66.49	4.28	.02848	7.54	3.16	.16	.00	.67
2.00	2.08	66.14	4.18	.02848	7.54	3.16	.16	.00	.67
1.90	1.92	65.79	4.09	.02848	7.54	3.16	.16	.00	.67
1.80	1.78	65.44	4.00	.02848	7.54	3.16	.16	.00	.67
1.70	1.67	65.10	3.91	.02848	7.54	3.16	.16	.00	.67
1.70	1.67	65.10	3.91	.02848	7.54	.99	.16	.00	.67
1.60	.00	63.85	3.61	.02848	7.54	.99	.16	.00	.67
1.50	.00	62.62	3.32	.02848	7.54	.99	.16	.00	.67
1.40	.00	61.42	3.06	.02848	7.54	.99	.16	.00	.67
1.30	.00	60.24	2.82	.02848	7.54	.99	.16	.00	.67
1.20	.00	59.09	2.60	.02848	7.54	.99	.16	.00	.67
1.10	.00	57.95	2.40	.02848	7.54	.99	.16	.00	.67
1.00	.00	56.84	2.21	.02848	7.54	.99	.16	.00	.67
1.00	.00	56.84	2.21	.02848	7.54	1.00	.16	.00	.67
.90	.00	55.45	1.99	.02848	7.54	1.00	.16	.00	.67
.80	.00	54.09	1.80	.02848	7.54	1.00	.16	.00	.67
.70	.00	52.76	1.62	.02848	7.54	1.00	.16	.00	.67
.60	.00	51.47	1.46	.02848	7.54	1.00	.16	.00	.67
.50	.00	50.21	1.31	.02848	7.54	1.00	.16	.00	.67
.40	.00	48.98	1.18	.02848	7.54	1.00	.16	.00	.67
.30	.00	47.78	1.07	.02848	7.54	1.00	.16	.00	.67
.20	.00	46.60	.96	.02848	7.54	1.00	.16	.00	.67
.10	.00	45.46	.86	.02848	7.54	1.00	.16	.00	.67
.00	.00	44.35	.78	.02848	7.54	1.00	.16	.00	.67

MINIMUM DISSOLVED OXYGEN = .00

TABLE 5
MODEL OUTPUT FROM FINAL EFFLUENT SET SIMULATION

TEXAS WATER COMMISSION
SIMPLIFIED STREETER-PHELPS STREAM MODEL

LITTLE CLEVELAND CREEK
JACKSBORO WWTP AT 0.70 MGD / 10 BOD5 / 3 NH3 /4 DO FINAL.DAT

METRIC UNITS
NO. OF STREAM SEGMENTS = 3
STEP SIZE = .10 KILOMETERS
MODEL ANALYSIS CEASES AT STREAM DISTANCE .00 KILOMETERS
K2 CALCULATED BY THE TEXAS REAERATION EQUATION
HYDRAULICS CALCULATED BY EQUATIONS V= .205*Q** .500 D= 1.050*Q** .400

DIST KM	KD 1/DA	KS 1/DA	KN 1/DA	DEPTH M	WIDTH M	VELO M/S	TEMP DEG C	FLOW CMS	BOD MG/L	NH3 MG/L	DO MG/L
2.80	.10	.00	.30	.26	3.28	.04	30.00	.03067	23.00	3.00	4.80
1.70	.10	.00	.30	.63	4.89	.01	30.00	.00000	.00	.00	.00
1.00	.10	.00	.30	.57	6.78	.01	30.00	.00000	.00	.00	.00

DIST KM	DO MG/L	BOD MG/L	NH3 MG/L	FLOW CMS	DOSAT MG/L	K2 1/DA	KD 1/DA	KS 1/DA	KN 1/DA
2.80	4.80	23.00	3.00	.03067	7.54	3.10	.16	.00	.67
2.70	4.69	22.88	2.94	.03067	7.54	3.10	.16	.00	.67
2.60	4.59	22.77	2.87	.03067	7.54	3.10	.16	.00	.67
2.50	4.51	22.65	2.81	.03067	7.54	3.10	.16	.00	.67
2.40	4.44	22.54	2.75	.03067	7.54	3.10	.16	.00	.67
2.30	4.39	22.42	2.69	.03067	7.54	3.10	.16	.00	.67
2.20	4.34	22.31	2.64	.03067	7.54	3.10	.16	.00	.67
2.10	4.31	22.19	2.58	.03067	7.54	3.10	.16	.00	.67
2.00	4.28	22.08	2.53	.03067	7.54	3.10	.16	.00	.67
1.90	4.27	21.97	2.47	.03067	7.54	3.10	.16	.00	.67
1.80	4.26	21.86	2.42	.03067	7.54	3.10	.16	.00	.67
1.70	4.25	21.74	2.37	.03067	7.54	3.10	.16	.00	.67
1.70	4.25	21.74	2.37	.03067	7.54	1.00	.16	.00	.67
1.60	3.52	21.35	2.19	.03067	7.54	1.00	.16	.00	.67
1.50	2.93	20.97	2.03	.03067	7.54	1.00	.16	.00	.67
1.40	2.47	20.59	1.88	.03067	7.54	1.00	.16	.00	.67
1.30	2.10	20.21	1.74	.03067	7.54	1.00	.16	.00	.67
1.20	1.82	19.85	1.61	.03067	7.54	1.00	.16	.00	.67
1.10	1.62	19.49	1.49	.03067	7.54	1.00	.16	.00	.67
1.00	1.48	19.14	1.38	.03067	7.54	1.00	.16	.00	.67
1.00	1.48	19.14	1.38	.03067	7.54	1.02	.16	.00	.67
.90	1.40	18.70	1.26	.03067	7.54	1.02	.16	.00	.67
.80	1.39	18.27	1.14	.03067	7.54	1.02	.16	.00	.67
.70	1.43	17.86	1.03	.03067	7.54	1.02	.16	.00	.67
.60	1.51	17.45	.94	.03067	7.54	1.02	.16	.00	.67
.50	1.62	17.05	.85	.03067	7.54	1.02	.16	.00	.67
.40	1.77	16.66	.77	.03067	7.54	1.02	.16	.00	.67
.30	1.92	16.28	.70	.03067	7.54	1.02	.16	.00	.67
.20	2.09	15.91	.64	.03067	7.54	1.02	.16	.00	.67
.10	2.27	15.55	.58	.03067	7.54	1.02	.16	.00	.67
.00	2.46	15.19	.52	.03067	7.54	1.02	.16	.00	.67

MINIMUM DISSOLVED OXYGEN = 1.39

TABLE 6
MODEL OUTPUT FROM ADVANCED TREATMENT EFFLUENT SET SIMULATION

TEXAS WATER COMMISSION
SIMPLIFIED STREETER-PHELPS STREAM MODEL

LITTLE CLEVELAND CREEK
JACKSBORO WWTP AT 0.70 MGD / 5 BOD5 / 2 NH3 /6 DO ADVNCD.DAT

METRIC UNITS
NO. OF STREAM SEGMENTS = 3
STEP SIZE = .10 KILOMETERS
MODEL ANALYSIS CEASES AT STREAM DISTANCE .00 KILOMETERS
K2 CALCULATED BY THE TEXAS REAERATION EQUATION
HYDRAULICS CALCULATED BY EQUATIONS V= .205*Q** .500 D= 1.050*Q** .400

DIST KM	KD 1/DA	KS 1/DA	KN 1/DA	DEPTH M	WIDTH M	VELO M/S	TEMP DEG C	FLOW CMS	BOD MG/L	NH3 MG/L	DO MG/L
2.80	.10	.00	.30	.26	3.28	.04	30.00	.03067	11.50	2.00	6.80
1.70	.10	.00	.30	.63	4.89	.01	30.00	.00000	.00	.00	.00
1.00	.10	.00	.30	.57	6.78	.01	30.00	.00000	.00	.00	.00

DIST KM	DO MG/L	BOD MG/L	NH3 MG/L	FLOW CMS	DOSAT MG/L	K2 1/DA	KD 1/DA	KS 1/DA	KN 1/DA
2.80	6.80	11.50	2.00	.03067	7.54	3.10	.16	.00	.67
2.70	6.64	11.44	1.96	.03067	7.54	3.10	.16	.00	.67
2.60	6.50	11.38	1.92	.03067	7.54	3.10	.16	.00	.67
2.50	6.38	11.33	1.88	.03067	7.54	3.10	.16	.00	.67
2.40	6.27	11.27	1.84	.03067	7.54	3.10	.16	.00	.67
2.30	6.17	11.21	1.80	.03067	7.54	3.10	.16	.00	.67
2.20	6.09	11.15	1.76	.03067	7.54	3.10	.16	.00	.67
2.10	6.02	11.10	1.72	.03067	7.54	3.10	.16	.00	.67
2.00	5.96	11.04	1.68	.03067	7.54	3.10	.16	.00	.67
1.90	5.91	10.98	1.65	.03067	7.54	3.10	.16	.00	.67
1.80	5.87	10.93	1.61	.03067	7.54	3.10	.16	.00	.67
1.70	5.83	10.87	1.58	.03067	7.54	3.10	.16	.00	.67
1.70	5.83	10.87	1.58	.03067	7.54	1.00	.16	.00	.67
1.60	5.36	10.68	1.46	.03067	7.54	1.00	.16	.00	.67
1.50	4.97	10.48	1.35	.03067	7.54	1.00	.16	.00	.67
1.40	4.67	10.29	1.25	.03067	7.54	1.00	.16	.00	.67
1.30	4.42	10.11	1.16	.03067	7.54	1.00	.16	.00	.67
1.20	4.24	9.92	1.08	.03067	7.54	1.00	.16	.00	.67
1.10	4.11	9.74	1.00	.03067	7.54	1.00	.16	.00	.67
1.00	4.01	9.57	.92	.03067	7.54	1.00	.16	.00	.67
1.00	4.01	9.57	.92	.03067	7.54	1.02	.16	.00	.67
.90	3.96	9.35	.84	.03067	7.54	1.02	.16	.00	.67
.80	3.94	9.14	.76	.03067	7.54	1.02	.16	.00	.67
.70	3.96	8.93	.69	.03067	7.54	1.02	.16	.00	.67
.60	4.01	8.72	.63	.03067	7.54	1.02	.16	.00	.67
.50	4.08	8.53	.57	.03067	7.54	1.02	.16	.00	.67
.40	4.17	8.33	.52	.03067	7.54	1.02	.16	.00	.67
.30	4.27	8.14	.47	.03067	7.54	1.02	.16	.00	.67
.20	4.37	7.96	.42	.03067	7.54	1.02	.16	.00	.67
.10	4.49	7.77	.39	.03067	7.54	1.02	.16	.00	.67
.00	4.60	7.60	.35	.03067	7.54	1.02	.16	.00	.67

MINIMUM DISSOLVED OXYGEN = 3.94

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 4/20/00 -1999

Loc-ation	AM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:32	21.6	9.18	7.80	
A	8:37	19.8	5.85	7.74	WATER MURKY FROM RAIN FALL
A2	8:40	19.4	7.50	7.84	" " " "
A3-100'	8:43	19.4	4.90	7.75	" " " "
A3	8:45	19.4	5.15	7.77	" " " "
A3n	8:50	18.9	3.77	7.76	" " " "
B	8:54	19.8	2.99	7.78	" " " "
B1e	9:00	19.3	3.28	7.75	" " " "
B1f	9:02	19.4	3.35	7.78	" " " "
B2	9:10	19.5	2.14	7.72	" " " "
C	9:14	19.2	1.95	7.70	" " " "
C1c	9:19	19.3	2.30	7.68	" " " "
C1e	9:23	19.5	2.37	7.61	" " " "

OTHER CONDITIONS

weather conditions:
temperature: 60
cloudy/clear: CLEAR
wind: NW 10 MPH

flow in creek above wwtp discharge (yes/none): -0-

flow depth at center of concrete dam (Sta A): 1 inch

METER CALIBRATION

	pH	D.O.
standard	7.00	7.52
calibration	6.99	7.60
standard	10.00	
calibration	10.00	

Certification:

[signature] (signature)

4/20/00 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 3-24-2000 -1999

Location	Pm time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:14	20.4	9.89	7.77	
A	1:18	20.6	10.34	7.90	Fish
A2	1:21	20.6	10.27	7.92	
A3-100'	1:24	20.2	9.54	7.98	minnows
A3	1:26	20.4	9.70	7.96	
A3n	1:30	18.7	9.06	7.97	
B	1:34	17.9	12.09	7.86	
B1e	1:39	18.7	12.02	7.95	
B1f	1:41	18.7	12.20	7.98	
B2	1:48	19.0	9.81	7.91	
C	1:53	18.9	5.45	7.86	
C1c	1:58	20.8	4.82	7.80	
C1e	2:02	19.4	11.98	7.97	

OTHER CONDITIONS

weather conditions:
temperature: 76
cloudy/clear: P.C.
wind: 20 mph W.

flow in creek above wwtp discharge (yes/none): NONE

flow depth at center of concrete dam (Sta A): 1"

METER CALIBRATION

	pH	D.O.
standard	7.00	6.75
calibration	7.00	6.62
standard	10.00	
calibration	10.02	

certification:
[signature] (signature)
3-24-2000 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 2-17-00 -1999

Location	time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:12"	17.7	10.00	7.64	
A	8:20"	15.4	8.56	7.82	
A2	8:30"	15.5	8.24	7.82	
A3-100'	8:40"	15.4	7.35	7.71	
A3	8:42"	13.4	7.40	7.75	
A3n	8:45"	12.3	7.22	7.87	
B	8:50"	12.2	6.75	8.02	
Ble	9:0"	12.1	9.15	8.10	
BIF	9:05"	12.0	7.48	8.20	
B2	9:10"	11.9	8.97	8.25	
C	9:15"	12.0	10.50	8.34	
Clc	9:20"	12.8	9.50	8.52	
Cle	9:25"	13.2	5.48	7.98	

OTHER CONDITIONS

weather conditions:

temperature: 65

cloudy/~~clear~~:

wind: Calm

flow in creek above wwtp discharge (yes/~~none~~): NONE

flow depth at center of concrete dam (Sta A): 1 inch

METER CALIBRATION

	pH	D.O.
standard	4.00	6.60
calibration	4.00	6.48
standard	7.00	
calibration	7.02	

Certification:

[signature] (signature)

2-17-00 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 1/20/00 -1999

Location	PM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:10	17.4	8.80	7.85	
A	1:15	15.1	8.45	7.75	
A2	1:17	13.1	10.02	7.90	
A3-100'	1:23	12.2	12.74	8.08	
A3	1:25	12.0	13.02	8.10	
A3n	1:28	13.0	14.88	8.15	
B	1:35	10.0	14.65	7.78	BEAVER DAM JUST BElow B
B1c	1:39	10.7	17.02	7.66	
B1f	1:40	10.5	17.28	7.63	
B2	1:49	10.3	16.03	7.63	
C	1:53	10.3	17.30	7.55	
C1c	1:59	10.9	16.40	7.68	
C1e	2:03	11.5	14.99	8.06	

OTHER CONDITIONS

weather conditions:
temperature: 45°
cloudy/clear: CLEAR
wind: N 5 mph

flow in creek above wwtp discharge (yes/none): NONE

flow depth at center of concrete dam (Sta A): 2.0"

METER CALIBRATION

	pH	D.O.
standard	7.00	7.10
calibration	7.01	7.20
standard	10.00	
calibration	10.02	

Certification:

[signature] (signature)

1/20/00 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 12/16/99 -1999

Loc-ation	A.M., time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:48	16.1	7.38	7.43	
A	8:52	10.4	5.50	7.65	
A2	8:54	10.0	7.50	7.75	
A3-100'	9:00	7.3	8.40	7.36	
A3	9:04	7.3	8.45	7.24	
A3n	9:09	6.3	8.59	7.20	
B	9:11	6.3	8.90	7.20	
B1e	9:16	6.0	9.01	7.42	
B1f	9:18	6.0	9.25	7.43	
B2	9:27	5.9	8.68	7.36	18" high BEAVER DAM above
C	9:32	5.9	7.68	7.24	IRON BRIDGE
C1c	9:38	6.0	8.44	7.15	30" high BEAVER DAM in
C1e	9:45	5.0	8.08	7.11	BEND ABOVE C1E

OTHER CONDITIONS
weather conditions:
temperature: 40°
cloudy/clear: CLEAR
wind: SW 5 mph

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): 2.0"

METER CALIBRATION

	pH	D.O.
standard	7.00	7.40
calibration	7.01	7.48
standard	10.00	
calibration	10.06	

certification:
[signature] (signature)
12/16/99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 11/30/99 -1999

Location	PM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:19	20.5	9.61	7.81	
A	1:24	16.9	8.72	7.81	
A2	1:28	16.2	10.39	8.09	minwows
A3-100'	1:33	14.2	11.95	7.70	
A3	1:35	14.1	11.99	7.73	
A3n	1:38	12.0	11.45	7.71	
B	1:43	11.3	9.40	7.58	
B1e	1:49	11.6	10.50	7.62	
B1f	1:51	11.6	10.62	7.62	
B2	1:59	11.2	5.49	7.57	BEAVER DAM HAS WATER BACKED
C	2:03	10.8	7.46	7.45	UP 18" DEEPER THAN NORMAL FROM C TO ABOVE B2
C1c	2:13	11.6	8.22	7.49	
C1e	2:16	12.9	10.80	7.62	

good Flow All The WAY To LAKE

OTHER CONDITIONS
weather conditions:
temperature: 55
cloudy/clear: CLEAR
wind: 5 mph

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): 2.0 in.

METER CALIBRATION

	pH	D.O.
standard	7.00	6.80
calibration	7.00	6.83
standard	10.00	
calibration	10.02	

Certification:
[signature] (signature)
11/30/99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 10-21-99 -1999

Location	AM time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:29	22.9	9.00	7.85	minnows
A	8:33	17.5	5.59	7.63	
A2	8:36	17.0	8.03	7.58	minnows
A3-100'	8:40	15.8	8.50	7.08	
A3	8:43	15.8	9.50	7.12	
A3n	8:47	14.6	11.29	7.50	minnows
B	8:50	14.5	9.80	7.09	
B1c	8:57	14.0	15.00	6.88	minnows
B1f	9:00	13.9	15.48	7.00	minnows
B2	9:08	13.5	11.02	6.68	
C	9:14	13.3	9.43	6.51	
C1c	9:20	13.8	8.00	6.45	fish
C1c	9:25	13.5	8.20	6.45	minnows

good Flow All THE WAY TO LAKE. WATER murky BOTTOM TURNED OVER

OTHER CONDITIONS
weather conditions:
temperature: 60°
cloudy/clear: CLEAR
wind: CALM

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): .5 INCHES

METER CALIBRATION

	pH	D.O.
standard	7.00	6.83
calibration	6.99	6.80
standard	10.00	
calibration	10.00	

certification:
[signature] (signature)
10-21-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 9-30-99 -1999

Loc-ation	AM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	9:25	24.6	8.02	7.53	
A	9:30	19.6	6.07	7.44	MINNOWS
A2	9:32	17.4	6.77	7.08	MINNOWS
A3-100'	9:38	14.5	7.87	6.95	MINNOWS
A3	9:40	14.6	8.02	7.05	MINNOWS
A3n	9:44	14.9	7.37	6.97	MINNOWS
B	9:48	15.7	3.90	7.05	MINNOWS
Blc	9:55	16.1	5.24	7.29	MINNOWS
Blf	9:57	15.7	6.15	7.29	MINNOWS (VERY LOW FLOW)
B2	10:05	17.2	3.88	7.07	NO FLOW
C	10:10	16.2	7.70	7.19	NO FLOW
Clc	10:16	17.1	6.28	7.02	
Clc	10:21	16.1	8.39	7.70	MINNOWS

OTHER CONDITIONS

weather conditions:
temperature: 65
cloudy/clear: CLEAR
wind: S 5 mph

flow in creek above wwtp discharge (yes/none): NONE

flow depth at center of concrete dam (Sta A): 0

METER CALIBRATION

	pH	D.O.
standard	7.00	5.90
calibration	7.01	6.01
standard	10.00	
calibration	10.00	

certification:

[signature] (signature)

9-30-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 9-23-99 -1999

Location	Pm time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:31	26.5	6.82	7.60	minnows
A	1:40	22.9	6.47	7.49	
A2	1:43	23.0	7.50	7.43	minnows
A3-100'	1:48	20.4	8.44	7.45	minnows
A3	1:51	20.6	8.71	7.41	minnows
A3n	1:56	18.3	8.64	7.40	minnows
B	2:02	18.1	8.00	7.24	minnows
B1e	2:10	18.5	8.25	7.30	minnows
B1f	2:12	18.2	8.88	7.25	minnows
B2	2:20	19.0	7.99	7.24	
C	2:25	19.9	6.19	7.38	
C1c	2:33	21.9	9.15	7.40	minnows
C1e	2:38	21.8	11.96	7.42	minnows

WATER CLEAR ALL THE WAY FROM 001 TO C1E. SEE APPRO. 2.5' DEEP
GOOD FLOW ALL THE WAY TO LAKE.

OTHER CONDITIONS
weather conditions:
temperature: 80
cloudy/clear: PC
wind: S 5 mph

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): 1½"

METER CALIBRATION

	pH	D.O.
standard	7.00	6.50
calibration	6.99	6.52
standard	10.00	
calibration	10.00	

certification:
[signature] (signature)
9-23-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 9-17-99 -1999

Loc-ation	AM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:47	22.3	6.32	7.38	
A	8:53	23.8	3.50	7.31	minnows
A2	8:55	23.5	5.07	7.33	minnows
A3-100'	9:00	22.1	5.30	7.13	
A3	9:03	22.0	5.57	7.27	
A3n	9:08	21.5	5.76	7.08	
B	9:13	21.2	5.37	7.49	
B1c	9:20	21.2	5.51	7.31	
B1f	9:23	21.1	6.10	7.38	minnows
B2	9:33	21.2	5.05	7.17	minnows
C	9:37	21.1	4.97	7.29	minnows
C1c	9:43	21.4	4.48	7.07	
C1e	9:47	21.1	4.32	6.99	minnows

good flow all the way to lake

OTHER CONDITIONS
weather conditions:
temperature: 65
cloudy/clear: cloudy
wind: calm

flow in creek above wwtp discharge (yes/none): none
flow depth at center of concrete dam (Sta A): 1"

METER CALIBRATION

	pH	D.O.
standard	7.00	6.00
calibration	6.99	6.03
standard	10.00	
calibration	10.00	

Certification:
[signature] (signature)
9-17-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 9-10-99 -1999

Location	PM time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	12:18	29.3	7.84	7.34	minnows
A	12:22	26.9	4.98	7.30	minnows & Fish
A2	12:25	28.1	6.68	7.30	minnows
A3-100'	12:34	26.0	7.02	7.43	minnows
A3	12:31	26.3	7.04	7.44	minnows
A3n	12:39	22.1	7.11	7.47	minnows
B	12:48	25.1	3.03	7.30	minnows
B1c	12.57	25.6	7.60	7.41	minnows & Fish
* B1f	1:00	27.2	7.86	7.46	minnows & Fish
B2	1:11	25.9	3.59	7.28	minnows (no flow)
C	1:16	26.3	2.53	7.10	no Flow
C1c	1:23	26.9	7.52	7.30	
C1c	1:27	29.1	7.30	7.65	minnows (windy)

* Flow down to dribble; WATER clear & Running All the way Back To 001

OTHER CONDITIONS
weather conditions:
temperature: 90°
cloudy/clear: PC
wind: W: 15 mph

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): 0
8 off course pumping

METER CALIBRATION

	pH	D.O.
standard	7.00	5.50
calibration	7.01	5.50
standard	10.00	
calibration	10.01	

certification:
[signature] (signature)
9-10-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 9-2-99 -1999

Location	PM time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:38	30.2	6.40	7.52	minnows
A	1:55	28.3	4.10	7.35	minnows
A2	1:57	28.5	4.59	7.21	minnows
A3-100'	2:03	27.8	4.96	7.16	WATER murky (dozier 100)
A3	2:06	27.7	4.93	7.18	" " " "
A3n	2:12	26.6	4.80	7.20	" " " "
B	2:17	26.5	3.96	7.24	" " "
B1e	2.25	26.1	3.88	7.20	minnows (murky)
B1f	2:27	26.2	4.90	7.16	minnows "
B2	2:35	26.7	3.50	7.27	minnows "
C	2:41	26.5	2.99	7.10	"
C1e	2:48	27.7	5.50	7.51	minnows "
C1e	2:52	28.7	2.39	7.44	minnows "

OTHER CONDITIONS

weather conditions:
temperature: 87°
cloudy/clear: PC
wind: E 10 TO 15 mph

flow in creek above wwtp discharge (yes/none): NONE

flow depth at center of concrete dam (Sta A): 1.5"

METER CALIBRATION

	pH	D.O.
standard	7.00	6.00
calibration	6.99	5.92
standard	10.00	
calibration	10.00	

certification:
Thomas E. Rhodes (signature)
9-2-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 8-26-99 -1999

Loc-ation	AM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:45	30.4	6.17	7.30	minnows
A	8:50	28.1	3.42	7.00	minnows
A2	8:53	27.4	4.22	7.22	minnows
A3-100'	8:58	26.5	3.46	7.12	minnows
A3	9:01	26.4	5.37	7.11	minnows
A3n	9:08	27.1	5.31	7.12	minnows
B	9:13	26.2	3.32	7.44	minnows
Ble	9:23	26.5	3.33	7.52	minnows & Fish
Blf	9:26	25.6	4.50	7.45	minnows & Fish
B2	9:35	27.0	2.81	7.38	CARP
C	9:43	26.6	1.50	6.87	
Clc	9:50	27.5	4.00	7.48	minnows
Clc	9:56	27.8	2.98	7.51	minnows & CARP

RAINFALL 0.45" 8-24-99

OTHER CONDITIONS
weather conditions:
temperature: 85°
cloudy/clear: CLEAR
wind: 2 OR 3 mph WEST

flow in creek above wwtp discharge (yes/none):
NONE
flow depth at center of concrete dam
(Sta A): NONE (Golf COURSE Pumping)

METER CALIBRATION

	pH	D.O.
standard	7.00	6.09
calibration	7.00	6.06
standard	10.00	
calibration	10.02	

certification:
[signature] (signature)
8-26-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 8-19-99 -1999

Location	PM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	12:41	31.4	6.15	7.35	minnows
A	12:46	30.0	4.44	7.20	minnows
A2	12:49	30.8	5.45	7.21	minnows
A3-100'	12:55	29.8	5.45	7.34	minnows
A3	12:58	29.3	6.39	7.52	minnows
A3n	1:04	29.2	5.38	7.41	minnows
B	1:11	28.6	3.85	7.22	minnows
Ble	1:20	28.5	4.50	7.39	minnows
Blf	1:23	28.2	5.79	7.33	minnows
B2	1:32	28.3	3.58	7.20	minnows
C	1:40	28.7	3.29	7.03	
Clc	1:48	29.4	5.32	7.24	Fish
Cle	1:56	32.2	10.71	9.04	CARP & minnows LOTS OF GREEN ALGAE

OTHER CONDITIONS

weather conditions:
temperature: 98
cloudy/clear: P.C
wind: N. 5 mph

flow in creek above wwtp discharge (yes/none):
NONE

flow depth at center of concrete dam (Sta A): NONE
GOLF COURSE pumping

METER CALIBRATION

	pH	D.O.
standard	7.00	7.08
calibration	7.00	7.06
standard	10.00	
calibration	10.01	

certification:

Thomas Plado 6 (signature)

8-19-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 8-12-99 -1999

Loc-ation	AM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:03	30.1	6.30	7.06	minnows
A	8:08	28.1	3.73	6.79	minnows
A2	8:11	28.0	4.45	6.74	minnows
A3-100'	8:18	26.8	3.41	6.89	minnows
A3	8:21	26.7	4.54	7.04	minnows
A3n	8:26	26.7	3.92	7.12	minnows
B	8:32	25.8	1.55	7.05	minnows; LITTLE Flow
B1o	8:47	26.9	3.73	7.35	minnows; NO Flow
B1f	8:49	26.6	2.78	7.26	minnows; NO Flow
B2	8:57	27.5	4.19	7.39	minnows; NO Flow
C	9:07	27.0	2.27	7.12	NO Flow
C1c	9:14	28.4	3.10	7.23	minnows
C1c	9:21	27.6	2.03	7.34	CARP & minnows

OTHER CONDITIONS
weather conditions:
temperature: 85
cloudy/clear: CLEAR
wind: 5 mph

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): 20 inches

METER CALIBRATION

	pH	D.O.
standard	7.00	6.48
calibration	6.99	6.40
standard	10.00	
calibration	9.98	

certification:
[signature] (signature)
8-12-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 8-5-99 -1999

Location	PM time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:25	25.0	6.50	7.11	minnows
A	1:29	30.5	5.24	6.97	minnows
A2	1:33	30.3	5.62	7.08	minnows
A3-100'	1:38	29.7	7.83	7.37	minnows
A3	1:41	29.8	7.75	7.49	minnows
A3n	1:47	28.3	7.47	7.42	minnows
B	1:54	27.6	6.34	7.46	minnows
Ble	2:01	27.7	5.51	7.37	minnows
Blf	2.04	27.5	6.19	7.30	minnows
B2	2.13	28.6	4.78	7.26	SEVERAL CARP 4 TO 5 lbs.
C	2:21	29.0	4.38	6.97	minnows
Clc	2:30	29.5	6.60	7.23	minnows
Clc	2:39	32.3	6.47	7.97	minnows

OTHER CONDITIONS

weather conditions:
temperature: 95
cloudy/clear: PC
wind: CALM

flow in creek above wwtp discharge (yes/none): NONE

flow depth at center of concrete dam (Sta A): .75" CREEK had good Flow all THE WAY TO THE LAKE.

METER CALIBRATION

	pH	D.O.
standard	4.00	6.75
calibration	4.01	6.71
standard	7.00	
calibration	6.99	

certification:
[signature] (signature)
8-5-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 7-29-99 -1999

Location	Am time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:40	29.5	6.25	7.11	
A	8:45	27.8	3.15	6.88	minnows
A2	8:48	26.6	3.53	7.03	minnows
A3-100'	8:55	26.5	2.20	6.84	minnows
A3	8:58	24.8	3.77	6.94	minnows
A3n	9:06	26.0	3.95	7.02	minnows
B	9:13	26.6	1.56	6.91	minnows
Ble	9:21	26.3	4.04	7.15	minnows
Blf	9:23	25.7	2.88	7.02	minnows
B2	9:32	27.1	2.49	6.89	minnows
C	9:40	27.3	2.57	6.91	
Clc	9:49	27.8	2.84	7.11	
Cle	9:57	27.7	3.59	7.31	minnows

OTHER CONDITIONS

weather conditions:
temperature: 85
cloudy/clear: clear
wind: calm

flow in creek above wwtp discharge (yes/none):
NONE

flow depth at center of concrete dam (Sta A): 0 golf course pumping

METER CALIBRATION

	pH	D.O.
standard	4.00	7.50
calibration	4.02	7.45
standard	7.00	
calibration	6.99	

certification:
[signature] (signature)
7-29-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 7-22-99 -1999

Location	P.M. time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:27	30.1	6.54	7.15	minnows
A	1:32	28.8	4.78	7.08	minnows
A2	1:35	29.2	4.91	7.03	minnows
A3-100'	1:41	29.0	6.93	7.35	minnows
A3	1:45	29.0	7.28	7.35	minnows
A3n	1:49	27.3	7.02	7.35	minnows
B	1:58	26.7	5.04	7.41	minnows
B1e	2:05	27.1	5.78	7.59	minnows
B1f	2:07	27.2	6.27	7.51	minnows
B2	2:18	27.7	5.82	7.54	minnows & Large Fish
C	2:25	28.8	4.33	7.13	
C1c	2:37	30.9	3.68	7.31	
C1e	2:43	31.5	5.62	7.83	minnows

OTHER CONDITIONS
weather conditions:
temperature: 89
cloudy/clear: PC
wind: 5-10 South

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): .75 inches

METER CALIBRATION

	pH	D.O.
standard	4.00	6.80
calibration	3.99	6.80
standard	7.00	
calibration	7.01	

certification:
Thomas E. [signature] (signature)
7-22-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 7-15-99 -1999

Location	AM time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	9:17	28.3	6.97	7.18	
A	9:22	26.9	3.07	6.91	minnows
A2	9:25	26.0	3.73	7.08	minnows
A3-100'	9:32	25.1	3.81	7.21	minnows
A3	9:36	25.3	5.99	7.38	minnows
A3n	9:44	24.7	5.94	7.37	minnows
B	9:49	25.5	3.47	7.20	minnows
Ble	9:57	25.3	3.80	7.19	minnows
Blf	10:00	25.0	4.46	7.16	minnows
B2	10:09	25.4	2.34	6.88	minnows
C	10:17	25.6	1.42	6.90	
Clc	10:24	28.0	2.89	7.02	
Cle	10:37	27.3	3.88	7.41	

OTHER CONDITIONS

weather conditions:
temperature: 75°
cloudy/clear: CLEAR
wind: SOUTH 15 mPH

flow in creek above wwtp discharge (yes/none): NONE

flow depth at center of concrete dam (Sta A): 0 golf course pumping

METER CALIBRATION

	pH	D.O.
standard	4.00	7.8
calibration	4.01	7.9
standard	7.00	
calibration	6.99	

certification:

[signature] (signature)

7-15-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 7-8-1999

Location	P.M time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:46	31.0	6.35	6.69	MINNOWS IN WATER
A	1:52	29.6	2.59	6.73	MINNOWS IN WATER 1*
A2	1:56	30.4	3.52	6.75	MINNOWS IN WATER
A3-100'	2:03	29.7	6.60	7.14	MINNOWS IN WATER
A3	2:07	29.7	6.75	7.30	MINNOWS IN WATER
A3n	2:13	28.9	6.36	7.47	MINNOWS IN WATER
B	2:21	29.1	4.50	7.28	MINNOWS IN WATER
Ble	2:34	28.2	4.70	7.29	MINNOWS IN WATER
Blf	2:36	28.8	4.97	7.23	MINNOWS IN WATER
B2	2:45	29.1	3.40	7.22	MINNOWS IN WATER
C	2:53	32.0	2.64	6.85	MINNOWS IN WATER
Clc	3:06	29.8	3.60	7.00	
Cle	3:15	32.6	7.55	8.29	FISH IN WATER

OTHER CONDITIONS

weather conditions:
temperature: 95°
cloudy/clear: PC
wind: 15 S.W.

flow in creek above wwtp discharge (yes/none): NONE

flow depth at center of concrete dam (Sta A): 1" BELOW 2*

METER CALIBRATION

	pH	D.O.
standard	4.00	7.00
calibration	4.00	6.94
standard	7.00	
calibration	6.99	

certification:
Thomas Rhodes (signature)
7-8-99 (date)

1* FLOW GOING UNDER CONCRET DAM
2* GOLF COURSE PUMPING WATER

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 7-1-99 -1999

Location	PM time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	1:32	29.9	8.21	6.99	
A	1:37	28.8	3.83	6.77	minnows in water
A2	1:42	28.8	5.03	6.73	minnows in water
A3-100'	1:57	28.8	6.17	7.06	
A3	1:59	29.9	6.39	7.00	minnow's in water
A3n	2:04	27.7	7.76	6.95	minnows in water
B	2:12	27.8	5.38	7.09	minnows in water
B1c	2:19	27.4	6.31	7.14	minnows in water
B1f	2:21	27.3	6.85	7.14	minnows in water
B2	2:30	28.0	4.52	7.05	minnows in water
C	2:38	28.7	3.24	6.94	minnows in water
C1c	2:52	29.6	4.45	7.09	
C1c	2:55	31.3	5.60	7.08	minnows in water

OTHER CONDITIONS
weather conditions:
temperature: 94°
cloudy/clear: CLEAR
wind: 25 mph South

flow in creek above wwtp discharge (yes/none):
NONE
flow depth at center of concrete dam (Sta A): 1.5 inches

METER CALIBRATION

	pH	D.O.
standard	7.00	8.01
calibration	6.99	7.99
standard	10.00	
calibration	10.00	

certification:
Thomas E. Rhodes (signature)
7-1-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 6-17-99 -1999

Location	Am time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	9:15	25.4	3.78	7.70	WATER Full of MINNOWS
A	9:30	24.3	2.10	7.04	
A2	9:35	24.0	1.77	7.10	MINNOWS IN WATER
A3-100'	9:45	23.1	2.14	7.25	MINNOWS IN WATER
A3	9:48	23.1	2.74	7.27	MINNOWS IN WATER
A3n	9:59	22.6	3.02	7.33	MINNOWS IN WATER
B	10:06	23.4	2.16	7.44	
Ble	10:13	22.3	2.29	7.33	MINNOWS IN WATER
Blf	10:15	23.0	2.67	7.40	MINNOWS IN WATER
B2	10:32	23.0	2.20	7.28	MINNOWS IN WATER
* C	10:40	23.8	1.44	7.09	MINNOWS IN WATER
Clc	10:50	23.4	1.71	7.30	
Cle	11:00	24.2	1.31	7.25	MINNOWS IN WATER

OTHER CONDITIONS
weather conditions:
temperature: 75°
cloudy/clear: Cloudy
wind: CAlm

flow in creek above wwtp discharge (yes/none): NONE
flow depth at center of concrete dam (Sta A): 0.5 inches

METER CALIBRATION

	pH	D.O.
standard	7.00	7.10
calibration	6.99	7.09
standard	10.00	
calibration	10.00	

certification:
[signature] (signature)
6-17-99 (date)

* LOG JAM FOR 50FT. ABOVE BRIDGE
* WATER Mud FROM HEAVY RAIN FAll, FROM LOCATION A3-100
TO C1E AT Johnson Lake

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 5-20-99 -1999

Loc-ation	P.M time	Temp-erature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	12:20	25.9	6.21	7.46	
A	12:39	24.6	2.71	6.99	
A2	12:34	24.9	3.52	7.18	
A3-100'	12:49	24.1	3.50	7.09	
A3	12:52	24.3	4.13	7.25	
A3n	1:00	23.1	4.33	7.15	
B	1:08	23.3	2.60	7.13	
B1c	1:18	22.3	3.51	7.03	
B1f	1:16	22.7	3.81	7.02	
B2	1:31	22.2	2.28	6.96	15" CRAPPIE IN WATER ALIVE
C	1:39	22.9	1.86	6.85	
C1c	1:47	24.0	5.21	7.17	
C1c	1:53	25.9	7.87	7.45	

OTHER CONDITIONS

weather conditions:
temperature: 80°
cloudy/clear: P/C
wind: 20 mph

flow in creek above wwtp discharge (yes/none): NO

flow depth at center of concrete dam (Sta A): 1.5"

METER CALIBRATION

	pH	D.O.
standard	7.00	6.8
calibration	7.01	6.6
standard	10.00	
calibration	10.00	

certification:
Thomas E. Rhodes (signature)
5-20-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 4-22 -1999

Location	time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	8:40AM	22.0	6.33	7.80	
A	8:50AM	20.3	6.02	7.21	
A2	8:55AM	20.3	4.85	7.31	
A3-100'	9:05AM	20.6	4.08	7.23	
A3	9:20AM	20.5	3.06	7.38	
A3n	9:25AM	20.5	3.25	7.38	
B	9:30AM	20.6	3.85	7.36	
B1e	9:40AM	20.3	2.10	7.25	
B1f	9:45AM	20.3	3.95	7.35	
B2	9:50AM	20.3	3.42	7.25	
C	10:00AM	20.3	1.15	7.19	
C1c	10:20AM	21.2	2.53	7.27	
C1e	10:25AM	21.3	4.90	7.03	

OTHER CONDITIONS

weather conditions:
temperature: 80
cloudy/clear: CLEAR
wind: 20-30 mPH

flow in creek above wwtp discharge (yes/none):
NONE

flow depth at center of concrete dam (Sta A): 2"

METER CALIBRATION

	pH	D.O.
standard	7.0	6.0
calibration	7.0	5.8
standard	10.0	NA
calibration	10.11	NA

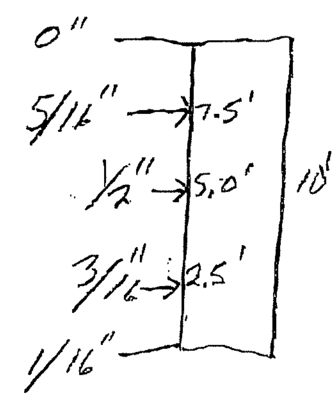
certification:
Dan Morgan (signature)
4-22-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 3-17-99

Location	time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	9:40 AM	18.4	9.20	7.67	
A	11:45 AM	17.8	8.07	7.45	CAUGHT LAST had To clEAR TRASh Above dam
A2	11:50 AM	16.4	8.88	7.47	" " " " " " " "
A3-100'	10 AM	15.5	7.09	7.34	
A3	9.55 AM	15.0	7.97	7.40	
A3b	10:05 AM	15.5	7.35	7.42	
B	10:10 AM	14.9	6.46	7.38	
B1c	10:29 AM	15.1	6.58	7.27	
B1f	10:30 AM	15.1	7.22	7.28	
B2	10:55 AM	15.5	6.61	7.45	SEE BELOW
C	11:10 AM	15.5	4.57	7.26	" "
C1c	11:22 AM	15.5	5.03	7.02	
C1e	11:30 AM	14.6	4.73	6.88	

note:

BRIdgE Above 001 ON Highway 199 & 281



OTHER CONDITIONS
weather conditions:
temperature: ______
Coudy/clear: cloudy
Wind: 3 mph South

flow in Little Cleveland Creek above wwtp discharge: ______

certification:
[signature] (signature)
3-17-99 (date)

P.H. CAL AT 8:40 AM 7.02 + 10.08 DAN
D.O CAl. AT 8:55 AM 101.7 DAN
D.O. SAT. 9 AM TEMP 21° + D.O. 8.88

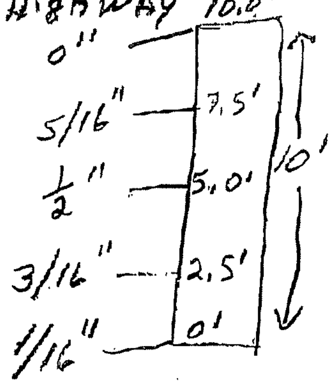
B2 - Didn'T Find STAKE, CAUGHT SAMPLE AT 2nd Big LOG BELOW CROSSING
WATER BARELY moving. LAKE has FIlled up.
C - WATER NOT MOVING, BACK WATER OF LAKE
" " " " "

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 3-17-99

Location	time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	9:40AM	18.4	9.20	7.67	
A	11:45AM	17.8	8.07	7.45	CAUGHT LAST had To CLEAR TRASh above dAm
A2	11:50AM	16.4	8.88	7.47	" " " " " " " "
A3-100'	10AM	15.5	7.09	7.34	
A3	9:55AM	15.0	7.97	7.40	
A3n	10:05AM	15.5	7.35	7.41	
B	10:16AM	14.9	6.46	7.38	
B1c	10:29AM	15.1	6.58	7.27	
B1f	10:30AM	15.1	7.23	7.28	
B2	10:55AM	15.5	6.61	7.45	SEE BElow
C	11:10AM	15.5	4.57	7.26	" "
C1c	11:22AM	15.5	5.03	7.02	
C1a	11:30AM	14.6	4.73	6.88	

note:

CONCRETE BOTTOM OF BRIDGE ABOVE 001 ON Highway 10.0' # 199 + 281
Flow in inches OVER CONCRETE



OTHER CONDITIONS
weather conditions:
temperature: 57-70
Cloudy/clear: cloudy
Wind: 5mph SOUTH

flow in Little Cleveland Creek above wwtp discharge: SEE DIAGRAM AT RIGHT

certification:
[signature] (signature)
3-17-99 (date)

P.H. CAL. AT 8:40AM 7.02 + 10.08 DAN
D.O. CAL. AT 8:55AM 101.7 DAN
D.O. SATURATION 9AM TEMP. 21 + DO. 8.88

(A) WATER DEPTH AT CENTER OF CONCRETE dAm 3 1/4"

(B2) didn'T Find STAKE. CAUGHT SAMPLE AT 2nd Big Log BElow PIPELINE CROSSING. WATER BARELY MOVING. LAKE has FILLED UP
(C) WATER NOT MOVING, BACKWATER OF LAKE.

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Sampling Date: 02-18-1999

Location	time	Temperature (C)	Dissolved Oxygen (mg/l)	pH	comments / notes
001	9:30am	*	9.73	7.65	
A	10:15am	*	6.12	7.20	
A2	10:25am	*	7.99	7.15	
A3-100'	1:10pm	*	7.48	7.80	
A3	1:20pm	*	8.34	7.91	
A3n	2:30pm	*	9.53	7.85	
B	2:45pm	*	6.32	7.52	
B1e	3:00pm	*	7.06	7.59	
B1f	3:05pm	*	8.05	7.59	
B2	3:15pm	*	7.45	7.60	
C	3:20pm	*	5.51	7.21	
C1c	3:35pm	*	5.73	7.22	
C1e	3:45pm	*	8.71	7.31	

note: * not recorded by site, but water temperatures were in 13-15 C range.

OTHER CONDITIONS
weather conditions:
temperature: 53-65 F
cloudy/clear: clear
wind: 10-35mph NW

flow in Little Cleveland Creek above wwtp discharge: none

certification:
[signature] (signature)
2-18-99 (date)

City of Jacksboro
Routine Monitoring Program for Little Cleveland Creek
Site Locations

Location	Description
001	at WWTP outfall, base of rocks below pipe
A	1' above upstream side of concrete dam
A2	at bottom of riffle area immediately below dam
A3-100'	upstream side of cattle crossing at gate
A3	near end of small riffles in cattle crossing area
A3n	just below last of large riffles above Johnson Lake
B	below samll drop at Hammon fenceline
B1e	just above 2nd rock outcrop
B1f	just below 2nd rock outcrop
B2	50' below apparent pipeline crossing
C	downstream side of Iron Bridge
C1c	upstream of last large bends above Johnson Lake
C1e	100' above junction of creek and Johoson Lake

Attachment B

Sensitivity Analysis for Backwater Areas

ATTACHEMENT B
SENSITIVITY ANALYSIS FOR BACKWATER AREAS

The lower end of Little Cleveland Creek (LCC) is a classic case of an arm or cove that is impounded or backed up by a reservoir, and hence can be considered part of the reservoir, but is also a tributary stream or creek. A good case can be made that these areas are neither lake nor creek, but separate waters that require separate and specific uses and criteria. These lake arms, creek mouths, backwater areas, or unique subunits, depending on one's perspective, pose an interesting regulatory and classification problem.

To better understand and quantify the problem, a modeling analysis was performed. The model used by the TCEQ for setting waste discharge permit levels, QUAL-TX, has been used on the lower LCC, but it is not suited for this analysis because it is limited to a steady-state representation and does not explicitly simulate photosynthesis including the effects of light level or wind sheltering differences. To perform the LCC modeling analysis, the U.S. Army Corps of Engineer's model CE-QUAL-W2, vs 3.2 was employed. This model has a well established track record of reservoir dissolved oxygen (DO) and photosynthesis simulations. The processes mentioned above are simulated explicitly in the model. CE-QUAL-W2 is a two-dimensional, longitudinal/vertical model.

This attachment describes the process of performing a sensitivity analysis for the area. Briefly, the CE-QUAL-W2 model is set up for lower LCC from km 1.0 to -0.3, along with additional segments for the rest of the lake, using field data that were previously obtained in an intensive survey. The model was adjusted to represent conditions observed, including the diurnal observations made in the lake. The simulations were performed assuming an ample supply of nutrients. The model was then used to explore the effects of shading and wind reaeration.

CONDITIONS DURING INTENSIVE SURVEY

Station 1, is an open part of the lake that is shallow (approximately 2 feet deep at the monitoring point) and open to the wind and sunlight. It had an elevated chlorophyll *a* concentration (85 ug/L) and DO levels ranged between 7 mg/L in the early morning and 15 mg/L in the mid afternoon. There did not appear to be any vascular submerged aquatic vegetation, with phytoplankton dominating the aquatic plants. Although conditions were generally calm during the sample event, some clay and/or soil turbidity persisted in the reservoir.

In contrast, Station 2 was in a sheltered area with trees and vegetation on both banks and many fallen tree limbs crossing the creek. A chainsaw was used to aid in gaining access. The most visible vegetation was duckweed (*Lemna minor*) that covered much of the surface. Below the surface was extensive submerged aquatic vegetation (SAV), with water milfoil (*Myriophyllum* spp.) being the major species. The water was very clear and chlorophyll *a* concentrations were low (6.2 ug/L). Probably because of the duckweed cover blocking light at the time of the observations, the DO level ranged from 0.35 to 1.17 mg/L.

There was an ample supply of nutrients at both stations. The primary differences between stations 1 and 2 were the differences in exposure to sunlight and wind. This, in turn, resulted in heavy duckweed coverage at Station 2 and its absence at Station 1. The main reason for this difference is that there was open water at station 1 where wind could blow the duckweed clear. Station 2 was very sheltered. It would require a strong wind to overcome the bank and tree shading and blow the duckweed to one side. Winds were generally light during the field work.

Another difference is the tree canopy that provided a substantial amount of shade at Station 2, where there was none at Station 1. Perhaps because of the shading there was an opportunity for SAV to develop and limit the growth of phytoplankton species.

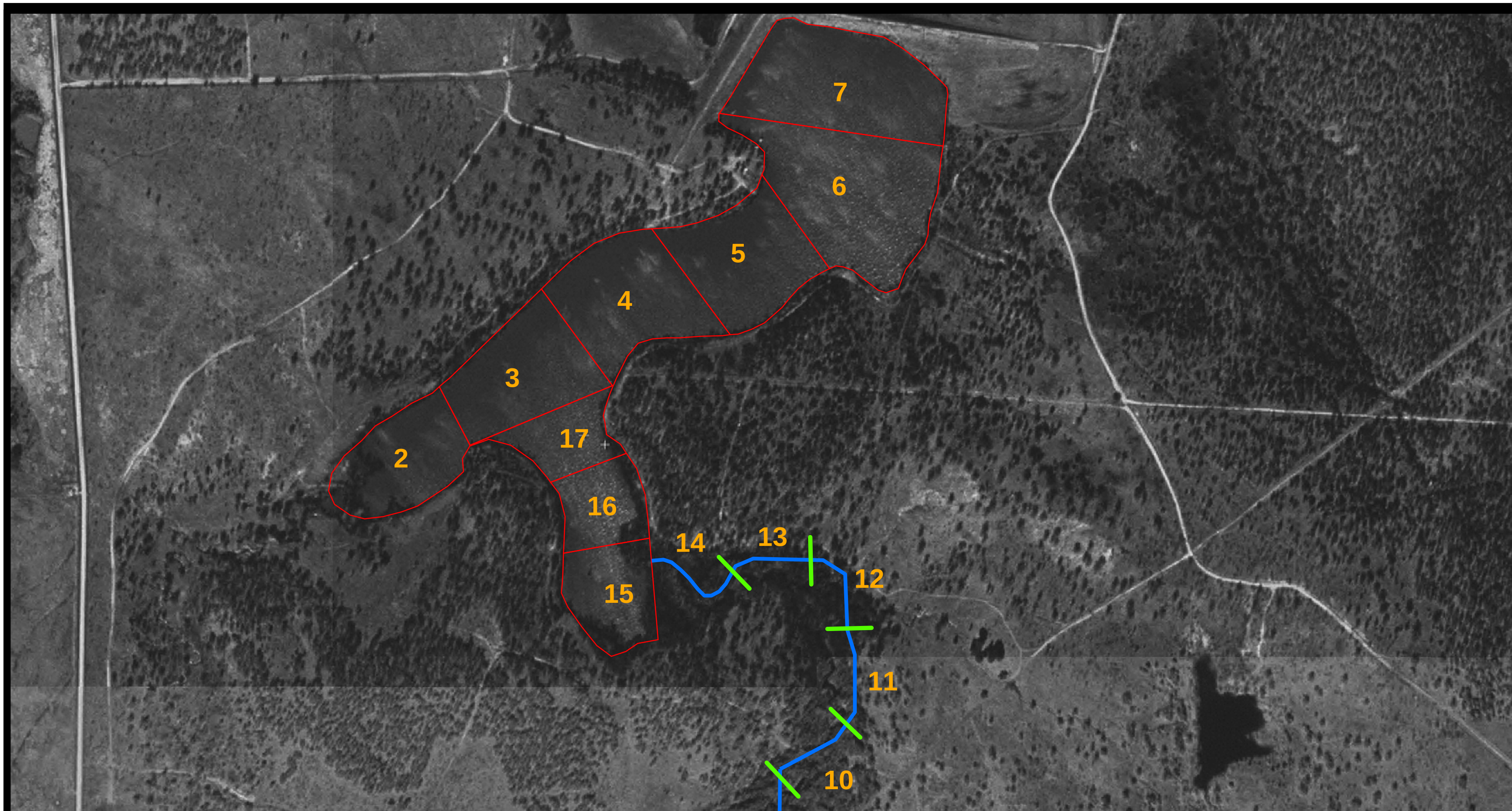
A third difference between the sites is the difference in aeration from wind waves. While wind was not a major factor during the survey, the difference in wind-wave reaeration would be a factor in the longer term.

MODEL CALIBRATION

The model geometry of the impounded arm (Stream km 0 to 1 in the QUAL-TX model) was based on the field survey conducted by Clinton Farris Surveying and Mapping Service in January 2001. During that survey five cross sections were measured in this reach of LCC. The model geometry of Johnson Lake was based on the depth measurements from the intensive survey performed in June 2005. The impounded arm was divided into 5 longitudinal segments. The cove immediately below the impounded arm (Stream -0.3 to 0 in the QUAL-TX model) was divided into 3 segments. The main body of the lake was divided into 6 segments. Each segment was further divided into layers of 0.3 meter thick. Figure B-1 shows the model segmentation employed.

Meteorological data required by the model include air temperature, dew point temperature, wind speed, wind direction, and cloud cover. Hourly data at the Wichita Falls Municipal Airport were obtained from the online store of the National Climatic Data Center and used as input to the model.

Usually the water budget of the model accounts for evaporation, seepage, direct precipitation on the lake, discharge from the lake, runoff and other components of inflow and outflow. The simulation was performed from May 31, 2005 to June 15, 2005. During this period there was no major runoff event. The lake was essentially full and the lake level fluctuated within 0.2 feet of the top of the riser pipe. Therefore, for the purpose of this sensitivity analysis, direct precipitation on the lake, runoff and outflow were assumed to be zero. Evaporation was estimated by the model based on the meteorological data. Seepage was determined to be 0.1 inch per day from the



0 500 1,000 2,000 3,000 Feet

PBSJ
6504 Bridge Point Pkwy, Ste. 200
Austin, Texas 78730
Phone: (512) 329-8342 Fax: (512) 327-2453

Fig. B-1
Model Segmentation

Prepared for: Trinity River Authority of Texas	
Job No.: 441399.00	Scale: 1 Inch = 750 Feet
Prepared by: Ashish Agrawal	Date: 08/22/2005
File: L:\Projects\Hydro\PROJECTS\441399Jacksboro\GIS\FigB-1.mxd	

calibration of the lake level simulation (Section 4.2). Daily average effluent discharge data were used as input to the impounded arm. Concentrations were estimated based on the observations in the intensive survey.

Since the model was intended only for exploring the effects of shading and wind reaeration, a detailed calibration was not necessary and also not supported by the amount of data available. Default or typical values were used for most model parameters, and adjusted where necessary to obtain a reasonable match with the observed data during the period from June 14 to June 15, 2005. Duckweed was represented by extensive shading.

Figure B-2 shows the daily data comparisons at the two stations for the period from 12:00 on the 14th to 12:00 on the 15th. The impounded arm of LCC was assumed to be 90% shaded and fully sheltered from wind.

SENSITIVITY ANALYSIS

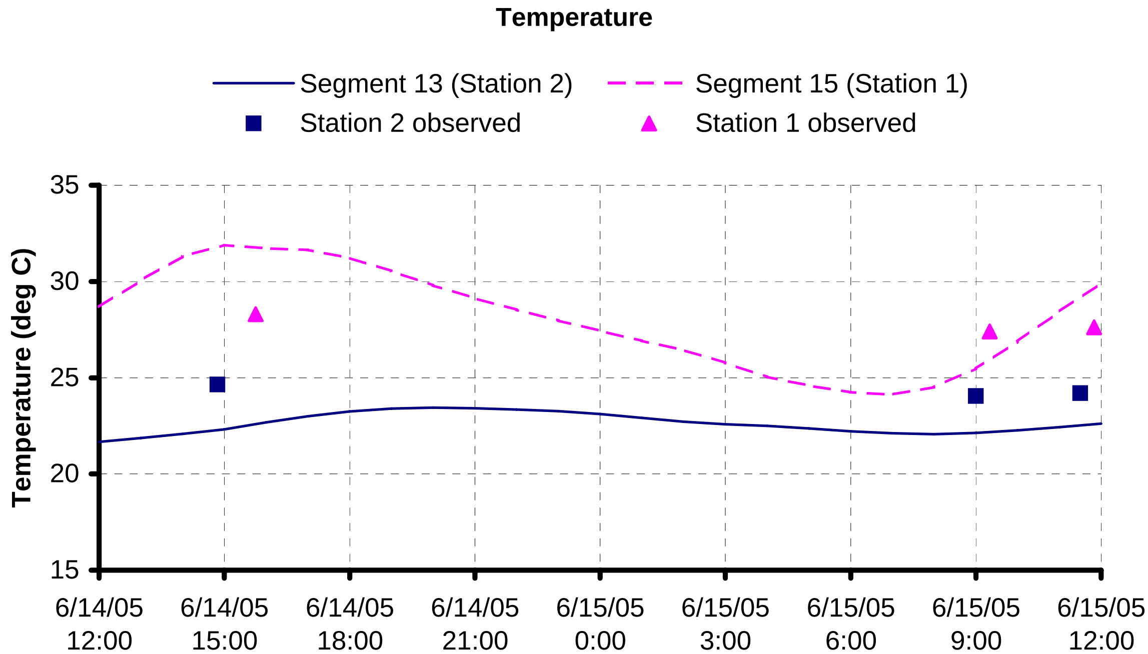
With the model reasonably calibrated to conditions in the backwater area, the next step is to explore the effects of the major processes controlling conditions. The two main variables considered in the sensitivity analysis are shading and wind sheltering. For these runs the comparison point is the lake at station 2. All comparisons are at the surface layer of the model.

Shading

The first comparison is done for shading with the wind sheltering coefficient set at zero, so that reaeration is at a minimum, and the amount of shading is varied between almost none (shade coefficient 0.9) and almost entirely shaded (coefficient at 0.1). Figure B-3 shows the responses for each parameter for the same one day period used in calibration, where the model was started two weeks earlier. In effect, the model has come fairly close to reaching equilibrium, but is still changing slowly. It has gotten sufficiently far along that differences in the shading can be clearly seen.

The temperature difference between heavy and no shade is about six degrees during the night, not too far from the 4 degree difference between station 1 (in full light) and station 2 (in shade). This might suggest that the appropriate shading coefficient might be in the 0.3 to 0.5 range. The DO response to shading ranges between full saturation and near zero. Having less shade and more light allows microalgae growth and thus more chlorophyll *a* (causing higher DO) and also produces higher $CBOD_5$ results from the organic biomass of the phytoplankton. The higher phytoplankton also produces higher nutrient uptake and lower NH_3-N levels, and increases the TSS and TKN levels, as would be expected.

FIGURE B-2
COMPARISON BETWEEN MODEL RESULTS AND FIELD OBSERVATIONS



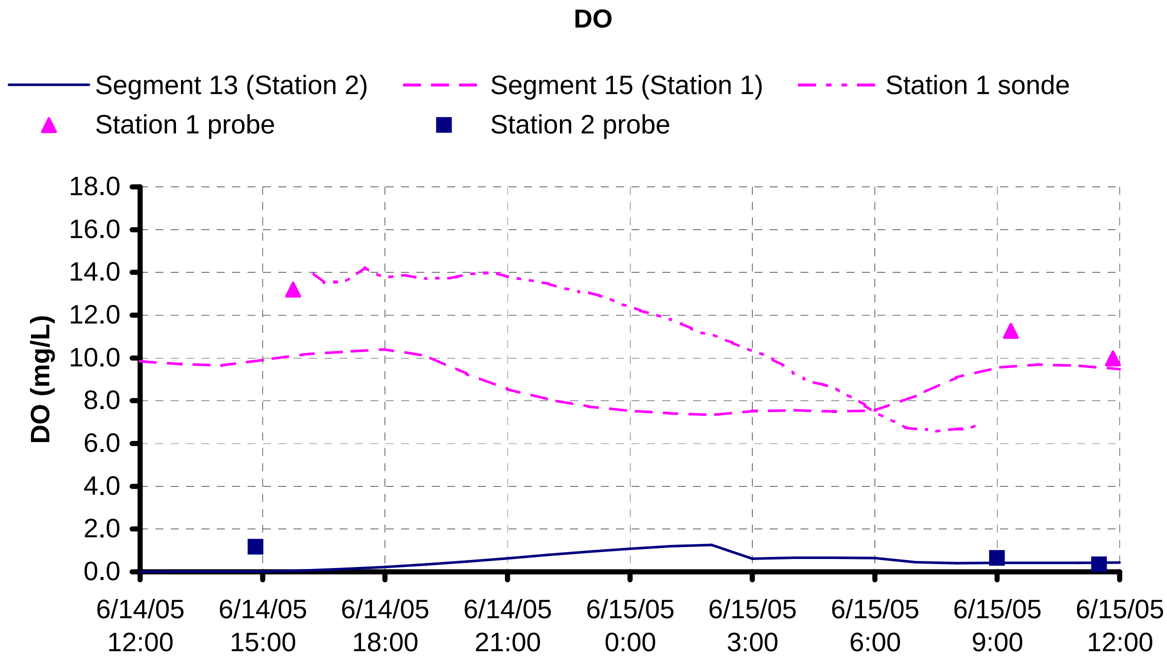
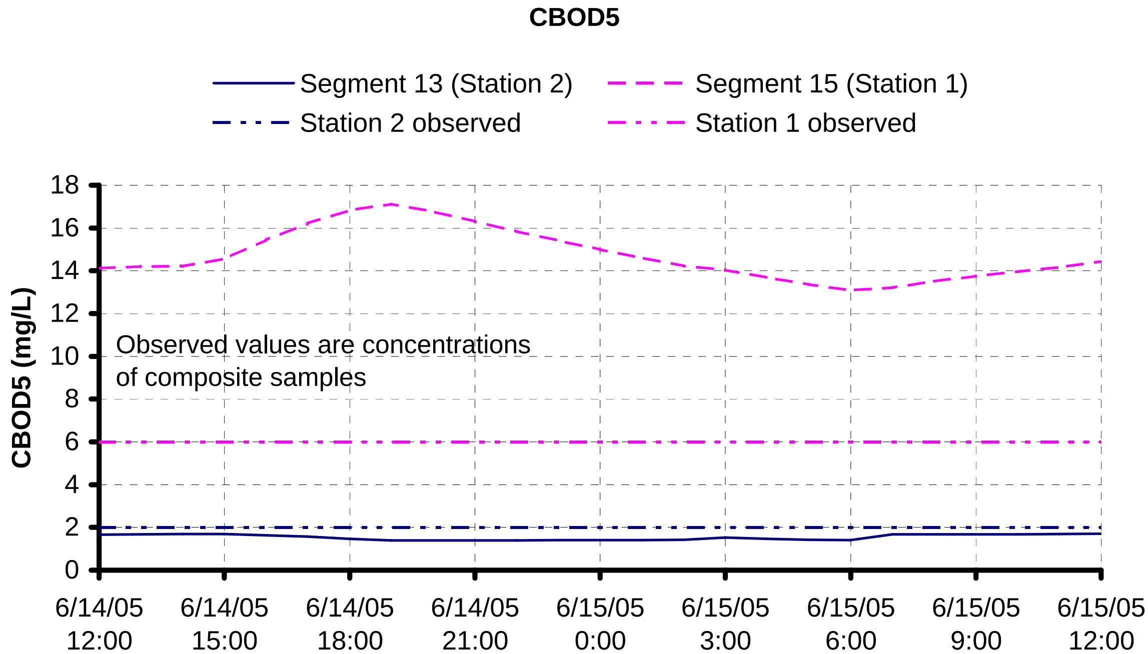


FIGURE B-2 (CONTINUED)
COMPARISON BETWEEN MODEL RESULTS AND FIELD OBSERVATIONS



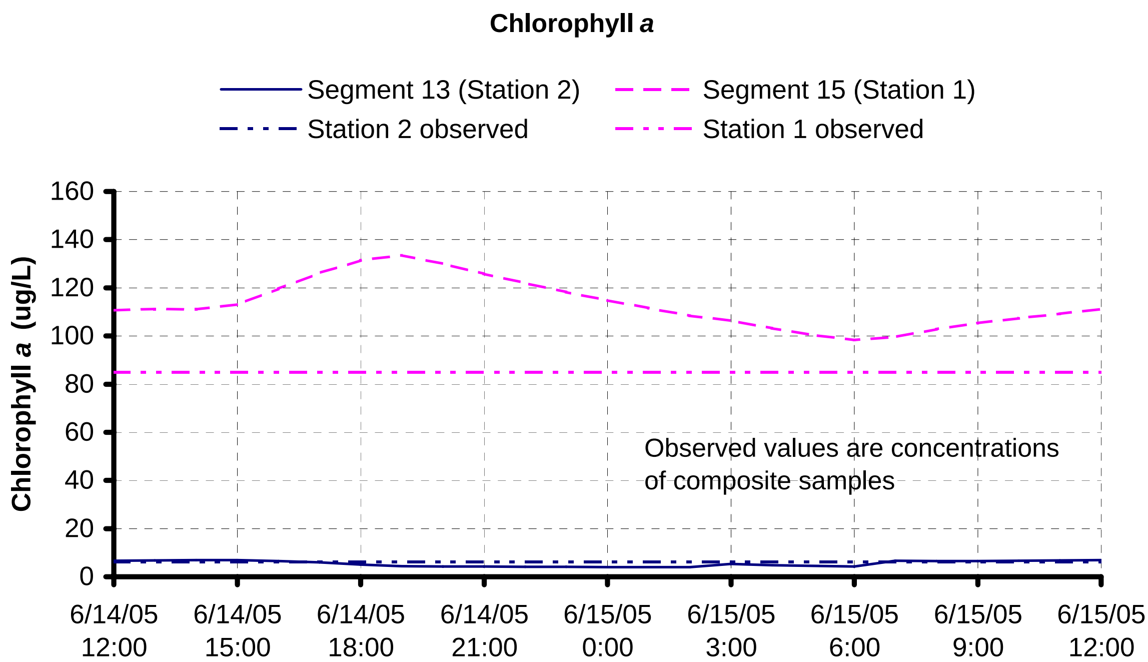
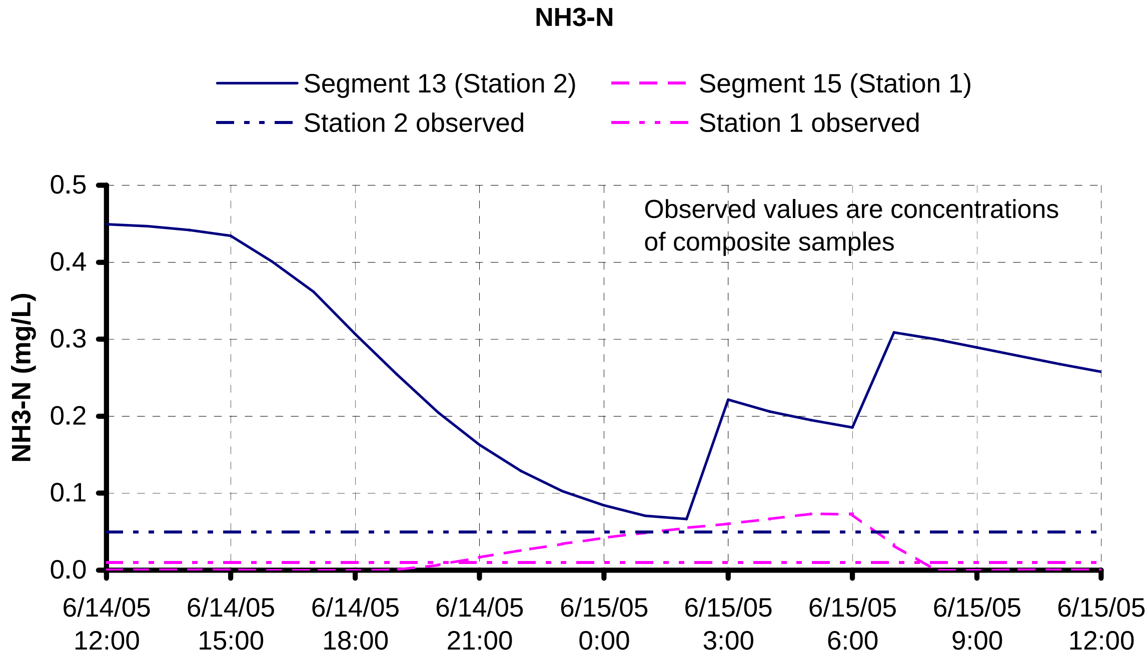


FIGURE B-2 (CONTINUED)
COMPARISON BETWEEN MODEL RESULTS AND FIELD OBSERVATIONS



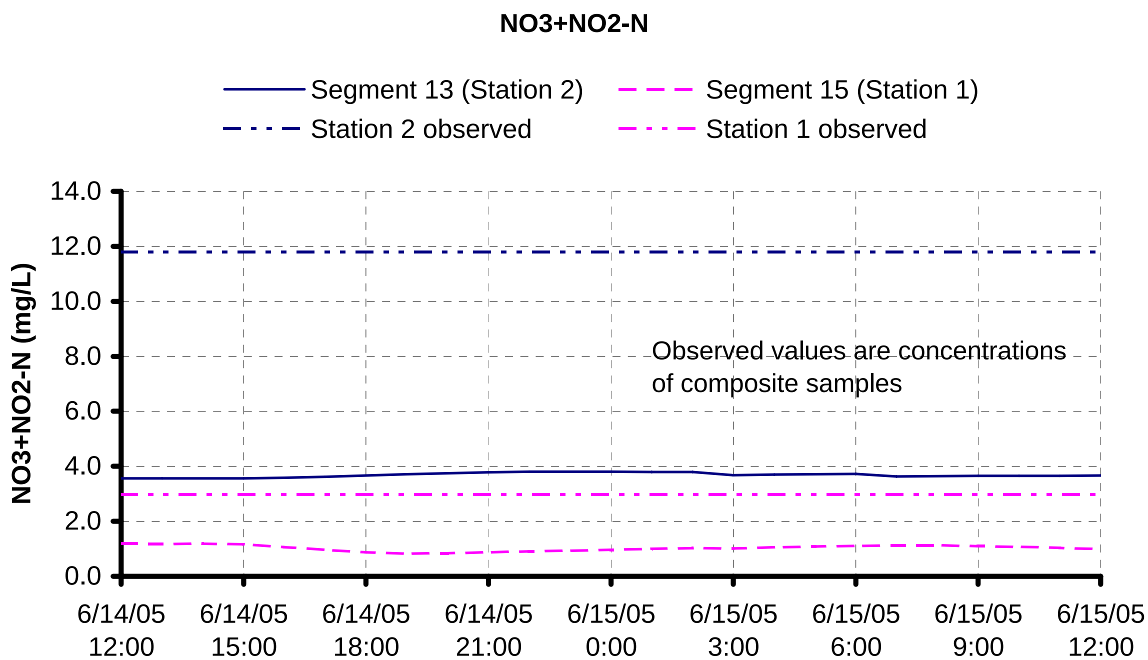
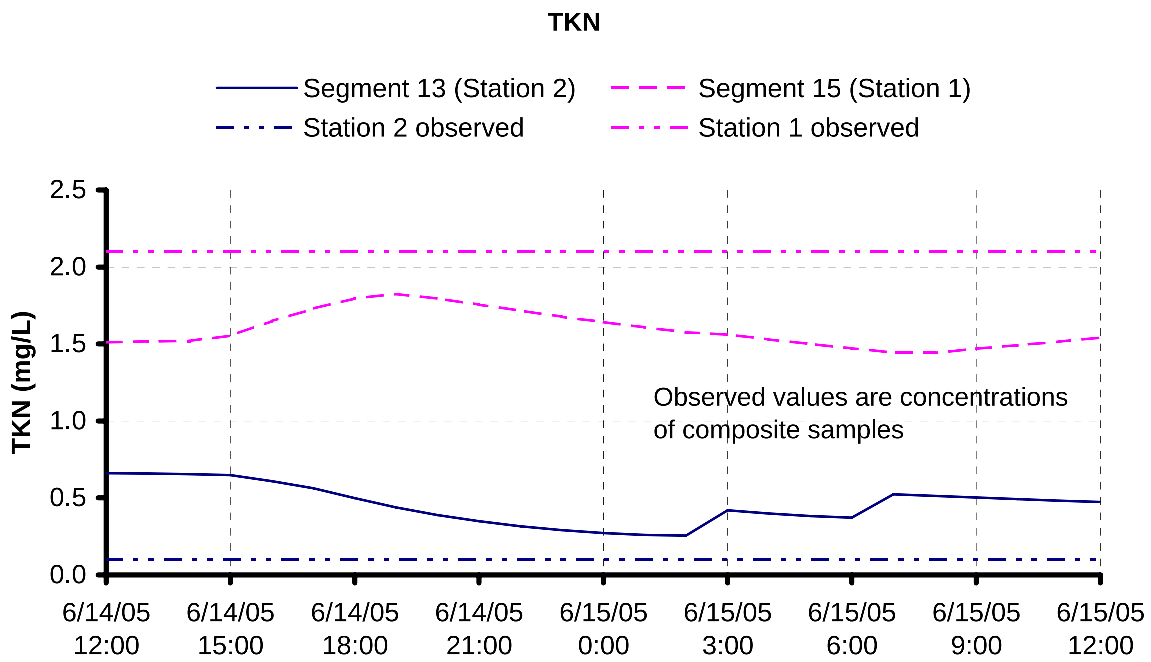


FIGURE B-2 (CONCLUDED)
COMPARISON BETWEEN MODEL RESULTS AND FIELD OBSERVATIONS



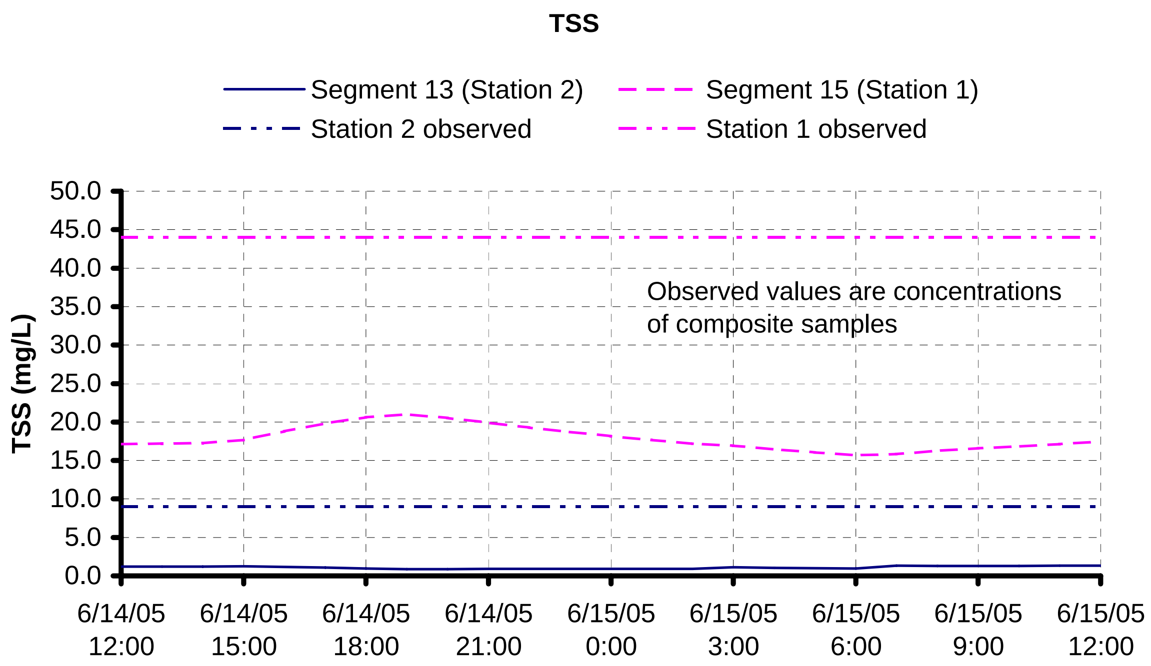
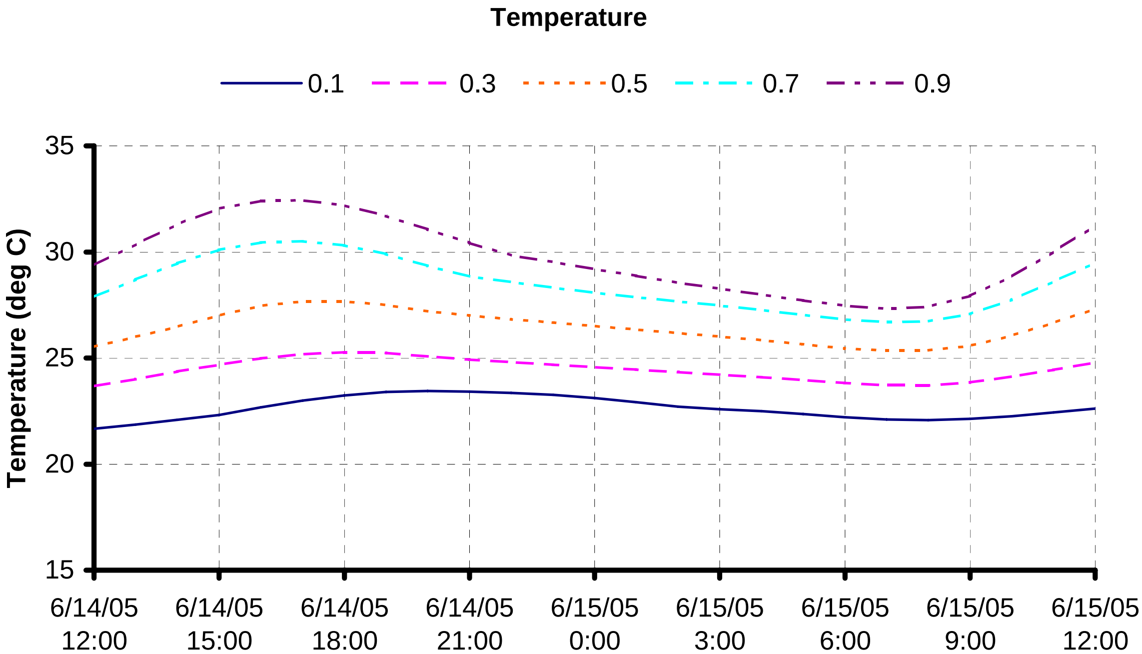


FIGURE B-3
RESULTS WITH VARYING AMOUNT OF SHADING AND WIND SHELTERING COEFF AT ZERO



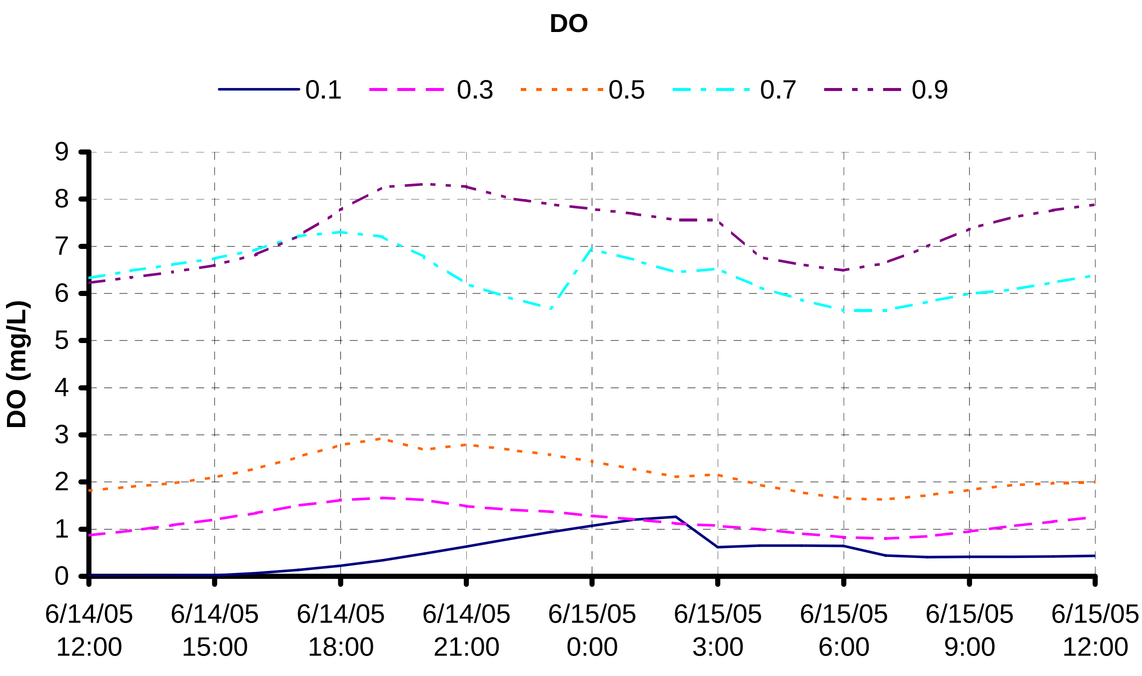
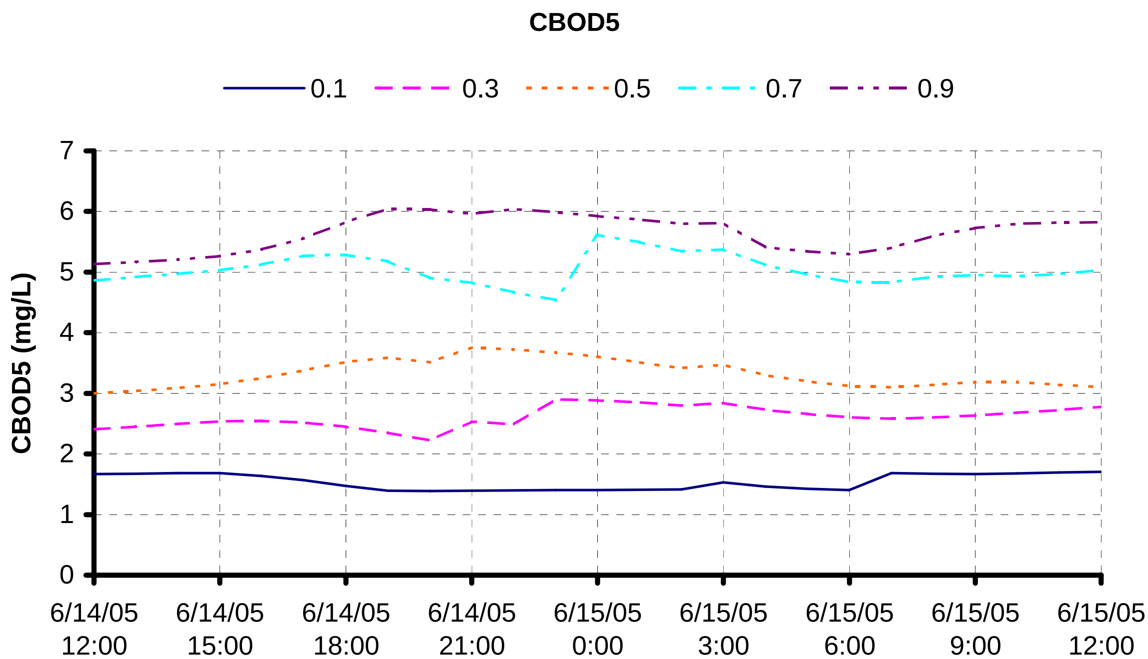


FIGURE B-3 (CONTINUED)
RESULTS WITH VARYING AMOUNT OF SHADING AND WIND SHELTERING COEFF AT ZERO



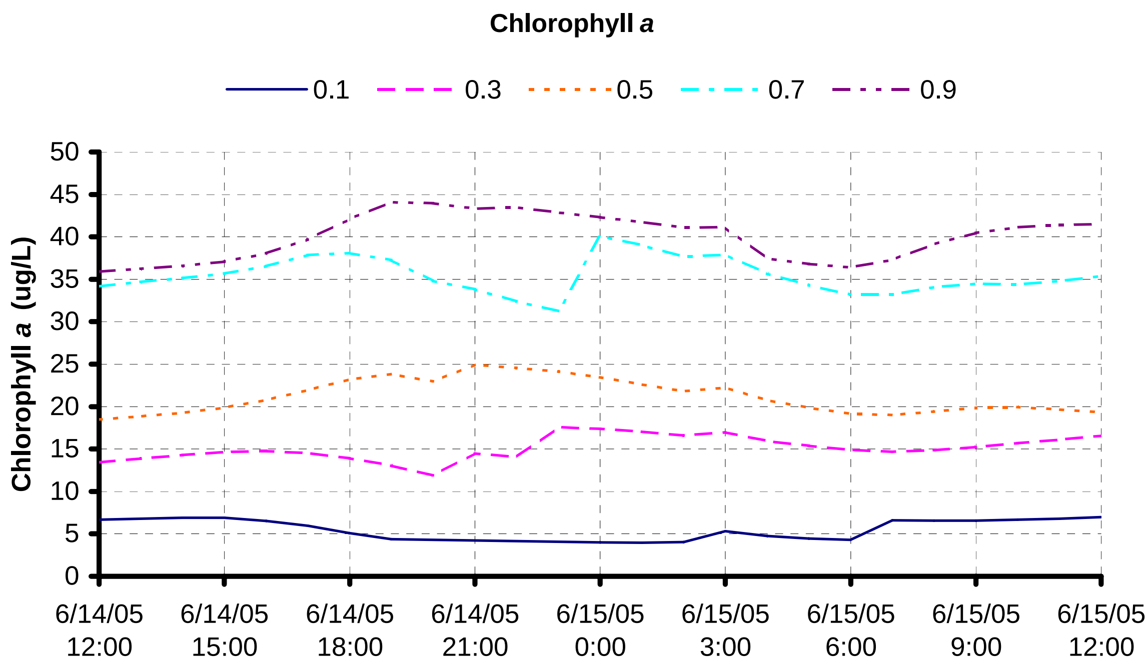
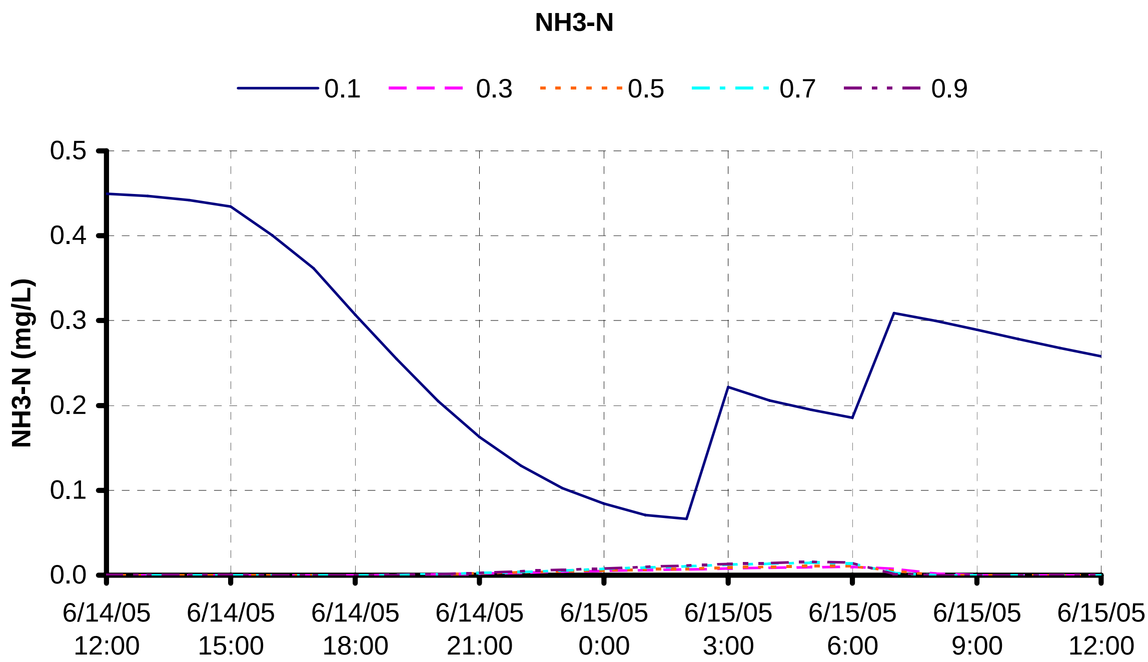


FIGURE B-3 (CONTINUED)
RESULTS WITH VARYING AMOUNT OF SHADING AND WIND SHELTERING COEFF AT ZERO



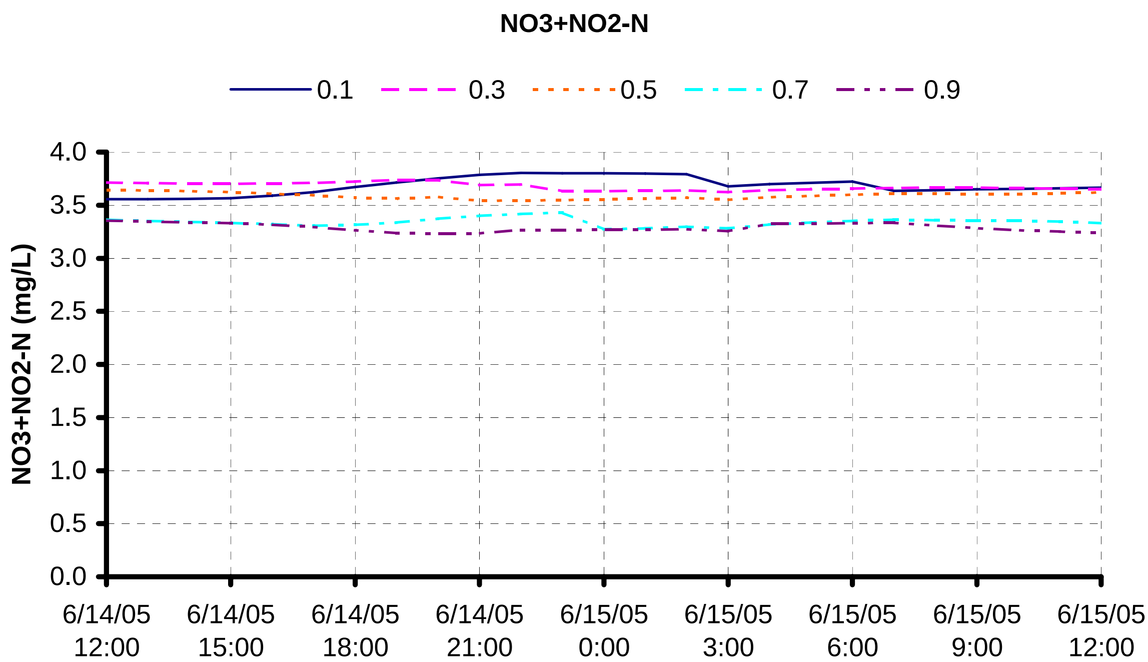
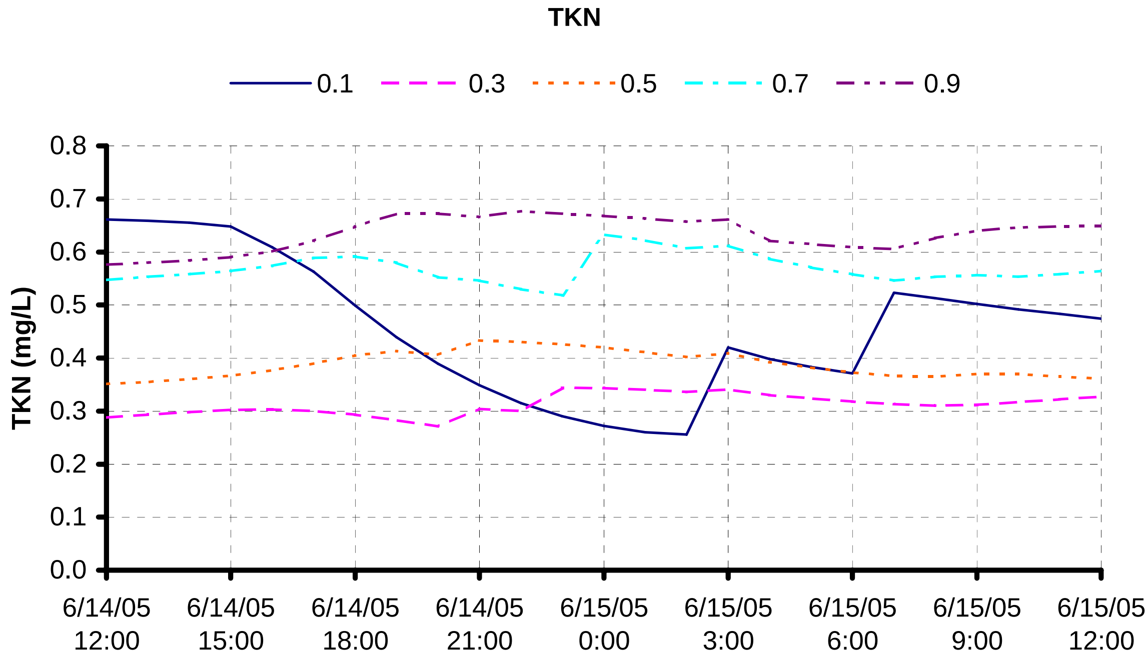
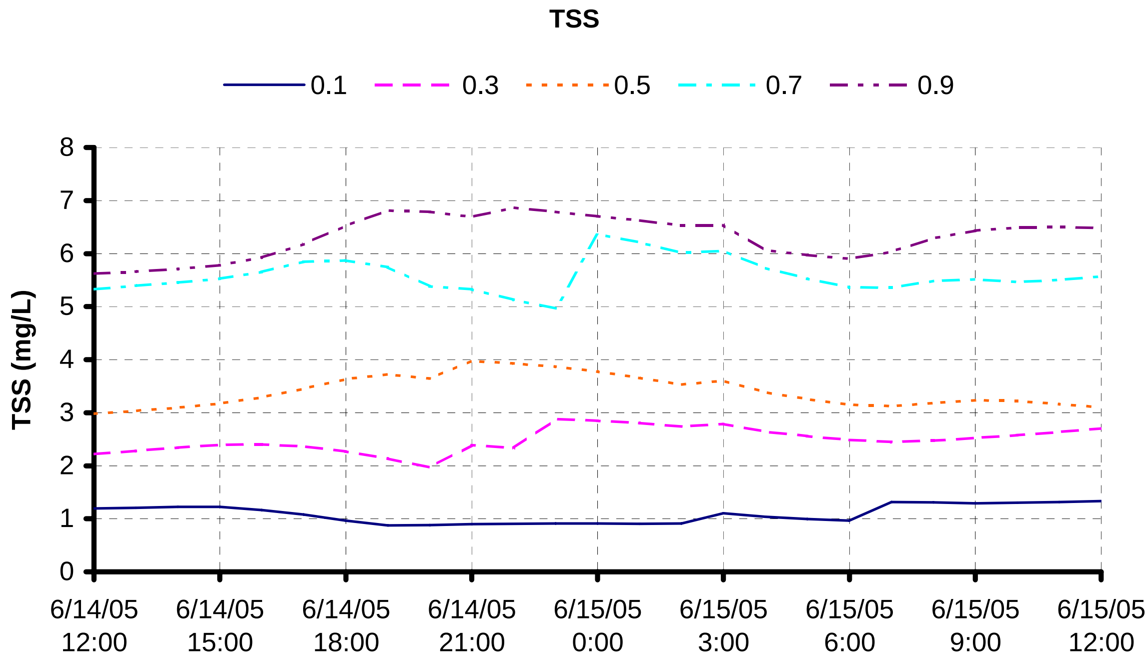


FIGURE B-3 (CONCLUDED)
RESULTS WITH VARYING AMOUNT OF SHADING AND WIND SHELTERING COEFF AT ZERO





Wind Sheltering

For the sensitivity analysis on the effects of wind sheltering, two different shading coefficients are employed, 0.1 and 0.5. The results are shown in Figures B-4 and B-5, respectively. In each case, the Wind Sheltering Coefficient (WSC) ranges from 0 (no wind) to 1 (full wind at Wichita Falls airport).

Shading at 0.1—With a high degree of shading, there is little response in temperature to wind mixing but a large response in DO levels. The DO changes are not a response to algal growth because of the shading effect, but are a response to wind-induced reaeration. The chlorophyll *a* shows only a very small response to wind mixing, primarily because of the effect that it has on vertical mixing of the model layers. The NH_3-N concentration is higher with no wind mixing, most likely in response to the low DO levels at that condition that reduce the amount of nitrification and also may spur sediment release. This same phenomena also shows up in the TKN results, because NH_3-N is a part of the TKN values.

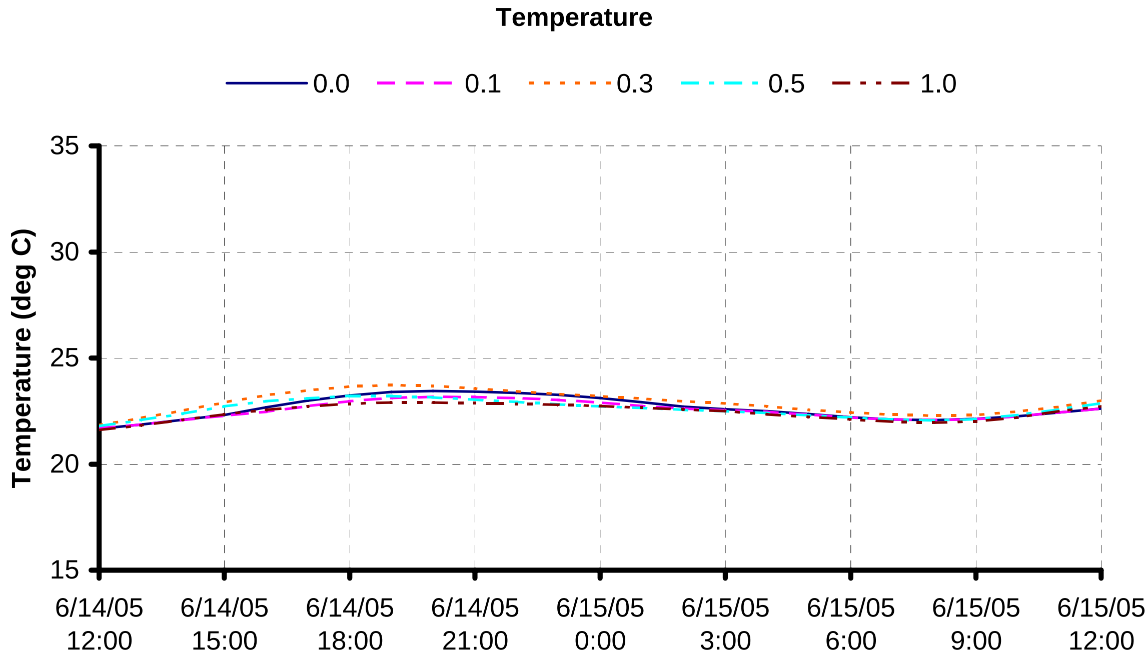
Shading at 0.5—With the shading coefficient set to 0.5, there is more of a response to light levels. Chlorophyll *a* concentrations are higher with more sunlight, but a high degree of wind sheltering still produces lower DO levels. With the higher chlorophyll *a* levels the NH_3-N levels take on a limiting concentration and exhibit a diurnal response to algal activity.

DISCUSSION

The sensitivity analysis results with CE-QUAL-W2 provide a reasonably clear explanation of the processes involved in generating lower DO levels in a lake backwater area in the presence of ample nutrients. If there were not a wastewater source upstream of this backwater area, the nutrient concentrations would be lower, but still adequate to support good aquatic plant growth. In that case the chlorophyll *a* concentrations would be expected to be somewhat lower, but the concentrations at Station 2 were already fairly low (6.2 ug/L). Even with lower chlorophyll *a*, the same effects on DO would be expected.

The main point is that the reduced light and wind mixing typical of backwater areas has a major effect on DO concentrations. There may be other contributing factors, but these alone appear to be sufficient to account for the general pattern of observed lower concentrations in backwater areas. The effect of shading and limited wind mixing appears to be sufficient to cause DO levels that are substantially less than one would expect in an open lake or a flowing tributary stream. While the DO levels are lower in these backwater areas, there is no corresponding evidence that aquatic habitat uses are impaired. To the contrary, these areas provide important seasonal nursery habitats, particularly for reservoir species (i.e., crappie, sunfish, and largemouth bass) that use protected areas and tributaries for spawning and recruitment.

FIGURE B-4
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.1



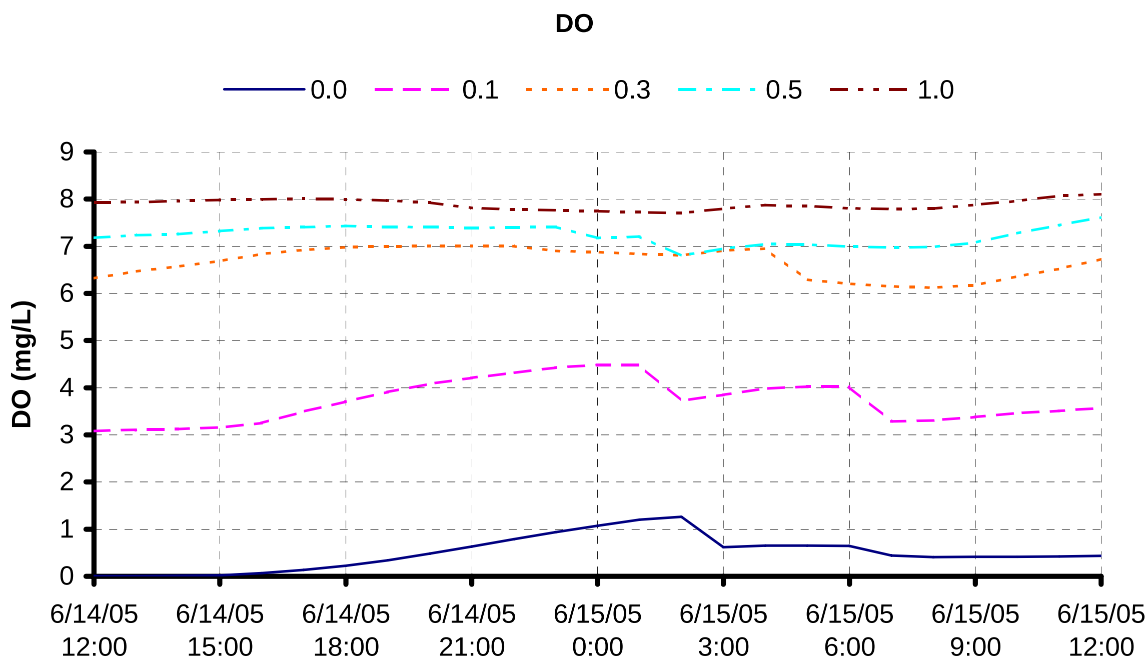
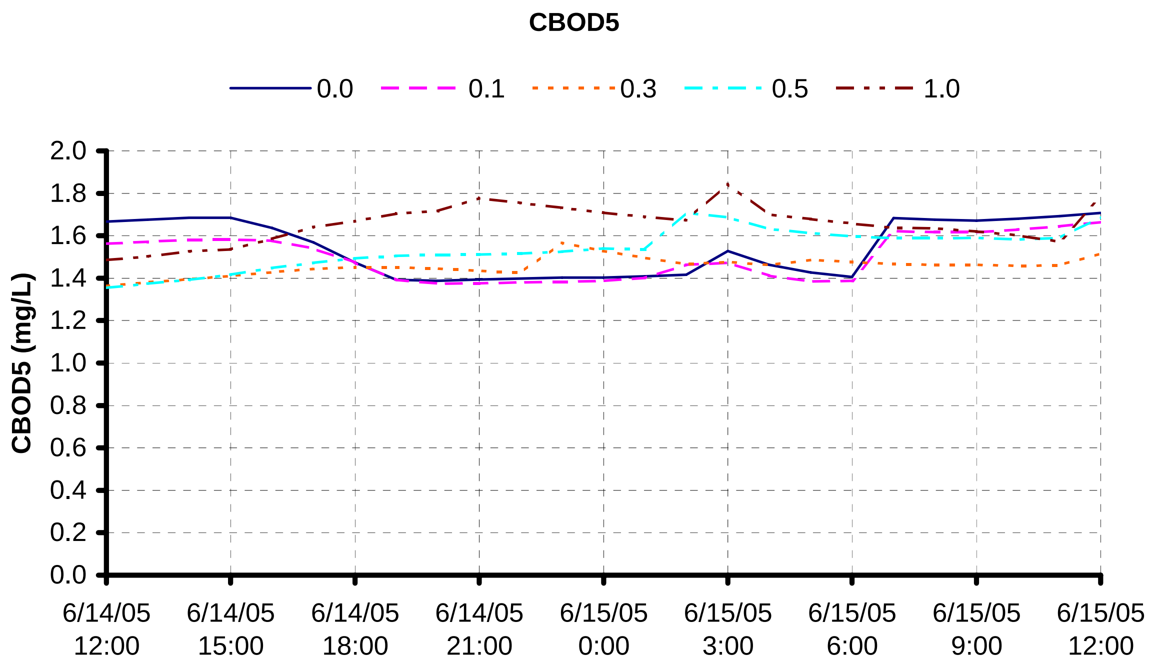


FIGURE B-4 (CONTINUED)
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.1



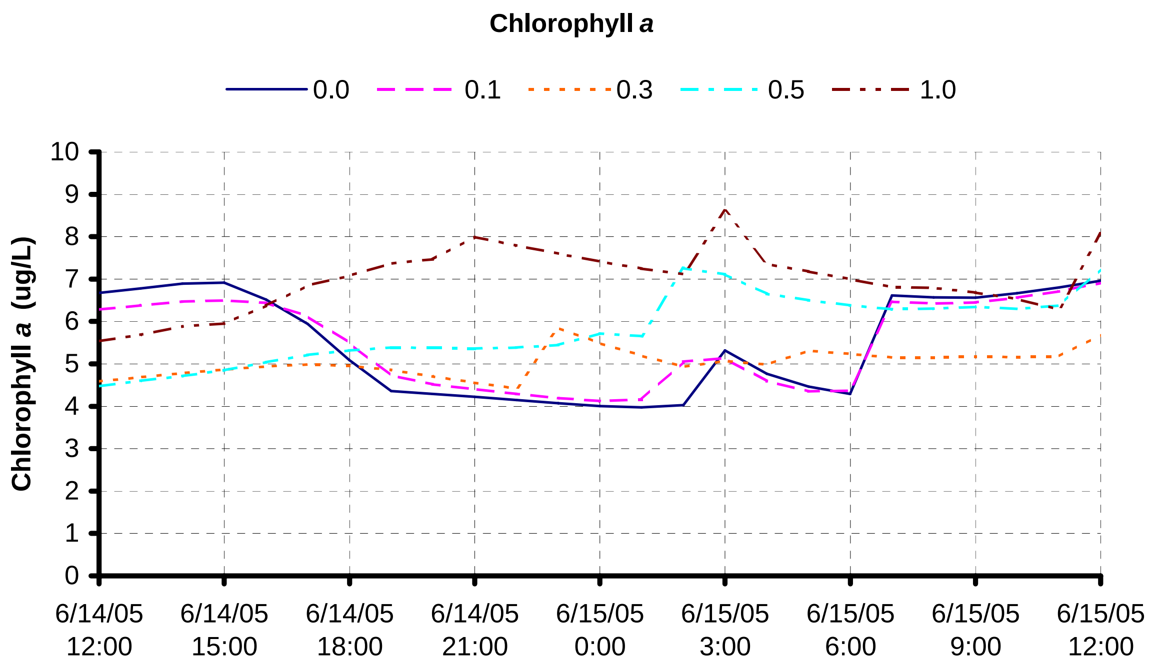
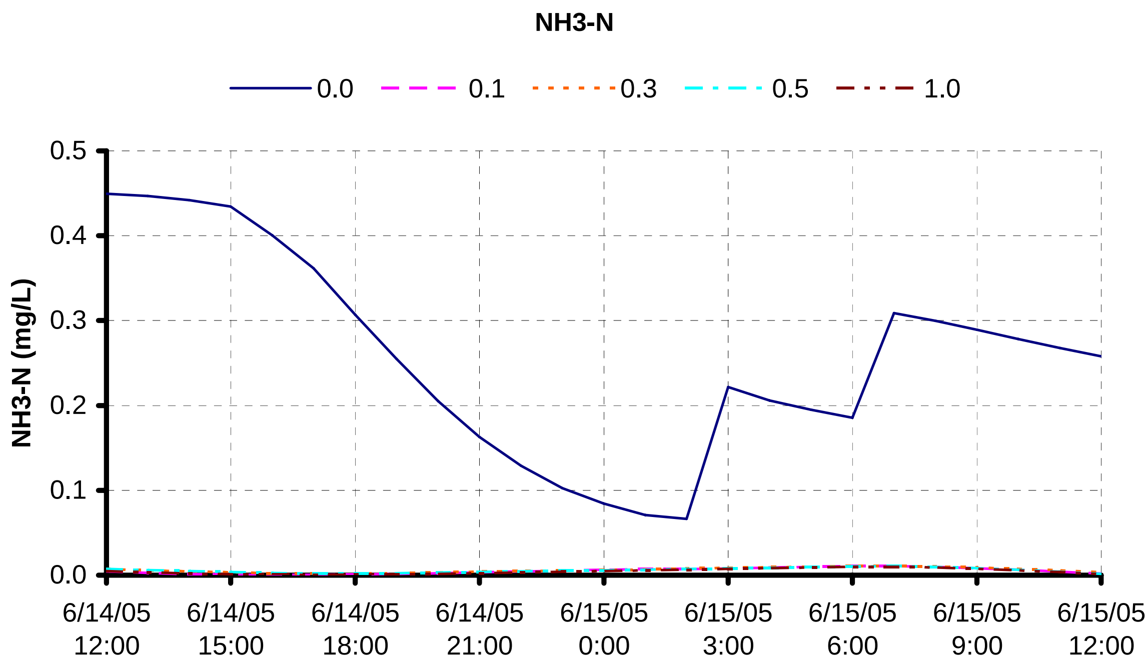


FIGURE B-4 (CONTINUED)
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.1



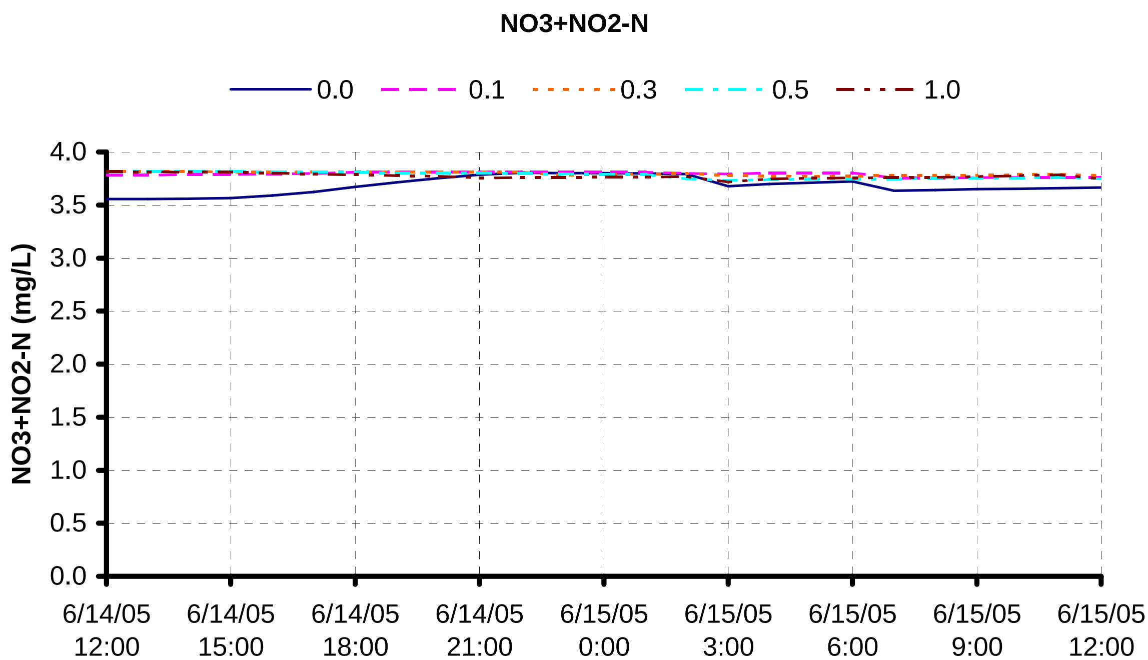
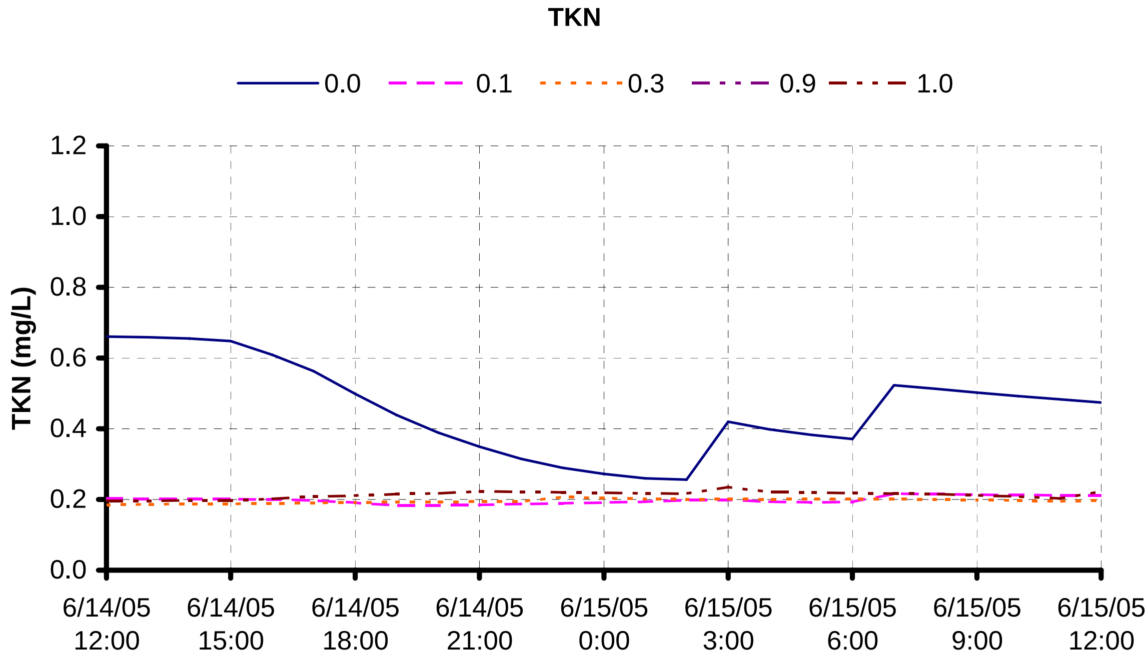


FIGURE B-4 (CONCLUDED)
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.1



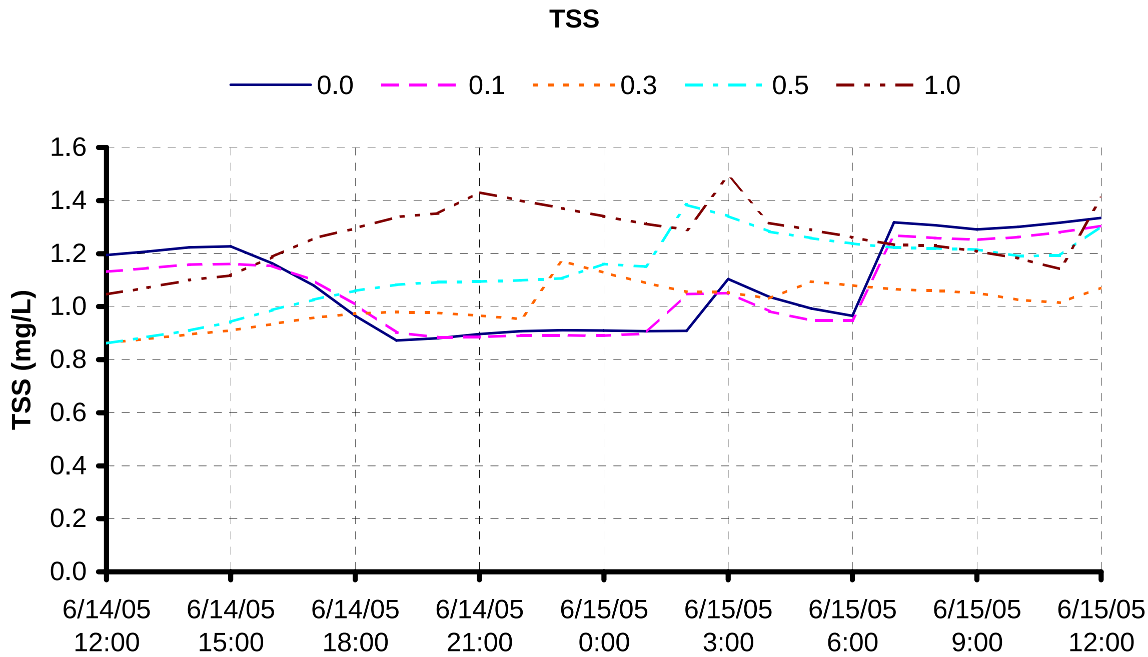
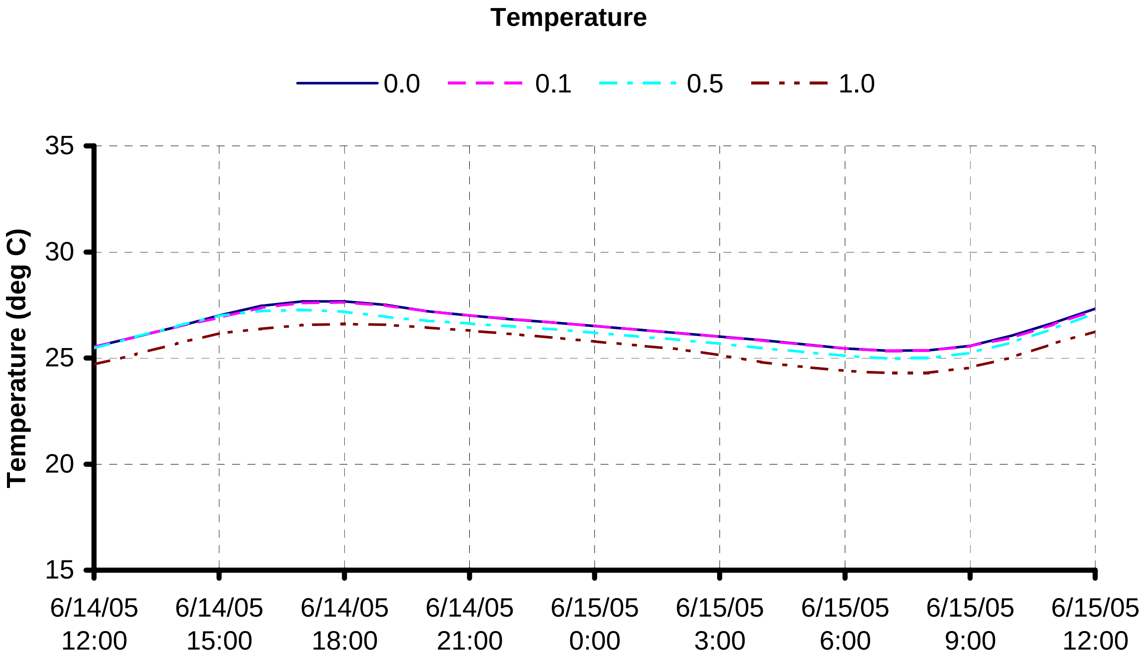


FIGURE B-5
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.5



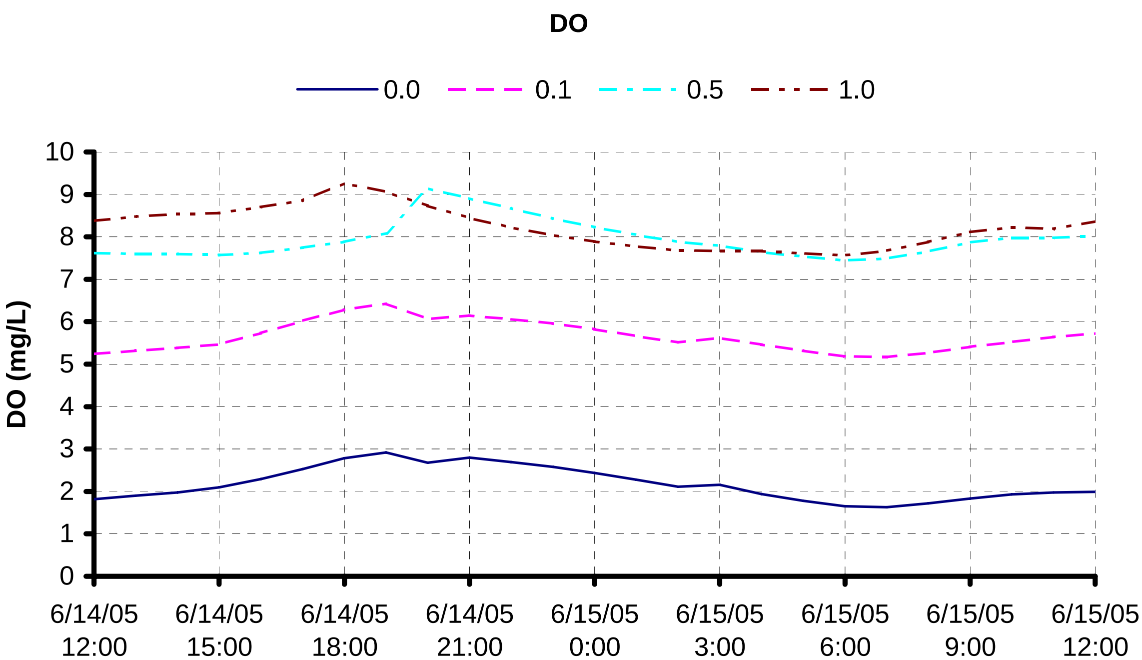
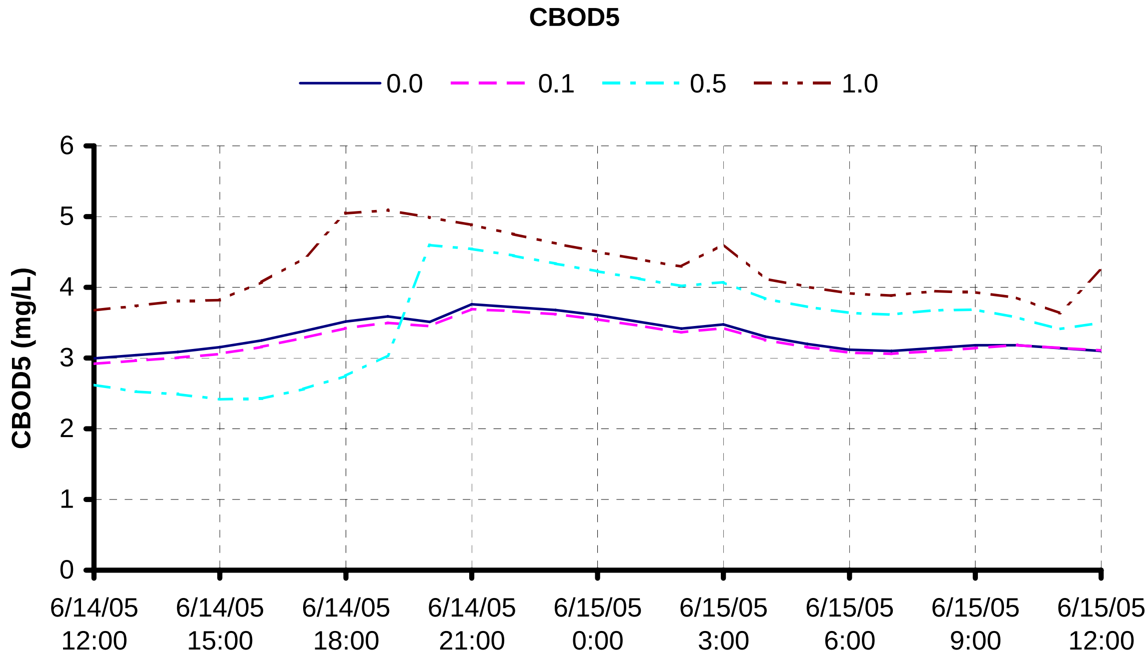


FIGURE B-5 (CONTINUED)
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.5



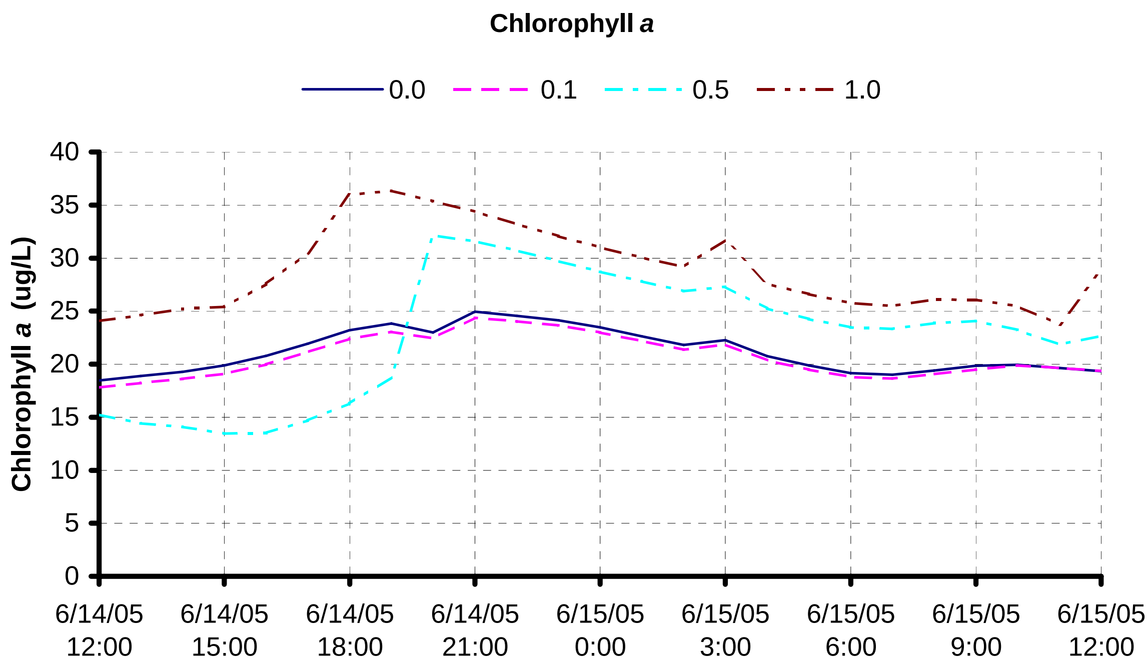
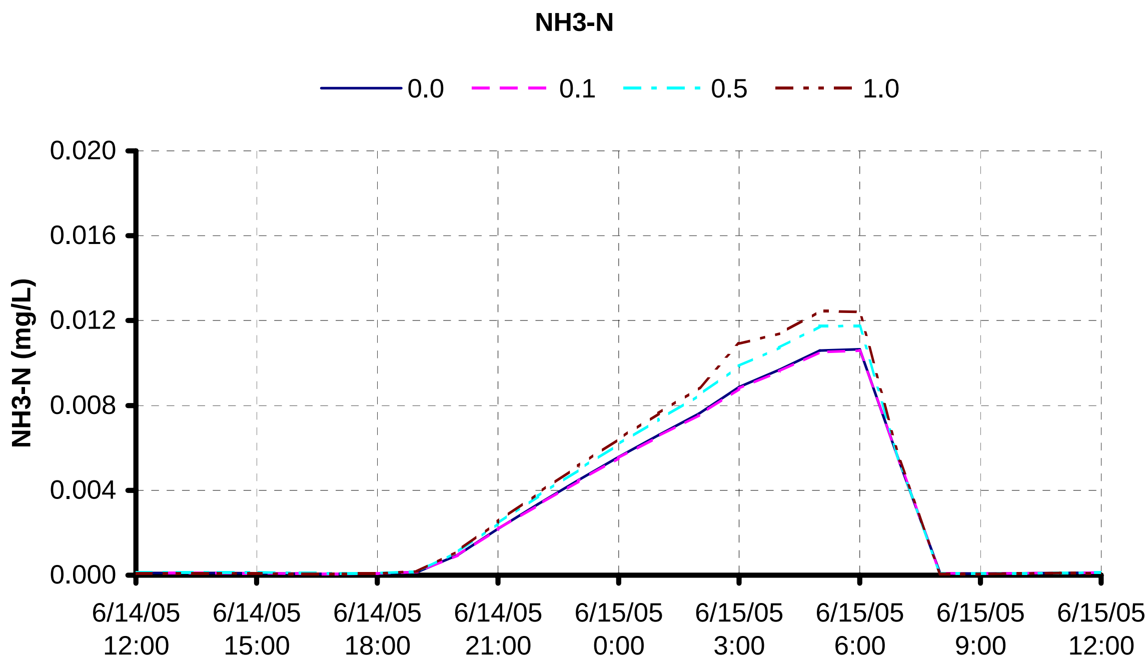


FIGURE B-5 (CONTINUED)
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.5



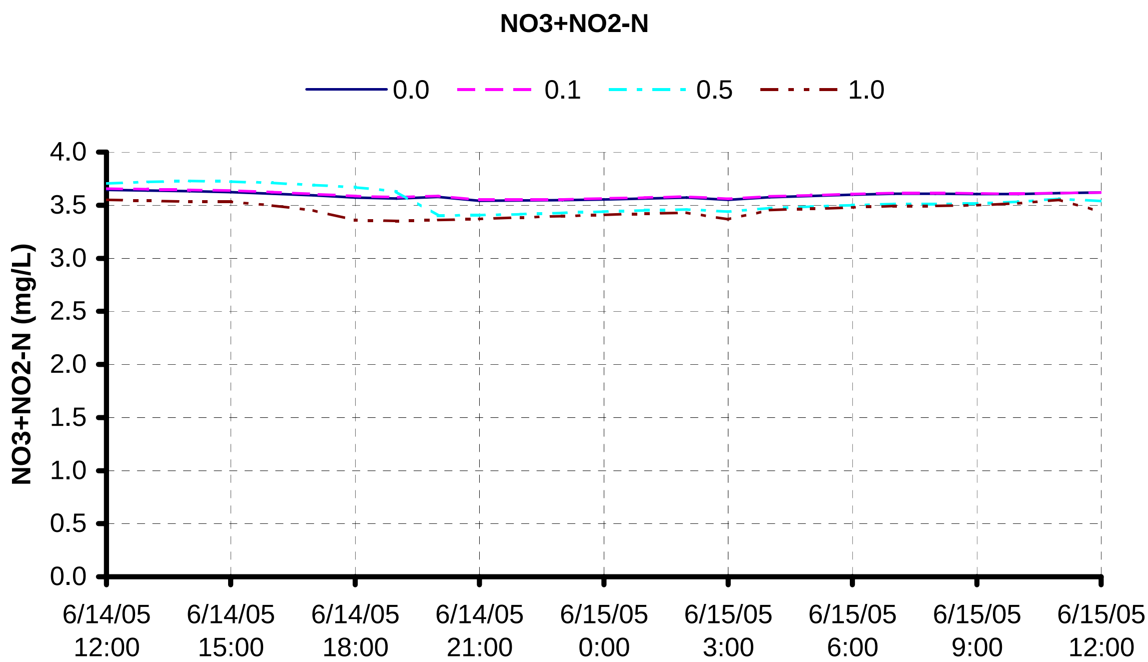
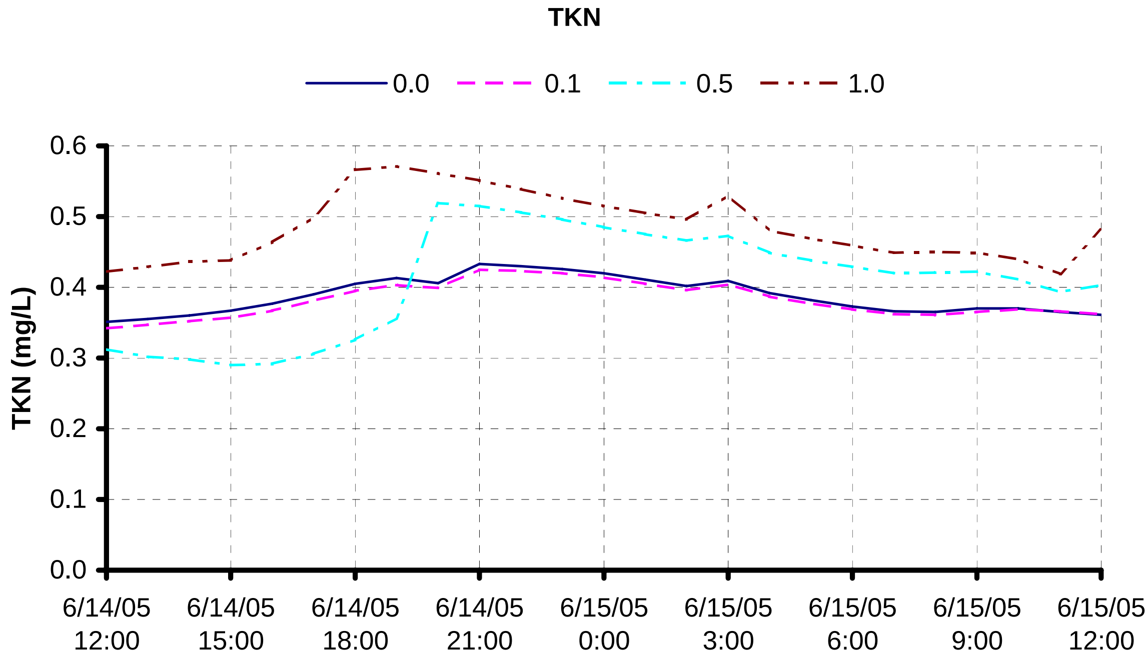
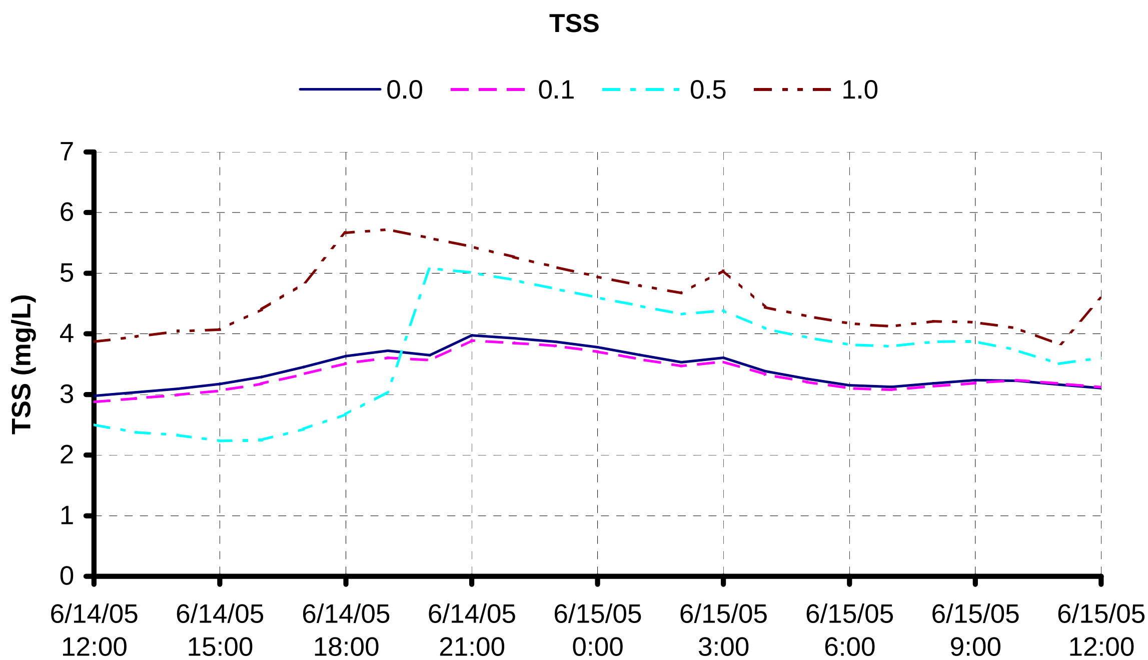


FIGURE B-5 (CONCLUDED)
RESULTS WITH VARYING AMOUNT OF WIND SHELTERING AND SHADING COEFF AT 0.5





In view of the explanation for the lower DO levels in lake backwater areas, it would seem appropriate to develop water quality criteria that are appropriate to the particular characteristics and uses of these areas. Having uses and criteria specific to coves and backwater areas included in the Texas Surface Water Quality Standards would make water quality analyses more relevant and useful.