optimizing environmental resources ♦ water, air, earth AquAeTer

April 12, 1999 980650B/8

Scott K. Bailey
Environmental Affairs
Packaged Products Division
Georgia-Pacific Corporation - Crossett Paper Operations
P.O. Box 3333
Crossett, Arkansas 71635

**RE: Transmittal of Total Maximum Daily Load Projections, Ouachita River from Felsenthal Lock and Dam, Arkansas to Sterlington, Louisiana**

Dear Mr. Bailey:

**AquAeTer, Inc.** has completed a draft analysis of the total maximum daily loads (TMDLs) for the Ouachita River downstream from Felsenthal Lock and Dam. The enclosed report presents a review of previous work and reports on the River, recent data collection results on the River, and results of QUAL2e model results for the river system since the hinge crest gates have been installed at the Felsenthal Dam.

In general, the DO resources have improved in the River since the U.S. Army, Corps of Engineers (COE) have begun releasing water over the top of the hinge crest gates installed in 1996. During high stage events, however, the River DOs still drop below 5 mg/L downstream from the Felsenthal Dam.

A description of all model inputs is contained in the report and the source of each model input is referenced. Data from the Georgia-Pacific synoptic river runs since 1996 are included in the report, and the dataset collected by Georgia-Pacific in August 1998 has been used to calibrate the QUAL2E model for current conditions. The November field study conducted by Georgia-Pacific and AquAeTer is discussed and data collected during this study are presented. The Georgia-Pacific studies and the November data collections confirm that algae play a major role in the oxygen resources of this system. Based on QUAL2E model runs, algae are responsible for about 50 percent or more of the dissolved oxygen in the River.

TMDLs were projected for the months of June, July, August and September. September was found to be the limiting period for allocation purposes. As requested by both Arkansas and Louisiana, a copy of the model input and output files on disk are included in the attached report.

If you should have questions or comments concerning the report, please call us by telephone at (615) 373-8532, by FAX at (615) 373-8512, or by electronic mail at smccormick or mcorn@aquaeter.com.

Sincerely,

**AquAeTer, Inc.**

smccormick
Shaleen T. McCormick
Project Scientist

Michael R. Corn
Michael R. Corn, P.E.
President

cc: T. Mayes Starke, Georgia-Pacific Corporation, Atlanta, Georgia
Tom Gathright, Georgia-Pacific Corporation, Crossett, Arkansas
W. Van Wurm, P.E., **AquAeTer, Inc.**
Doug S. Smith, P.E., **AquAeTer, Inc.**

# TOTAL MAXIMUM DAILY LOAD PROJECTIONS
# OUACHITA RIVER

## FELSENTHAL LOCK AND DAM, ARKANSAS
## TO
## STERLINGTON, LOUISIANA

## VOLUME 1
## REPORT

**Prepared for:**

**ARKANSAS DEPARTMENT OF ENVIRONMENTAL QUALITY**
LITTLE ROCK, ARKANSAS

**LOUISIANA DEPARTMENT OF ENVIRONMENTAL QUALITY**
BATON ROUGE, LOUISIANA

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April 1999

*optimizing environmental resources* - water, air, earth

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# EXECUTIVE SUMMARY

Georgia-Pacific Corporation (Georgia-Pacific) operates a pulp and paper mill, a chemical plant, and a building products plant in Crossett, Arkansas, near the Arkansas-Louisiana state line. The facility employs a combined total of approximately 3,000 people. The pulp and paper mill consists of a Kraft pulp mill, bleach plant, and eight paper machines. The chemical plant consists of a resin plant and a tall oil plant, and the building products plant includes one plywood plant with seven lines and a stud mill.

The wastewater and process area stormwaters from the Georgia-Pacific Crossett Complex are collected and conveyed to an on-site industrial wastewater treatment system which treats the wastewaters using both physical-chemical and biological treatment technologies for removing solids and organics. The wastewater treatment system operates with an average treatment efficiency of 95 percent or greater for the removal of biochemical oxygen demand (BOD). The Crossett Mill wastewater treatment system effluent is discharged to the Ouachita River through Coffee Creek at Ouachita River Mile (ORM) 222, approximately 5 miles downstream from Felsenthal Lock and Dam. The effluent discharge is regulated by the Arkansas Department of Pollution Control and Ecology (ADPC&E) under a water-quality based effluent limit (WQBEL), National Pollutant Discharge Elimination System (NPDES) Permit. This permit limits the Mill to more restrictive treatment requirements than those required by Technology-Based Effluent Limit Guidelines required at similar mills.

This report presents a study which has been performed to determine the available wasteload allocation for the Ouachita River from Felsenthal Lock and Dam (ORM 227) to Sterlington, Louisiana (ORM 192) which will meet water quality standards. This determination is based on data from historical sources, including: **1)** the 1992 "Development of a Water Quality Model of the Ouachita River," HydroQual Report (HydroQual 1992a); **2)** Georgia-Pacific synoptic and diurnal River measurements; **3)** the United States Army Corps of Engineers (USACOE); **4)** the United States Geological Survey (USGS); and **5)** the United States Environmental Protection Agency (USEPA). In addition, the results of a November 1998 field study performed by Georgia-Pacific and **AquAeTer, Inc.** are used to evaluate the wasteload allocation. The field study provided confirmation that algae are present in the Ouachita River and that the algae are a contributing source of oxygen in the River system.

Based on the data resources listed above, additional literature sources, and engineering judgement, a QUAL2E model (Brown and Barnwell 1987) was developed and calibrated for the Ouachita River from Felsenthal Lock and Dam (ORM 227) to just downstream from Sterlington, Louisiana (ORM 190). The period of time used for the model calibration was August 27, 1998, the date on which synoptic water quality measurements were collected by Georgia-Pacific during a low-flow high-temperature period on the Ouachita River. The River flow during this period was 980 cubic feet per second (cfs), which is near the 7-day average flow with a 10-year recurrence interval (7Q10 and Q7-10 are equivalent in this report) for August of 802 cfs. The water temperature measured during this period and used in the calibration model was 31.5 °C. A sensitivity analysis was performed on the calibrated model and indicated that the critical model parameters were background temperature, the algae contribution to dissolved oxygen (DO), the reaeration rate, and the sediment oxygen demand (SOD) rate. The calibrated and tested model was then used to project the available wasteload allocation in the River for ultimate carbonaceous biochemical oxygen demand ($CBOD_u$). The $CBOD_u$ values were converted to 5-day BOD ($BOD_5$ ) using a ratio of $CBOD_u$:$BOD_5$ equal to 4, as presented in the HydroQual Report (1992a).

Wasteload allocation predictions were made for the low-flow, high temperature period of June through September using the monthly 7Q10 flow and both monthly mean temperatures and monthly 90th percentile temperatures at the applicable DO standard, as presented in Tables E-1 and E-2.

The month of September was found to have the minimum assimilative capacity available for wasteload allocation. Both Arkansas and Louisiana will require a 10 percent safety factor built into the maximum model projections in order to establish the total maximum daily loads (TMDLs) for the River. The TMDL projections are presented for the most critical conditions that can occur during water-quality limited periods (low flows and high temperatures), and the monitored conditions from which the model parameters were developed also included periods of non-point source contributions to the Ouachita River system. The resultant TMDLs developed are as follows:

**FOR AVERAGE WATER TEMPERATURE**

| MONTH | 7Q10 (cfs) | AVERAGE WATER TEMPERATURE (°F/°C) | WLA $BOD_5$ (lbs/day) | TMDL $BOD_5$ (lbs/day) |
|---|---|---|---|---|
| June | 1,049 | 80.6/27 | 30,212 | 27,190 |
| July | 894 | 86/30 | 19,797 | 17,817 |
| August | 802 | 86/30 | 11,071 | 9,964 |
| September | 829 | 80.6/27 | 8,163 | 7,346 |

**FOR 90th PERCENTILE WATER TEMPERATURES**

| MONTH | 7Q10 (cfs) | 90th PERCENTILE TEMPERATURE (°F/°C) | WLA $BOD_5$ (lbs/day) | TMDL $BOD_5$ (lbs/day) |
|---|---|---|---|---|
| June | 1,049 | 87.8/31 | 22,706 | 20,435 |
| July | 894 | 89.4/31.9 | 16,228 | 14,605 |
| August | 802 | 88.9/31.6 | 8,069 | 7,262 |
| September | 829 | 85.6/29.8 | 6,568 | 5,911 |

## TABLE E-1. TMDL PROJECTIONS AT MEAN TEMPERATURES
## OUACHITA RIVER FROM FELSENTHAL DAM, AR TO STERLINGTON, LA

| MONTH (1) | TEMP. (°F/°C) | MONTHLY 7Q10 FLOW (cfs) | DO SAT (mg/L) | OUACHITA HEADWATER DO (mg/L) (1) | WLA CBODu (mg/L) (2) | WLA CBODu (lbs/day) (2) | 5-DAY BOD (mg/L) (3) | 5-DAY BOD (lbs/day) (3) | 5-DAY BOD 10% SF (lbs/day) (3) | DO STANDARD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| June | 80.6 / 27 | 1049 | 7.97 | 6.53 | 322 | 120,847 | 81 | 30,212 | 27,190 | 3 |
| July | 86 / 30 | 894 | 7.56 | 6.20 | 211 | 79,188 | 53 | 19,797 | 17,817 | 3 |
| August | 86 / 30 | 802 | 7.56 | 6.20 | 118 | 44,285 | 30 | 11,071 | 9,964 | 4.5 |
| September | 80.6 / 27 | 829 | 7.97 | 6.53 | 87 | 32,651 | 22 | 8,163 | 7,346 | 5 |

**NOTES:**

1) Ouachita River headwater DO equals 82 percent of saturation.
2) Values determined at Georgia-Pacific flow = 45 mgd.
3) Assume CBODu:CBOD5 = 4.

## TABLE E-2. TMDL PROJECTIONS AT 90th PERCENTILE TEMPERATURES
## OUACHITA RIVER FROM FELSENTHAL DAM, AR TO STERLINGTON, LA

| MONTH (1) | TEMP. (°F/°C) | MONTHLY 7Q10 FLOW (cfs) | DO SAT (mg/L) | OUACHITA HEADWATER DO (mg/L) (1) | WLA CBODu (mg/L) (2) | WLA CBODu (lbs/day) (2) | WLA 5-DAY BOD (mg/L) (3) | WLA 5-DAY BOD (lbs/day) (3) | TMDL 5-DAY BOD 10% SF (lbs/day) (3) | DO STANDARD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| June | 87.8 / 31 | 1049 | 7.43 | 6.09 | 242 | 90,823 | 61 | 22,706 | 20,435 | 3 |
| July | 89.4 / 31.9 | 894 | 7.32 | 6.00 | 167 | 62,675 | 42 | 16,228 | 14,605 | 3 |
| August | 88.9 / 31.6 | 802 | 7.36 | 6.03 | 86 | 32,276 | 22 | 8,069 | 7,262 | 4.5 |
| September | 85.6 / 29.8 | 829 | 7.59 | 6.22 | 70 | 26,271 | 18 | 6,568 | 5,911 | 5 |

**NOTES:**

1) Ouachita River headwater DO equals 82 percent of saturation.
2) Values determined at Georgia-Pacific flow = 45 mgd.
3) Assume CBODu:CBOD5 = 4.

# SECTION 1

# INTRODUCTION

## BACKGROUND

The Ouachita River originates in the Ouachita Mountains of Arkansas near the Oklahoma border and flows approximately 605 miles to the confluence with the Tensas River near Trinity, Louisiana where these two rivers form the Black River. The Black River flows a few more miles and joins the Red River to form the Atchafalaya River around Acme, Louisiana, as presented in Figure 1-1 and the Ouachita River Basin map presented in Appendix 1. The river in the study area flows to the southeast and at the Arkansas/Louisiana border has a drainage area of approximately 10,835 square miles (HydroQual 1992a). Data for a 48.9-mile reach of the Ouachita River between Ouachita River Mile (ORM) 239.1, upstream from the Felsenthal Lock and Dam, to ORM 190.2 downstream from Sterlington, Louisiana are presented in this report. The river reaches between the new Felsenthal Lock and Dam at about ORM 227.1 and Sterlington, Louisiana at about ORM 191.6 are the focus of the water quality modeling. River schematics are presented in Figures 1-2 and 1-3, and topographic maps of the study area are presented in Appendix 1.

Tributaries to the Ouachita River along the reaches from Felsenthal Dam to Sterlington include:

- Coffee Creek (ORM 222);
- Pierre Creek (ORM 211);
- Possum Bayou (ORM 207.5);
- Bayou de Butte (ORM 203);
- Boggy Bayou (ORM 199);

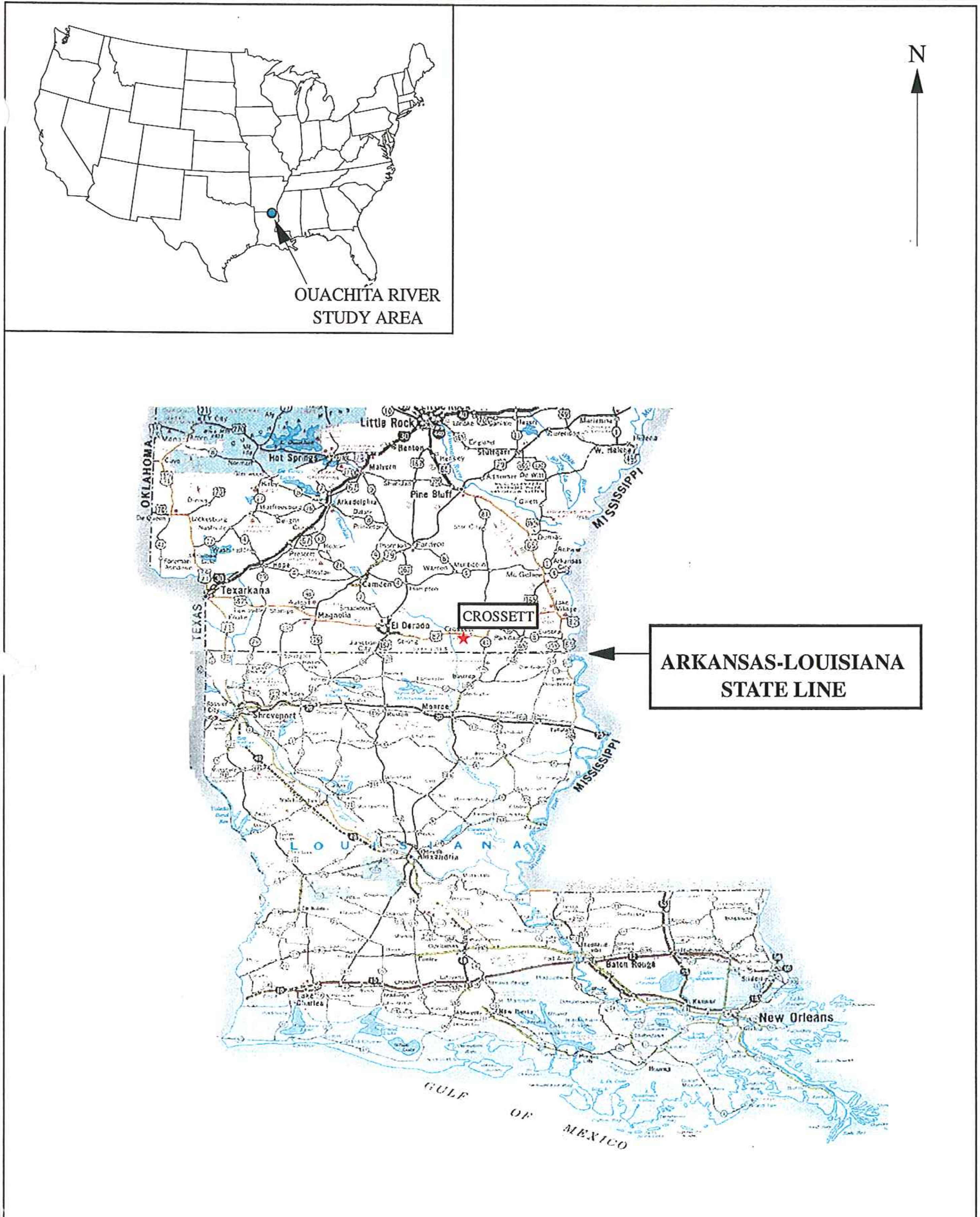
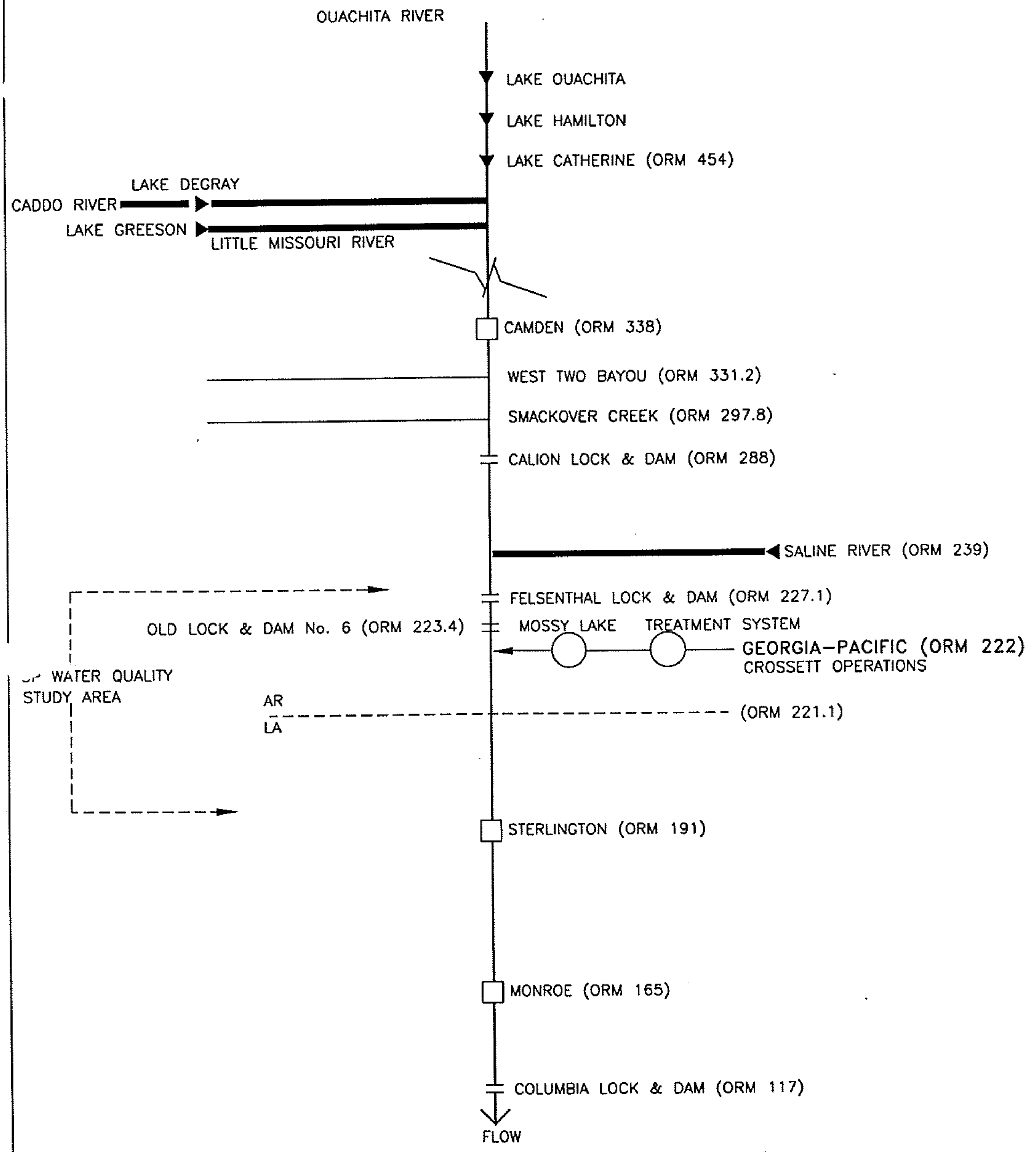


**FIGURE 1-1**
LOCATION MAP



NOT TO SCALE

FIGURE 1-2
OUACHITA RIVER PHYSICAL SYSTEM

AquAeTer

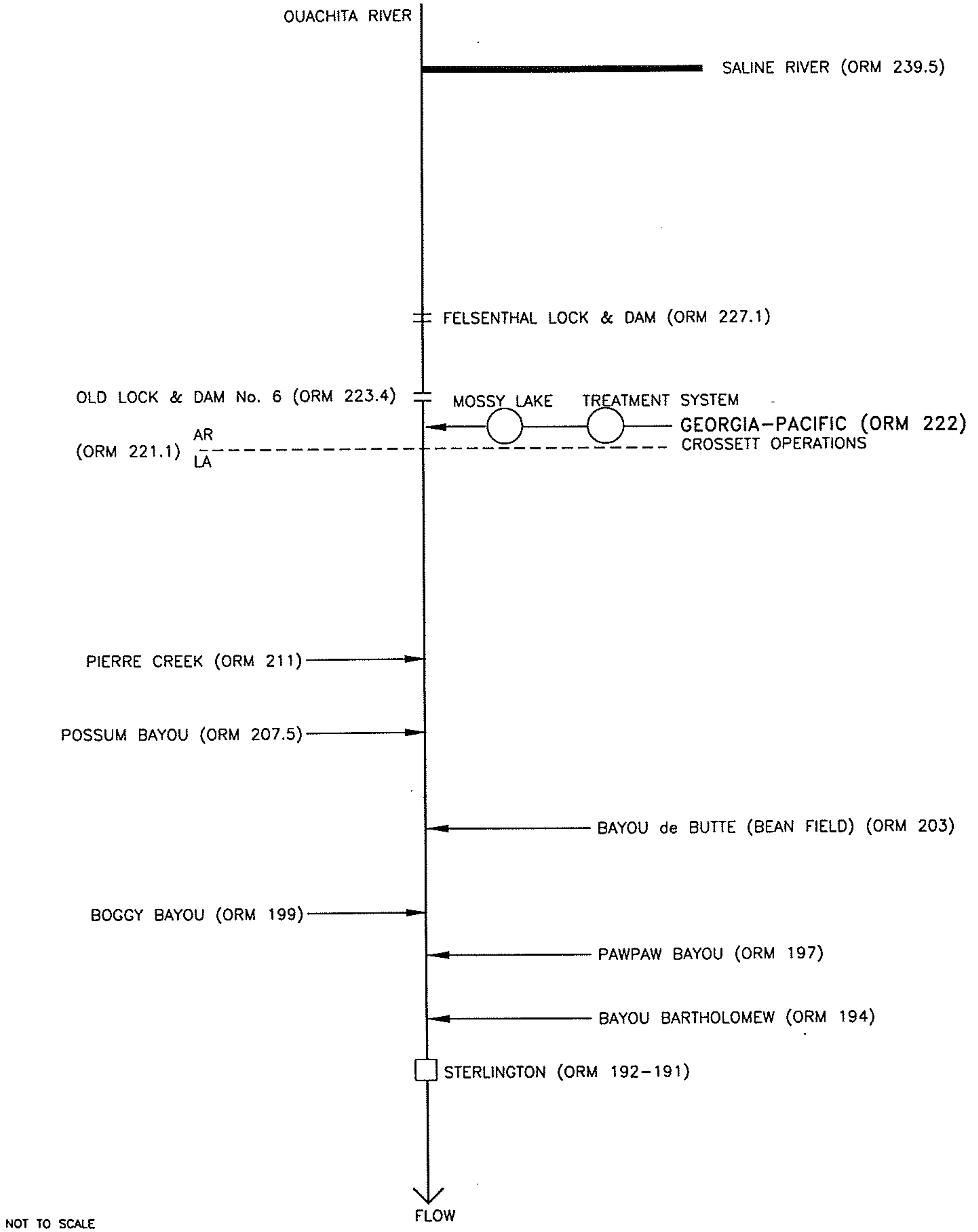


FIGURE 1-3
STUDY AREA PHYSICAL SYSTEM

AquAeTer

- Papaw Bayou (ORM 197); and
- Bayou Bartholomew (ORM 194).

Major discharges along this 48.9-mile system include:

- Georgia-Pacific Corporation's (Georgia-Pacific) pulp and paper mill at Crossett, Arkansas (Coffee Creek);
- An approximate 19,000-acre bermed soybean field, which drains into Bayou de Butte;
- Bayou Bartholomew, which receives primarily non-point source runoff and a point source discharge from Lake Bayou Bartholomew;
- The Town of Sterlington's publicly owned treatment works (POTW) located at about ORM 192; and
- Koch Nitrogen, which is located at Sterlington around ORM 191.5.

The new Felsenthal Lock and Dam at ORM 227 became operational beginning in June 1985. Prior to this date, the old Felsenthal Lock and Dam had been located 3.7 miles downstream at ORM 223.2. Original construction of the new Felsenthal Dam at ORM 227 included three Tainter gates that release water from the bottom of the dam. In 1996, a 188-foot long and 4-foot tall hinge crest gate was also installed. According to Larry Dawson (1998), Lockmaster, Felsenthal Lock and Dam, if the water level in the river drops too low, the Tainter gates are closed accordingly, and the hinge crest gates remain open at all times; that is, during low flow periods, all or most of the River flows over the hinge crest gates thereby providing reaeration to waters flowing from Felsenthal Reservoir downstream. A view of the hinge crest gate from the downstream side of the dam is presented in Figure 1-4.

**FIGURE 1-4**
VIEW OF THE HINGE CREST GATE
FELSENTHAL LOCK AND DAM

## USE ATTAINABILITY ANALYSIS

In 1993, a Dissolved Oxygen Use Attainability Analysis (UAA) for the Ouachita River from Felsenthal, Arkansas to Sterlington, Louisiana was completed by Georgia-Pacific (Taylor, et.al. 1993). Later, UAA's were prepared and submitted to the United States Environmental Protection Agency (USEPA) by both the Arkansas Department of Pollution Control and Ecology (ADPC&E) and the Louisiana Department of Environmental Quality (LDEQ). The UAA's prepared by Arkansas and Louisiana proposed modifying the water quality criteria for dissolved oxygen (DO) standards in the Ouachita River from Felsenthal, Arkansas to the Arkansas-Louisiana border (Arkansas UAA) and from the border to the Columbia Lock and Dam at Columbia, Louisiana (Louisiana UAA). Due to low DO characteristics of the Ouachita River, which occurred as a result of both natural and anthropogenic causes, the background DO concentrations downstream from Felsenthal Dam during periods of flooding were lower than both the Arkansas and Louisiana DO standard of 5 mg/L. Background DOs were routinely below the Arkansas and Louisiana DO standards in the months of April through August when flooding or receding floods cause DO in the river to drop below the standards. However, based on fisheries and macrobenthos investigations conducted by Arkansas and by Dr. Neal Douglas at Northeast Louisiana University (Taylor, et.al. 1993), the biological health of the River was good. Therefore, the adjustment of the DO standards to reflect the naturally occurring conditions would not affect the use designations assigned to the Ouachita River by both states.

Results of the UAA indicated that both naturally-occurring flooding (primary cause) and existing conditions caused by the Felsenthal Dam pool (secondary cause) resulted in river DO concentrations being suppressed to below the 5 mg/L Arkansas and Louisiana DO standard for extended periods from April through September. DO concentrations upstream from Coffee Creek lower than 5 mg/L were found to occur 47 percent of the time during the months from May through September during the 5-year period from 1987 through 1992. Most of the low DO levels occurred at stages when the Felsenthal Dam was effectively flooded out; that is, the upper pool and lower pool were at or close to the same elevation. The cause for the low DOs experienced at high river stages (flood conditions) was believed to be the biochemical oxygen demand (BOD) exerted by forest litter in the flood plain. During 1991, a high stage flow period, DOs upstream from Coffee Creek were below 5 mg/L for 100 percent of the days in May, June, and July, with the DO being less than 2 mg/L for 100 percent of the time in May and June. DO was also less than 5 mg/L for 15 percent of the days in September. For the 5-year period from 1987 to 1992, DOs just upstream from Coffee Creek were less than 5 mg/L for 53 and 55 percent of the time in May and June, respectively, for 71 percent of the time in July, for 38 percent of the time in August, and for 17 percent of the time in September.

The UAA reports recommended adjustment of DO standards to reflect these natural events and both states have adopted these recommendations in their respective water quality regulations. Current Arkansas regulations specify that from ORM 223 to ORM 221.1 (Arkansas-Louisiana state line), the site-specific seasonal DO criteria are 3 mg/L for June and July, 4.5 mg/L for August, and 5 mg/L for September through May. Louisiana regulations also specify the same seasonal DO criteria, and both Arkansas and Louisiana regulations specifically state that "these seasonal criteria may be unattainable during or following naturally occurring high flows, (i.e., river stage above 65 feet measured at the lower gauge at the Felsenthal Lock and Dam, Station No. 89-o, and also for the two weeks following the recession of flood waters below 65 feet), which occurs from May through

August. Naturally occurring conditions which fail to meet criteria should not be interpreted as violations of these criteria."

The release of Ouachita River waters over the hinge crest gate has improved the DO in the River during low river flow periods. However, synoptic river DO measurements taken by Georgia-Pacific during periods of high river stage in August 1996 and July 1997 support the UAA recommended DO standards. The minimum DO measured during these two synoptic river runs and the corresponding river stage are presented in Table 1-1. The bottom lip of the hinge crest gate on the Felsenthal Dam is at an elevation of 64 feet, and the upper pool is maintained at an elevation of 65 feet. During the higher stage periods, low DO waters from the marsh areas still impact the River DO.

## GEORGIA-PACIFIC CORPORATION CROSSETT OPERATIONS

Georgia-Pacific owns and operates a pulp and paper mill, a chemical plant, and a building products plant in Crossett, Arkansas, located in the southeast corner of the state as shown in Figure 1-1. The pulp and paper mill consists of a Kraft pulp mill, bleach plant, and eight paper machines. The facility employs approximately 1,800 people. Two of the paper machines produce fine paper (tablet, envelope, and writing paper), one paper machine produces board stock (cartons and food grade), and five paper machines produce tissue. The combined production of the pulp and paper mill is approximately 2,000 tons per day.

The Georgia-Pacific chemical plant at Crossett consists of a resin plant, with five kettles and one resin mixer, and a tall oil plant. The resin plant manufactures phenol-formaldehyde resins, urea-formaldehyde resins, wet strength resin, dry strength resin, Novacote, and resi-mix resin. The tall

TABLE 1-1. MINIMUM DO AND CORRESPONDING RIVER STAGE

| DATE | MINIMUM DO (mg/L) (1) | MAXIMUM RIVER STAGE (feet) (2,3) | AVERAGE RIVER STAGE (feet) (4) |
|---|---|---|---|
| August 14, 1996 | 3.4 | 62.7 | 58.9 |
| July 8, 1997 | 3.5 | 64.7 | 62.1 |

NOTES:

1) The minimum DO for both August 14, 1996 and July 8, 1997 was measured at ORM 194.
2) River stage represents the elevation of the lower pool as measured at the Felsenthal Lock and Dam.
3) The maximum river stage observed for the time period encompassing the day of measurement plus seven days preceding the sampling date.
4) The average river stage observed during the time period encompassing the day of measurement plus seven days preceding the sampling date.

oil plant consists of several units, including: **1)** the tall oil fractionation plant; **2)** the rosin size plant; **3)** the rosin derivatives plant; **4)** the dispersed size plant; and **5)** the tall oil acidulation plant. The chemical plant employees 220 people.

The building products plant presently consists of one plywood plant with 7 lines and a stud mill. The plywood plants operate five lathes, seven presses, and two glue lines. The stud mill operates one planer. The building products plant employs a total of 760 people and produces approximately two-million board feet per day.

The wastewater and process-area stormwaters from the Georgia-Pacific Crossett Complex, as described above, are collected and conveyed to an on-site industrial wastewater treatment system, which treats the wastewaters using both physical-chemical and biological treatment technologies for removing solids and organics from the wastestreams. The treatment processes include the following seven steps:

1. Nutrient addition required for biological treatment;
2. Screening for removal of large solids and debris;
3. Primary clarification for solids removal;
4. Settling for fine solids and ash removal;
5. Equalization for flow and organic loading consistency to the downstream biological treatment system;
6. Aerated stabilization basin (ASB) for biological reduction of organics and a quiescent zone for removal of biological solids; and
7. Final polishing pond for further treatment and solids removal prior to discharge to the receiving stream.

A wastewater treatment train schematic is presented in Figure 1-5. The Georgia-Pacific treatment system has been designed to provide advanced secondary treatment to ensure that water quality standards are met in the Ouachita River.

The wastewaters from the plant are collected in two separate wastestreams: **1)** a high-solids content wastestream of approximately 24 million gallons per day (mgd), collected from the paper machines, recovery area, and pulp mill; and **2)** a low-solids content wastestream of approximately 23 mgd, collected from the utilities area, bleach plant, plywood, and chemical operations.

The high-solids content wastestream is first conveyed to a bar screen, where large solids and debris are collected and removed, and then to a 300-foot diameter primary clarifier. Solids removed from the clarifier are processed through a belt press to a solids content of greater than 25 percent and are then disposed. Wastewater discharged from the clarifier is combined with the low solids wastestream.

Nutrients are added to the low-solids wastestream at the mill. This wastestream is then combined with the clarifier effluent and the combined wastestreams of about 47 mgd pass through the active settling basin. The overflow rate of the active settling basin is maintained so that the rate does not exceed approximately 200 gallons per square foot per day. The active basin is operated on a 6 to 8 week rotation, at which time it is removed from service for solids removal, and the flow is diverted to the other basin. Basin selection is determined by solids discharge and removal operations. These basins provide solids removal so that the downstream ASB is primarily receiving a soluble organic loading.

The combined effluent from the active settling basin gravity flows to the surge basin where, depending on operational needs, water is held for equalization, additional settling, and stormwater

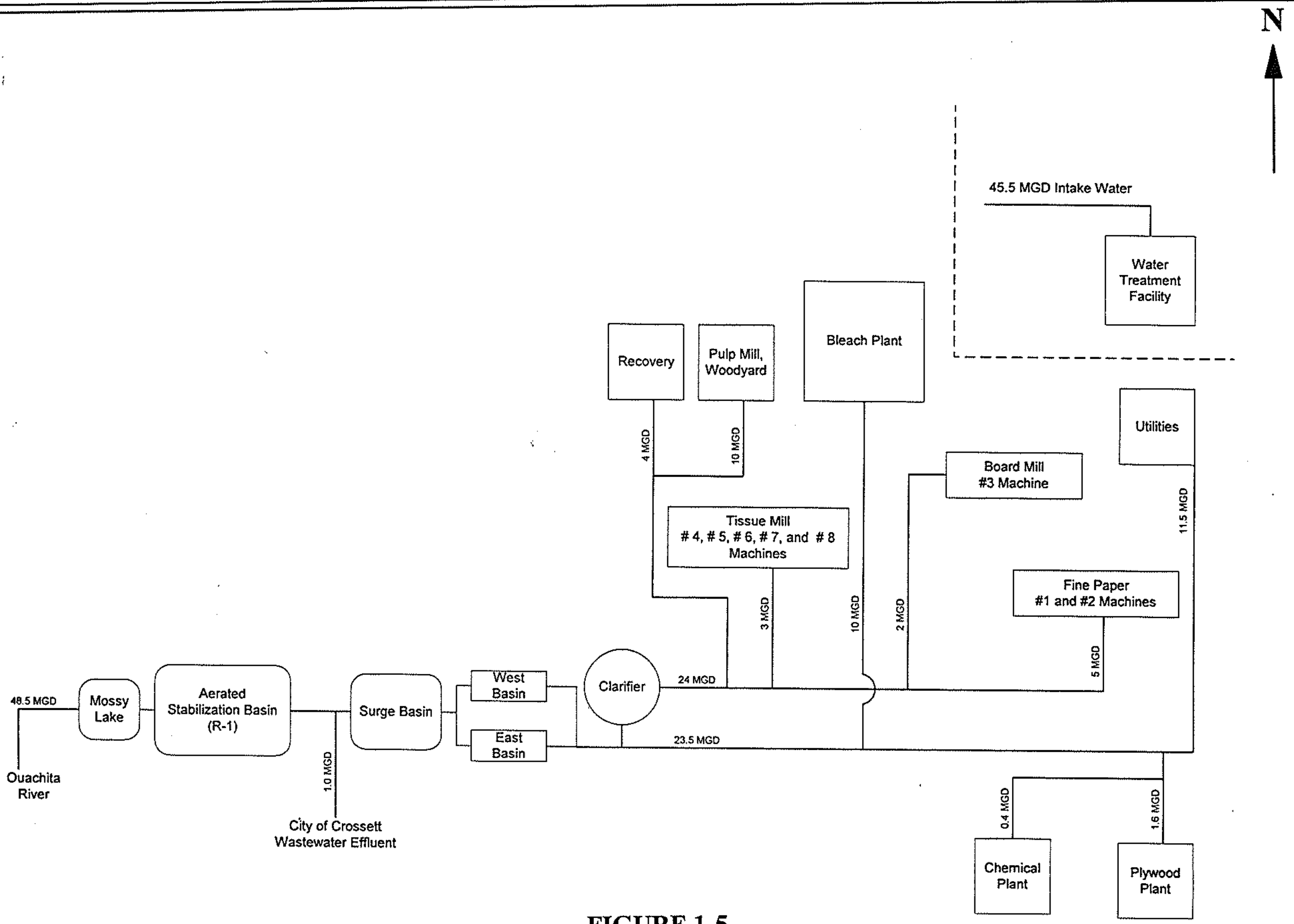


**FIGURE 1-5**
WASTEWATER TREATMENT SCHEMATIC
GEORGIA-PACIFIC CROSSETT MILL

management. This basin provides a steady flow with an organic content that has been equalized for feed into the downstream biological treatment system (the ASB). The effluent from the surge/equalization basin is measured and sampled prior to gravity flow to the ASB. In addition, wastewater discharged from the City of Crossett's two facultative ponds mixes with effluent from the "surge basin" and flows into the ASB.

The ASB is a 232-acre, 600 million-gallon basin with 2,845 horsepower (hp) of total surface aeration capacity. The ASB provides biological treatment to the organic content in the combined wastestreams from the facility. Retention time in the ASB is approximately 12 to 13 days, based on pond volume and flow. The treated ASB effluent is discharged through three mechanically-adjusted gates, which allow the flow from the ASB to be controlled. Flow is measured and samples are collected for National Pollutant Discharge Elimination System (NPDES) analysis at these gates. The effluent biochemical oxygen demand, as determined by a 5-day test ($BOD_5$), from the ASB averages about 31.2 mg/L with a range of 11.3 to 67.6 mg/L. The treatment efficiency across the ASB averages about 72.0 percent with a range of 37.5 to 88.0 percent. At high stages in the Ouachita River (greater than or equal to 62 feet above the National Geodetic Vertical Datum of 1929 or ft NGVD), this location is the final permitted discharge point, Outfall 001, to the River. When the River comes back into its banks (less than 62 ft NGVD), the treated effluent gravity flows to Mossy Lake, where further solids settling occurs prior to discharge to the receiving stream, Coffee Creek.

Mossy Lake is a 600-acre shallow lake that provides final polishing of the treated effluent prior to discharge into Coffee Creek. The Mossy Lake discharge is controlled by operation of a single weir gate. Flow is measured and samples collected for NPDES analysis at permitted Outfall 002. The effluent $BOD_5$ from Mossy Lake averages about 11.4 mg/L with a range of 5.3 to 25.0

mg/L. The $BOD_5$ removal efficiency across Mossy Lake averages about 59.3 percent with a range of 47.0 to 69.0 percent. On average, the $BOD_5$ treatment efficiency from the ASB influent to the Mossy Lake effluent is 92 percent, when averaged over the past two years during periods when the system is not flooded. The treatment efficiency from the raw influent to the solids removal system to the discharge at Mossy Lake is typically greater than 95 percent. Average flow from Mossy Lake is about 48.5 mgd with a range of 19.6 to 94.0 mgd. Coffee Creek flows from Mossy Lake about 0.5 mile to the Ouachita River, and the Creek enters the River at about ORM 222.

The effluent guideline limits (technology limits) for the mill derived from the 1986 NPDES permit would allow an effluent discharge of 19,370 lbs/day $BOD_5$. The mill treats to a higher level than the technology limits and is meeting water quality effluent limits as required to ensure that DO and stream water quality standards are maintained. Effluent $BOD_5$ limits of 8,000 lbs/day or less, depending on River flow, are met from the treatment system. Additionally, Georgia-Pacific routinely monitors the River during critical summer low-flow high-temperature months in order to document compliance with the River DO standards.

## OBJECTIVE

The objective of this report is to determine the available wasteload allocation for the Ouachita River from ORM 227 at Felsenthal Dam to ORM 192 at Sterlington necessary to meet water quality standards. This determination is based on data from historical sources, including the 1992 "Development of a Water Quality Model of the Ouachita River" HydroQual Report (HydroQual 1992a), Georgia-Pacific synoptic and diurnal river measurements, the United States Army Corps of Engineers (USACOE), the United States Geological Survey (USGS), the USEPA, the Georgia-Pacific/**AquAeTer, Inc. (AquAeTer)** November 1998 study, literature sources, and engineering judgement. These data resources are discussed further in Section 2 of this report.

The QUAL2E calibration model, created to project the total maximum daily loads (TMDLs) predictions, and a description of the sensitivity analysis performed on this model are presented in Section 3. The TMDLs projected by the calibrated model are presented in Section 4.

# SECTION 2

# DATA RESOURCES

Several resources were used to provide the baseline of data needed to establish initial and boundary conditions for calibrating the wasteload allocation model QUAL2E (Brown and Barnwell 1987) for the Ouachita River near Crossett, Arkansas. These resources include historical sources, literature sources, engineering judgement, and field data collected during the November 1998 Georgia-Pacific/**AquAeTer** Ouachita River field study. As previously presented, the primary study area for the Ouachita River was from Felsenthal Lock and Dam, ORM 227, to Sterlington, Louisiana, ORM 192. The following section presents the data resources used in preparing the wasteload allocation model.

## HISTORICAL SOURCES

Historical sources utilized include the following: **1)** July 27, 1992 HydroQual, Inc. report titled "Development of a Water Quality Model of the Ouachita River;" **2)** field data collected by Georgia-Pacific for Coffee Creek and the Ouachita River; **3)** data provided by the USACOE; **4)** data provided by the USGS; and **5)** data provided by USEPA.

### HydroQual Report

A water quality model of the Ouachita River was originally developed by Hydroscience, Inc. as part of the "Ouachita River Basin Water Quality Management Plan" (HydroQual, 1992a) for the State of Louisiana. HydroQual, Inc. made improvements to this water quality model in 1981 to use in setting the Georgia-Pacific mill's permit limits. In 1992, HydroQual, Inc. verified and further improved this previous model by conducting a study of about 47 miles of the Ouachita River from ORM 237 in the Felsenthal Reservoir to about ORM 189 downstream Sterlington. The purpose of this study, "Development of a Water Quality Model of the Ouachita River," was to determine the impact of Georgia-Pacific's discharge on the DO content of the river during critical river flow conditions. Specific data obtained from the HydroQual Report are detailed in Section 3 of this report.

The HydroQual Report was used as the basis for developing the calibration model. The model hydraulics, including the velocity and depth exponents and coefficients, were used as presented in the HydroQual Report. The Report appendices presented water quality data, including dissolved oxygen, temperature, BOD, nutrients, sediment oxygen demand (SOD), and flow data, that were used as appropriate in the development of the QUAL2E calibration model. The BOD ($k_1$) decay rates presented in the HydroQual Report of 0.05/day for background and 0.1/day for the River downstream from Coffee Creek, were used as the basis for the rates in the QUAL2E model. The HydroQual Report, however, did not present nitrogen decay rates in the water quality model. In response to comments from LDEQ, organic nitrogen hydrolosis ($k_{orgN}$) and ammonia ($k_{NH3}$) decay rates of 0.1/day were assumed based on a study performed upstream on the Ouachita River near Camden, Arkansas and on rates presented in a study performed by Dr. Ray Whittemore of the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI) (Bowie et al., 1985). Based on the addition of nitrogen rates, the BOD decay rate downstream from Coffee Creek was modified to 0.075/day, because HydroQual had essentially used one inclusive river decay rate ($k_r \approx k_1 + k_{orgN} + k_{NH3}$).

Georgia-Pacific Corporation

Georgia-Pacific typically conducts synoptic river runs of the Ouachita River from ORM 239.1 to ORM 190.2 for the collection of water quality data once per month during the summer months of July, August, and September. In 1998, Georgia-Pacific collected water quality data during a synoptic river run in the month of June, as well. These data have been used to update the information presented in the HydroQual Report to reflect current River conditions in the QUAL2E model.

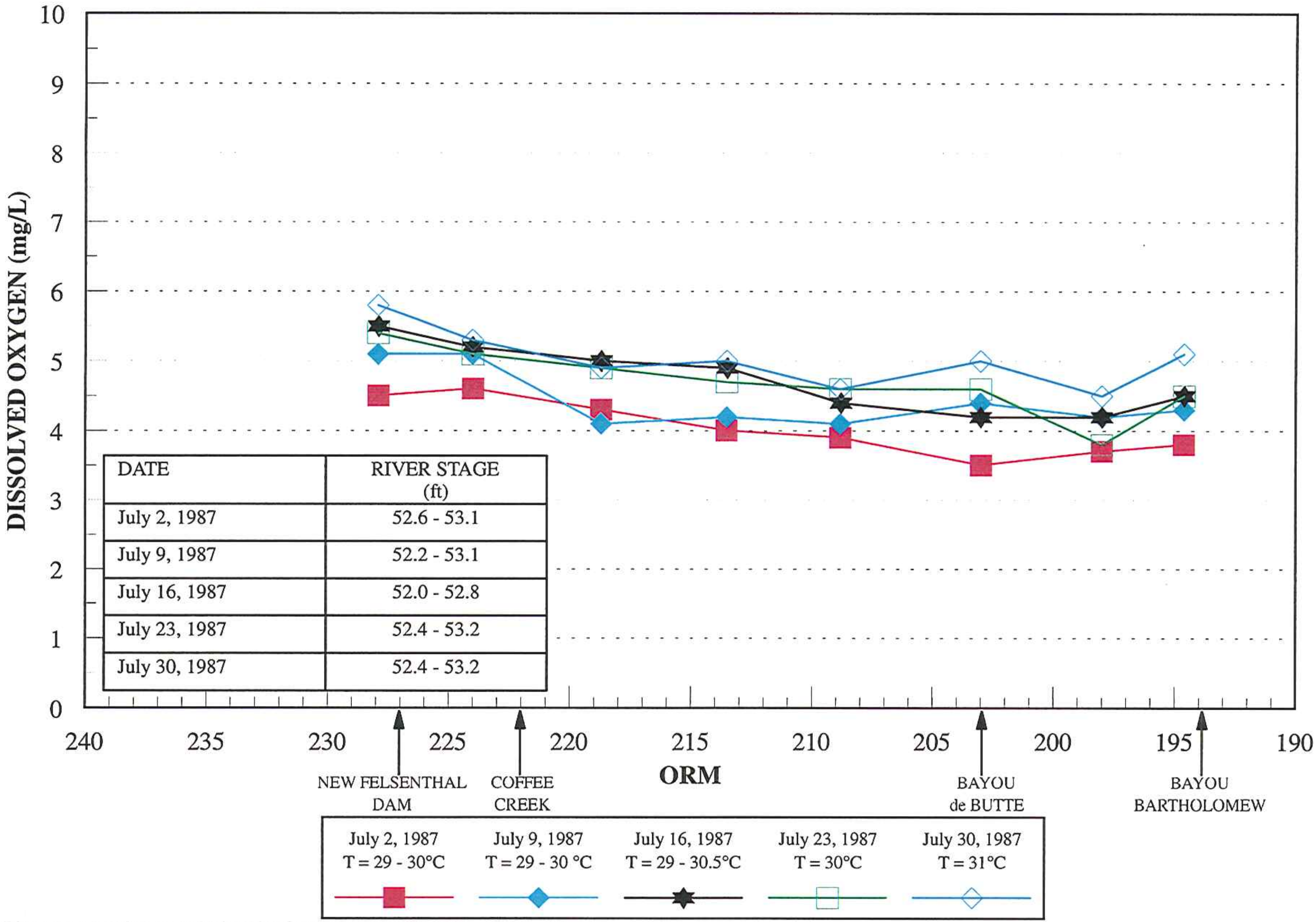
DO and temperature measurements collected by Georgia-Pacific in July 1987 and presented in the HydroQual Report are presented in Figure 2-1 and in Appendix 2. Stage data, as summarized in Figure 2-1, are presented in Appendix 3. These DO measurements reflect the condition of the River in 1987 when water was released only from the three Tainter gates which discharged water from the bottom of Felsenthal Reservoir. This scenario no longer represents conditions on the Ouachita River since the construction of the hinge crest gates in 1996. These gates allow releases over the Dam, thereby reaerating the reservoir water as it is discharged downstream. According to Larry Dawson (1998), Lockmaster, Felsenthal Lock and Dam, if the water level in the River drops too low, the Tainter gates are closed accordingly, and the hinge crest gate remains open at all times. Therefore, it was determined that the River conditions represented by the July 1987 data are no longer applicable to the Ouachita River downstream from Felsenthal Dam.

The 1996 synoptic river DO and temperature measured by Georgia-Pacific are presented as Figure 2-2 and in Appendix 2. All three measurement dates show an increase in DO between ORM 229 and ORM 224, indicating that reaeration is occurring over the Felsenthal Dam (ORM 227). These measurements correspond to the periods after the installation in 1996 of the hinge crest gate.

# FIGURE 2-1

## JULY 1987 RIVER DO MEASURED BY GEORGIA-PACIFIC

### OUACHITA RIVER NEAR CROSSETT, ARKANSAS



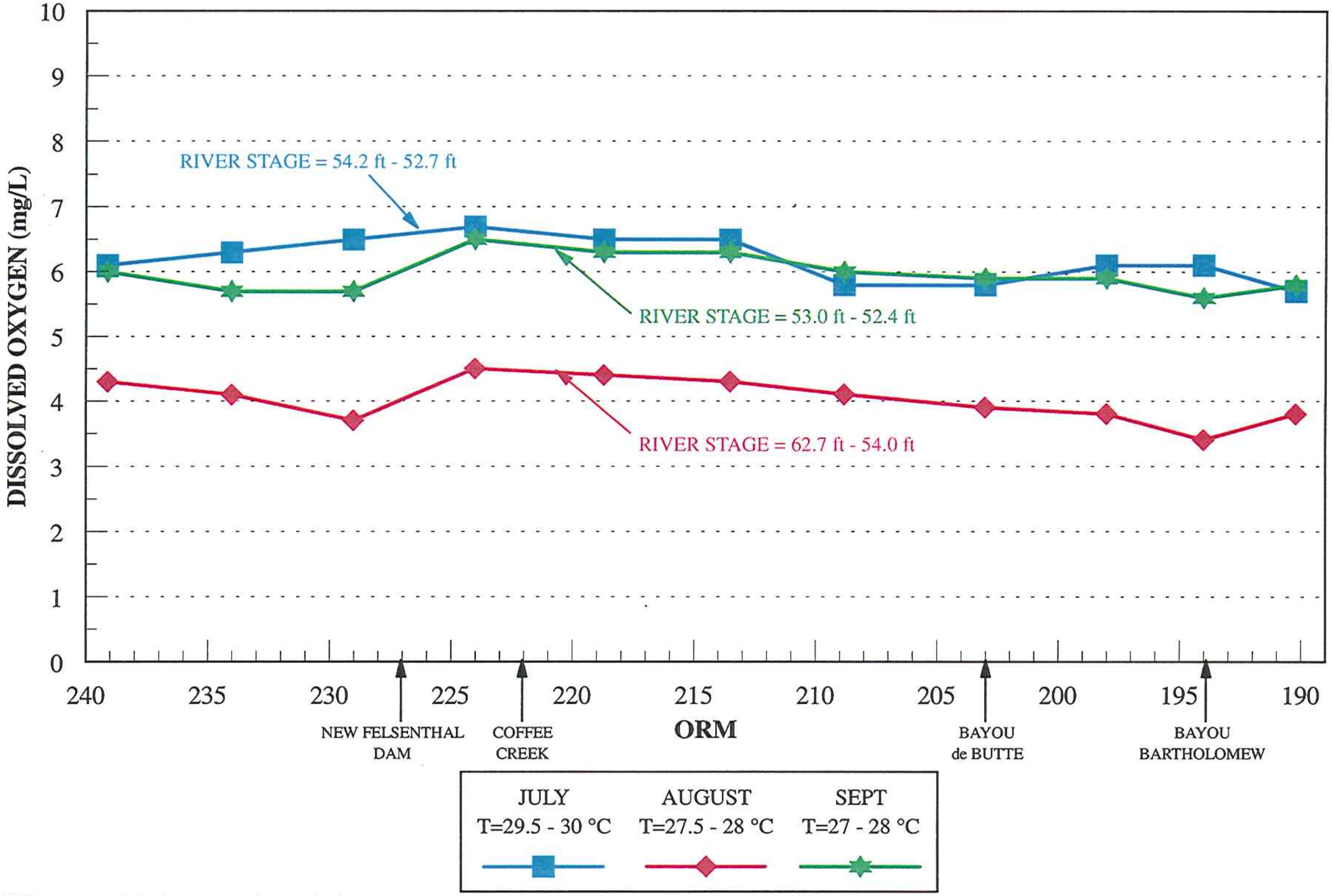
| DATE | RIVER STAGE (ft) |
|---|---|
| July 2, 1987 | 52.6 - 53.1 |
| July 9, 1987 | 52.2 - 53.1 |
| July 16, 1987 | 52.0 - 52.8 |
| July 23, 1987 | 52.4 - 53.2 |
| July 30, 1987 | 52.4 - 53.2 |

River stage equals max and min value for week preceeding DO measurement.

## FIGURE 2-2

### 1996 RIVER DO MEASURED BY GEORGIA-PACIFIC

OUACHITA RIVER NEAR CROSSETT, AR



DO measured during a one day period.
River stage equals max and min value for week preceeding DO measurement.

The Ouachita River was near flood stage one week prior to the August 14, 1996 sampling date, and the effects of this high stage are reflected in the decreased DO values, with all measurements for August 14, 1996 being below 5 mg/L. The decrease in DO at ORM 194 observed on August 14, 1996 is thought to result from flooding and subsequent contribution from non-point sources entering the Ouachita River via Bayou de Butte (beanfield drainage) and Bayou Bartholomew. The flow in Bayou Bartholomew was estimated at 465 (cubic feet per second) cfs on August 14, 1996 as compared to flows less than 200 cfs during other measurement periods. Additionally, increased turbidity during these periods is believed to decrease the algal productivity for oxygen.

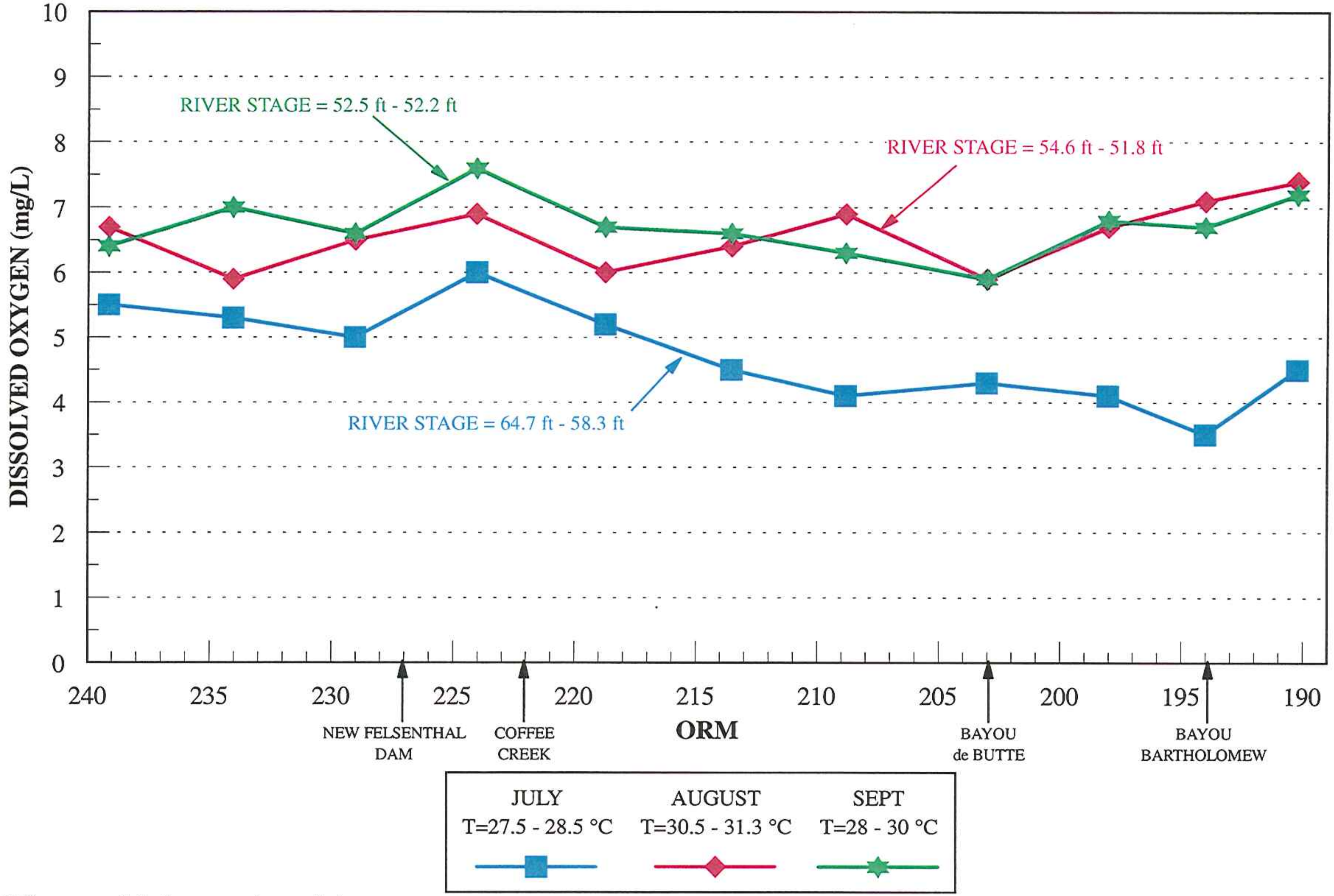
The 1997 synoptic river DO and temperature values measured by Georgia-Pacific are presented in Figure 2-3 and in Appendix 2. As in 1996, all three measurement dates show an increase in DO between ORM 229 and ORM 224, indicating that reaeration is occurring over the Felsenthal Dam (ORM 227). The Ouachita River was near flood stage one week prior to the July 8, 1997 sampling date, and the effects of this high stage are reflected in the decreased DO values, with DO measurements in much of the River being below 5 mg/L. In addition, the low DO at ORM 194 is thought to result from non-point source impacts to the River because the flow in Bayou Bartholomew was estimated at 1,320 cfs, as compared to flows less than 200 cfs during other measurement periods.

The 1998 synoptic river DO and temperature values measured by Georgia-Pacific at the 5-foot depth are presented in Figure 2-4 and in Appendix 2. Stage data for 1996 through 1998 are presented in Appendix 3. The August 27, 1998 and September 18, 1998 measurement data show an increase in DO between ORM 229 and ORM 224, indicating reaeration over the Felsenthal Dam (ORM 227). According to Mr. Larry Dawson (1998), Lockmaster, Felsenthal Lock and Dam, the

# FIGURE 2-3

## 1997 RIVER DO MEASURED BY GEORGIA-PACIFIC

### OUACHITA RIVER NEAR CROSSETT, AR

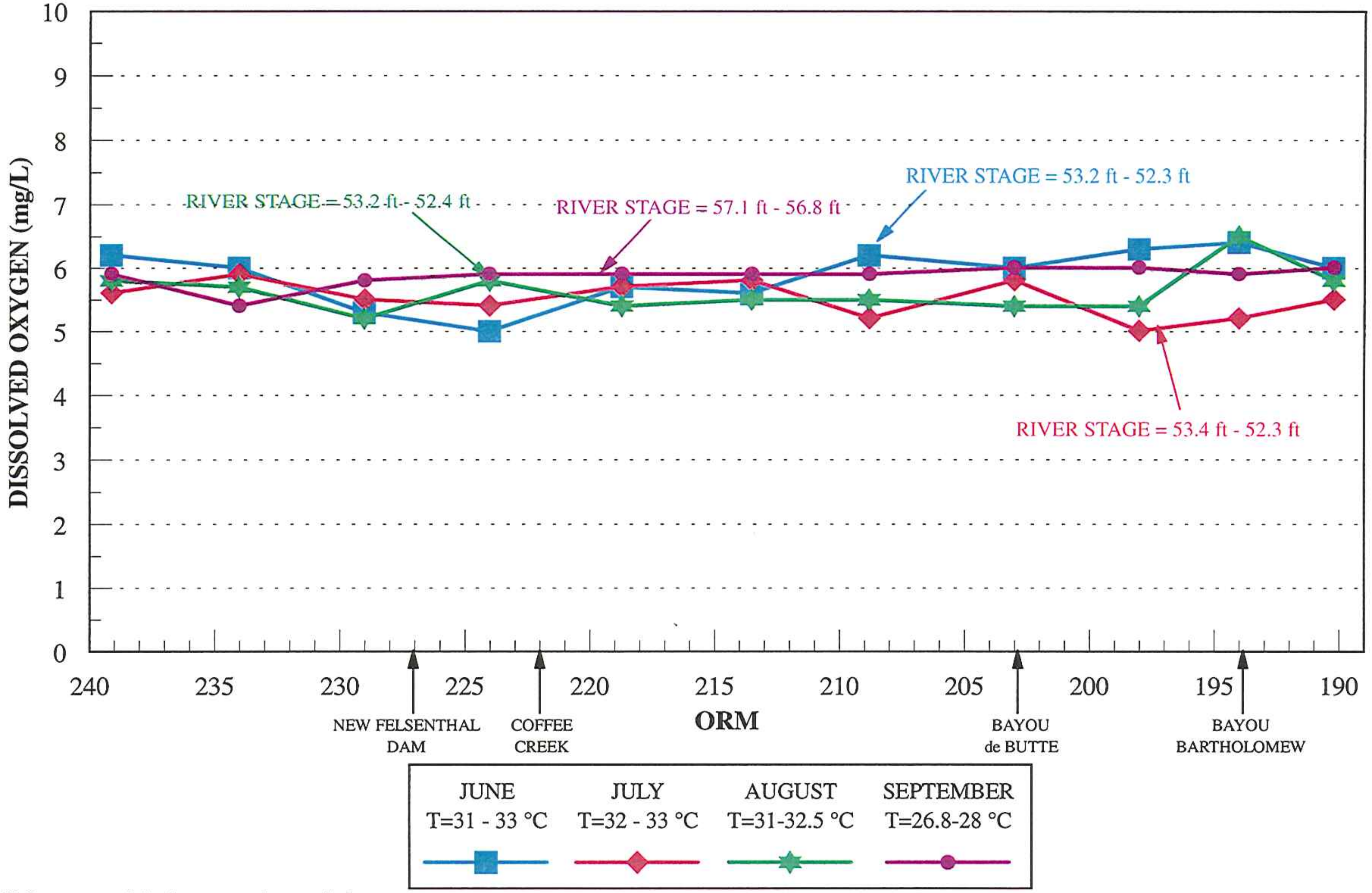


DO measured during a one day period.
River stage equals max and min value for week preceeding DO measurement.

# FIGURE 2-4

## 1998 RIVER DO MEASURED BY GEORGIA-PACIFIC

OUACHITA RIVER NEAR CROSSETT, AR



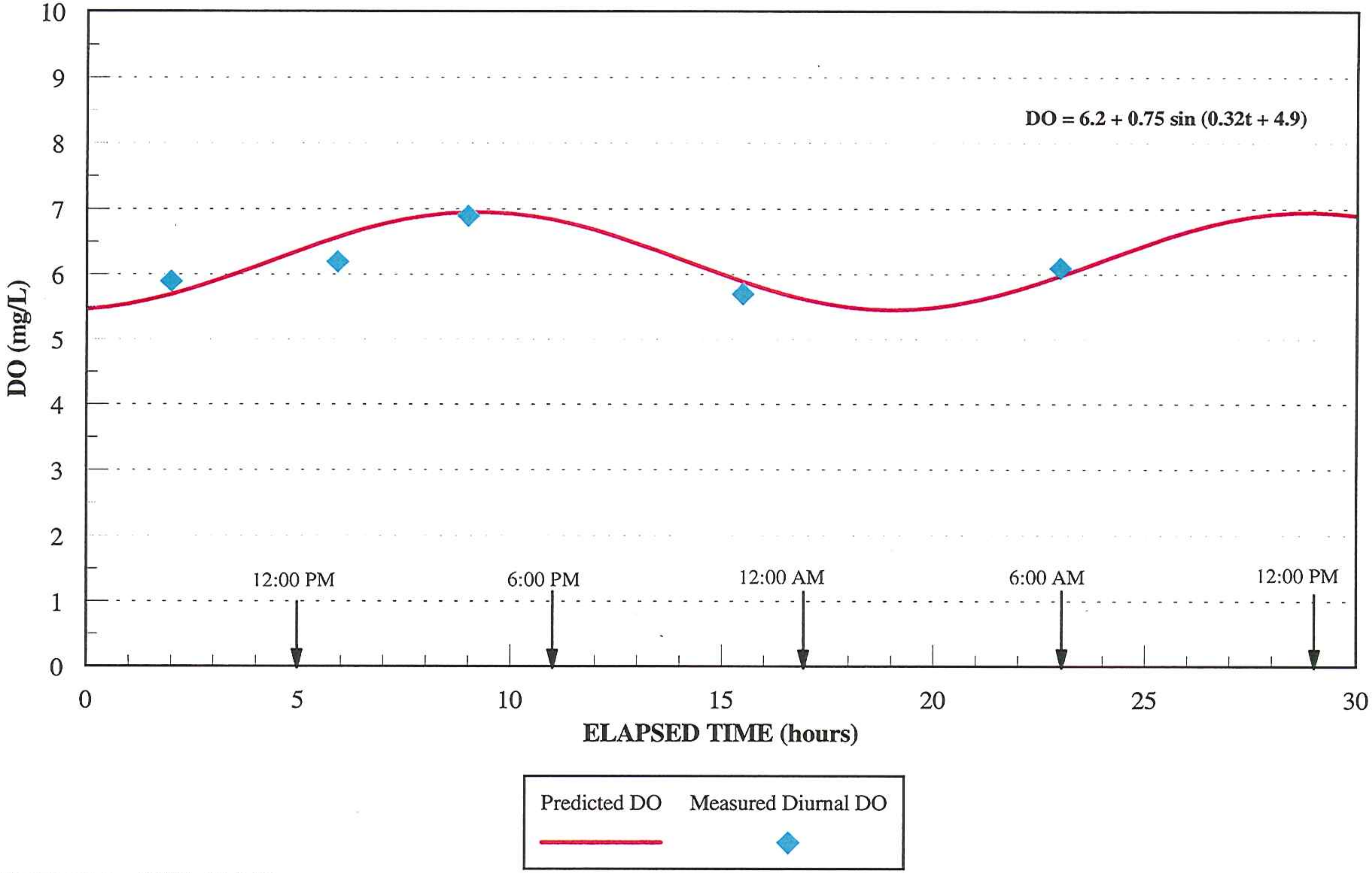
DO measured during a one day period.
Depth of Measurement = 5 ft.
River stage equals max and min value for week preceeding DO measurement.

lack of reaeration over the dam in June and July is possibly due to dredging work being performed upstream from the dam during those months.

Diurnal DO data were measured by Georgia-Pacific at depths of 1-foot and 5-feet at ORM 224, ORM 208.8, and ORM 189.3. The diurnal DO was measured at ORM 224 and ORM 208.8 on August 5, 1998 and at ORM 189.3 on July 1, 1998. At a depth of 5-feet , the diurnal variation in DO at ORM 224 was 1.5 mg/L, the diurnal variation in DO at ORM 208.8 was 2.0 mg/L, and the diurnal variation in DO at ORM 189.3 was 0.8 mg/L, as presented in Figures 2-5 through 2-7. The diurnal DO data measured by Georgia-Pacific at the 1-foot depth are presented in Figures 2-8 through 2-10. At the 1-foot depth, the diurnal variation in DO at ORM 224 was 2.4 mg/L, the diurnal variation at ORM 208.8 was 2.8 mg/L, and the diurnal variation at ORM 189.3 is 1.6 mg/L. To be conservative, the diurnal DO variation at the 5-foot depth is used in the modeling. The diurnal DO and temperatures at both the 1-foot and 5-foot depths are also presented in Appendix 2. The diurnal DO data were used to adjust the DO measurements collected during the synoptic river runs. The synoptic DO measurements were adjusted to reflect the average DO value during the diurnal variation based on the time of day the DO measurement was collected. Diurnal DO data were not collected on the days on which the synoptic river runs were performed, but were used to adjust the DO to an average (of the diurnal swing) DO that would have occurred at each River station on the synoptic river run day. The adjustments should be reliable since both the diurnal and synoptic DO measurements were collected during the summer months when flows and temperatures in the River were essentially near or at low-flow high-temperature conditions.

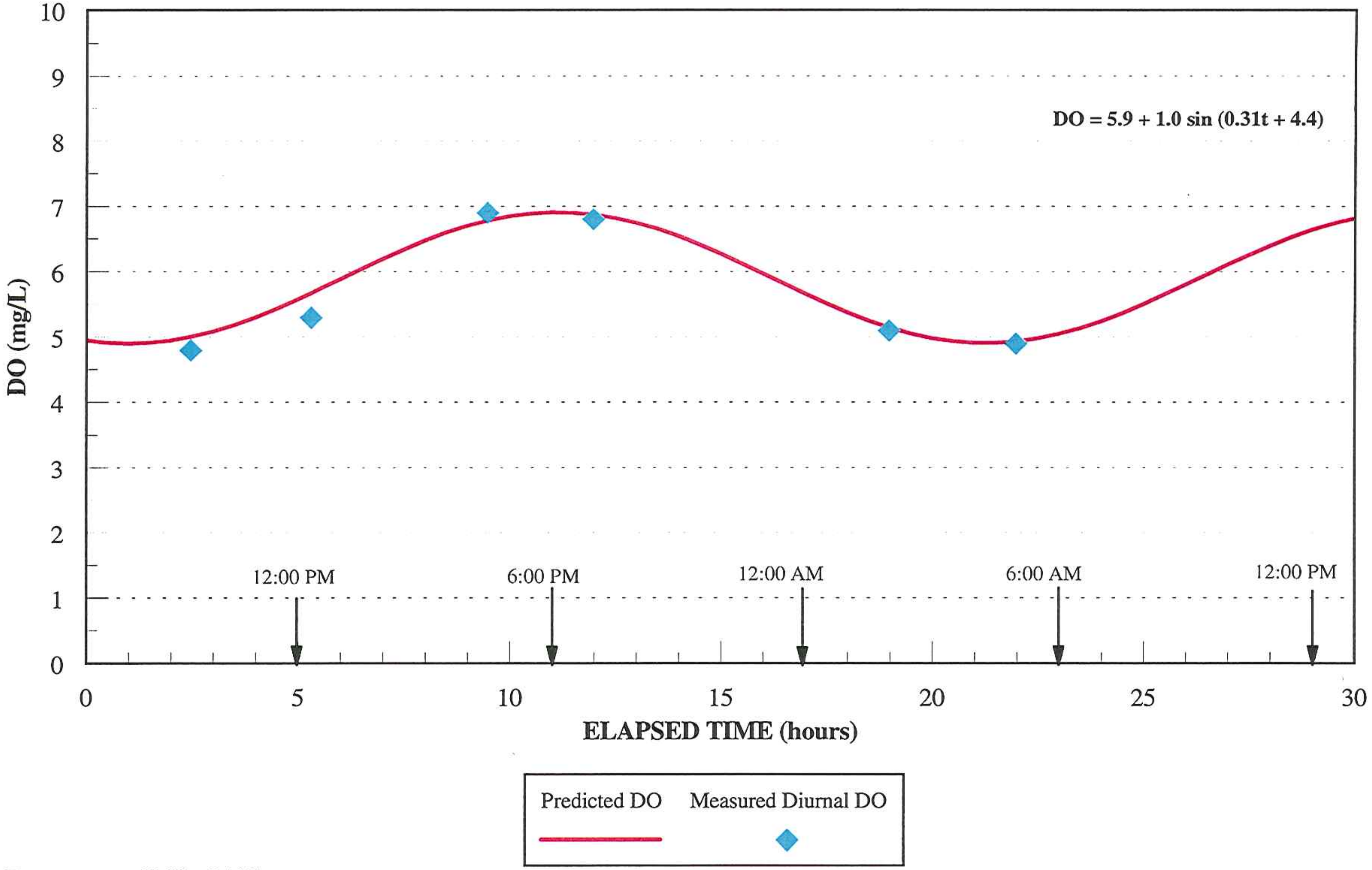
As presented in Figure 2-11, the diurnal DO data (measured on August 5, 1998) are plotted for ORM 224 as the solid line. The diamond points are the actual diurnal DO measurements, plotted

## FIGURE 2-5
## DIURNAL DISSOLVED OXYGEN ANALYSIS (5 ft DEPTH)
ORM 224



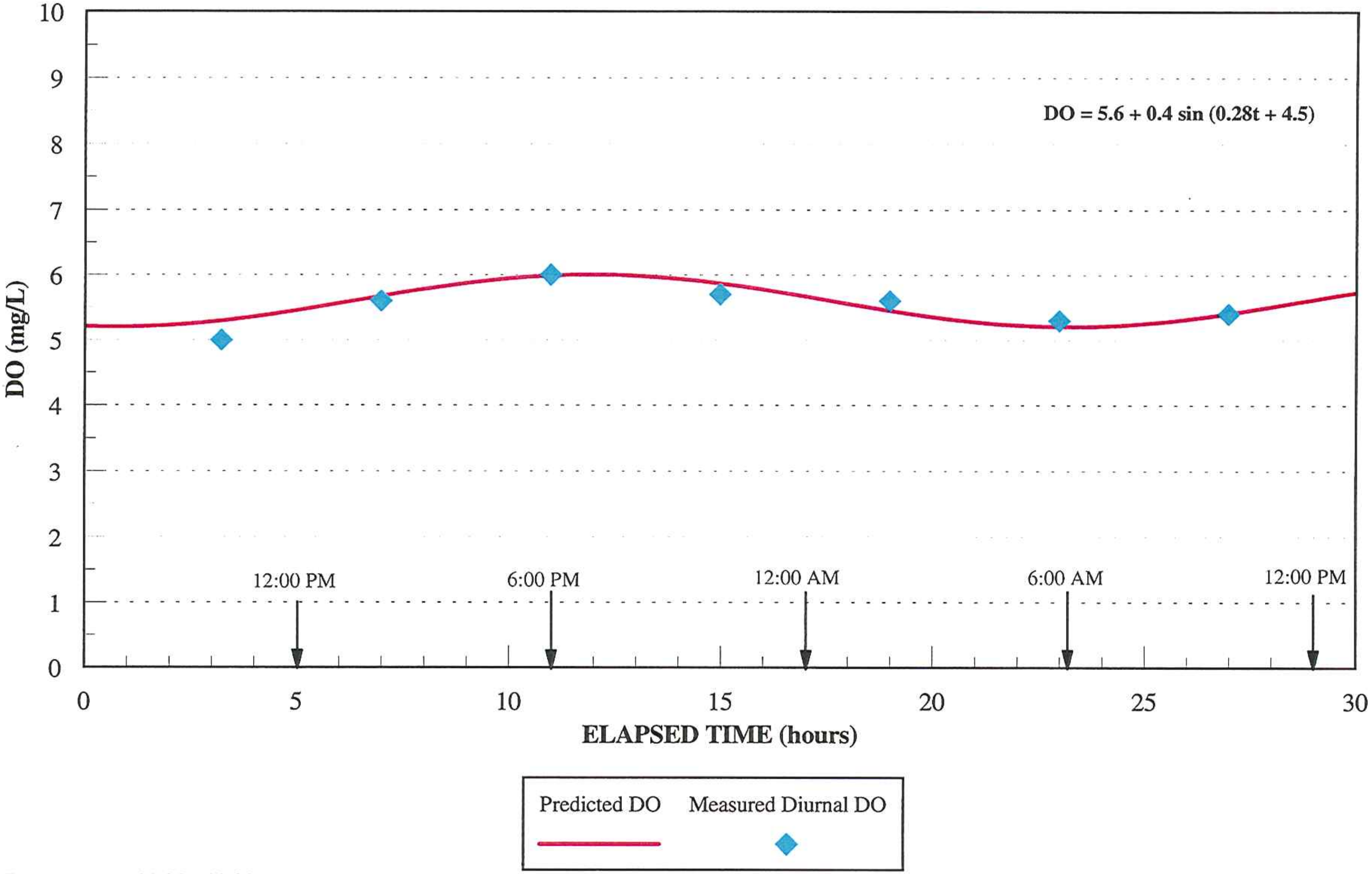
Temperature = 32 °C - 32.5 °C.
DO measured on August 5, 1998.
ORM 224 is located between New Felsenthal Dam and Coffee Creek.

## FIGURE 2-6
## DIURNAL DISSOLVED OXYGEN ANALYSIS (5 ft DEPTH)
### ORM 208.8



Temperature = 33 °C - 34 °C.
DO Measured on August 5, 1998.
ORM 208.8 is located approximately midway between Coffee Creek and Sterlington,

# FIGURE 2-7
## DIURNAL DISSOLVED OXYGEN ANALYSIS (5 ft DEPTH)
ORM 189.3

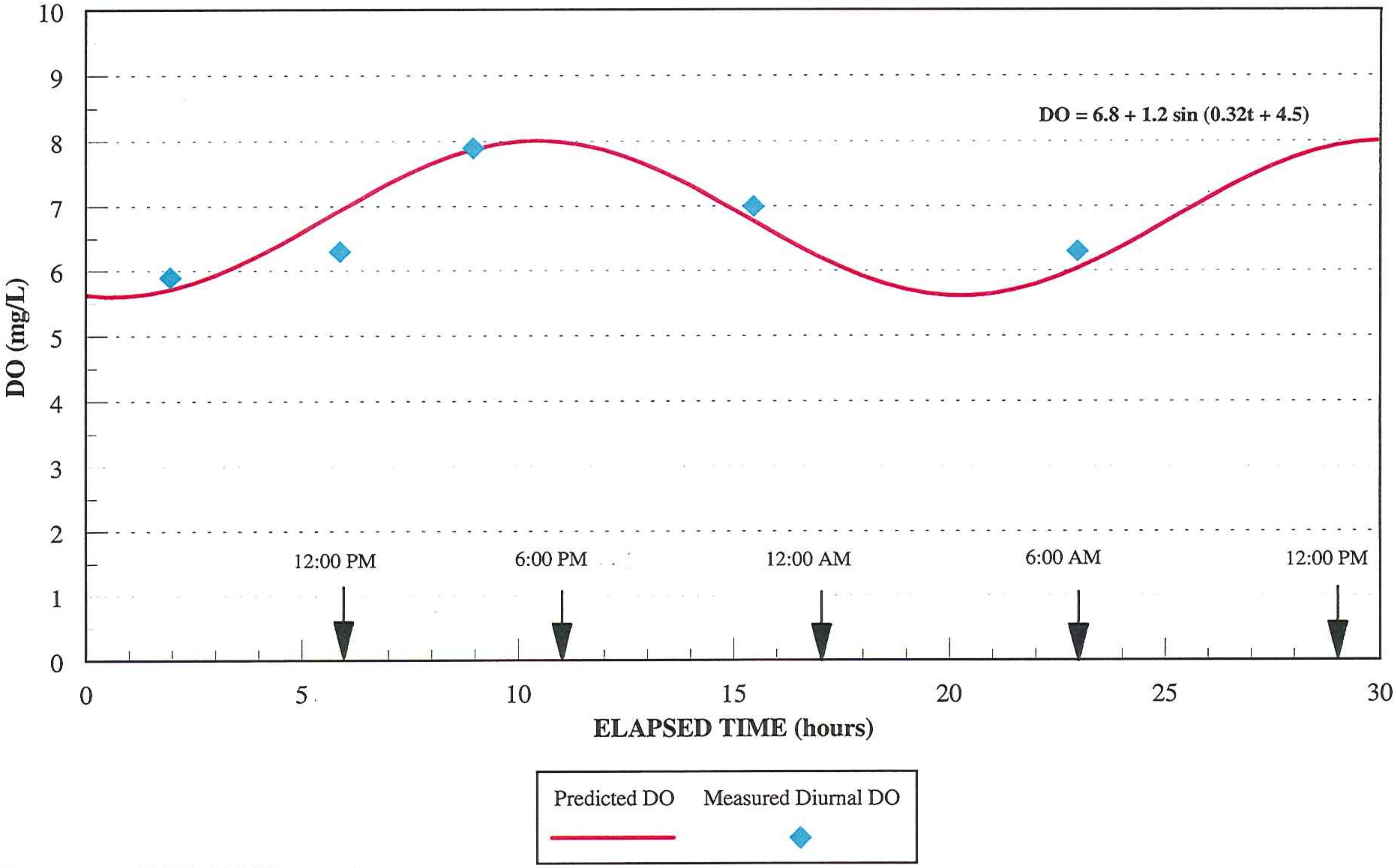


Temperature = 32 °C - 33 °C.
DO measured on July 1, 1998.
ORM 189.3 is located near Sterlington, LA.

## FIGURE 2-8

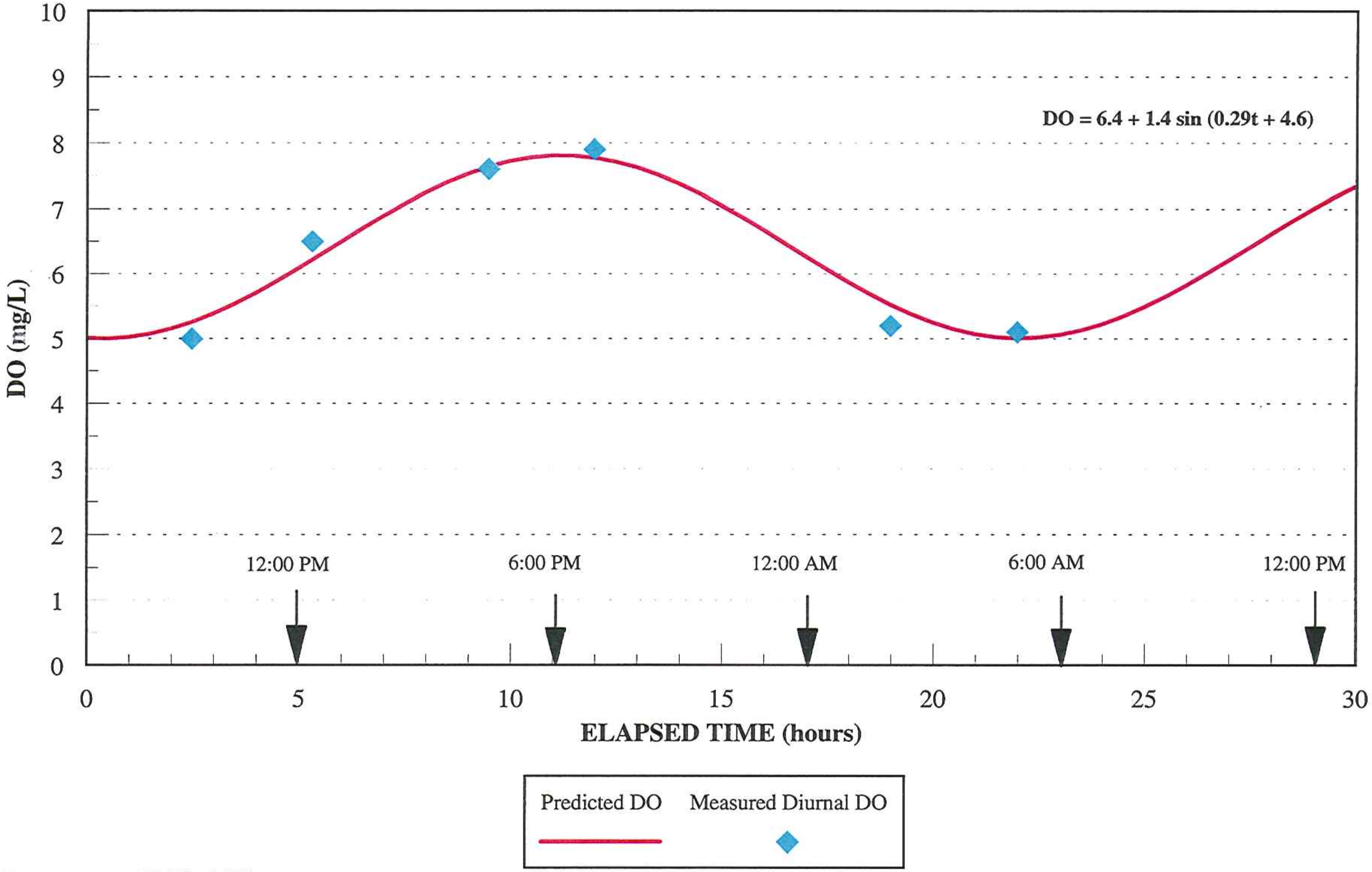
## DIURNAL DISSOLVED OXYGEN ANALYSIS (1-FOOT DEPTH)

ORM 224



Temperature = 32 °C - 34.5 °C.
DO measured on August 5, 1998.
ORM 224 is located between New Felsenthal Dam and Coffee Creek.

# FIGURE 2-9
## DIURNAL DISSOLVED OXYGEN ANALYSIS (1-FOOT DEPTH)
ORM 208.8

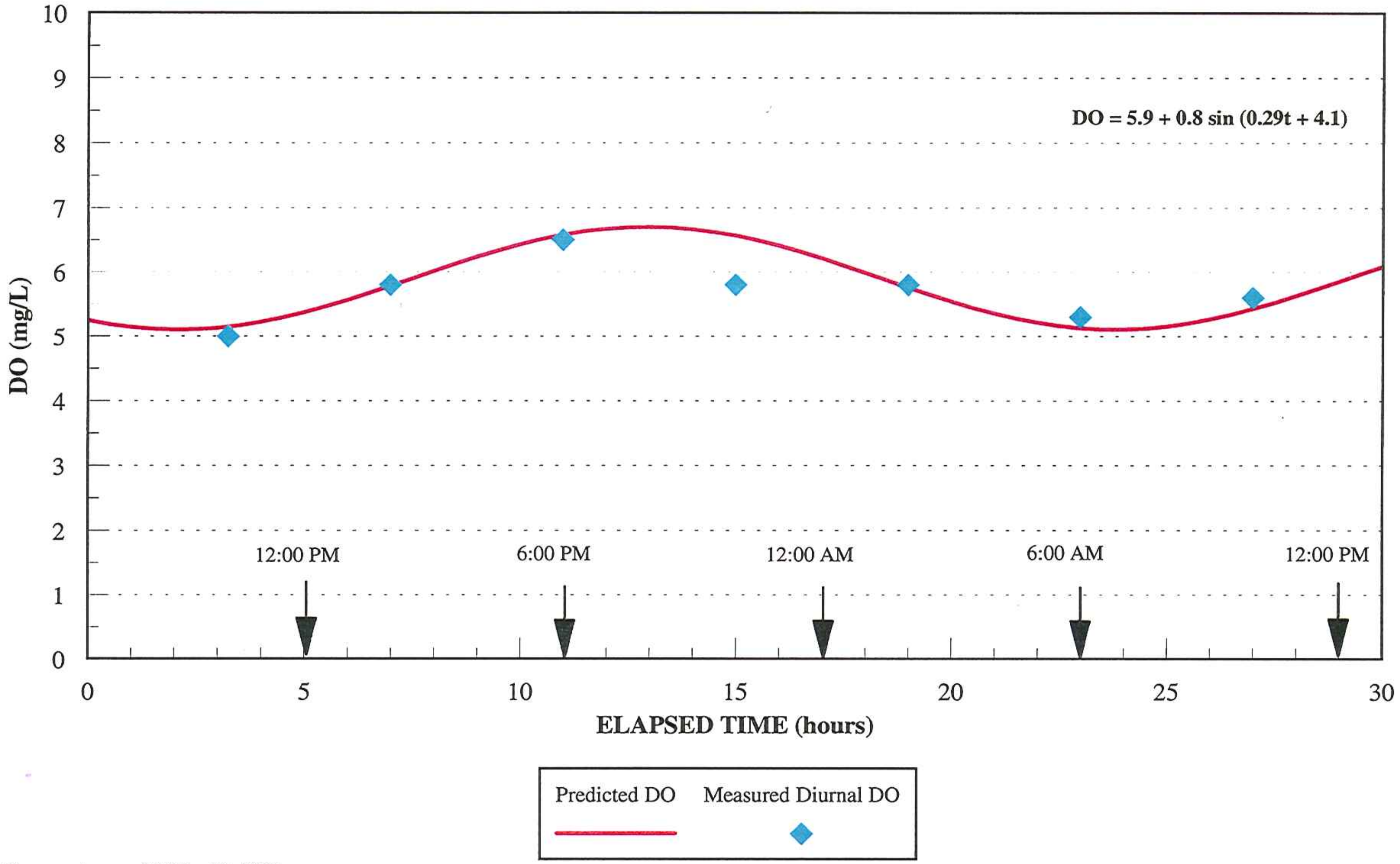


Temperature = 33 °C - 34°C.
DO measured on August 5, 1998.
ORM 208.8 is located approximately midway between Coffee Creek and Sterlington,

## FIGURE 2-10

## DIURNAL DISSOLVED OXYGEN ANALYSIS (1-FOOT DEPTH)

ORM 189.3

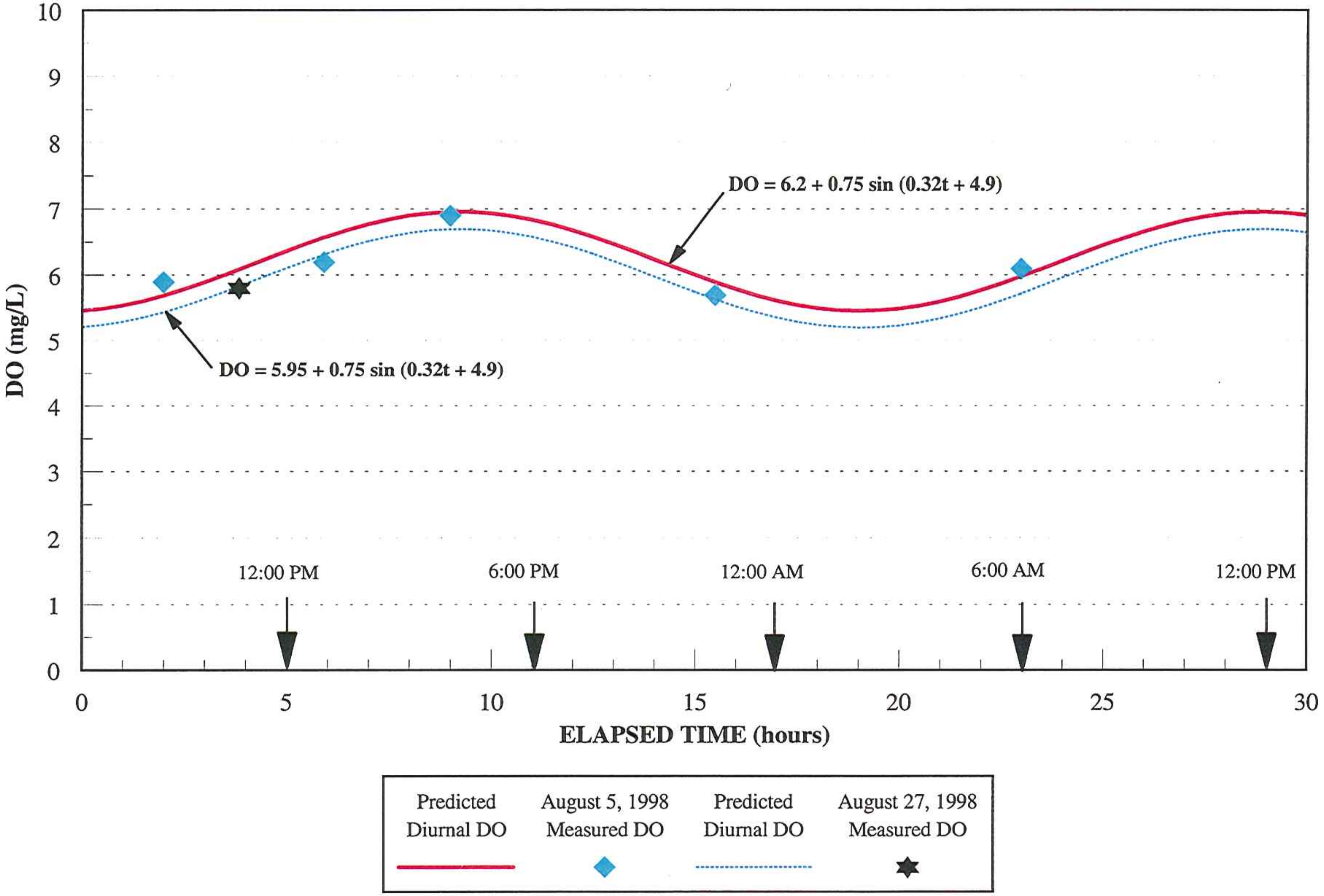


Temperature = 32 °C - 33.5 °C.
DO measured on July 1, 1998.
ORM 189.3 is located near Sterlington, LA.

## FIGURE 2-11

## EXAMPLE OF DIURNAL DO SINE CURVE TRANSLATION TO AUGUST 27, 1998 DATA

### OUACHITA RIVER NEAR CROSSETT, ARKANSAS



DO measured at ORM 224 (located between New Felsenthal Dam and Coffee Creek) at the time collected. The starred point is the DO measurement collected during the August 27, 1998 synoptic river run, plotted at the time of day collected. The diurnal DO sine curve, plotted as the solid line, has been shifted down to meet the August 27, 1998 data point. This process allows an average daily DO value (5.95 mg/L, as previously presented in Figure 2-11) for each synoptic DO station to be estimated for calibrating the QUAL2E model. This calibration data set developed reflects the same point in time for each station (the daily average DO point for the station).

In addition to DO and temperature measurements, Georgia-Pacific collected pH and secchi disc measurements during the 1998 synoptic river runs, as well as collecting water quality measurements in Coffee Creek and Bayou Bartholomew. Georgia-Pacific also provided discharge flows and 5-day BOD values for Coffee Creek along with the water quality data for the dates of the 1998 synoptic river runs, as presented in Appendix 2.

### United States Army Corps of Engineers

Daily stage data for the Ouachita River at the Felsenthal Lock and Dam were acquired from the Hydraulics Branch, Vicksburg District, USACOE, as presented in Appendix 3. Stage data were obtained for 1987 and 1996 through 1998.

### United States Geological Survey

The USGS Water Data Reports for Arkansas and Louisiana for the 1992 water year were used as a resource for phosphorus data for the headwater and several of the point sources. The USGS office in Ruston, Louisiana was also used as a resource for Bayou Bartholomew (collected from the gauge located near Jones, Louisiana) and Ouachita River flow data (collected from the gauge located at Old Lock and Dam No. 6 at ORM 223.4). All USGS data are presented in Appendix 3. The only 1998 flow data available are provisional data provided by the USGS. The provisional data are used in the modeling. At this time, provisional flow data for Bayou Bartholomew are only available through August 16, 1998.

United States Environmental Protection Agency

The USEPA maintains a computerized database, STORET, for the STOrage and RETrieval of chemical, physical, and biological data regarding the water quality of waterways within and contiguous to the United States. Information available from STORET includes: **1)** geographical, political, and descriptive collection site information; **2)** parametric water quality data, such as measurements of the physical characteristics and chemical composition of water, fish tissue or sediment; **3)** biological field surveys; and **4)** stream flow data. Two Chlorophyll *a* data points were obtained from STORET (1998) for the Ouachita River near the study area, as presented in Appendix 3. A chlorophyll *a* concentration of 2.8 µg/L was measured on September 15, 1981 near Felsenthal, and a second chlorophyll *a* concentration of 2.4 µg/L was measured near Crossett, Arkansas also on September 15, 1981.

For comparison, chlorophyll *a* was obtained from STORET (1998) for four southern lakes, as presented in Table 2-1 and Appendix 3. The data summarized in Table 2-1 present the maximum and minimum chlorophyll *a* measurements from the four lakes. The chlorophyll *a* values for the lakes range from 0.8 µg/L to 35.1 µg/L.

**TABLE 2-1. CHLOROPHYLL a DATA FROM SOUTHERN LAKES**

| LOCATION | FLUOROMETRIC CORRECTED METHOD | | | | | | FLUOROMETRIC UNCORRECTED METHOD | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DATE | TIME | MAX CHL a (ug/L) | DATE | TIME | MIN CHL a (ug/L) | DATE | TIME | MAX CHL a (ug/L) | DATE | TIME | MIN CHL a (ug/L) |
| Lake Allatoona<br>Atlanta, GA | 17-Jul-89 | 11:30 | 13 | 21-Aug-90 | 16:35 | 2.7 | 14-Nov-73 | 09:00 | 20.8 | 14-Nov-73 | 08:30 | 2.9 |
| Lake Murray<br>Columbia, SC | 23-Oct-97 | 12:10 | 35.1 | 10-Apr-80 | 11:45 | 0.8 | 22-Sep-73 | 15:00 | 10.1 | 09-Jul-73 | 15:10 | 4.4 |
| Lake Martin<br>Mongomery, AL | - | - | - | - | - | - | 18-Jun-73 | 17:00 | 27.3 | 19-Mar-73 | 09:20 | 1.4 |
| Ross Barnett Reservoir<br>Jackson, MS | - | - | - | - | - | - | 27-Aug-73 | 15:05 | 14.9 | 14-Jun-73 | 17:00 | 3.4 |

**NOTES:**

1) Chlorophyll a data was obtained from STORET for a 25-year period of record.
2) "-" - no data available.

## LITERATURE SOURCES

Literature sources consulted for the determination of model parameters include primarily the QUAL2E manual (Brown and Barnwell, 1987) and "Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling" Bowie et al. 1985). The data obtained from these sources will be presented in detail in Section 3 of this report.

Other literature consulted included Open-Channel Hydraulics (Chow 1959), Standard Methods (APHA 1995), and the National Solar Radiation Database (1998). Selected pages from these literature sources are presented in Appendix 4.

As previously stated, the value for the organic nitrogen hydrolysis rate and the ammonia oxidation rate used in the QUAL2E model for the Ouachita River near Crossett, Arkansas, of 0.1/day for each rate, are assumed based on a river system with low nitrogen mass loadings. Additional support for the ammonia oxidation rate is found in Table 3-22, "Summary of Nitrification Rates," on page 172 of Rates, Constants, and Kinetics (Bowie 1985), which refers to a study performed in 1980 by Dr. Ray Whittemore of the NCASI on the Ouachita River. This reference suggests nitrogen decay rates of 0.1 per day for ammonia nitrogen decay.

## GEORGIA-PACIFIC/AQUAETER NOVEMBER 1998 FIELD STUDY

Georgia-Pacific and **AquAeTer** performed a field study to collect additional water quality data on the Ouachita River downstream from Felsenthal Reservoir, Arkansas on November 10 - 12, 1998. The weather during the study period was partly cloudy on November 10, sunny on November 11, and overcast and raining on November 12. Water temperatures were in the range of 16 to 17 degrees Celsius (°C). The study reaches extended just upstream from Felsenthal Reservoir at ORM

229 to about ORM 191.6, just downstream from the LA Highway 2 Bridge at Sterlington, Louisiana. Additional *in situ* data were also collected in Felsenthal Reservoir. The main goals of this intense, synoptic, water-quality study were to collect additional data on algae, chlorophyll *a*, and nutrients in the River system. These data are used in this report to update the wasteload allocation prediction model runs which had been based on the synoptic water quality surveys conducted by Georgia-Pacific in 1996, 1997, and 1998, as well as, previous HydroQual and NCASI model parameters.

The study was performed to provide data to confirm or adjust parameters and rates previously established for the Ouachita River. Data were collected as instantaneous points and are, therefore, qualitative when trying to set rates. To determine quantitative rates, the data must be collected with time-of-travel following the same slug of water downstream. The data collected as instantaneous points when the river flow and temperature conditions are steady, as opposed to data collected with time-of-travel, can be used with adjustments for diurnal variations, for input into the QUAL2E model. The synoptic (run-of-the-river) data should allow a semi-quantitative analysis of the rates and parameters established during past studies. In addition, the bottle BOD decay rates measured with the time-series BOD analyses can be used as a qualitative estimate of the river ultimate carbonaceous BOD ($CBOD_{u)}$ rate. Field notes from the study are presented in Appendix 5.

### *In Situ* Measurements

Run-of-the-River *in situ* water quality measurements, including DO, water temperature, pH, and specific conductance at 25 °C (conductivity) from ORM 224 to ORM 192 were collected. Yellow Springs Instruments (YSI) Model 50B DO meters, Orion Model 230A pH meters, YSI Model 30 conductivity meters, as well as a Hydrolab Multiparameter data sonde, were used to record

DO, pH and conductivity, as presented in Table 2-2. Additionally, light intensity measurements, using an Extech Model 401025 light meter, and secchi disc measurements, using a Watermark limnological weighted secchi disc, were made during the study, as presented in Table 2-3.

The *in situ* dissolved oxygen data measured during the period from November 10 to 12, 1998 at a depth of 5 feet are presented in Figure 2-12, and isopleths of the dissolved oxygen data at depth measured on November 12, 1998 are presented in Figure 2-13. Due to fluctuations in River flow, as presented in Table 2-4, and water temperature, a noticed increase in DO occurs between November 10, 1998 and November 11 and 12, 1998. As shown in Figure 2-13, the DO gradually decreases downstream from ORM 224 to ORM 192. In addition, a band of higher DO values is observed at mid-depth in the River. A DO sag is not evident in the River, and algal DO production was low during this period as compared to the summer period. DO in the stream gradually decreased with distance downstream and reflects a decreasing reaeration rate with distance into the downstream reservoir. DO began to rise around ORM 194 to 191.6, most likely due to the influence of Bayou Bartholomew and increased algal activity from higher nitrogen availability in this area.

The light intensity measurements are a snapshot in time of light intensity and may change by the moment based on time of day or cloud cover. The measurements collected during the field study, as presented previously in Table 2-3, are in the range of the average November light intensity of 383 BTU/ft$^2$-day reported by the National Solar Radiation Database for Little Rock, Arkansas and provide a relative comparison of the light intensity at different times of day and weather conditions during the study. The average light intensity measured during the study period was 211 BTU/ft$^2$/day (Note: actual measurements were in ft candles; 1 ft candle = 0.12 BTU/ft$^2$/day). This lower value reflects the overcast and rainy periods during the study period. The secchi disc measurements for

**TABLE 2-2. IN-SITU WATER QUALITY MEASUREMENTS**
**OUACHITA RIVER NEAR CROSSETT, ARKANSAS**

| ORM | DATE | TIME | DEPTH (ft) | DO (mg/L) | TEMPERATURE (°C) | CONDUCTIVITY (mS/cm) | pH (S.U.) |
|---|---|---|---|---|---|---|---|
| 239.1 | 11/10/98 | 09:40 | 1 | 7.69 | 16.71 | 0.106 | 7.40 |
| | | 09:50 | 3 | 7.73 | 16.71 | 0.106 | 7.30 |
| | | 09:52 | 5 | 7.53 | 16.71 | 0.106 | 7.28 |
| | | 09:53 | 8 | 7.45 | 16.71 | 0.107 | 7.26 |
| | | 09:54 | 11 | 7.43 | 16.71 | 0.107 | 7.25 |
| | | 09:55 | 14 | 7.40 | 16.71 | 0.106 | 7.25 |
| | | 09:57 | 17 | 7.39 | 16.71 | 0.106 | 7.25 |
| | | 09:58 | 20 | 7.39 | 16.71 | 0.106 | 7.23 |
| | | 09:59 | 23 | 7.39 | 16.71 | 0.106 | 7.23 |
| | | 10:00 | 26 | 7.37 | 16.71 | 0.106 | 7.23 |
| | | 10:01 | 29 | 7.37 | 16.71 | 0.106 | 7.22 |
| 234 | 11/10/98 | 10:50 | 1 | 7.80 | 16.88 | 0.100 | 7.31 |
| | | 10:54 | 3 | 7.70 | 16.90 | 0.100 | 7.28 |
| | | 10:55 | 5 | 7.62 | 16.88 | 0.100 | 7.27 |
| | | 10:56 | 8 | 7.58 | 16.88 | 0.100 | 7.25 |
| | | 10:57 | 11 | 7.55 | 16.86 | 0.100 | 7.25 |
| | | 10:58 | 14 | 7.50 | 16.88 | 0.100 | 7.24 |
| | | 10:59 | 17 | 7.48 | 16.85 | 0.100 | 7.23 |
| | | 11:00 | 20 | 7.45 | 16.85 | 0.100 | 7.22 |
| | | 11:01 | 23 | 7.43 | 16.85 | 0.100 | 7.21 |
| | | 11:02 | 26 | 7.43 | 16.86 | 0.100 | 7.21 |
| | | 11:02 | 29 | 7.41 | 16.85 | 0.100 | 7.20 |
| | | 11:03 | 32 | 7.40 | 16.85 | 0.100 | 7.20 |
| 229 | 11/10/98 | 11:20 | 1 | 7.37 | 17.07 | 0.106 | 7.34 |
| | | 11:21 | 3 | 7.25 | 17.07 | 0.106 | 7.30 |
| | | 11:22 | 5 | 7.21 | 17.05 | 0.105 | 7.28 |
| | | 11:23 | 8 | 7.19 | 17.03 | 0.106 | 7.26 |
| | | 11:24 | 11 | 7.17 | 17.03 | 0.106 | 7.24 |
| | | 11:25 | 14 | 7.16 | 17.03 | 0.105 | 7.23 |
| | | 11:26 | 16 | 7.15 | 17.03 | 0.105 | 7.22 |
| 224 | 11/10/98 | 11:26 | 1 | 7.48 | 17.03 | 0.099 | 7.38 |
| | | 11:28 | 3 | 7.33 | 17.03 | 0.099 | 7.33 |
| | | 11:30 | 5 | 7.21 | 17.03 | 0.099 | 7.27 |
| | | 11:31 | 8 | 7.20 | 17.03 | 0.099 | 7.24 |
| | | 11:32 | 11 | 7.21 | 17.03 | 0.099 | 7.22 |
| | | 11:33 | 14 | 7.19 | 17.03 | 0.099 | 7.21 |
| | | 11:34 | 17 | 7.19 | 17.03 | 0.099 | 7.20 |
| | | 11:34 | 19 | 7.19 | 17.03 | 0.099 | 7.19 |
| | 11/11/98 | 12:15 | 1 | 8.16 | 26.80 | 0.0935 | 8.12 |
| | | -- | 3 | 8.23 | 16.70 | 0.0935 | 8.06 |
| | | 18:00 | 1 | 8.09 | 16.70 | 0.0969 | 8.02 |
| | | -- | 3 | 8.18 | 16.70 | 0.0969 | 8.04 |
| | 11/12/98 | 09:00 | 1 | 8.70 | 16.20 | -- | -- |
| | | | 3 | 8.62 | 16.20 | -- | -- |
| | | | 5 | 8.75 | 16.30 | -- | -- |
| | | | 8 | 8.80 | 16.30 | -- | -- |
| Coffee Creek | 11/10/98 | 14:10 | 1 | -- | 17.27 | 0.201 | 7.72 |
| | | 14:17 | 1 | 6.40 | 17.27 | 0.201 | -- |
| 218.7 | 11/10/98 | 15:35 | 1 | 7.74 | 17.15 | 0.131 | 7.30 |
| | | 15:36 | 3 | 7.70 | 17.13 | 0.131 | 7.29 |
| | | 15:37 | 5 | 7.62 | 17.15 | 0.131 | 7.28 |
| | | 15:38 | 8 | 7.60 | 17.15 | 0.131 | 7.29 |
| | | 15:39 | 11 | 7.58 | 17.15 | 0.131 | 7.29 |
| | | 15:39 | 14 | 7.52 | 17.15 | 0.131 | 7.29 |
| | | 15:40 | 15 | 7.48 | 17.15 | 0.131 | 7.28 |

## TABLE 2-2. IN-SITU WATER QUALITY MEASUREMENTS
## OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| ORM | DATE | TIME | DEPTH (ft) | DO (mg/L) | TEMPERATURE (°C) | CONDUCTIVITY (mS/cm) | pH (S.U.) |
|---|---|---|---|---|---|---|---|
| 213.5 | 11/10/98 | 16:47 | 1 | 7.37 | 17.18 | 0.126 | 7.18 |
| | | 16:48 | 3 | 7.30 | 17.18 | 0.126 | 7.19 |
| | | 16:49 | 5 | 7.26 | 17.20 | 0.126 | 7.20 |
| | | 16:50 | 8 | 7.22 | 17.22 | 0.125 | 7.20 |
| | 11/12/98 | 11:00 | 1 | 8.65 | 16.00 | -- | -- |
| | | | 3 | 8.69 | 16.10 | -- | -- |
| | | | 5 | 8.70 | 16.10 | -- | -- |
| | | | 9 | 8.73 - 8.8 | 16.00 | -- | -- |
| | | 10:45 | 12 | -- | 16.00 | -- | -- |
| 208.8 | 11/11/98 | 13:58 | 1 | 7.87 | 16.80 | 0.124 | 7.71 |
| | | | 3 | 7.83 | 16.70 | 0.123 | 7.76 |
| | 11/12/98 | 13:15 | 1 | 8.65 | 15.97 | 0.1323 | 7.60 |
| | | | 3 | 8.49 | 16.00 | 0.1323 | 7.48 |
| | | | 5 | 8.51 | 15.99 | 0.1323 | 7.42 |
| | | | 8 | 8.66 | 15.99 | 0.1323 | 7.40 |
| | | | 11 | 8.67 | 15.99 | 0.1322 | 7.39 |
| | | | 14 | 8.72 | 15.97 | 0.1324 | 7.37 |
| | | | 16 | 8.70 | 15.99 | 0.1324 | 7.35 |
| 203 | 11/12/98 | 14:19 | 1 | 8.51 | 15.96 | 0.1296 | 7.36 |
| | | 14:24 | 3 | 8.44 | 15.96 | 0.1296 | 7.31 |
| | | 14:27 | 5 | 8.60 | 15.97 | 0.1297 | 7.29 |
| | | 14:30 | 8 | 8.66 | 15.96 | 0.1297 | 7.27 |
| | | 14:32 | 11 | 8.68 | 15.96 | 0.1298 | 7.26 |
| 198 | 11/11/98 | 13:16 | 1 | 8.40 | 17.10 | 0.126 | -- |
| | | 13:18 | 3 | -- | 17.20 | 0.127 | -- |
| | | 13:30 | 5 | 8.60 | 17.10 | 0.126 | -- |
| | | 13:20 | 8 | -- | -- | 0.125 | -- |
| | 11/12/98 | 15:03 | 1 | 8.52 | 15.97 | 0.1328 | 7.31 |
| | | 15:06 | 3 | 8.30 | 15.96 | 0.1328 | 7.30 |
| | | 15:08 | 5 | 8.46 | 15.97 | 0.1328 | 7.28 |
| | | 15:11 | 8 | 8.42 | 15.97 | 0.1327 | 7.27 |
| | | 15:14 | 11 | 8.57 | 15.97 | 0.1328 | 7.26 |
| | | 15:17 | 14 | 8.55 | 15.97 | 0.1326 | 7.25 |
| 197 | 11/11/98 | 13:40 | 5 | 8.45 | 17.10 | 0.127 | -- |
| | 11/12/98 | 15:33 | 1 | 8.41 | -- | -- | -- |
| | | | 5 | 8.37 | -- | -- | -- |
| 196 | 11/11/98 | 13:47 | 5 | 8.45 | 17.10 | 0.127 | -- |
| | 11/12/98 | 15:50 | 1 | 8.17 | -- | -- | -- |
| | | | 5 | 8.17 | -- | -- | -- |
| 195 | 11/11/98 | 13:55 | 5 | 8.45 | 17.10 | 0.126 | -- |
| | 11/12/98 | 15:57 | 1 | 8.15 | -- | -- | -- |
| | | | 5 | 8.15 | -- | -- | -- |
| 194 | 11/11/98 | 14:02 | 5 | 8.39 | 17.10 | 0.126 | -- |
| | 11/12/98 | 16:15 | 1 | 8.19 | 16.08 | 0.130 | 7.35 |
| | | 16:17 | 3 | 8.22 | 16.07 | 0.130 | 7.31 |
| | | 16:20 | 5 | 8.20 | 16.07 | 0.130 | 7.29 |
| | | 16:22 | 8 | 8.26 | 16.07 | 0.130 | 7.28 |
| | | 16:22 | 11 | 8.31 | 16.07 | 0.1301 | 7.27 |
| | | | 14 | 8.33 | 16.07 | 0.1301 | 7.26 |
| | | | 17 | 8.37 | 16.07 | 0.130 | 7.26 |
| 193 | 11/11/98 | 14:10 | 5 | 8.44 | 17.10 | 0.129 | -- |
| | 11/12/98 | 16:35 | 1 | 8.30 | -- | -- | -- |
| | | 16:37 | 5 | 8.23 | -- | -- | -- |

## TABLE 2-2. IN-SITU WATER QUALITY MEASUREMENTS OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| ORM | DATE | TIME | DEPTH (ft) | DO (mg/L) | TEMPERATURE (°C) | CONDUCTIVITY (mS/cm) | pH (S.U.) |
|---|---|---|---|---|---|---|---|
| 191.6 | 11/11/98 | 09:16 | 1 | 8.26 | 18.10 | 0.126 | 7.00 |
|  |  | 09:17 | 3 | 8.67 | 17.90 | 0.126 | 6.67 |
|  |  | 09:22 | 5 | 8.58 | 17.80 | 0.126 | -- |
|  |  | 09:29 | 8 | 8.67 | 17.70 | 0.126 | -- |
|  |  | 09:33 | 11 | 8.66 | 17.50 | 0.126 | -- |
|  |  | 09:44 | 14 | 8.52 | 17.30 | 0.126 | -- |
|  |  | 09:54 | 17 | 8.54 | 17.50 | 0.126 | -- |
|  |  | 10:04 | 20 | 8.40 | 17.30 | -- | -- |
|  |  | 10:46 | 1 | 8.42 | 17.90 | -- | -- |
|  |  | 10:57 | 3 | 8.53 | 17.90 | -- | -- |
|  |  | 11:03 | 5 | 8.36 | 17.90 | -- | -- |
|  | 11/12/98 | 06:30 | 1 | 8.35 | 16.80 | -- | -- |
|  |  |  | 3 | 8.55 | 16.80 | -- | -- |
|  |  |  | 5 | 8.74 | 16.80 | -- | -- |
|  |  |  | 8 | 8.61 | 16.80 | -- | -- |
|  |  |  | 11 | 8.43 - 8.60 | 16.90 | -- | -- |
|  |  |  | 14 | 8.43 | 16.90 | -- | -- |
|  |  |  | 17 | 8.45 | 16.90 | -- | -- |
|  |  | 16:54 | 1 | 8.29 | 16.29 | 0.1285 | 7.44 |
|  |  |  | 3 | 8.30 | 16.29/16.41 | 0.1285 | 7.38 |
|  |  |  | 5 | 8.27 | 16.27 | 0.1285 | 7.34 |
|  |  |  | 8 | 8.21 | 16.26 | 0.1285 | 7.32 |
|  |  |  | 11 | 8.25 | 16.26 | 0.1285 | 7.30 |
|  |  |  | 14 | 8.37 | 16.27 | 0.1286 | 7.30 |
|  |  | 17:20 | 17 | 8.40 | 16.26 | 0.1287 | 7.27 |

**NOTE:**

--" data not available

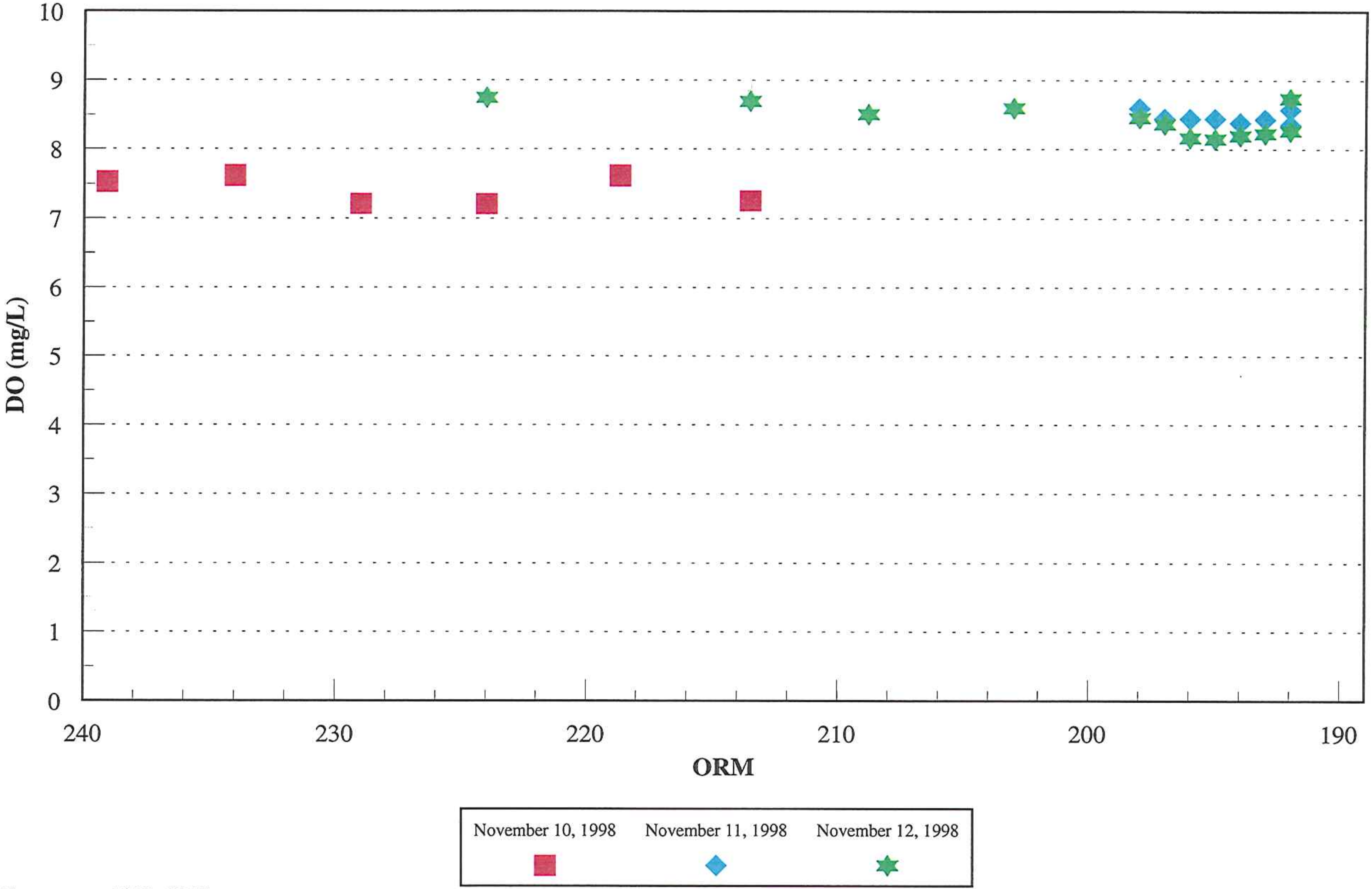
## TABLE 2-3. SECCHI DISK AND LIGHT INTENSITY MEASURMENTS
## OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| ORM | DATE | TIME | LIGHT INTENSITY (ft candles) | LIGHT INTENSITY (BTU/ft^2-day) | VANISHING DEPTH (ft) | REAPPEARANCE DEPTH (ft) | AVERAGE DEPTH (ft) |
|---|---|---|---|---|---|---|---|
| 239.1 | 11/10/98 | 09:39 | 2500 | 300 | 2.60 | 2.75 | 2.68 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.68 |
| | | 09:40 | | | 3.00 | 2.80 | 2.90 |
| | | | | | 3.00 | 3.00 | 3.00 |
| | | | | | 3.00 | 2.80 | 2.90 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.93 |
| 234 | 11/10/98 | 10:50 | 5300 | 636 | 3.00 | 2.90 | 2.95 |
| | | | | | 2.80 | 2.70 | 2.75 |
| | | | | | 2.80 | 2.70 | 2.75 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.82 |
| 229 | 11/10/98 | 11:20 | 6000 | 720 | 3.00 | 2.90 | 2.95 |
| | | | | | 2.90 | 2.80 | 2.85 |
| | | | | | 2.90 | 2.80 | 2.85 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.88 |
| 224 | 11/10/98 | 11:26 | 2750 | 330 | 2.70 | 2.60 | 2.65 |
| | | | | | 2.80 | 2.60 | 2.70 |
| | | | | | 2.80 | 2.60 | 2.70 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.68 |
| | 11/12/98 | 09:00 | 199 - 200 | | 2.20 | 2.00 | 2.10 |
| | | | (avg = 199.5) | 24 | 2.20 | 2.10 | 2.15 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.13 |
| Coffee Creek | 11/10/98 | 14:10 | -- | -- | 0.30 | 0.20 | 0.25 |
| | | | | | AVERAGE SECCHI DEPTH | | 0.25 |
| 218.7 | 11/10/98 | 15:35 | 956 | 115 | 2.00 | 1.90 | 1.95 |
| | | | | | 2.00 | 1.80 | 1.90 |
| | | | | | 1.90 | 1.80 | 1.85 |
| | | | | | AVERAGE SECCHI DEPTH | | 1.90 |
| 213.5 | 11/12/98 | 11:00 | 610 - 690 | | 2.60 | 2.40 | 2.50 |
| | | | (avg = 650) | 78 | AVERAGE SECCHI DEPTH | | 2.50 |
| 208.8 | 11/12/98 | 13:15 | 1430 | 172 | 2.10 | 2.00 | 2.05 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.05 |
| 203 | 11/12/98 | 14:19 | 675 | 81 | 2.00 | 2.00 | 2.00 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.00 |
| 198 | 11/11/98 | 13:16 | -- | -- | 2.10 | 1.90 | 2.00 |
| | | | | | 2.20 | 2.30 | 2.25 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.13 |
| | 11/12/98 | 15:03 | 510 - 520 | | 2.25 | 2.20 | 2.23 |
| | | | (avg = 515) | 62 | AVERAGE SECCHI DEPTH | | 2.23 |
| 197 | 11/11/98 | 13:40 | -- | -- | 2.30 | 2.25 | 2.28 |
| | | | | | 2.40 | 2.30 | 2.35 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.31 |
| 196 | 11/11/98 | 13:47 | -- | -- | 2.40 | 2.25 | 2.33 |
| | | | | | 2.30 | 2.20 | 2.25 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.29 |
| 195 | 11/11/98 | 13:55 | -- | -- | 2.30 | 2.10 | 2.20 |
| | | | | | 2.40 | 2.20 | 2.30 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.25 |
| 194 | 11/11/98 | 14:02 | -- | -- | 2.30 | 2.15 | 2.23 |
| | | | | | 2.40 | 2.30 | 2.35 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.29 |
| | 11/12/98 | 16:15 | 141 | 17 | 2.10 | 2.00 | 2.05 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.05 |
| 193 | 11/11/98 | 14:10 | -- | -- | 2.30 | 2.20 | 2.25 |
| | | | | | 2.30 | 2.15 | 2.23 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.24 |
| 191.6 | 11/11/98 | 09:16 | -- | -- | 2.17 | 2.04 | 2.11 |
| | | | | | 2.20 | 2.05 | 2.13 |
| | | | | | AVERAGE SECCHI DEPTH | | 2.12 |
| | 11/12/98 | 16:54 | 4 | 0.5 | -- | -- | -- |

## FIGURE 2-12

## DISSOLVED OXYGEN MEASURED AT A 5-FOOT DEPTH

### OUACHITA RIVER NEAR CROSSETT, ARKANSAS



Temperature = 16 °C - 17 °C.
DO measurements collected at various times of day.

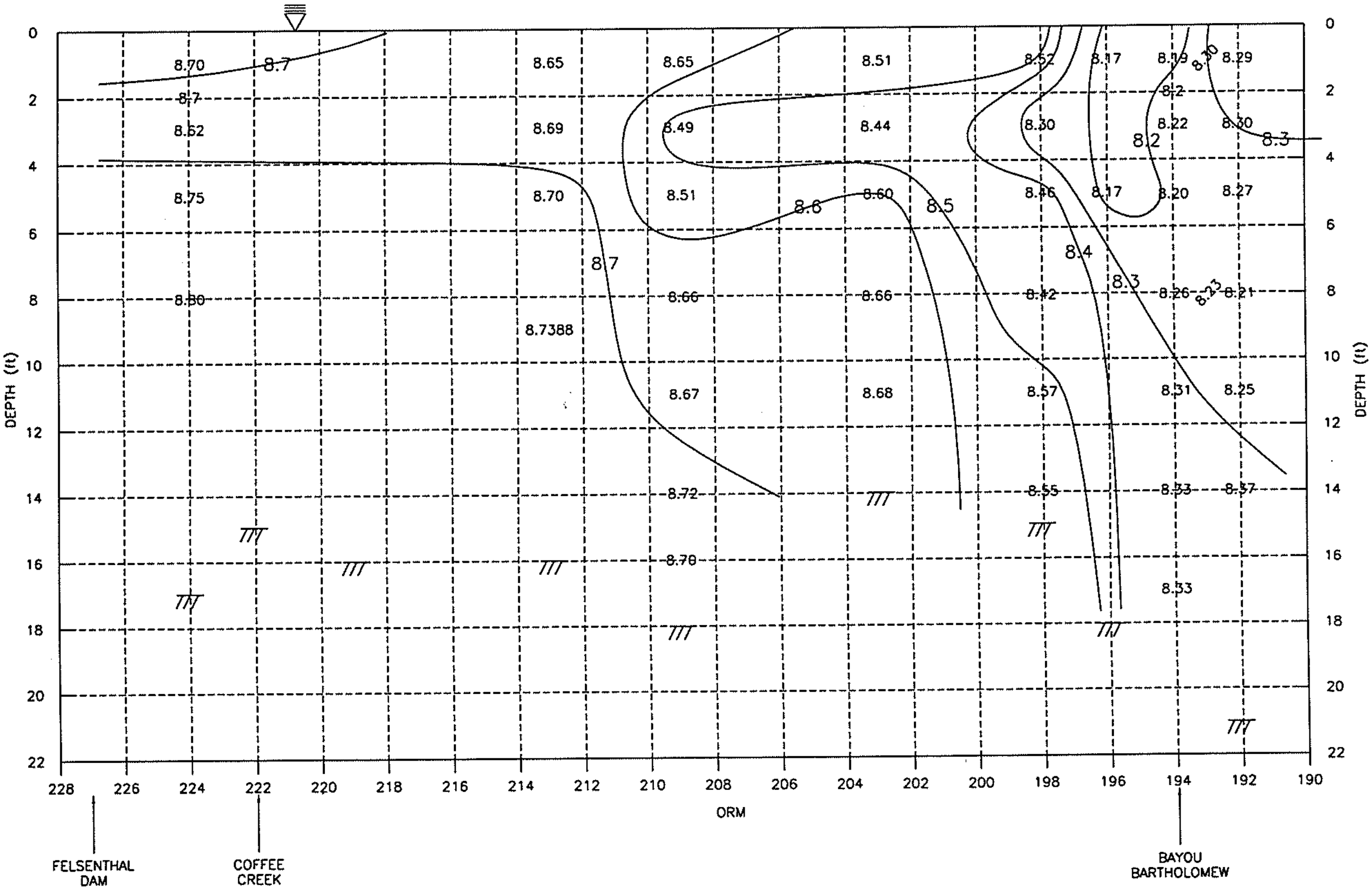


FIGURE 2–13
DO PROFILE – NOVEMBER 12, 1998 DATA
OUACHITA RIVER NEAR CROSSETT, ARKANSAS

**TABLE 2-4. FLOW AND BOD-5 DATA RECORDED BY GEORGIA-PACIFIC DURING THE NOVEMBER FIELD STUDY**

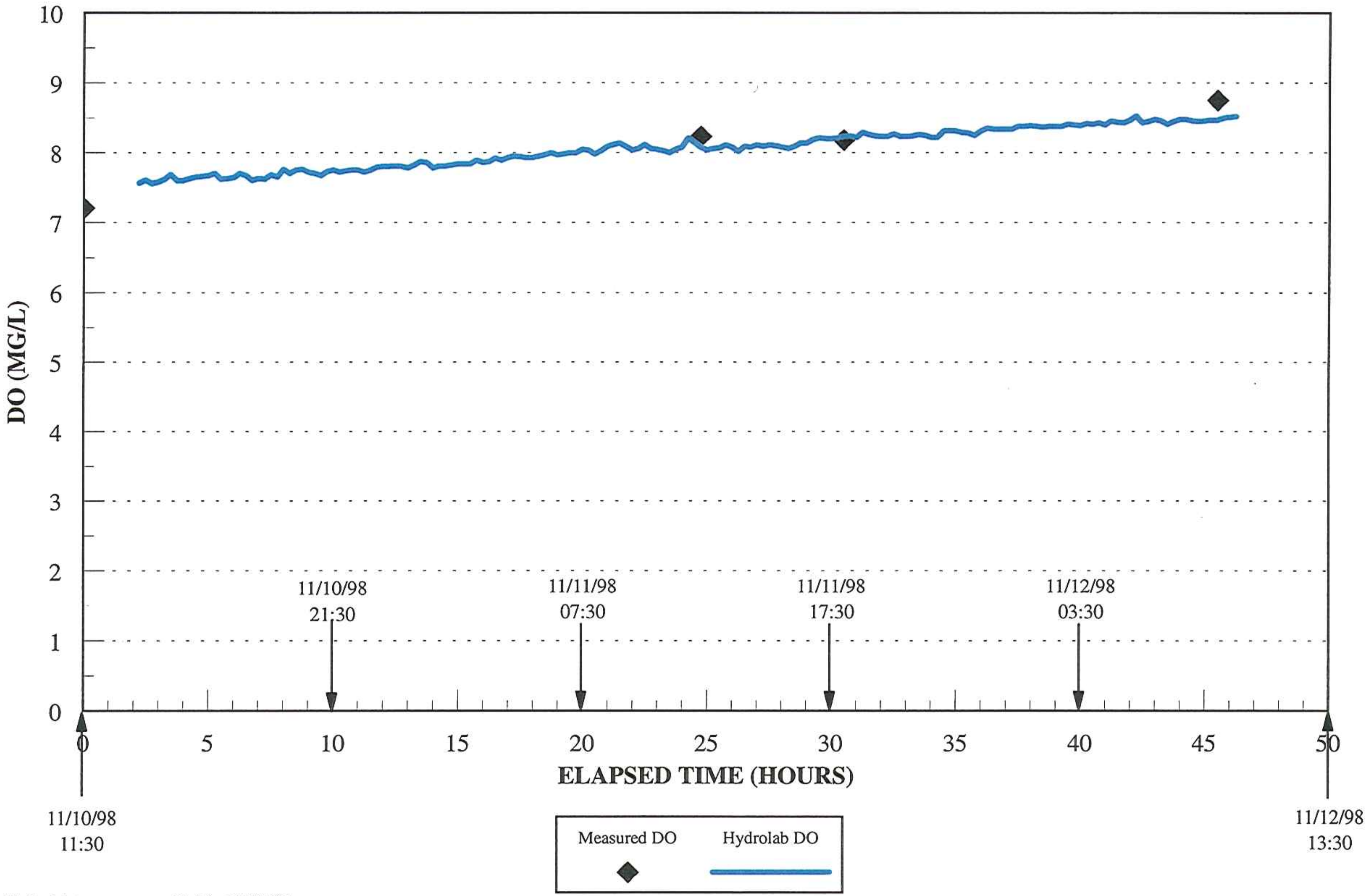
| DATE | OUACHITA RIVER Q (cfs) | GP CROSSETT Q (mgd) | GP CROSSETT Q (cfs) | GP CROSSETT BOD-5 (lbs/day) | GP CROSSETT BOD-5 (mg/L) |
|---|---|---|---|---|---|
| | | | | | |
| 01-Nov-98 | | 40.9 | 63.3 | | |
| 02-Nov-98 | 2,654 | 42.9 | 66.4 | | |
| 03-Nov-98 | 1,998 | 42.8 | 66.2 | 3,248 | 9.1 |
| 04-Nov-98 | 2,281 | 41.3 | 63.9 | 3,341 | 9.7 |
| 05-Nov-98 | 2,669 | 42.3 | 65.4 | 3,140 | 8.9 |
| 06-Nov-98 | 2,590 | 42.8 | 66.2 | | |
| 07-Nov-98 | | 42.8 | 66.2 | | |
| 08-Nov-98 | | 42.8 | 66.2 | | |
| 09-Nov-98 | 2,518 | 44.0 | 68.1 | | |
| 10-Nov-98 | 3,178 | 46.3 | 71.6 | 3,089 | 8.0 |
| 11-Nov-98 | 1,806 | 44.8 | 69.3 | 2,877 | 7.7 |
| 12-Nov-98 | 2,607 | 47.4 | 73.3 | 3,340 | 8.4 |
| 13-Nov-98 | 2,598 | 55.2 | 85.4 | | |
| **Average** | **2,490** | **44.6** | **69.0** | **3,173** | **8.6** |

the study range over the study area from 1.9 feet to 2.68 feet and are dependent upon the amount of available light, with the most accurate measurements collected between the hours of 1000 and 1400.

Hydrolab Multiparameter continuous recording sondes were used at three river stations (ORM 224, 208.8, and 192). The probes were set to monitor the 5-foot depth, which was previously discussed with both Arkansas and Louisiana as an appropriate depth to compare the DO model results. DO, water temperature, pH, and conductivity were monitored continuously over an approximate 48-hour period. This period bracketed the light and dark bottle 24-hour measurement period. The results of the Hydrolab DO measurements are compared to the *in situ* DO measurements, as presented in Figures 2-14 through 2-16. The *in situ* measurements used for comparison at ORM 208.8 include measurements made at both 3 and 5 feet, as well as two measurements made at ORM 213.5. In addition, the *in situ* measurements used for comparison at ORM 224 also include measurements made at both 3 and 5 feet. The raw Hydrolab data, including DO, water temperature, pH, and conductivity are presented in Appendix 6. During the November study, the River was mixed top to bottom and no significant differences in DO were observed from near surface to near bottom.

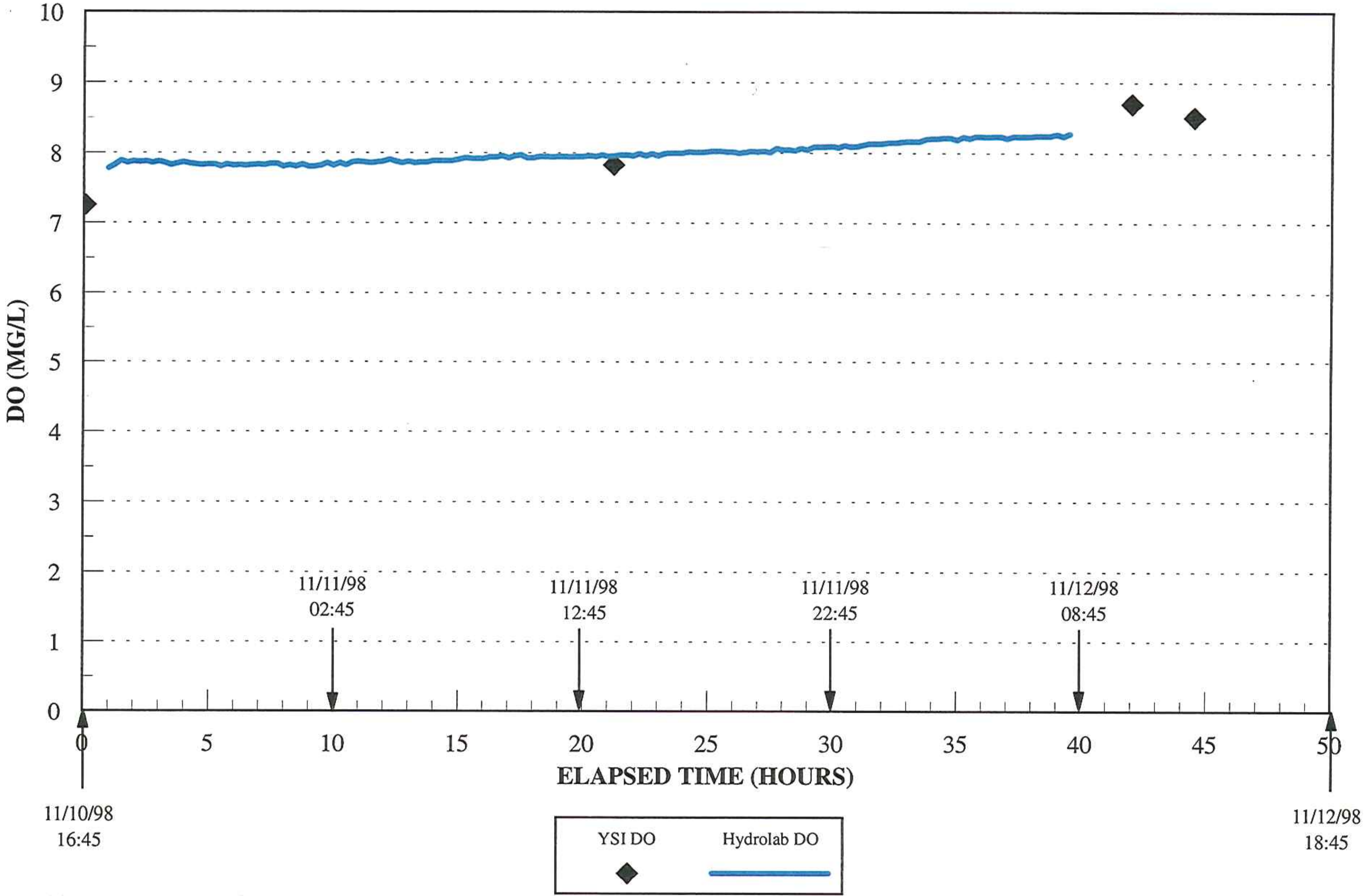
The Hydrolabs did not record significant variations in diurnal DO during this study. This is most likely due to changing flows, decreasing temperatures (17 to 16 °C), and overcast weather. As shown in Figures 2-14 through 2-16, the DO increased steadily throughout the study period. This increase of about 1 mg/L is also shown in the *in situ* DO measurements using the YSI DO meters, as presented in Figure 2-12. The increases in DO throughout the study period due to the temperature drop causing the DO saturation value to increase most likely dampened any observable diurnal DO variations, which were around 0.4 mg/L. In addition, although on November 11, 1998

## FIGURE 2-14
## HYDROLAB DISSOVLED OXYGEN
ORM 224



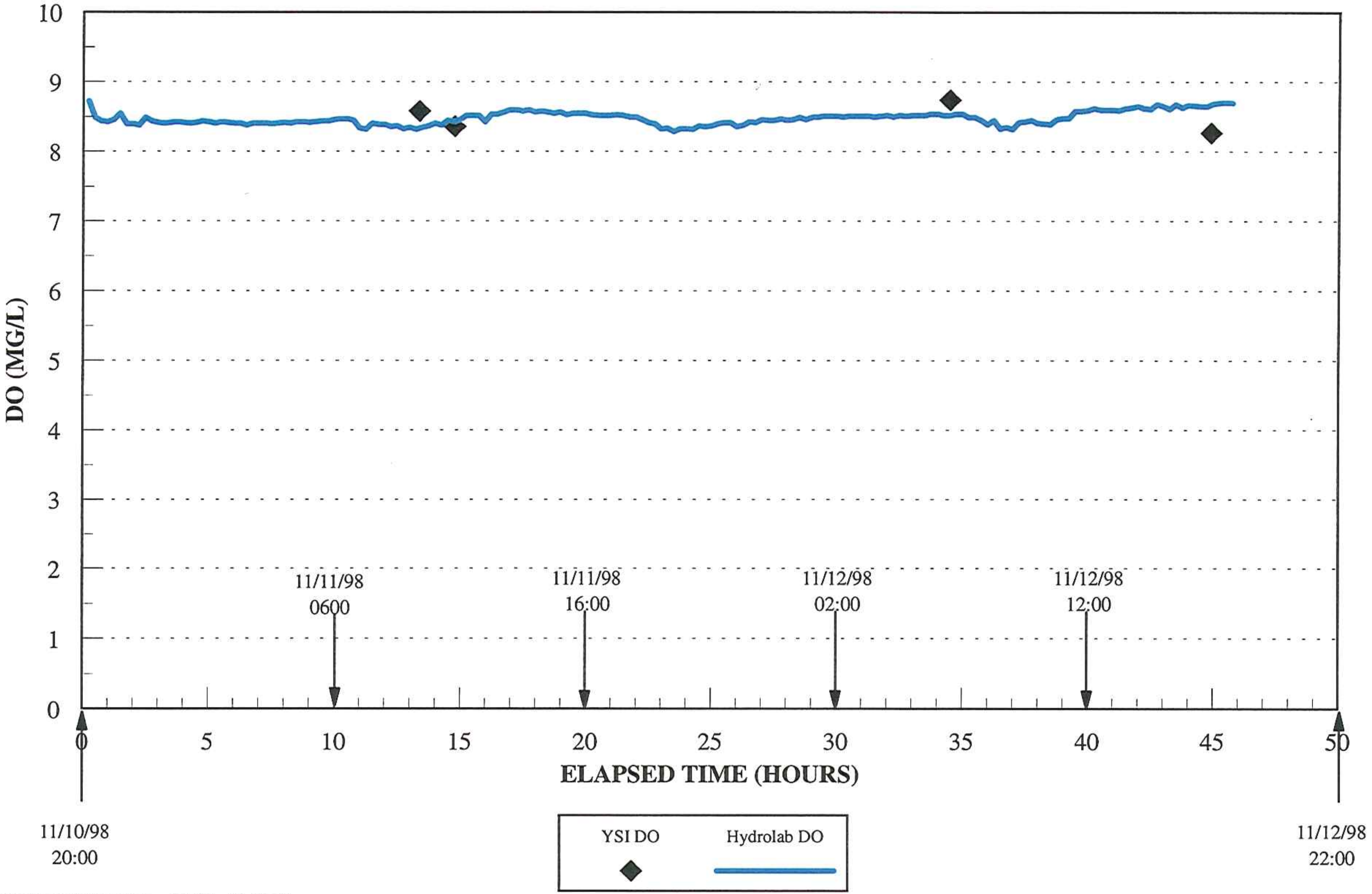
Hydrolab temp range = 17.06 - 15.79 °C

## FIGURE 2-15
## HYDROLAB DISSOLVED OXYGEN
### ORM 208.8



Hydrolab temp range = 17.25 - 16.17 °C

## FIGURE 2-16
## HYDROLAB DISSOLVED OXYGEN
## ORM 192



Hydrolab temp range = 18.40 - 16.42 °C

the skies were clear, the Ouachita River study area had been experiencing overcast weather and rain for several days preceding the study.

As will be discussed later in this section, a diurnal DO variation of 0.4 mg/L was observed at ORM 192 during the light and dark bottle measurements. During the summer months, as documented by Georgia-Pacific's measurements during the summer of 1998, diurnal DO variations on the order of 0.8 to 2.0 mg/L were observed in the Ouachita River system from ORM 224 to ORM 192 at a depth of 5 feet.

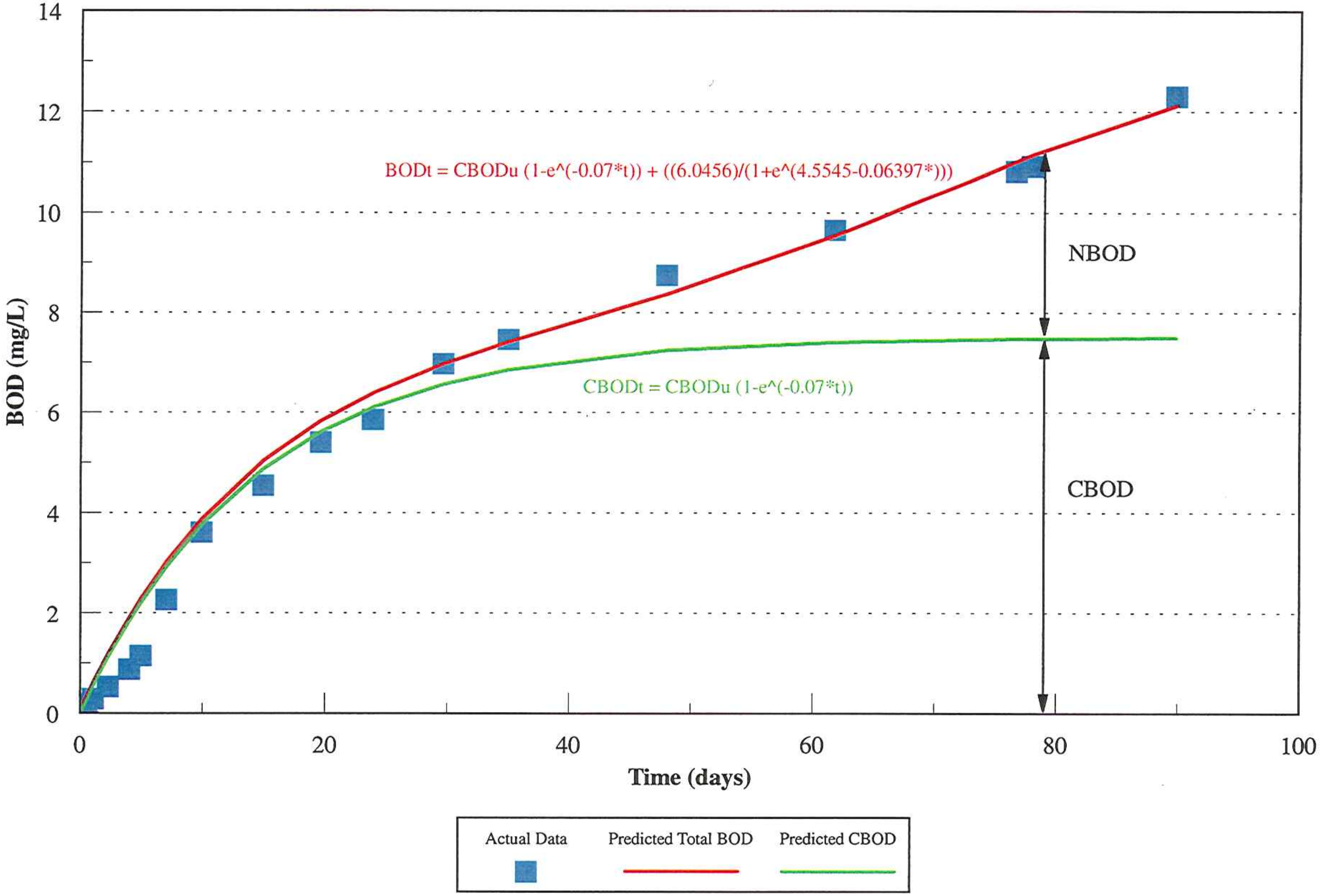
### Time-Series BOD Analyses and Water Chemistry

On November 10 and November 12, 1998, samples were collected for both time-series biochemical oxygen demand (BOD) analyses and water chemistry analyses at eight Ouachita River stations and one Coffee Creek station (Coffee Creek is the plant effluent). In addition, one duplicate sample was collected on both November 10 and 12, 1998. Composite water samples were collected from depths of 20 percent (%), 60 %, and 80 % of the total depth from the surface by pumping equal volumes of river water into a 5-gallon container using a submersible pump. On November 10, samples were set-up in the field on November 12 due to inclement weather (heavy rainfall), individual carboys were filled and taken to the field laboratory for set-up. The sample was aerated and then transferred by siphoning from the bottom of the 5-gallon container to the sample bottles. Two 2L BOD sample bottles and a 1-gallon brown glass jug used for make-up water were filled for each station. Additionally from the same carboy, the appropriate bottles were filled for water chemistry analyses and nitrogen analyses. In order to avoid introducing air bubbles to the BOD bottles, water was siphoned from the bottom of the 5-gallon container to the bottom of the BOD bottle. Also, water transferred from the 5-gallon container was allowed to overfill the top of the BOD bottle. Initial dissolved oxygen readings were read in the field for the samples collected on November 10, 1998 and in the laboratory for the samples collected on November 12, 1998. The BOD was determined by measuring the decrease in DO over time. The dissolved oxygen concentration in the BOD bottles was read using a YSI meter with a BOD probe. Samples were read in the field laboratory until they were transported back to the **AquAeTer** Brentwood, Tennessee laboratory. The field laboratory was kept near 20 °C.

The time-series BOD analysis is a 90-day test to estimate $CBOD_u$. As mentioned above, BOD for a particular bottle is not measured directly, but rather the decrease in DO is measured over time to determine BOD. Industrial discharges often contain materials that exert a demand on the amount of dissolved oxygen present in water including a carbonaceous biochemical oxygen demand (CBOD) and a nitrogenous biochemical oxygen demand (NBOD). The CBOD is usually exerted before the NBOD by heterotrophic organisms which are capable of deriving energy for oxidation from an organic carbon source. Likewise, the NBOD is exerted by organisms capable of deriving energy for oxidation from a nitrogenous source. Since the nitrogenous demand occurs later than the carbonaceous demand (as a result of the lag of growth of nitrifying bacteria necessary for the oxidation of nitrogen forms), time-series BOD curves determined from sample bottles which have both CBOD and NBOD show two distinct stages. The ratio of the projected $CBOD_u$ to the $BOD_5$ is used to convert the $CBOD_u$ to $BOD_5$ (which is the NPDES-required monitored parameter).

A time-series BOD curve for Coffee Creek Sample B is shown in Figure 2-17. A 10 percent Coffee Creek sample with 90 percent background water (water from ORM 224) was used for the

# FIGURE 2-17
## TIME-SERIES BOD
### 10% COFFEE CREEK, SAMPLE B



effluent time-series BOD analysis. This mixture approximates the relative amounts of river water and effluent during low-flow conditions. The equation that fits the data is of the following form:

$$BOD_t = CBOD_u * \left(1 - e^{(-k_1 * t)}\right) + \frac{(NBOD_u)}{\left(1 + e^{(A - k_n * t)}\right)} \qquad \textbf{(2-1)}$$

where

$CBOD_u$ = ultimate carbonaceous biochemical oxygen demand (mg/l),

$k_1$ = carbonaceous rate of oxidation of organic material ($day^{-1}$),

$t$ = time, days,

$NBOD_u$ = ultimate nitrogenous biochemical oxygen demand (mg/l),

$A$ = time adjustment factor, dimensionless,

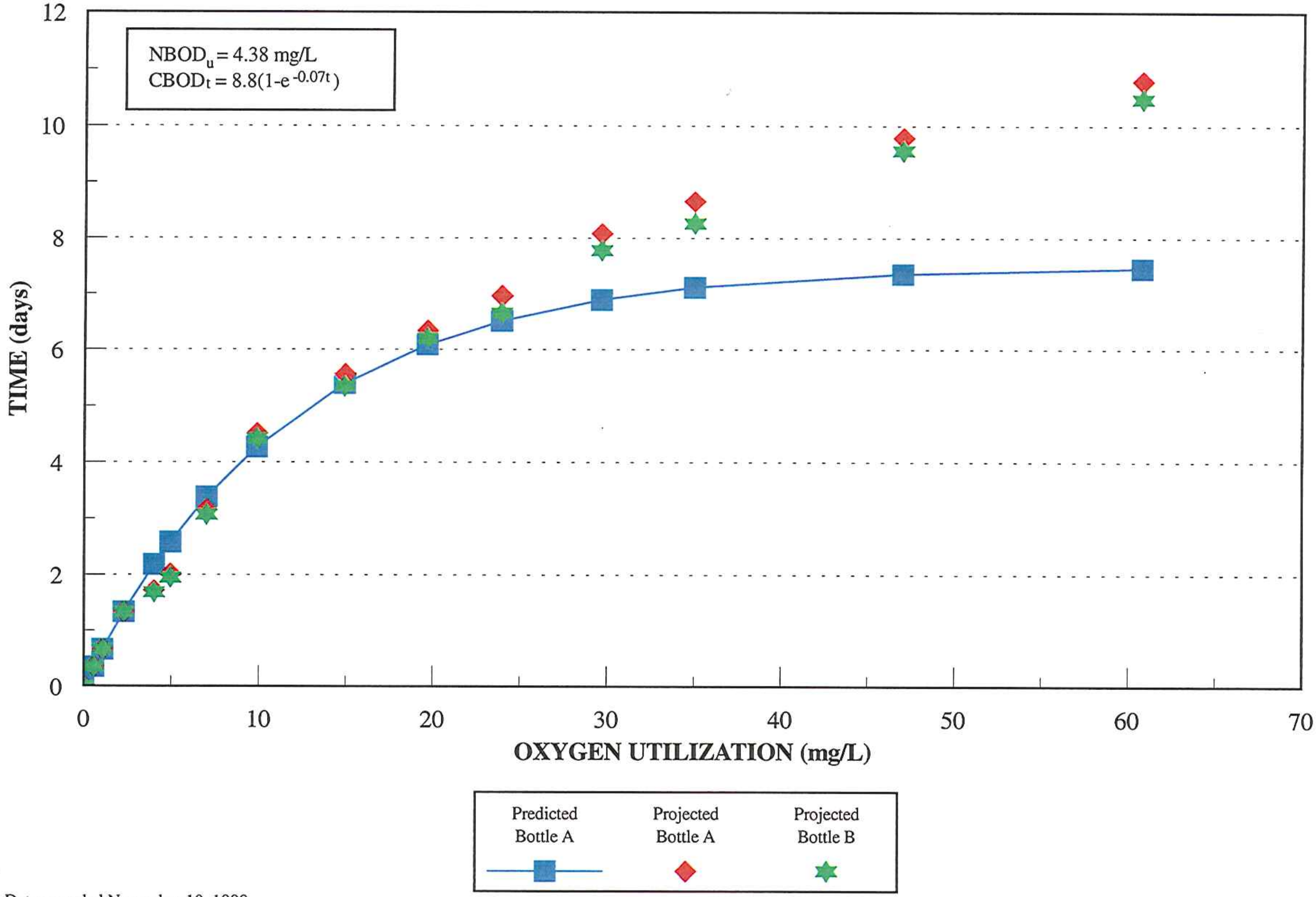
$k_n$ = rate of oxidation of nitrogen containing material ($day^{-1}$).

The first portion of Equation 2-1 predicts the CBOD. As can be seen from Figure 2-17, most of the BOD is due to CBOD for approximately the first 35 days. The oxidation of organic matter in a BOD bottle involves a complex set of sequential reactions in which a portion of the organic matter oxidized by microbes is used to create new microbes (Thomann and Mueller, 1987). As a result, the CBOD is almost never a simple mathematical relationship, but varies according to the type of carbonaceous material present in the bottle. The organic components present in paper mill effluents are both easily degradable (e.g., methanols) and somewhat hard to degrade (e.g., tannins and ligins). In Figure 2-17, the data show that there is a fast CBOD component which is exerted prior to day 10 and a slow (second order) CBOD demand that begins about day 10. Because the QUAL2E model assumes first-order kinetics, a two-stage CBOD analysis cannot be modeled.

Therefore, a single first order decay rate was calculated for the $CBOD_u$ analysis, as shown in Figure 2-17. A simplification of the CBOD over time assumes first-order kinetics, as shown in the first portion of Equation 2-1. The second portion of Equation 2-1 shows the contribution to the overall BOD by NBOD. As indicated by Figure 2-17, after 35 days, the NBOD becomes the primary source of BOD. The raw DO and time data for each BOD bottle were entered into the software program LTBOD, Version 2.01 (Georgia Environmental Protection Division, Water Quality Management Program). The program determined initial values for $CBOD_u$ rate constant, $K_1$, as well as other predictive parameters in Equation 2-1. Equation 2-1 was then tabulated along with the time and BOD data for each bottle. To ensure that realistic parameters were used in the predictive equation, the parameters given by the LTBOD program were adjusted as presented in Figure 2-18 to determine the $CBOD_u$ alone. As a starting point, the $NBOD_u$ parameter was adjusted to match the theoretical $NBOD_u$. The theoretical $NBOD_u$ was obtained from chemical analysis of each sample for Total Kjeldahl Nitrogen (TKN). The chemical analyses performed on the samples are discussed below. The TKN for each bottle was multiplied by 4.57 (the stoichiometric oxygen usage in the entire nitrification process from organic-nitrogen to ammonia-nitrogen to nitrate) to give an approximate upper bound for the NBOD contribution to BOD. Once this upper bound was established, the other parameters were adjusted to give the best fit to the data.

A BOD bottle containing undiluted effluent was not prepared because the depletion of oxygen from the BOD bottle would be too rapid. Instead, a mass balance was performed using the BOD information from the Coffee Creek bottle (10 percent effluent) and the background bottle (ORM 224) according to the following equation:

## FIGURE 2-18
## TIME-SERIES BOD
### 10% COFFEE CREEK, 90% ORM 224



Data recorded November 10, 1998

$$CBOD_{u,0.9ORM224:0.1cc} * 1.0 = CBOD_{u,ORM224} * (0.9) + CBOD_{u,GP} * (0.1) \tag{2-2}$$

where $CBOD_{u,cc}$ = ultimate carbonaceous biochemical oxygen demand predicted for Coffee Creek (mg/l). The other parameters have analogous meanings. Equation 2-2 was solved for $CBOD_u$ as follows:

$$CBOD_{u,cc} = \frac{CBOD_{u,0.9ORM224:0.1cc} * 1.0 - CBOD_{u,ORM224} * 0.9}{0.1} . \tag{2-3}$$

Using $CBOD_{u,0.9ORM224:0.1cc}$ = 8.8 mg/L, and $CBOD_{u,\ ORM224}$ = 2.5 mg/L, the ultimate carbonaceous biochemical oxygen demand for the Coffee Creek discharge is $CBOD_u$ = 65.5 mg/l. The $CBOD_5$ for Coffee Creek can be calculated as follows:

$$\begin{aligned} CBOD_5 &= CBOD_u\ (1 - e^{-k_1 t}) \\ CBOD_5 &= 65.5\ mg/L\ (1 - e^{0.070/day\ *5\ days}) \\ CBOD_5 &= 19.34\ mg/L \end{aligned} \tag{2-4}$$

Therefore, the ratio of $CBOD_u$ to $CBOD_5$ for the Coffee Creek discharge to the Ouachita River can be determined as follows.

$$\frac{65.6}{19.34} = 3.39 \tag{2-5}$$

The results of the time-series BOD analyses are presented in Table 2-5 and all individual BOD analyses are presented in Appendix 7. The water chemistry samples, collected from the same 5-gallon carboy as the time-series BOD samples, were analyzed by Specialized Assays, Inc. located in Nashville, Tennessee, for the following constituents, as presented in Table 2-6 and in Appendix 7:

1. TKN (filtered and unfiltered);
2. Ammonia;
3. Nitrite plus nitrate;
4. Total phosphorus (filtered and unfiltered);
5. Dissolved orthophosphate; and
6. Chlorophyll *a*.

The filtered and unfiltered TKN and total phosphorous were analyzed to determine if these constituents are present in a particulate form, and therefore, if settling of organic nitrogen or phosphorous is occurring in the River system. As is shown in Table 2-7, TKN concentrations are low in the River and the filtered TKN and the unfiltered TKN were essentially the same, which indicates that the majority of TKN in the system is dissolved. In addition, approximately 70 percent of the total phosphorus, on average, in the River system is dissolved. Therefore, it is assumed that no settling of organic nitrogen and minimal settling of organic phosphorus occurs throughout the system.

The dissolved orthophosphate is measured at levels of less than 0.01 mg/L throughout the system. During a discussion with Mr. Bob Ambrose (1998), USEPA Athens, Mr. Ambrose stated that the dissolved orthophosphate is the form of phosphorus that is primarily available for algae

TABLE 2-5. TIME-SERIES BOD ANALYSES

| SAMPLE ID | TOTAL TIME (days) | TKN (mg/L) | NBOD (mg/L) | CBODu (mg/L) | k1 (per day) | CBOD5 (mg/L) | CBODu:CBOD5 |
|---|---|---|---|---|---|---|---|
| ORM 224 | 89.90 | 0.36 | 1.65 | 2.50 | 0.070 | 0.74 | 3.39 |
| 10 % CC:90 % ORM 224 | 89.75 | 0.96 | 4.38 | 8.80 | 0.070 | 2.60 | 3.39 |
| Coffee Creek (calculated) | - | 6.34 | 28.97 | 73.15 | 0.070 | 21.60 | 3.39 |
| ORM 222 (calculated) | - | 0.49 | 2.25 | 4.06 | 0.070 | 1.20 | 3.39 |
| ORM 218.7 | 89.80 | 0.42 | 1.92 | 3.90 | 0.060 | 1.01 | 3.86 |
| ORM 218.7 Duplicate | 89.80 | 0.42 | 1.92 | 3.50 | 0.080 | 1.15 | 3.03 |
| ORM 213.5 | 87.59 | 0.29 | 1.33 | 3.80 | 0.070 | 1.12 | 3.39 |
| ORM 213.5 Duplicate | 88.17 | 0.29 | 1.33 | 3.70 | 0.070 | 1.09 | 3.39 |
| ORM 208.8 | 87.64 | 0.30 | 1.37 | 3.50 | 0.070 | 1.03 | 3.39 |
| ORM 203 | 87.65 | 0.21 | 0.96 | 3.20 | 0.045 | 0.64 | 4.96 |
| ORM 198 | 87.63 | 0.23 | 1.05 | 3.10 | 0.070 | 0.92 | 3.39 |
| ORM 194 | 87.63 | 0.33 | 1.51 | 2.90 | 0.073 | 0.89 | 3.27 |
| ORM 191.6 | 87.70 | 0.19 | 0.87 | 2.85 | 0.069 | 0.83 | 3.43 |

## TABLE 2-6. NITROGEN AND PHOSPHORUS SERIES LABORATORY RESULTS
## OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| ORM | DATE | TIME | TOTAL DEPTH (1) (ft) | TOTAL P AS P (UNFILT.) (2) (mg/L) | TOTAL P AS P (FILT.) (mg/L) | ORTHO PO4 AS P (UNFILT.) (mg/L) | ORTHO PO4 AS P (FILT.) (mg/L) | TKN AS N (UNFILT.) (4) (mg/L) | TKN AS N (FILT.) (mg/L) | NH3 AS N (UNFILT.) (mg/L) | NO2+NO3 AS N (UNFILT.) (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 224 | 10-Nov-98 | 13:10 | 20 | 0.051 | 0.044 | < 0.01 | - | 0.36 | 0.22 | 0.10 | 0.18 |
| Coffee Creek | 10-Nov-98 | 15:35 | 2 | 0.794 | 0.624 | 0.45 | - | 6.34 | 5.40 | 3.56 | 0.21 |
| 218.7 | 10-Nov-98 | 16:07 | 16 | 0.069 | 0.048 | < 0.01 | - | 0.36 | 0.42 | 0.14 | 0.18 |
| 218.7 Dup | 10-Nov-98 | 16:07 | 16 | 0.064 | 0.058 | - | < 0.01 | 0.21 | 0.78 (3) | 0.14 | 0.18 |
| 213.5 | 12-Nov-98 | 10:45 | 13 | 0.037 | 0.018 | - | < 0.01 | 0.20 | 0.10 | 0.29 | 0.27 |
| 213.5 Dup | 12-Nov-98 | 10:48 | 13 | 0.034 | < 0.010 | - | < 0.01 | 0.11 | < 0.10 | 0.22 | 0.27 |
| 208.8 | 12-Nov-98 | 13:14 | 17 | 0.036 | 0.026 | - | < 0.01 | 0.20 | 0.10 | 0.30 | 0.24 |
| 203 | 12-Nov-98 | 14:35 | 13 | 0.021 | 0.021 | - | < 0.01 | 0.13 | 0.21 | 0.20 | 0.22 |
| 198 | 12-Nov-98 | 15:10 | 15 | 0.021 | < 0.010 | - | < 0.01 | < 0.10 | 0.10 | 0.23 | 0.21 |
| 194 | 12-Nov-98 | 16:08 | 18 | 0.029 | < 0.010 | - | < 0.01 | < 0.10 | < 0.10 | 0.33 | 0.20 |
| 191.6 | 12-Nov-98 | 16:40 | 21 | < 0.010 | 0.026 | - | < 0.01 | 0.11 | 0.19 | 0.53 | 0.19 |

**NOTES:**

1) Samples are composited at 0.2, 0.6, and 0.8 of total depth.
2) P - phosphorous; Ortho PO4 - orthophosphate; TKN - Total Kjeldahl Nitrogen; ORM - Ouachita River Mile
3) Suspect value. Unfiltered TKN adjusted to filtered TKN value, See Appendix 7 for laboratory data.
4) All nitrogen data are as reported by the laboratory. In analyzing the data, the unfiltered TKN value cannot be less than either the filtered TKN or unfiltered ammonia. The highest value of unfiltered TKN, filtered TKN or unfiltered ammonia value of the unfiltered TKN for determining organic nitrogen and the stochiometric oxygen requirement to nitrify all TKN or organic nitrogen plus ammonia-nitrogen to nitrate-nitrogen.

TABLE 2-7. NITROGEN AND PHOSPHORUS SERIES MASS BALANCE FOR UNFILTERED TKN
OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| PARAMETER | HEADWATER FLOW (cfs) | ORM 224 HEADWATER CONC. (mg/L) | COFFEE CREEK FLOW (mgd) | COFFEE CREEK FLOW (cfs) | COFFEE CREEK CONC. (mg/L) | TOTAL FLOW (cfs) | FULLY MIXED CONC. (mg/L) | ORM 218.7 CONC. (mg/L) |
|---|---|---|---|---|---|---|---|---|
| TKN | 3,178 | 0.36 | 46.3 | 71.6 | 6.34 | 3,250 | 0.49 | 0.29 |
| Org-N | 3,178 | 0.26 | 46.3 | 71.6 | 2.78 | 3,250 | 0.32 | 0.15 |
| NH3 | 3,178 | 0.1 | 46.3 | 71.6 | 3.56 | 3,250 | 0.18 | 0.14 |
| NO2+NO3 | 3,178 | 0.18 | 46.3 | 71.6 | 0.21 | 3,250 | 0.18 | 0.18 |
| Total P | 3,178 | 0.051 | 46.3 | 71.6 | 0.79 | 3,250 | 0.07 | 0.067 |
| Org-P | 3,178 | 0.041 | 46.3 | 71.6 | 0.43 | 3,250 | 0.05 | 0.057 |
| Dis. Ortho PO4 | 3,178 | 0.01 | 46.3 | 71.6 | 0.36 | 3,250 | 0.02 | 0.01 |

NOTES:

1) Headwater flow value for November 10, 1998.
2) Org-N = TKN - NH3; Org-P = Total P - Dis. Ortho PO4
3) ORM - Ouachita River Mile; TKN - total Kjedahl nitrogen; NH3 - ammonia; NO2+NO3 - nitrite plus nitrate; P - phosphorous; Dis. Ortho PO4 - dissolved orthophosphate
4) With the exception of Coffee Creek, dissolved orthophosphate results are reported as less than 0.01 mg/L.
5) The laboratory ran dissolved orthophosphate on unfiltered samples. Therefore, the dissolved orthophosphate value for Coffee Creek is estimated based on a ratio of total phosphorus filtered to total phosphorus unfiltered.
6) Parameters for ORM 218.7 are an average of the original sample and a duplicate sample.

growth. He also stated that concentrations of dissolved orthophosphate less than 0.01 mg/L may still provide sufficient nutrient for phytoplankton growth. Mr. Ambrose stated that the Michaelis-Menton half-saturation constant for phosphorus can be less than 0.01 mg/L and that these observations appear to be consistent with conditions experienced in the Ouachita River during the field study.

An increase in ammonia was observed near ORM 192, as shown in Table 2-6. According to Mr. Kirk Cormier of LDEQ (1998), the Town of Sterlington and Koch Nitrogen both discharge in this area and may provide an additional source of ammonia in the River.

The Coffee Creek water chemistry sample was not diluted and therefore, the laboratory results presented previously in Table 2-6 represent an undiluted sample. A complete mix mass balance comparison was made between the laboratory results for Coffee Creek mixed with background water (ORM 224) to the laboratory results for ORM 218.7, the first station downstream from Coffee Creek, as presented in Tables 2-7 and 2-8. As can be seen in these tables, the fully mixed results compare well with the laboratory results for ORM 218.7.

### Chlorophyll *a*

Chlorophyll *a* measurements were collected by two methods, *in situ* measurements and laboratory analysis, as presented in Appendix 8. Several samples were submitted to Specialized Assays, Inc. for chlorophyll *a* analysis; however, these samples were all below the laboratory method detection limit of 5 μg/L.

*In situ* chlorophyll *a* measurements were obtained using a Turner Designs Model 10AU continuous flow fluorometer factory equipped to record chlorophyll *a* and calibrated to a chlorophyll *a* calibration standard provided by Turner Designs. A submersible pump was used to pump water

## TABLE 2-8. NITROGEN AND PHOSPHORUS SERIES MASS BALANCE FOR FILTERED TKN OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| PARAMETER | HEADWATER FLOW (cfs) | ORM 224 HEADWATER CONC. (mg/L) | COFFEE CREEK FLOW (mgd) | COFFEE CREEK FLOW (cfs) | COFFEE CREEK CONC. (mg/L) | TOTAL FLOW (cfs) | FULLY MIXED CONC. (mg/L) | ORM 218.7 CONC. (mg/L) |
|---|---|---|---|---|---|---|---|---|
| TKN | 3,178 | 0.22 | 46.3 | 71.6 | 6.34 | 3,250 | 0.35 | 0.29 |
| Org-N | 3,178 | 0.12 | 46.3 | 71.6 | 2.78 | 3,250 | 0.18 | 0.15 |
| NH3 | 3,178 | 0.1 | 46.3 | 71.6 | 3.56 | 3,250 | 0.18 | 0.14 |
| NO2+NO3 | 3,178 | 0.18 | 46.3 | 71.6 | 0.21 | 3,250 | 0.18 | 0.18 |
| Total P | 3,178 | 0.051 | 46.3 | 71.6 | 0.79 | 3,250 | 0.07 | 0.067 |
| Org-P | 3,178 | 0.041 | 46.3 | 71.6 | 0.43 | 3,250 | 0.05 | 0.057 |
| Dis. Ortho PO4 | 3,178 | 0.01 | 46.3 | 71.6 | 0.36 | 3,250 | 0.02 | 0.01 |

**NOTES:**

1) Headwater flow value for November 10, 1998.
2) Org-N = TKN - NH3; Org-P = Total P - Dis. Ortho PO4
3) ORM - Ouachita River Mile; TKN - total Kjedahl nitrogen; NH3 - ammonia; NO2+NO3 - nitrite plus nitrate; P - phosphorous; Dis. Ortho PO4 - dissolved orthophosphate
4) With the exception of Coffee Creek, dissolved orthophosphate results are reported as less than 0.01 mg/L.
5) The laboratory ran dissolved orthophosphate on unfiltered samples. Therefore, the dissolved orthophosphate value for Coffee Creek is estimated based on a ratio of total phosphorus filtered to total phosphorus unfiltered.
6) Parameters for ORM 218.7 are an average of the original sample and a duplicate sample.

from the River through the fluorometer. Water samples were also pumped from specified depths for the collection of chlorophyll *a* samples analyzed in the **AquAeTer** laboratory. The samples were field-filtered and stored on dry ice prior to transportation to the laboratory. Once the samples arrived at the **AquAeTer** laboratory, they were kept frozen until analysis using USEPA Method 445.0 (Standard Methods 10200H) as presented in Appendix 8. All laboratory analyses were completed within nine days from sample collection.

The laboratory chlorophyll *a* measured ranged from 1.57 µg/L to 3.5 µg/L, as presented in Table 2-9. The laboratory chlorophyll *a* was measured from water samples collected and field filtered at depths of 1, 3, and 5 feet, and near bottom in two locations. The results show that the chlorophyll *a* is well distributed over the water column. As presented in Figure 2-19, at a 5-foot depth, an increase in chlorophyll *a* occurs at ORM 218.7 and 213.5 and again at ORM 196. These chlorophyll *a* increases are most likely due to nutrients provided to the system by Georgia-Pacific at the upper two stations and by either the Town of Sterlington or Koch Nitrogen at ORM 192.

The *in situ* chlorophyll *a* measurements are relative measurements which are related to the laboratory measurements through a ratio. The relative *in situ* measurements for each station are multiplied by an average ratio (for each station) of laboratory chlorophyll *a* to the relative *in situ* chlorophyll *a* to determine the *in situ* chlorophyll *a* result, as presented in Table 2-10. As shown in Figure 2-19, the shape of the *in situ* data curve and the laboratory data curve compare well. The one exception to this is the laboratory data point at ORM 229 at a depth of 5 feet. The laboratory data point at this location is equal to 0.46 µg/L; however, as shown in Table 2-10, the calculated *in situ* measurement at ORM 229, at a depth of 5 feet, is 1.94 µg/L, which is in the range of all of the *in situ* measurements at ORM 229, as well as in the range of the laboratory measurements at 1 and 3 feet.

## TABLE 2-9. LABORATORY CHLOROPHYLL a MEASUREMENTS
## OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| STATION ID (ORM) | DEPTH (ft) | DATE | TIME | LABORATORY CHLOROPHYLL a (ug/L) |
|---|---|---|---|---|
| 229 | 1 | 10-Nov-98 | 11:28 | 2.32 |
| | 3 | 10-Nov-98 | 11:32 | 1.72 |
| | 5 | 10-Nov-98 | 11:36 | 0.46 |
| 224 | 1 | 10-Nov-98 | 13:10 | 2.00 |
| | 3 | 10-Nov-98 | 13:15 | 1.72 |
| | 5 | 10-Nov-98 | 13:16 | 2.08 |
| 218.7 | 1 | 10-Nov-98 | 15:26 | 2.50 |
| | 3 | 10-Nov-98 | 15:26 | 2.26 |
| | 5 | 10-Nov-98 | 15:26 | 2.82 |
| 213.5 | 1 | 12-Nov-98 | 11:00 | 2.32 |
| | 1 Duplicate | 12-Nov-98 | 11:00 | 1.57 |
| | 3 | 12-Nov-98 | 10:57 | 1.64 |
| | 5 | 12-Nov-98 | 10:54 | 2.59 |
| 208.8 | 1 | 12-Nov-98 | 13:15 | 2.33 |
| | 3 | 12-Nov-98 | 13:15 | 1.76 |
| | 5 | 12-Nov-98 | 13:15 | 2.20 |
| | 14 | 12-Nov-98 | 13:15 | 2.71 |
| 203 | 1 | 12-Nov-98 | 14:19 | 2.88 |
| | 3 | 12-Nov-98 | 14:24 | 2.13 |
| | 5 | 12-Nov-98 | 14:27 | 2.22 |
| 198 | 1 | 12-Nov-98 | 15:03 | (1) |
| | 3 | 12-Nov-98 | 15:06 | 2.18 |
| | 5 | 12-Nov-98 | 15:08 | (1) |
| 194 | 1 | 12-Nov-98 | 16:15 | (1) |
| | 3 | 12-Nov-98 | 16:17 | 2.43 |
| | 5 | 12-Nov-98 | 16:20 | 2.19 |
| 192 | 1 | 12-Nov-98 | 16:54 | 2.73 |
| | 3 | 12-Nov-98 | 16:58 | 2.88 |
| | 5 | 12-Nov-98 | 17:02 | 3.24 |
| | 17 | 12-Nov-98 | 17:20 | 3.50 |

**NOTE:**

1) The sample cuvettes were destroyed upon centrifuging.

# FIGURE 2-19

## CHLORPHYLL-A MEASUREMENTS AT 5 FT DEPTH

### OUACHITA RIVER NEAR CROSSETT, ARKANSAS

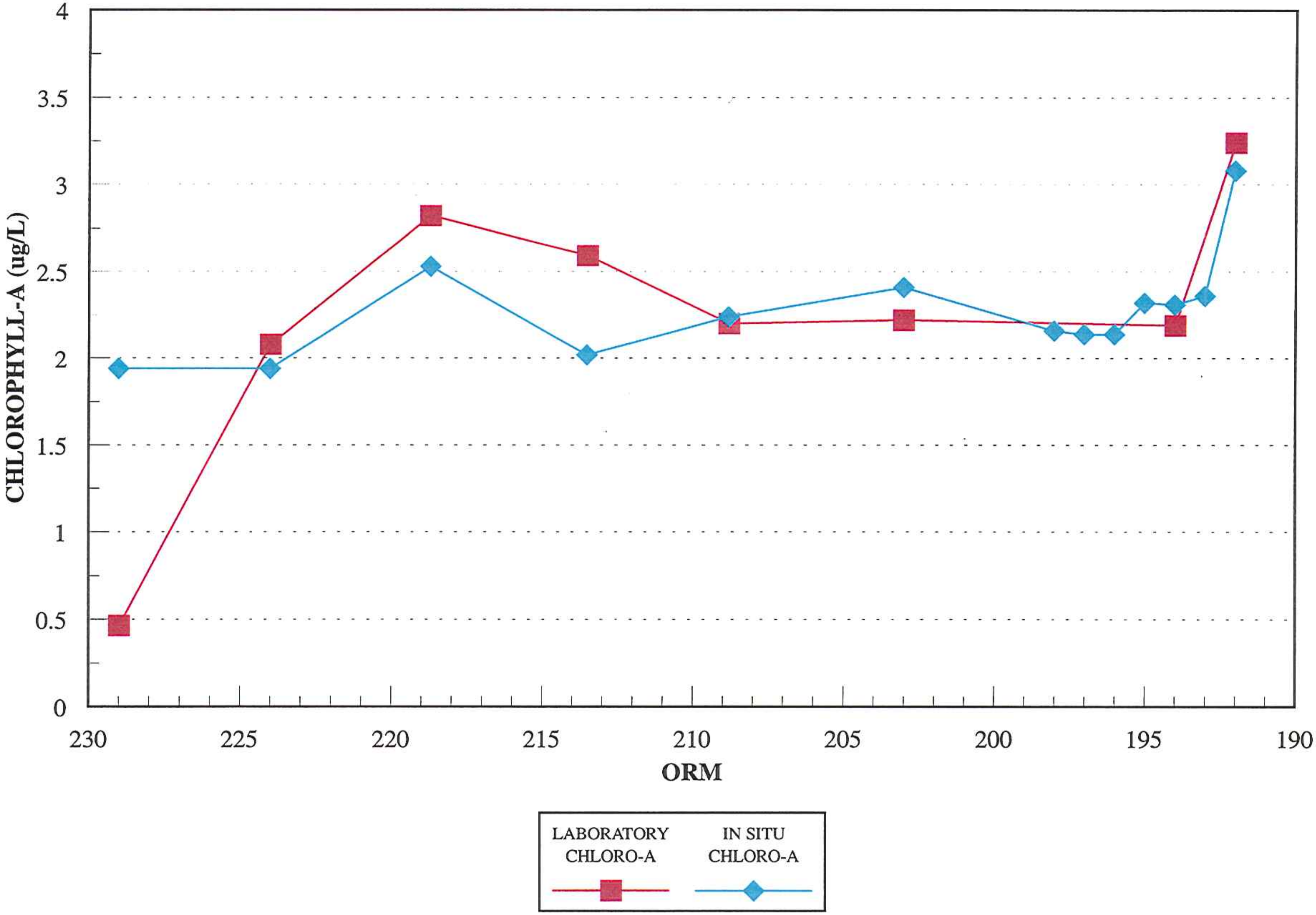


TABLE 2-10. IN SITU CHLOROPHYLL a MEASUREMENTS
OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| ORM | DATE | TIME | DEPTH (ft) | MEASURED IN SITU CHLOROPHYLL a (units) (1) | LABORATORY CHLOROPHYLL a (ug/L) (2) | RATIO OF LAB. CHL-a: REL. IN SITU CHL a | AVERAGE RATIO AT ORM | CALCULATED IN SITU CHLOROPHYLL a (ug/L) |
|---|---|---|---|---|---|---|---|---|
| 229 | 11/10/98 | 11:28 | 1 | 37.3 | 2.32 | 0.062 | 0.056 (3) | 2.08 |
| | | 11:32 | 3 | 35.0 | 1.72 | 0.049 | | 1.95 |
| | | 11:36 | 5 | 34.8 | 0.46 | 0.013 | | 1.94 |
| | | 11:38 | 8 | 33.9 | - | - | | 1.89 |
| | | 11:40 | 11 | 34.1 | - | - | | 1.90 |
| | | 11:41 | 14 | 33.9 | - | - | | 1.89 |
| | | 11:42 | 17 | 33.6 | - | - | | 1.87 |
| | | 11:42:30 | 20 | 33.8 | - | - | | 1.88 |
| | | 11:43 | 23 | 33.9 | - | - | | 1.89 |
| | | 11:44 | 26 | 33.6 | - | - | | 1.87 |
| | | 11:45 | 29 | bottom | - | - | | - |
| 224 | 11/10/98 | 13:10 | 1 | 36.7 | 2.00 | 0.054 | 0.053 | 1.93 |
| | | 13:15 | 3 | 36.8 | 1.72 | 0.047 | | 1.93 |
| | | 13:16 | 5 | 36.9 | 2.08 | 0.056 | | 1.94 |
| | | 13:23 | 8 | 36.4 | - | - | | 1.91 |
| | | 13:24 | 11 | 36.3 | - | - | | 1.91 |
| | | 13:24:30 | 14 | 36.5 | - | - | | 1.92 |
| | | 13:25 | 16 | 36.2 | - | - | | 1.90 |
| 218.7 | 11/10/98 | 15:26 | 1 | 42.8 | 2.50 | 0.058 | 0.059 | 2.51 |
| | | | 3 | 43.2 | 2.26 | 0.052 | | 2.54 |
| | | | 5 | 43.1 | 2.82 | 0.065 | | 2.53 |
| | | | 8 | 43.2 | - | - | | 2.54 |
| | | | 11 | 42.2 | - | - | | 2.48 |
| 213.5 | 11/12/98 | 11:00 | 1 | 41.9 - 42.1 | - | - | 0.048 | - |
| | | | 1 ft avg = | 42 | 2.32 | 0.055 | | 2.04 |
| | | | 1 | 41.9 - 42.1 | - | - | | - |
| | | | 1 ft avg = | 42 | 1.57 | 0.037 | | 2.04 |
| | | | 3 | 41.7 - 42.1 | - | - | | - |
| | | | 3 ft avg = | 41.9 | 1.64 | 0.039 | | 2.03 |
| | | | 5 | 41.7 | 2.59 | 0.062 | | 2.02 |
| | | | 9 | 42.1 | - | - | | 2.04 |
| | | 10:45 | 12 | 41.8 | - | - | | 2.03 |
| 208.8 | 11/12/98 | 13:15 | 1 | 42.8 - 43.3 | - | - | 0.052 | - |
| | | | 1 ft avg = | 43.1 | 2.33 | 0.054 | | 2.25 |
| | | | 3 | 43.0 | 1.76 | 0.041 | | 2.25 |
| | | | 5 | 42.6 - 43.0 | - | - | | - |
| | | | 5 ft avg = | 42.8 | 2.20 | 0.051 | | 2.24 |
| | | | 8 | 42.9 | - | - | | 2.24 |
| | | | 11 | 42.3 | - | - | | 2.21 |
| | | | 14 | 43.1 | 2.71 | 0.063 | | 2.25 |
| | | | 16 | 43.0 | - | - | | 2.25 |
| 203 | 11/12/98 | 14:19 | 1 | 43.1 - 43.5 | - | - | 0.056 | - |
| | | | 1 ft avg = | 43.3 | 2.88 | 0.067 | | 2.41 |
| | | 14:24 | 3 | 43.4 | 2.13 | 0.049 | | 2.41 |
| | | 14:27 | 5 | 43.4 | 2.22 | 0.051 | | 2.41 |
| | | 14:30 | 8 | 43.3 - 46.0 | - | - | | - |
| | | | 8 ft avg = | 44.7 | - | - | | 2.48 |
| | | 14:32 | 11 | 43.6 - 44.0 | - | - | | - |
| | | | 11 ft avg = | 43.8 | - | - | | 2.43 |
| 198 | 11/12/98 | 15:03 | 1 | 45.0 - 48.0 | - | - | 0.048 | - |
| | | | 1 ft avg = | 46.5 | - | - | | 2.21 |
| | | 15:06 | 3 | 45.5 - 46.1 | - | - | | - |
| | | | 3 ft avg = | 45.8 | 2.18 | 0.048 | | 2.18 |
| | | 15:08 | 5 | 45.1 - 45.6 | - | - | | - |
| | | | 5 ft avg = | 45.3 | - | - | | 2.16 |
| | | 15:11 | 8 | 44.4 | - | - | | 2.11 |
| | | 15:14 | 11 | 44.4 | - | - | | 2.11 |
| | | 15:17 | 14 | 44.2 | - | - | | 2.10 |
| 197 | 11/12/98 | 15:33 | 1 | 44.2 - 44.6 | - | - | 0.048 (4) | - |
| | | | 1 ft avg = | 44.4 | - | - | | 2.13 |
| | | | 5 | 44.6 | - | - | | 2.14 |

**TABLE 2-10. IN SITU CHLOROPHYLL a MEASUREMENTS**
**OUACHITA RIVER NEAR CROSSETT, ARKANSAS**

| ORM | DATE | TIME | DEPTH (ft) | MEASURED IN SITU CHLOROPHYLL a (units) (1) | LABORATORY CHLOROPHYLL a (ug/L) (2) | RATIO OF LAB. CHL-a: REL. IN SITU CHL a | AVERAGE RATIO AT ORM | CALCULATED IN SITU CHLOROPHYLL a (ug/L) |
|---|---|---|---|---|---|---|---|---|
| 196 | 11/12/98 | 15:50 | 1 | 44.4 - 45.1 | - | - | 0.048 (4) | - |
| | | | 1 ft avg = | 44.8 | - | - | | 2.15 |
| | | | 5 | 44.6 | - | - | | 2.14 |
| 195 | 11/12/98 | 15:57 | 1 | 44.8 - 45.1 | - | - | 0.052 (5) | - |
| | | | 1 ft avg = | 45 | - | - | | 2.34 |
| | | | 5 | 44.6 - 44.8 | - | - | | - |
| | | | 5 ft avg = | 44.7 | - | - | | 2.32 |
| 194 | 11/12/98 | 16:15 | 1 | 44.6 | - | - | 0.052 | 2.30 |
| | | 16:17 | 3 | 44.7 | 2.43 | 0.054 | | 2.31 |
| | | 16:20 | 5 | 44.8 | 2.19 | 0.049 | | 2.31 |
| | | 16:22 | 8 | 44.8 - 45.1 | - | - | | - |
| | | | 8 ft avg = | 45 | - | - | | 2.32 |
| | | | 11 | 45.0 | - | - | | 2.32 |
| | | | 14 | 44.8 - 45.1 | - | - | | - |
| | | | 14 ft avg = | 45 | - | - | | 2.32 |
| | | | 17 | 44.5 | - | - | | 2.30 |
| 193 | 11/12/98 | 16:35 | 1 | 45.0 | - | - | 0.052 (5) | 2.34 |
| | | 16:37 | 5 | 45.4 | - | - | | 2.36 |
| 191.6 | 11/12/98 | 16:54 | 1 | 44.8 - 46.9 | - | - | 0.069 | - |
| | | | 1 ft avg = | 45.9 | 2.73 | 0.059 | | 3.15 |
| | | | 3 | 45.0 | 2.88 | 0.064 | | 3.08 |
| | | | 5 | 45.0 | 3.24 | 0.072 | | 3.08 |
| | | | 8 | 45.5 | - | - | | 3.12 |
| | | | 11 | 44.5 | - | - | | 3.05 |
| | | | 14 | 44.6 | - | - | | 3.06 |
| | | 17:20 | 17 | 44.5 | 3.50 | 0.079 | | 3.05 |

OTES:

1) Measured in situ on a Turner Designs Model 10AU continuous flow fluorometer. Measurements are relative and must be corrected using ratio comparisons to laboratory values.
2) Measured on a Turner Designs Model 10AU fluorometer in the AquAeTer laboratory using a field filtered sample.
3) Ratio of corrected chlorophyll a to relative in situ chlorophyll a is computed from 1 ft and 3 ft measurments. The 5 ft measurement appears to be an outlier when compared to all data collected.
4) Used ratio from ORM 198.
5) Used ratio from ORM 194.
6) "-" - data not available.

Therefore, the laboratory measurement of 0.46 μg/L is considered an outlier. The *in situ* measurements using the fluorometer provide an effective tool for measuring the chlorophyll *a*.

Light and Dark Bottle Analysis

Primary productivity was measured using the light and dark bottle analysis on the second day of the field study at ORM 224, 208.8, and 192. In performing the light and dark bottle analysis, water samples were collected in 5-gallon carboys from 1 foot, 3 feet, and 5 feet depths, using a submersible pump. The collected sample was allowed to equilibrate for about 5 minutes. Then, clear (light) 300-mL BOD bottles and dark 300-mL BOD bottles were filled using a Tygon tube with one weighted end inserted into the bottom of the carboy, and the other end inserted into the bottom of the BOD bottle being filled. All of the bottles were filled with care to avoid aerating the samples. DO concentrations in three light bottles, one near the beginning of the filling, one in the middle, and one near the end were read using either a BOD bottle probe or by Winkler titration.

Separate DO, water temperature, and pH readings were made when possible at each depth as the bottles were read. An attempt was made to collect and set out the bottles before 10 a.m. and to read the bottles at 1000 to 1200, 1400 to 1600, 1800 to 2000, and at 0400 to 0600 the next day. Instrument and equipment (boat) problems were experienced during the study, in particular at ORM 224 and ORM 208.8. Therefore, the light and dark bottles were set out and read as close to the above specified times as possible; however, these times were not met in all cases. The light and dark bottle readings at ORM 191.6 are considered the best dataset.

The results of the light and dark bottle analyses are presented in Table 2-11 and in Appendix 9. As shown in Table 2-11, the dark bottle measurements for several of the sample locations may

## TABLE 2-11. NET PRODUCTIVITY FROM LIGHT AND DARK BOTTLE MEASURMENTS
## OUACHITA RIVER NEAR CROSSET, ARKANSAS, NOVEMBER 11, 1998

| ORM | DEPTH (ft) | LB (mg/L) | DB | IB (mg/L) | t (days) | GROSS PROD. (mg/L/day) | GROSS PROD. (mg/m3/day) | RESP. (mg/L/day) | RESP. (mg/m3/day) | NET PROD. (mg/L/day) | NET PROD. (mg/m3/day) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 224 | 1 | 10.10 | 10.00 | 9.95 | 1.17 | 0.09 | 85 | -0.04 | -43 | 0.13 | 128 |
|  | 3 | 10.00 | 10.00 | 9.75 | 1.15 | 0.00 | 0 | -0.22 | -217 | 0.22 | 217 |
|  | 5 | 10.20 | 10.20 | 9.97 | 1.12 | 0.00 | 0 | -0.21 | -205 | 0.21 | 205 |
| 208.8 | 1 | - | - | - | - | - | - | - | - | - | - |
|  | 3 | 9.45 | 9.25 | 9.37 | 0.71 | 0.28 | 282 | 0.17 | 169 | 0.11 | 113 |
|  | 5 | 9.55 | 9.53 | 9.25 | 0.78 | 0.03 | 26 | -0.36 | -359 | 0.38 | 385 |
| 191.6 | 1 | 8.95 | 8.55 | 8.75 | 0.99 | 0.40 | 404 | 0.20 | 202 | 0.20 | 202 |
|  | 3 | 8.74 | 8.44 | 8.62 | 0.97 | 0.31 | 309 | 0.19 | 186 | 0.12 | 124 |
|  | 5 | 8.79 | 8.59 | 8.65 | 0.95 | 0.21 | 211 | 0.06 | 63 | 0.15 | 147 |

Avg. 190

**NOTES:**

1) Refer to Appendix 9 for the times and temperatures associated with the DO measurements.
2) LB - DO in light bottle at maximum production
   DB - DO in dark bottle at approximately 24 hours
   IB - DO in initial bottle at beginning of incubation
   t - incubation period in days (the total incubation period)
3) ORM - Ouachita River Mile; DO - dissolved oxygen; prod. - productivity; resp. - respiration

be suspect due to the likelihood of the presence of air bubbles in the dark bottles. Air bubbles were observed in some of the light bottles due to a temperature decrease from the time of bottle setup to the time of bottle reading and it is assumed that this may also have occurred in some of the dark bottles. The dark bottle DO at both stations ORM 224 and 208.8 at the approximate 24-hour reading should be compared with Station ORM 191.6 data for samples at the same depth to assess the amount of respiration occurring in the River.

As presented in Table 2-11, the gross productivity measured in the light and dark bottles ranged from 0 mg/m$^3$/day to 404 mg/m$^3$/day (0 mg/L/day to 0.40 mg/L/day). The net productivity ranged from 113 mg/m$^3$/day to 385 mg/m$^3$/day (0.11 mg/L/day to 0.38 mg/L/day). The maximum DO diurnal swing of 0.4 mg/L is significantly different from the *in situ* DO diurnal variations measured in the summer months of 0.8 mg/L to 2.8 mg/L. Bob Ambrose, USEPA Athens stated that a diurnal swing of 0.4 mg/L was expected given the chlorophyll *a* measurements of 2 to 5 µg/L, based on this experience (Ambrose 1998). Based on data reported by Jernigan and Corn (1993) and Taylor, et. al. (1997) for the Red River, chlorophyll *a* concentrations from 6 to 20 µg/L were measured during periods when the diurnal DO swing ranged from about 1.5 to 2 mg/L. Primary productivity measurements ranged from around 1,700 to 3,700 mg/m$^3$/day for these periods (Taylor, et. al. 1997). This difference between the summer months and the November measurements is most likely due to the cooler temperatures and overcast rainy weather experienced during the November study period. In addition, although the weather on November 11, 1998 during the light and dark bottle measurements was sunny, several days of rain and overcast weather had preceded the study. This may also have had an impact on the diurnal DO swing measured. The diurnal DO swings measured by Georgia-Pacific during the low-flow, high temperature summer months were consistent with those reported for the Red River.

Algae Analysis. Water samples were collected at ORM 229, 224, 208.8, and 191.6 for algal analyses. These samples were collected at depths of 1 foot and 5 feet and pumped directly into 2.5-gallon cubitainers for each sample. The samples were preserved in the field with Lugol's solution and placed on dry ice. The samples were analyzed in the **AquAeTer** laboratory for algae identification and algae counts in accordance with Standard Methods 10200F (APHA, 1998), as presented in Appendix 2. In addition, the samples collected at ORM 229, upstream from Felsenthal Dam, and at ORM 224, downstream from Felsenthal Dam were analyzed to distinguish alive/dead algae in accordance with Standard Methods 10200F (Phytoplankton Counting Techniques). One duplicate sample was collected on both November 10 and November 12 of the study.

Algal species from the Division Chrysophyta were most abundant (about 68 percent) in the water samples collected. This division contains 6,650 unicellular species, including golden algae, yellow-green algae, and diatoms. Chrysophyta are photosynthetic, unicellular organisms that are abundant in freshwater environments, but there are filamentous and colonial forms as well. As such, this division is particularly important in lakes, where they are the primary source of food for zooplankton. Most Chrysophyta are autotrophic, or able to produce organic nutrients from inorganic materials through photosynthesis. However, nearly all species become facultatively heterotrophic (obtaining organic nutrients from the environment) in the absence of adequate light or in the presence of plentiful dissolved food. When this occurs, the chrysoplast atrophies and the alga may turn predacious, feeding on bacteria or other diatoms. Examples of the predominant genus observed, *Synura*, are presented in Appendix 8. *Synura* are diatoms belonging to the Class Bacillariophyceae.

Members of this class are characterized by a thin siliceous cell wall. The diversity of diatoms is reported to be greatest where there is low individual density, such as in infertile lakes, while diversity is low in fertile lakes where there is high individual density.

Chrysophyta contain chlorophylls *a* and *c*, which are masked by the accessory carotenoid pigment. Accordingly, Chrysophyta are grouped mainly by color depending on the proportion of green (chlorophyll) to yellow (carotene) and brown (xanthophyll) pigments. Carotenoids cannot transfer sunlight energy directly to the photosynthetic pathway, but must pass absorbed energy to chlorophyll; and are therefore, termed accessory pigments. Accessory pigments also allow absorption of a wider range of light frequencies. Chlorophyll *c* is found in the members of this division, as well as, the dinoflagellates (Pyrrhophyta).

Generally, chlorophyll *a* concentration increases downstream as a function of additional sources of nitrogen at Georgia-Pacific and Sterlington. The low species diversity observed remained similar from ORM 224 to Sterlington. Abundance appeared to be lower at ORM 208.8, but greater in the river than in the Felsenthal reservoir. *In situ* fluorometer chlorophyll *a* measurements indicated similar concentrations from top to bottom of the water column. Measured chlorophyll *a* concentrations may not accurately reflect the algal abundance or productivity in a system dominated by golden-brown algae. Secchi disk measurements (approximately 2 to 3 feet) suggest sufficient turbulence in the river for algae to be stratified evenly throughout the water column; however, such measurements would normally indicate that algae would be primarily present in the near surface zone. These parameters are summarized in Table 2-12.

Taylor, et. al. (1997) reported a similar phenomena for the Red River where river turbulence caused the algae to be mixed top to bottom. During the Taylor study period, the algal productive

TABLE 2-12. ALGAL DISTRIBUTION IN THE OUACHITA RIVER

| LOCATION | DATE | ALGAL SPECIES | ALGAL TYPE | ALGAL SPECIES (number) | ALGAL UNITS (number/mL) | ALGAL COMPOSITION (%) | CHLOROPHYL a @ 5 ft (ug/L) | SECCHI DISC DEPTH (ft) |
|---|---|---|---|---|---|---|---|---|
| ORM 229 | 10-Nov-98 | Chlorophyta | Green algae | 3 | 0.9 | 30.0% | 1.94 | 2.88 |
| | | Euglenphyta | Euglenoids algae | 1 | 0.1 | 3.3% | | |
| | | Pyrrophyta | Yellow-brown algae | 2 | 0.2 | 6.7% | | |
| | | Chrysophyta | Yellow-green algae | 5 | 1.8 | 60.0% | | |
| | | | | **11** | **3.0** | **100.0%** | | |
| ORM 224 | 10-Nov-98 | Chlorophyta | Green algae | 2 | 0.7 | 5.2% | 2.08 | 2.68 |
| | | Euglenophyta | Euglenoids algae | 1 | 0.2 | 1.5% | | |
| | | Pyrrophyta | Yellow-brown algae | 1 | 0.6 | 4.4% | | |
| | | Chrysophyta | Yellow-green algae | 9 | 12 | 88.9% | | |
| | | | | **13** | **13.5** | **100.0%** | | |
| ORM 208.8 | 11-Nov-98 | Chlorophyta | Green algae | 4 | 1.6 | 24.2% | 2.20 | 2.05 |
| | | Euglenphyta | Euglenoids algae | 0 | 0 | 0.0% | | |
| | | Pyrrophyta | Yellow-brown algae | 1 | 0.6 | 9.1% | | |
| | | Chrysophyta | Yellow-green algae | 9 | 4.4 | 66.7% | | |
| | | | | **14** | **6.6** | **100.0%** | | |
| ORM 191.6 | 11-Nov-98 | Chlorophyta | Green algae | 2 | 3 | 21.1% | 3.24 | 2.12 |
| | | Euglenphyta | Euglenoids algae | 0 | 0 | 0.0% | | |
| | | Pyrrophyta | Yellow-brown algae | 2 | 3.4 | 23.9% | | |
| | | Chrysophyta | Yellow-green algae | 11 | 7.8 | 54.9% | | |
| | | | | **15** | **14.2** | **100.0%** | | |

zone extended from the river surface to the bottom of the water column. River turbulence provided the energy necessary for the algae to reach the euphotic zone, which for the River was the upper 1 ft of the water column, frequently enough for the algae to receive light for production.

In general, diatoms are favored in well-mixed water columns as the preponderance of accessory pigments allows tolerance to light limitation resulting from vertical mixing or turbulence. Species of this group tend to be medium sized, but having shapes distorted from spherical forms. Such distorted shapes, flat disks or long needle-like shapes, allow a more efficient dispersal of light harvesting centers. Therefore an association exists between medium size, distorted shape, and the ability to use dilute light. Similarly, distortions of the spherical form can result in a two to five fold reduction in algal sinking rate with respect to an equivalent sphere. Chrysophyta would be expected at autumn overturn when river conditions revert to low light and high nutrient content.

Although low total numbers of algae per milliliter were observed, these algae occurred throughout the water column. In comparison, algae are typically concentrated in the upper euphotic zone of a lake and are not diluted throughout the water column as observed in the Ouachita River. Additionally, live algal cells could be distinguished using the staining technique presented in Standard Methods 10200F (APHA 1998); however, no dead cells were readily distinguishable. Based on Internet queries, this is apparently a common problem with this method. Regardless, live algae cells were noted both upstream and downstream from the dam.

It is believed that nitrogen is the primary driver of algal health in this system. Nitrogen concentrations in the Georgia-Pacific effluent serve as a positive stimulus to river algae. It is also important to note that to some extent the success of diatoms is dependent on the supply of silicon.

Bathymetry

Bathymetric profiles of the river were made at ORM 224, 222, 208.8, and 192 using a Raytheon model DE-719C Survey Fathometer® or equivalent equipment. The profiles were collected by first measuring the width of the river using a Sokkisha Rangefinder and a range pole and then by profiling the river from bank to bank at a constant speed using the Fathometer. The bathymetric profiles of the River are presented in Appendix 10. The River increases in cross-sectional area from about 3,600 square feet at ORM 224 to about 8,500 square feet at ORM 191.6.

## PRIMARY PRODUCTIVITY ANALYSIS (ODUM METHOD)

Primary productivity of the plant community in a river system can be related to changes in dissolved oxygen and can be estimated in flowing water by the free-water diurnal curve method (Standard Methods 10300D, APHA 1998 ). The single-station free-water method utilizes hourly or continuous DO concentrations and water temperatures for a 24-hour period at a single station in the river. Diurnal measurements of DO and temperature were taken by Georgia-Pacific on August 5, 1998 for ORM 224 and ORM 208.8 and on June 30, 1998 for ORM 189.3. The diurnal measurements were collected every 4 to 6 hours over a 24-hour period and were used to estimate primary productivity in the Ouachita River using the single-station method, as presented in Appendix 9.

In performing the single-station free-water diurnal curve method to determine primary productivity, a sine curve equation for DO was developed from the Georgia-Pacific diurnal DO measurements at a depth of 5-feet, as presented in Figures 2-5 through 2-7. Hourly DO values were estimated from the sine curve equations and were then corrected for stream reaeration; that is, the oxygen addition to the River from stream reaeration over the 24-hour period was converted to an equivalent hourly value and subtracted from the hourly changes in DO.

The reaeration rates at 20°C were calculated for each river mile using the following O'Connor-Dobbins equations, as taken from the QUAL2E manual (Brown and Barnwell, 1987):

$$k_2 = \frac{(D_m u)^{0.5}}{d^{1.5}} \tag{2-1}$$

and

$$D_m = 1.9x10^{-3}(1.037)^{T-20} \tag{2-2}$$

where:

$k_2$ = reaeration rate, per day
$D_m$ = molecular diffusion coefficient, ft²/day;
u = mean velocity, ft/day; and
d = mean stream depth, ft.

In calculating stream reaeration, the mean stream depth was determined from bathymetric profiles collected during the November 1998 Georgia-Pacific/**AquAeTer** river study. The mean velocity was determined using an average river flow and the cross-sectional area of the Ouachita River, as calculated from the bathymetric profiles. The average river flow was calculated from Ouachita River flow data obtained from the USGS in Ruston, Louisiana using the flow from the day of the DO measurements plus the two preceding days. The corrected change in hourly DO was then plotted against time in hours, and the area under the curve, during the photoperiod, was calculated to obtain the gross primary productivity at the River station. The change in hourly DO over the dark hours (respiratory period) was utilized to calculate the community respiration. Net productivity was then determined by subtracting respiration from gross productivity.

The results of the single-station method for each of the three river miles, including calculations of gross primary productivity, respiration, and net primary productivity, are presented in Table 2-13. The results show that the greatest gross productivity (3.28 mg/L/day), respiration (2.20 mg/L/day), and net productivity (1.08 mg/L/day) occurred at ORM 208.8. The gross productivity at ORM 224 and ORM 189.3 (1.68 mg/L/day and 1.50 mg/L/day, respectively) is similar. However, net productivity of 0.70 mg/L/day was estimated at ORM 189.3, while no net productivity was measured at ORM 224. Although the calculated gross productivity is less than the calculated respiration at ORM 224, the value is within the dissolved oxygen standard deviation of 0.1 mg/L; and therefore, the 1.68 mg/L/day gross productivity and the 1.76 mg/L/day respiration can be considered the same number.

The results generally correspond to the chlorophyll *a* measurements taken at the 5-foot depth during the November 1998 Georgia-Pacific/**AquAeTer** river study, particularly to the measurement at ORM 192, as presented in Figure 2-19. As shown by the chlorophyll *a* measurements, the chlorophyll *a* levels are low at ORM 224, most likely due to a lack of nutrients, and increase in the middle reaches of the study area. This increase is likely due to the nutrients provided by the discharge from Coffee Creek. The chlorophyll *a* levels increase a second time near ORM 192, again most likely due to an influx of nutrients from either non-point sources or from the Town of Sterlington or Koch Nitrogen. Additionally, the stations with a positive net productivity also showed an increase in chlorophyll *a* levels during the November study.

## TABLE 2-13. STREAM PLANT COMMUNITY PRODUCTIVITY CALCULATIONS OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| ORM | PRODUCTIVITY PERIOD (hr) | RESPIRATION PERIOD (hr) | GROSS PRODUCTIVITY (mg/L/day) | RESPIRATION (mg/L/day) | NET PRODUCTIVITY (mg/L/day) |
|---|---|---|---|---|---|
| 224 | 13 | 11 | 1.68 | 1.76 | -0.08 |
| 208.8 | 13 | 11 | 3.28 | 2.20 | 1.08 |
| 189.3 | 14 | 10 | 1.50 | 0.80 | 0.70 |

# SECTION 3

# PREDICTIVE MODEL DEVELOPMENT

## INTRODUCTION

To establish the wasteload allocation that will meet applicable stream water quality standards and uses, it is necessary to have knowledge of the assimilative capacity of the receiving stream. Various studies of the assimilative capacity of the Ouachita River near Crossett, Arkansas have been conducted to establish wasteload allocations in the River that will ensure compliance with dissolved oxygen standards. The results of the studies were used to calibrate the QUAL2E model (Brown and Barnwell 1987) and to make wasteload allocation projections at critical low-flow conditions. As an aid in quantifying the assimilative capacity of the Ouachita River downstream from Felsenthal Lock and Dam, the QUAL2E model was used to predict the downstream DO from ORM 227 to ORM 190. The development of the model was initially based on a July 27, 1992 report prepared by HydroQual, Inc. titled, "Development of a Water Quality Model of the Ouachita River." The period of time used for the calibration model is August 27, 1998, the date of synoptic water quality measurements collected by Georgia-Pacific. The information provided in the HydroQual Report, in combination with other historical and literature sources and an additional field study performed by Georgia-Pacific and **AquAeTer** in November 1998, was used to develop a QUAL2E water quality model of the Ouachita River from ORM 227 to ORM 190.

The general approach was to construct and calibrate the QUAL2E model using the previous HydroQual model parameters as a starting point for the new model, new data collected since the HydroQual work, and measured data and historical and literature sources. Model calibration was accomplished by inserting the measured and historical values, and if necessary, slightly adjusting accomplished by inserting the measured and historical values, and if necessary, slightly adjusting rates and parameters one at a time based on field observations, sound scientific judgement, and past experience.

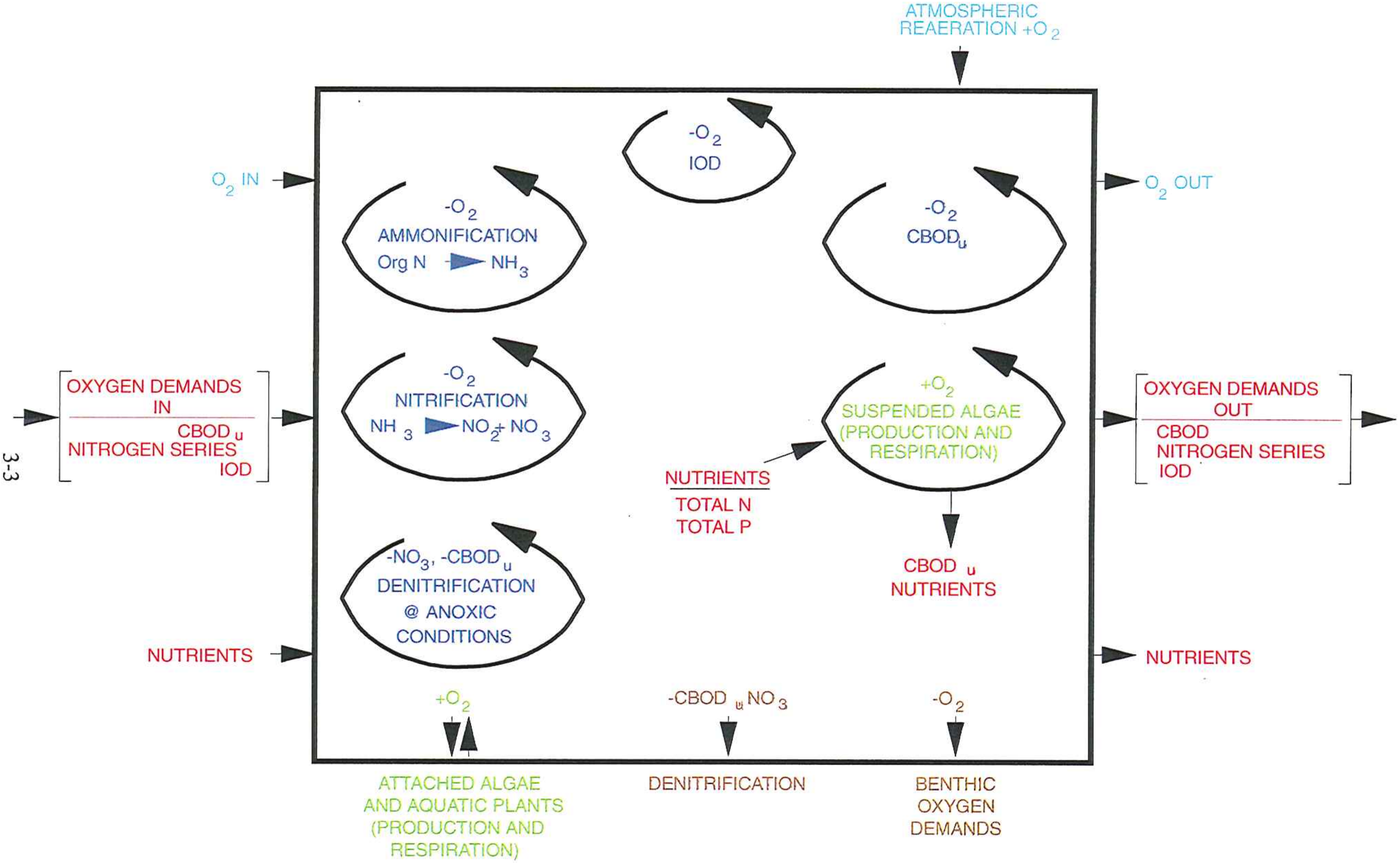
## DESCRIPTION OF THE MODEL

The model used for simulating the assimilative capacity of the Ouachita River was the USEPA wasteload allocation model, "The Stream Quality Model QUAL2E" (Norton, et al., 1974; NCASI, 1985; Barnwell, 1985; Brown and Barnwell, 1987). A complete description of the model is provided in the cited references. Basically, QUAL2E is a backwards-in-time (BIT) or implicit backward, one-dimensional finite-difference mass-balance model. QUAL2E numerically integrates the advective-dispersion mass transport equation for water quality constituents under steady-state stream hydraulic conditions. DO is the primary water quality constituent modeled and the sources and sinks for DO are depicted in Figure 3-1. The basic equation is presented as:

$$\frac{\partial c}{\partial t} = \frac{\partial \left( A_x D_L \frac{\partial c}{\partial x} \right)}{A_x \partial x} - \frac{\partial (A_x \bar{u} c)}{A_x \partial x} + \frac{dc}{dt} + \frac{s}{V} \qquad \textbf{(3-1)}$$

where:

$c$ = Constituent concentration, mg/L;
$A_x$ = River cross-sectional area, ft$^2$;
$x$ = Longitudinal distance, ft;
$D_L$ = Dispersion coefficient, ft$^2$/sec;
$t$ = Time of travel (days);
$\bar{u}$ = Mean river velocity, ft/sec;
$s$ = Constituent source or sink, lbs/day; and
$V$ = Incremental volume, ft$^3$.



$O_2$ BALANCE = ASSETS - LIABILITIES = DO - OXYGEN DEMANDS

**FIGURE 3-1**
SCHEMATIC OF THE OXYGEN BALANCE CALCULATIONS IN QUAL2E

The terms on the right hand side of the equation represent dispersion, advection, constituent changes, and external sources or sinks. A summary of the different mathematical equations used in the program is presented in Table 3-1.

The model was used to predict River dissolved oxygen concentrations as affected by the following constituents:

- $CBOD_u$ decay with River time of travel;
- Organic-nitrogen hydrolysis to ammonia-nitrogen;
- Ammonia-nitrogen conversion through nitrification to nitrite ($NO_2$) and then to nitrate ($NO_3$);
- Reaeration due to physical oxygen transfer;
- Algal net production of oxygen (either +/- $O_2$);
- SOD;
- Background water quality condition; and
- Point source loadings to the River.

The primary goal of the modeling effort was to sum the oxygen sources and subtract the oxygen uses under a set of constant hydraulic conditions (steady-state). In simplest mathematical terms, this is:

$$O_2 \text{ into subreach} - O_2 \text{ depleted} + O_2 \text{ added} = O_2 \text{ out of subreach} \qquad \textbf{(3-2)}$$

## MODEL INPUTS

Hydraulic characteristics and stream biological and chemical process rates were input into the model for the mathematical calculations. The model-generated output was then compared

# TABLE 3-1

## SUMMARY OF DIFFERENTIAL EQUATIONS TO BE SOLVED BY QUAL2E

Conservative Mineral (C)

$$\frac{\partial C}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial C}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u C)}{A_x \partial x}$$

Algae (A)

$$\frac{\partial A}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial A}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u A)}{A_x \partial x} + \mu A - \rho A - \frac{\sigma_1}{d} A$$

Organic Nitrogen ($N_o$)

$$\frac{\partial N_o}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial N_o}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u N_o)}{A_x \partial x} + \alpha_1 \rho A - \beta_3 N_o - \sigma_4 N_o$$

Ammonia Nitrogen ($N_1$)

$$\frac{\partial N_1}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial N_1}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u N_1)}{A_x \partial x} + \beta_3 N_o - \beta_1 N_1 + \frac{\sigma_3}{d} - F_1 \alpha_1 \mu A$$

Nitrite Nitrogen ($N_2$)

$$\frac{\partial N_2}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial N_2}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u N_2)}{A_x \partial x} + \beta_1 N_1 - \beta_2 N_2$$

Nitrate Nitrogen ($N_3$)

$$\frac{\partial N_3}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial N_3}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u N_3)}{A_x \partial x} + \beta_2 N_2 - (1 - F_1) \alpha_1 \mu A$$

Organic Phosphorus ($P_1$)

$$\frac{\partial P_1}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial P_1}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u P_1)}{A_x \partial x} + \alpha_2 \rho A - \beta_4 P_1 - \sigma_5 P_1$$

Dissolved Phosphorus ($P_2$)

$$\frac{\partial P_2}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial P_2}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u P_2)}{A_x \partial x} + \beta_4 P_1 - \frac{\sigma_2}{d} - \alpha_2 \mu A$$

Biochemical Oxygen Demand (L)

$$\frac{\partial L}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial L}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u L)}{A_x \partial x} - (K_1 + K_3) L$$

Dissolved Oxygen (O)

$$\frac{\partial O}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial O}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u O)}{A_x \partial x} + \left(K_2 (O^* - O) + (\alpha_3 \mu - \alpha_4 \rho) A - K_1 L - \frac{K_4}{d} - \alpha_5 \beta_1 N_1 - \alpha_6 \beta_2 N_2\right)$$

Coliform (E)

$$\frac{\partial E}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial E}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u E)}{A_x \partial x} - K_5 E$$

Arbitrary Non-Conservative (R)

$$\frac{\partial R}{\partial t} = \frac{\partial \left(A_x D_L \frac{\partial R}{\partial x}\right)}{A_x \partial x} - \frac{\partial (A_x u R)}{A_x \partial x} - K_6 R - \sigma_6 R + \frac{\sigma_7}{d}$$

against data collected during synoptic River water quality measurements. These model inputs established numbers for the mathematical algorithms in the computer program. The following basic input data were required:

- Stream description including total length to be modeled, length of stream subdivision (reaches), and location of tributary junctions;
- Stream hydraulic data, such as flow, velocity, slope, and depth;
- Water temperatures;
- Reaeration rates;
- Deoxygenation rate functions including $CBOD_u$, organic-nitrogen decay, and ammonia-nitrogen decay;
- Algal productivity and respiration rates through chlorophyll *a* concentrations and productivity, and SOD rates;
- Background (headwater) water quality; and
- Loadings from point sources (discharges and withdrawals).

### River Description

A 37-mile long segment of the Ouachita River from ORM 227, immediately downstream from Felsenthal Lock and Dam, to ORM 190, was selected for modeling. A stream reach was defined as being a length of stream where no significant change occurs in the hydraulic, physical, or biological characteristics of the stream. The reaches can be of varying lengths with up to 50 total reaches and up to 20 computational elements (subreaches) per reach. Each subreach is analyzed by the model.

The 37-mile Ouachita River segment being modeled is shown schematically in Figure 3-2. The study segment was divided into eight reaches according to locations of stream sampling stations and hydraulic characteristics of the reaches. Predictive model calculations were made for 0.25-mile subreaches in each of the eight reaches.

### River Hydraulic Data

A critical aspect of the predictive modeling was to determine the time of travel at a given flow condition. Time is critical in the modeling because carbonaceous and nitrogenous materials introduced into the River decay at a certain rate. This rate is a function of time and is expressed in units per day ($day^{-1}$). Thus, the resultant DO of a parcel of water is related to the time it has taken to travel downstream. Oxygen is added at a certain rate to the stream by natural turbulent reaeration processes, also reported in units per day ($day^{-1}$). The time required for a parcel of water containing effluent to flow downstream from the discharge point is then used to mathematically predict how these various deoxygenation and reaeration rates affect the DO in the River. The time of travel also provides an estimate of the average velocity within a given reach length, which with distance, can be used to develop predictive equations for travel times for various flows.

Relationships between River flow and velocity and River flow and depth were established for the Ouachita River near Crossett, Arkansas in the HydroQual (1992a) Report, as follows:

$$\mathrm{v} = \mathrm{a}\mathrm{Q}^{\mathrm{b}} \qquad \textbf{(3-3)}$$

$$D = cQ^{d} \qquad \textbf{(3-4)}$$

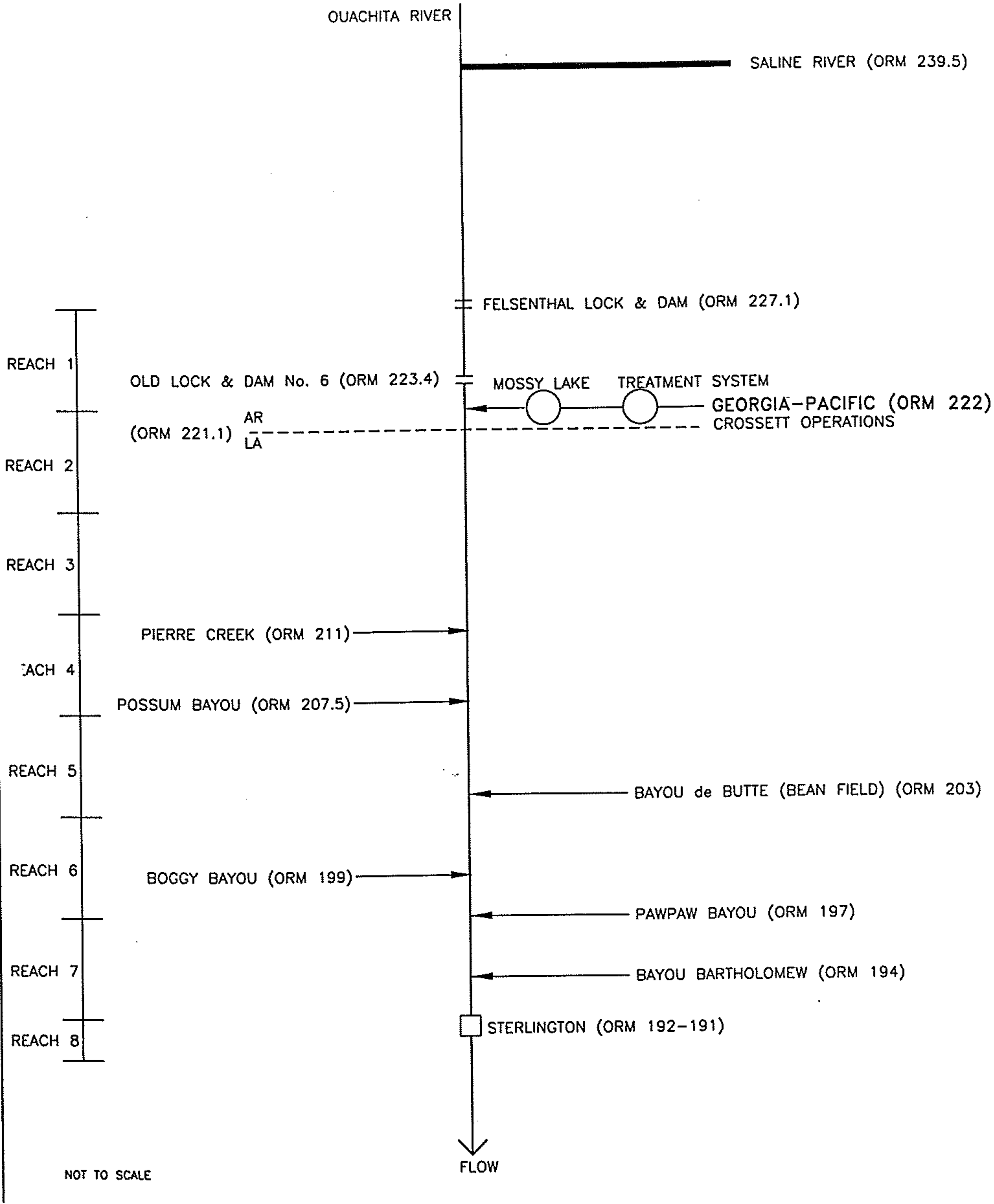


FIGURE 3-2
STUDY AREA

AquAeTer

where:

v = Average velocity in the reach, ft/sec;
a = Coefficient on flow for velocity, unitless;
Q = River flow, cfs;
b = Exponent on flow for velocity, unitless;
D = Average depth in the reach, ft;
c = Coefficient on flow for depth, unitless; and
d = Exponent on flow for depth, unitless.

HydroQual based the determination of the velocity and depth coefficients and exponents of the channel geometry and time-of-travel relationships on the HEC II floodplain model developed by the USACOE. The velocity coefficients and exponents range from 0.0002 to 0.00046 and 0.897 to 0.946, respectively. The depth coefficients and exponents range from 7.17 to 15.03 and 0.011 to 0.05, respectively. Reach by reach velocity and depth equations are presented in Table 3-2.

### Ouachita River DO and Temperature

Water temperature is a physical characteristic that affects biological oxygen uptake rates, reaeration rates, algal growth rates, and DO saturation. A rise in stream temperature increases the metabolic activity of aquatic organisms, thus increasing the amount of oxygen required by bacteria, algae, and larger organisms. Also, as the water temperature increases, the reaeration rate ($k_2$) increases. However, oxygen saturation potential decreases with rising temperature.

The Ouachita River temperature value of 31.5 °C used for the calibration model was an average temperature calculated from the water temperatures measured at all of the synoptic River measurement stations on August 27, 1998. The DO values utilized in the model are also those

TABLE 3-2. QUAL2E HYDRAULIC COEFFICIENTS

| REACH | ORM | COEFFICIENT FOR VELOCITY (a) | EXPONENT FOR VELOCITY (b) | COEFFICIENT FOR DEPTH (c) | EXPONENT FOR DEPTH (d) |
|---|---|---|---|---|---|
| 1 | 227 to 222 | 0.00046 | 0.897 | 7.17 | 0.050 |
| 2 | 222 to 217 | 0.00046 | 0.897 | 7.17 | 0.050 |
| 3 | 217 to 212 | 0.00046 | 0.897 | 7.17 | 0.050 |
| 4 | 212 to 207 | 0.00046 | 0.897 | 8.00 | 0.050 |
| 5 | 207 to 202 | 0.00028 | 0.946 | 12.00 | 0.018 |
| 6 | 202 to 197 | 0.00028 | 0.946 | 12.00 | 0.018 |
| 7 | 197 to 192 | 0.00020 | 0.930 | 15.03 | 0.011 |
| 8 | 192 to 190 | 0.00020 | 0.930 | 15.03 | 0.011 |

collected during the August 27, 1998 synoptic River measurements. The DO values were adjusted for diurnal DO variation, as discussed in detail in Section 2 of this report.

Reaeration Rate

The replenishment of the oxygen resources in a stream occurs through two sources: **1)** physical gas transfer from the atmosphere; and **2)** algal or other aquatic plant production of oxygen through photosynthesis. Typically, the major source of oxygen in free-flowing streams is from physical gas transfer resulting from hydraulic turbulence in the stream. Turbulent flow patterns increase exposure of surface water to the overlying air layer. In lakes or stream pool areas where turbulence is at a minimum or in waters containing a large biomass of algae, algal production of oxygen can become a major oxygen source. Algal oxygen production in the Ouachita River was found to be significant, with diurnal swings of 0.8 to 2.0 mg/L measured during the summer months at a depth of 5 feet. The diurnal swing during the November survey was about 0.4 mg/L.

As presented in the HydroQual Report, stream reaeration in the model is predicted by the O'Conner-Dobbins equation as follows:

$$k_2^{20} = \frac{(D_m u)^{0.5}}{d^{1.5}} \qquad \textbf{(3-5)}$$

where:

$k_2^{20}$ = reaeration coefficient at 20 °C (1/day);
$D_m$ = $1.91\text{x}10^{-3}\ (1.037)^{T-20}$ (ft$^2$/day);
u = mean velocity (ft/day); and
d = mean stream depth (ft).

NCASI conducted river studies on the Ouachita River near El Dorado, Arkansas and Sterlington, Louisiana in 1980. As part of these studies, radiotracer reaeration measurements were made on these segments of the Ouachita. The results of the reaeration measurements were reported by NCASI in their Technical Bulletin 375. A copy of this Bulletin is presented as Appendix 3 to this submittal. The NCASI found that the O'Connor Dobbins equation, for the Ouachita River, gave a close prediction to the actual measured rate (0.17/day measured vs 0.16/day predicted). The reaeration rates measured and other pertinent data are as follows:

| **LOCATION (ORM)** | **QUAL2E (cfs)** | **$k_2$ @ 20 °C (per day)** | **v (ft/sec)** | **d (ft)** | **delta S (ft)** |
|---|---|---|---|---|---|
| 320 to 310 | 850 | 0.17 | 0.50 | 8 to 18 | ~0 |
| 192 to 190 | | 0.040 | 0.095 | 15 to 16 | ~0 |

Note: Delta S is change in water surface elevation in reach.

The $k_2$ measured at Sterlington at ORM 192 was not considered as good as the $k_2$ measured at ORM 320 to 310, because the reaeration rate was very low due to very low krypton concentrations. The Tsivoglou-Neal (1976) equation based on the energy dissipation model with a changing slope is not appropriate for zero stage-change streams according to Tsivoglou (1977) and Neal (1978). Using the O'Connor Dobbins equation, the predicted reaeration rates for the Ouachita River in the study segments when flow ranged from 980 to 1,263 cfs in the water mass monitored downstream from the release point ranged from 0.46/day at 31.5 °C around ORM 222 to 0.15/day at 31.5 °C around ORM 198.

### Deoxygenation Rates

There are many potential sinks for DO in a river system including flowing-load BOD, chemical demands, sludge deposits, attached slime growths, respiration of aquatic plants and algae, and general SOD. The QUAL2E model uses the following deoxygenation rates: **1)** a carbonaceous river deoxygenation rate coefficient ($k_r$); **2)** an organic-nitrogen deoxygenation rate coefficient ($k_{Org\text{-}N}$); **3)** an ammonia-nitrogen deoxygenation rate coefficient ($k_{NH3\text{-}N}$); and **4)** a SOD rate coefficient per unit area ($k_{SOD}$). A brief discussion of the dissolved oxygen sinks and deoxygenation rates follows.

Ultimate Carbonaceous BOD Deoxygenation Rate. The BOD ($k_1$) decay rates presented in the HydroQual Report of 0.05/day for background and 0.1/day for the River downstream from Coffee Creek, were used as the basis for the rates in the QUAL2E model. The HydroQual (1992a) Report, however, did not present nitrogen decay rates in the water quality model. In response to comments from LDEQ, organic nitrogen hydrolysis ($k_{orgN}$) and ammonia ($k_{NH3}$) decay rates of 0.1/day were assumed based on a study performed upstream on the Ouachita River near Camden, Arkansas and on rates presented in a study performed under the direction of Dr. Ray Whittemore of NCASI (Bowie, et al., 1985). Based on the addition of nitrogen rates, the BOD decay rate downstream from Coffee Creek was modified to 0.075/day, because HydroQual had essentially used one inclusive river decay rate ($k_r \approx k_1 + k_{orgN} + k_{NH3}$). Downstream from ORM 207, the BOD decay rate was returned to 0.05/day because this region of the River is beyond the influence of the Georgia-Pacific discharge during low flow scenarios and $CBOD_u$ concentrations had decreased to below background levels. NCASI reported a BOD decay rate of 0.05/day for this segment of the Ouachita River (Hydroqual 1992).

Nitrogenous BOD and Nitrogen Deoxygenation Rates. Nitrogen exists in nature in many forms because of the high number of oxidation states it can assume. The nitrogen oxidation state of -3 is the form most closely associated with plants and animals. At the other extreme, the oxidation state of nitrate-nitrogen is +5. In the environment, changes from one oxidation state to another can be biologically accomplished by living organisms. Forms of nitrogen that are most prevalent in wastewater effluent discharges and that are most important in the stream oxygen balance are ammonia (as $NH_3$-N), nitrate (as $N0_3$ -N), and organic-nitrogen in the form of amines. The presence of nitrogen in effluent discharges is undesirable since unionized ammonia ($NH_3$-N at high levels) is toxic to fish and other aquatic organisms, and ammonium ions ($NH_4^+$-N) or ammonia ($NH_3$-N) consume oxygen resulting in a depletion of dissolved oxygen in the receiving stream. Also, nitrogen is used as a nutrient by aquatic plants and can therefore contribute to eutrophication.

Nitrogen processes that are important to the stream oxygen balance include:

- Ammonification: organic-nitrogen to ammonia-nitrogen through hydrolysis using 3.43 mg/L $O_2$ per 1 mg/L organic nitrogen hydrolyzed;
- Nitrification: ammonia-nitrogen to nitrate with an intermediate nitrite step using inorganic carbon as $CO_2$ using 1.14 mg/L $O_2$ per 1 mg/L organic nitrogen nitrified; and
- Denitrification: nitrate conversion to free nitrogen using organic carbon such as $CBOD_u$ and nitrate for the oxygen source.

As previously stated, organic nitrogen hydrolysis ($k_{orgN}$) and ammonia ($k_{NH3}$) decay rates of 0.1/day were assumed in the model, based on previous studies on the Ouachita River and on a $k_{NH3}$ rate determined in the NCASI studies (Bowie, et al., 1985). This river has very low organic nitrogen and ammonia nitrogen concentrations.

QUAL2E also requires an input value for the intermediate nitrite step during nitrification. Because nitrite converts to nitrate quickly in the environment, this rate can seldom be actually determined. Additionally, there are many nonconservative losses of nitrate in the environment, and the rate of nitrate formation cannot be reliably calculated. Therefore, the nitrite-nitrogen oxidation rate was set at 1.0/day in order for the model to simulate the immediate conversion of nitrite to nitrate and to avoid projecting a buildup of nitrite in the River. NCASI (Bowie, et al., 1985) gives a $k_{NO2}$ of 0.5/day.

Denitrification occurs in the absence of oxygen. Since the Ouachita River was aerobic during the field studies, denitrification was not considered in the modeling process.

Algal Productivity and Respiration. Algal productivity and respiration were observed to be an influence on diurnal DO concentrations in the Ouachita River as indicated from the observed sinusoidal DO variation. As discussed in Section 2, the daily mean DO for three stations (ORM 224, ORM 208.8, and ORM 190.2) was determined by fitting a sinusoidal curve to the observed measurements. The mean, amplitude, period and phase shift of the DO sine function at each station was determined based on an estimate of the mean, observation of peak and minimal DOs, and time of day. Daily peak oxygen concentrations at each station occurred in the late afternoon, which is consistent with algal productivity characteristics. Diurnal swings of approximately 0.8 mg/L to 2.0 mg/L were measured in the River at a depth of 5-feet during the summer months and an algal swing of around 0.4 mg/L was measured during the November study.

QUAL2E uses chlorophyll *a* concentrations for estimating suspended algal (phytoplankton) biomass. The primary algal kinetic parameters used in QUAL2E are the maximum algal growth rate, the algal respiration rate, algal settling, and the light extinction coefficient.

Due to slow velocities and low reaeration rates, algae are considered to be a significant source of oxygen in the Ouachita River. During the November 1998 field study, chlorphyll *a* concentrations were measured in the range of 1.5 to 3.5 ug/L. These chlorophyll *a* levels were measured during cooler water temperature conditions (16°C to 17°C), where limited algae growth might be expected. In addition, when performing light and dark bottle measurements during the November study, gross productivity on the order of 0.2 to 0.4 mg/L/day was measured in the River. Bob Ambrose (1998) of USEPA Athens stated in a telephone communication that the gross productivity of 0.4 mg/L in the light and dark bottles was consistent with the chlorophyll *a* levels measured. Measurements of diurnal DO variation in July and August 1998, from 0.8 mg/L to 2.0 mg/L at a depth of 5-feet and up to 2.8 mg/L at a depth of 1-foot, indicate that increased algal activity occurs in the River during the summer months. Using the Odum analysis performed on the summer diurnal DO curves, a net primary productivity in the River in the range of -0.08 mg/L/day (ORM 224) to 1.08 mg/L/day (ORM 208.8) was calculated. These calculations should be used as qualitative results since the calculations are dependent upon the reaeration rates estimated. As previously discussed, work on the Red River reported by Jernigan and Corn (1993) and Taylor, et. al. (1997) indicated that chlorophyll *a* concentrations in the Red River were from 6 to 20 μg/L when the diurnal DO variation was around 1.5 to 2 mg/L. Based on these observations, as well as algal counts which show the presence of algae in the River, a chlorophyll *a* concentration of 8.4 ug/L was assumed for the background River condition. This value is reasonable in light of the additional diurnal DO variation in the River during the summer months (the critical low flow period) when compared to chlorphyll *a* levels measured in November.

Light extinction in the Ouachita River is a critical component of the QUAL2E model with respect to algal impacts. Secchi disc measurements were collected throughout the summer of 1998, as well as during the November 1998 field study, as presented in Table 3-3. Secchi disc measurements serve as an approximation of light extinction in the River with some uncertainties due to the amount of light available during measurement and the individual performing the measurement. The secchi disc measurements were converted to light extinction coefficients using the following empirical relationship (Thomann and Mueller, 1987):

$$K_e = \frac{1.7 \ to \ 1.9}{z_s} \tag{3-6}$$

where:

$K_e$ = light extinction coefficient, 1/m; and
$z_s$ = secchi depth, m.

The light extinction coefficients used in the calibration model, with some adjustment, are based on the August 27, 1998 synoptic measurements.

Longitudinal Dispersion Coefficient. Dispersion is a convective transport mechanism that is generally used to describe transport associated with spatially averaged velocity variation. In 1959, Elder derived the following expression relating the dispersion constant $D_L$ coefficient to the shear velocity, assuming that only the vertical velocity gradient was important for streamflow:

TABLE 3-3. SUMMARY OF SECCHI DISC MEASUREMENTS
OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| ORM | 25-JUN-98 | | 21-JUL-98 | | 27-AUG-98 | | 18-SEP-98 | | 10-NOV-98 | | AVERAGE LIGHT EXT. COEF. (1/ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | SECCHI DEPTH (ft) | LIGHT EXT. COEF. (1/ft) | SECCHI DEPTH (ft) | LIGHT EXT. COEF. (1/ft) | SECCHI DEPTH (ft) | LIGHT EXT. COEF. (1/ft) | SECCHI DEPTH (ft) | LIGHT EXT. COEF. (1/ft) | SECCHI DEPTH (ft) | LIGHT EXT. COEF. (1/ft) | |
| 224 | 2.6 | 0.69 | 2.8 | 0.64 | 3.13 | 0.58 | 1.58 | 1.1368421053 | 2.68 | 0.67 | 0.74 |
| 218.7 | 2 | 0.90 | 2.3 | 0.79 | 2.29 | 0.79 | 1.50 | 1.2 | 1.90 | 0.95 | 0.93 |
| 213.5 | 1.8 | 1.00 | 1.9 | 0.95 | 2.58 | 0.70 | 1.50 | 1.2 | 2.50 | 0.72 | 0.91 |
| 208.8 | 1.8 | 1.00 | 1.9 | 0.95 | 2.51 | 0.72 | 1.50 | 1.2 | 2.05 | 0.88 | 0.95 |
| 203 | 1.7 | 1.06 | 1.9 | 0.95 | 2.35 | 0.77 | 1.53 | 1.1803278689 | 2.00 | 0.90 | 0.97 |
| 198 | 1.8 | 1.00 | 1.9 | 0.96 | 2.53 | 0.71 | 1.58 | 1.1368421053 | 2.23 | 0.81 | 0.92 |
| 194 | 1.7 | 1.06 | 1.9 | 0.97 | 2.50 | 0.72 | 1.58 | 1.1368421053 | 2.05 | 0.88 | 0.95 |
| 192 | - | - | - | - | - | - | - | - | 2.12 | 0.85 | 0.85 |
| 191.6 | 1.7 | 1.06 | 2.0 | 0.91 | 2.42 | 0.74 | 1.58 | 1.1368421053 | - | - | 0.96 |

$$D_L = Kdu^* \tag{3-7}$$

where:

$K$ = dispersion constant, unitless coefficient;
$d$ = average depth of reach, feet (ft); and
$u^*$ = shear velocity, feet/second (ft/s).

A more appropriate equation for the dispersion coefficient for wide channel flow, first suggested by Fischer, et. al. (1975), is:

$$D_L = \frac{(0.011u^2W^2)}{du^*} \tag{3-8}$$

where:

$d$ = average depth of reach, ft;
$W$ = width of stream, ft;
$u$ = average stream velocity, ft/s; and
$u^*$ = average shear velocity, ft/s.

The average shear velocity is defined as:

$$u^* = C\sqrt{RS_e} \tag{3-9}$$

where:

$R$ = hydraulic radius ($R=d$ for a wide channel), ft;
$C$ = Chezy's coefficient, $ft^{1/6}$; and
$S_e$ = slope of the energy grade line, ft/ft.

Chezy's coefficient is given by:

$$C = \frac{R^{\frac{1}{6}}}{n} \qquad \textbf{(3-10)}$$

where:

n = Manning roughness coefficient for different types of channels, unitless.

A value of n = 0.035 was chosen for the study area as Manning's roughness coefficient, following the guidance of Chow (1959).

The slope of the energy gradient line is given by:

$$S_e = \left( \frac{un}{1.486\, R^{\frac{2}{3}}} \right)^2 . \qquad \textbf{(3-11)}$$

The following expression, relating the dispersion constant, $D_L$ to the dispersion constant coefficient, K, can then be solved for K:

$$D_L = 3.82 Knud^{(\frac{5}{6})} . \qquad \textbf{(3-12)}$$

The dispersion constants used in the model ranged from 7 to 38. Calculation of the dispersion constants is presented in Table 3-4. These constants are in line with similar size rivers and represent a laminar flow stream.

## TABLE 3-4. DISPERSION CONSTANT CALCULATIONS
## OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| REACH | RRM | | d (ft) | R (ft) (2) | n (unitless) | C (ft^(1/6)) (3) | Se (ft/ft) | u* (ft/sec) (4) | u (ft/sec) | w (ft) | DL (ft$^2$/sec) (5) | K (unitless) (6) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FROM | TO | | | | | | | | | | |
| 1 | 227 | 222 | 10.5 | 10.5 | 0.035 | 42.3 | 0.00019 | 1.888 | 0.41 | 400 | 15 | 38 |
| 2 | 222 | 217 | 10.5 | 10.5 | 0.035 | 42.3 | 0.00019 | 1.888 | 0.41 | 400 | 15 | 38 |
| 3 | 217 | 212 | 10.5 | 10.5 | 0.035 | 42.3 | 0.00019 | 1.888 | 0.41 | 300 | 8 | 22 |
| 4 | 212 | 207 | 10.5 | 10.5 | 0.035 | 42.3 | 0.0002 | 1.937 | 0.41 | 300 | 8 | 21 |
| 5 | 207 | 202 | 13.8 | 13.8 | 0.035 | 44.2 | 0.00019 | 2.266 | 0.36 | 300 | 4 | 10 |
| 6 | 202 | 197 | 13.8 | 13.8 | 0.035 | 44.2 | 0.00019 | 2.266 | 0.36 | 400 | 7 | 17 |
| 7 | 197 | 192 | 16.3 | 16.3 | 0.035 | 45.5 | 0.00019 | 2.532 | 0.23 | 400 | 2 | 7 |

NOTES:
1) d=depth; R=hydraulic radius; n=Manning roughness coefficient; C=Chezy's coefficient; Se=the slope of the energy grade line; u*=shear velocity; u=mean velocity; w=mean width; DL=longitudinal dispersion coefficient; K=dispersion constant.
2) Assumed R is equivilant to d for wide channels.
3) C=R^(1/6)/n
4) u*=C(@sqrt(R*Se))
5) DL=(0.011*u^2*w^2)/d/u*
6) DL=3.82Knud^(5/6); QUAL2E Manual, 1987

### Sediment Oxygen Demand

SOD measurements were reported in the HydroQual (1992a) Report to be in the range of 0.051 to 0.071 $g/ft^2/day$.

### Background Water Quality

The background (headwater) water quality input parameters for the Ouachita River were determined from a variety of sources including the August 27, 1998 water quality synoptic River measurements and data presented in the HydroQual (1992a) Report. Specific input parameters for the predictive model will vary as headwater conditions differ throughout the year. These parameters include flow, temperature, DO, $CBOD_u$, Org-N, $NH_3$-N, $NO_2$-N, $NO_3$-N, Org-P, Dissolved-P, and Chlorophyll *a*. Values used as background inputs for the calibration model are as follows:

Flow = 980 cfs

Temp. = 31.5 °C

DO = 5.95 mg/L

$CBOD_u$ = 3.75 mg/L

ORG N-N = 0.484 mg/L

$NH_3$ -N = 0.05 mg/L

$NO_3$ = 0.40 mg/L

$NO_2$ = 0.10 mg/L

ORG P-P = 0.07 mg/L

DIS P-P = 0.04 mg/L

CHLORO*a* = 8.4 $mg/m^3$

## QUAL2E ASSUMPTIONS AND LIMITATIONS

In the development and application of any type of predictive model, it is important to keep in mind the assumptions and limitations associated with the model. Listed below are a series of assumptions and limitations associated with the developed model.

### Steady-State Kinetics

This assumption is basic to the type of model used. It is unlikely that any natural system ever achieves absolute steady-state conditions, but with proper conservatism, steady-state modeling is useful. In general, variable conditions can be estimated as a series of steady-state conditions with discrete inputs. It is also possible to estimate solution bounds by using steady-state modeling at the upper and lower limits of a variable input, such as stream flow or temperature.

### Oxygen Balance Assumptions

The only demands for oxygen are assumed to be from flowing-load BOD of carbonaceous or nitrogenous origin and from sediment oxygen demand. The only sources of oxygen in the model are from tributaries, atmospheric reaeration, and photosynthesis by suspended algae. The model does not include photosynthesis from attached algae or submerged aquatic vegetation. Most of the algae in the Ouachita River system are believed to be suspended in the water column. Neither attached algae nor submerged algae are believed to play a major role in the oxygen balance in the main channel.

### Practical Flow Range

According to the HydroQual Report, the hydraulic relationships in the model are valid within the range of 780 to 5,460 cfs. Extrapolated model results above this flow range should be used with discretion; however, critical 7Q10 high temperature conditions for the river occur within these flow values.

### Ammonia Loss

Ammonia is converted from $NH_4$-N to $NH_3$-N as pH increases. $NH_3$-N is stripped by the physical turbulence of the River. QUAL2E assumes that all ammonia loss is through the nitrification process and no NH3-N is lost preferentially to the atmosphere. Given the low reaeration rates, this loss to the atmosphere would be low in any regards.

### Nonpoint Sources

The impact of nonpoint sources during critical summer conditions has been factored into the headwater DO saturation. DO has been measured during periods of high river stage and the resultant low DO swamp waters impact to these DOs have been included in the determination of background.

The STORET database has been reviewed and other background data are within the values used for headwater inputs. The effect of turbidity from tributaries, such as Bayou Bartholomew, an algal DO production has been documented during the Georgia-Pacific synoptic river run. During low-flow periods, these periods are of short duration and tend to flatten the DO curve versus a rising DO curve at Sterlington during low flows. No direct adjustment to the model has been made to account for the turbidity influences on DO; however, these periods are covered by the average DO percent saturation value calculated for high storage events.

## CALIBRATION MODEL

### Inputs and Assumptions

The input rates and parameters for the calibration model are summarized in Tables 3-5 through 3-7. The calibrated model and output are presented in Appendix 11.

The Ouachita River flow of 980 cfs that occurred on August 27, 1998 was input into the model as the headwater flow. The initial temperature of the stream was input at 31.5 °C. This value represents the average temperature of all Ouachita River stations during the August 27, 1998 synoptic water quality measurements. The $CBOD_u$ deoxygenation rate for the study was 0.05 $day^{-1}$ at 20 °C for background conditions and 0.075 $day^{-1}$ at 20 °C for River reaches influenced by the Georgia-Pacific discharge. The reaeration rate at 20 °C was calculated by the model using the O'Conner-Dobbins equation to be in the range of 0.25/day at ORM 224 to 0.09/day near ORM 192. The SOD rate input for each reach ranged from 0.051 to 0.071 $g/ft^2$-day at 20 °C. The organic-nitrogen and ammonia-nitrogen rates ($k_{Org\text{-}N}$ and $k_{NH3\text{-}N}$) were input at 0.1 $day^{-1}$ at 20 °C. The nitrite-nitrogen rate was set at 1.0 $day^{-1}$ at 20 °C to avoid nitrite accumulation. An organic phosphorus decay rate of 0.05/day at 20°C was input into the model to maintain trace phosphorous levels in the model to provide for algae growth in the lower reaches of the system. As presented in Section 2, the chlorophyll *a* data measured during the November 1998 field study showed that chlorophyll *a* levels increased downstream from Coffee Creek and again in the lower reaches of the River, indicating continued algae growth in this region.

**TABLE 3-5. SUMMARY OF MODEL INPUTS**
**OUACHITA RIVER NEAR CROSSETT, ARKANSAS**
**AUGUST 27, 1998 CALIBRATION MODEL**
**HEADWATER AND POINT SOURCE DATA**

| LOCATION | PARAMETER | UNIT | VALUE | DATA SOURCE |
|---|---|---|---|---|
| Headwater | Flow | (cfs) | 980 | USGS Ruston, LA provisional data |
| | Temp | (°F) | 88.7 | 27-Aug-98 Georgia-Pacific measurement, average over study area |
| | DO | (mg/L) | 5.95 | 27-Aug-98 Georgia-Pacific measurement, adjusted for diurnal variation |
| | CBODu | (mg/L) | 3.75 | Derived from HydroQual 1992 data (1) |
| | Org N-N | (mg/L) | 0.484 | HydroQual 1992 (1) |
| | NH3-N | (mg/L) | 0.05 | HydroQual 1992 (1) |
| | NO3 | (mg/L) | 0.4 | HydroQual 1992 (1) |
| | NO2 | (mg/L) | 0.1 | HydroQual 1992 (1) |
| | Org P-P | (mg/L) | 0.07 | USGS Water Resources Data (1) |
| | Dis P-P | (mg/L) | 0.04 | USGS Water Resources Data (1) |
| | CHL a | (ug/L) | 8.4 | Engineering judgement |
| Coffee Creek | Flow | (cfs) | 42.1 | 27-Aug-98 Georgia-Pacific measurement (2) |
| | Temp | (°F) | 86.9 | 27-Aug-98 Georgia-Pacific measurement |
| | DO | (mg/L) | 3.5 | 27-Aug-98 Georgia-Pacific measurement |
| | CBODu | (mg/L) | 48.8 | 27-Aug-98 Georgia-Pacific measurement (2) |
| | Org N-N | (mg/L) | 2.73 | HydroQual 1992 (1); verified by 10-Nov-98 study |
| | NH3-N | (mg/L) | 3.56 | 10-Nov-98 study |
| | NO3 | (mg/L) | 0.4 | HydroQual 1992 (1) |
| | NO2 | (mg/L) | 0.1 | HydroQual 1992 (1) |
| | Org P-P | (mg/L) | 0.22 | HydroQual 1992 (1) |
| | Dis P-P | (mg/L) | 0.589 | HydroQual 1992 (1) |
| | CHL a | (ug/L) | 1 | Engineering judgement; HydroQual 1992 (1) |
| Pierre Creek | Flow | (cfs) | 1 | Engineering judgement |
| | Temp | (°F) | 88.7 | Assumed to be same as headwater |
| | DO | (mg/L) | 5.5 | Assumed to be 75% saturation |
| | CBODu | (mg/L) | 5 | Engineering judgement |
| | Org N-N | (mg/L) | 0.484 | Assumed to be same as headwater |
| | NH3-N | (mg/L) | 0.05 | Assumed to be same as headwater |
| | NO3 | (mg/L) | 0.4 | Assumed to be same as headwater |
| | NO2 | (mg/L) | 0.1 | Assumed to be same as headwater |
| | Org P-P | (mg/L) | 0.07 | Assumed to be same as headwater |
| | Dis P-P | (mg/L) | 0.04 | Assumed to be same as headwater |
| | CHL a | (ug/L) | 1 | Engineering judgement; HydroQual 1992 (1) |
| Possum Bayou<br>Boggy Bayou<br>PawPaw Bayou | Flow | (cfs) | 0.1 | Engineering judgement |
| | Temp | (°F) | 88.7 | Assumed to be same as headwater |
| | DO | (mg/L) | 5.5 | Assumed to be 75% saturation |
| | CBODu | (mg/L) | 2.8 | HydroQual 1992 headwater CBODu (1) |
| | Org N-N | (mg/L) | 0.484 | Assumed to be same as headwater |
| | NH3-N | (mg/L) | 0.05 | Assumed to be same as headwater |
| | NO3 | (mg/L) | 0.4 | Assumed to be same as headwater |
| | NO2 | (mg/L) | 0.1 | Assumed to be same as headwater |
| | Org P-P | (mg/L) | 0.07 | Assumed to be same as headwater |
| | Dis P-P | (mg/L) | 0.04 | Assumed to be same as headwater |
| | CHL a | (ug/L) | 1 | Engineering judgement; HydroQual 1992 (1) |

## TABLE 3-5. SUMMARY OF MODEL INPUTS
OUACHITA RIVER NEAR CROSSETT, ARKANSAS
AUGUST 27, 1998 CALIBRATION MODEL
HEADWATER AND POINT SOURCE DATA

| LOCATION | PARAMETER | UNIT | VALUE | DATA SOURCE |
|---|---|---|---|---|
| Bayou De Butte | Flow | (cfs) | 1 | Engineering judgement |
| | Temp | (°F) | 88.7 | Assumed to be same as headwater |
| | DO | (mg/L) | 5.5 | Assumed to be 75% saturation |
| | CBODu | (mg/L) | 5 | Engineering judgement based on knowledge of bean field |
| | Org N-N | (mg/L) | 5 | Engineering judgement based on knowledge of bean field |
| | NH3-N | (mg/L) | 5 | Engineering judgement based on knowledge of bean field |
| | NO3 | (mg/L) | 0.4 | Assumed to be same as headwater |
| | NO2 | (mg/L) | 0.1 | Assumed to be same as headwater |
| | Org P-P | (mg/L) | 0.07 | Assumed to be same as headwater |
| | Dis P-P | (mg/L) | 1 | Engineering judgement based on knowledge of bean field |
| | CHL a | (ug/L) | 1 | Engineering judgement; HydroQual 1992 |
| Bayou Bartholomew | Flow | (cfs) | 222 | 162 cfs from latest USGS gauge measurement at Jones, LA (1) |
| | | | | Estimated additional flow from Lake Bayou Bartholomew |
| | Temp | (°F) | 85.1 | 27-Aug-98 Georgia-Pacific measurement (2) |
| | DO | (mg/L) | 5.4 | 27-Aug-98 Georgia-Pacific measurement (2) |
| | CBODu | (mg/L) | 2.8 | HydroQual 1992 headwater CBODu (1) |
| | Org N-N | (mg/L) | 0.484 | Assumed to be same as headwater |
| | NH3-N | (mg/L) | 0.05 | Assumed to be same as headwater |
| | NO3 | (mg/L) | 0.4 | Assumed to be same as headwater |
| | NO2 | (mg/L) | 0.1 | Assumed to be same as headwater |
| | Org P-P | (mg/L) | 0.07 | Assumed to be same as headwater |
| | Dis P-P | (mg/L) | 0.04 | Assumed to be same as headwater |
| | CHL a | (ug/L) | 8.4 | Assumed to be same as headwater |
| Town of Sterlington | Flow | (cfs) | 0.77 | Engineering judgement, typical small town wastewater treatment |
| | Temp | (°F) | 88.7 | Assumed to be same as headwater |
| | DO | (mg/L) | 3 | Engineering judgement, typical small town wastewater treatment |
| | CBODu | (mg/L) | 60 | Engineering judgement, typical small town wastewater treatment |
| | Org N-N | (mg/L) | 12 | Engineering judgement, typical small town wastewater treatment |
| | NH3-N | (mg/L) | 12 | Engineering judgement, typical small town wastewater treatment |
| | NO3 | (mg/L) | 2 | Engineering judgement, typical small town wastewater treatment |
| | NO2 | (mg/L) | 0.1 | Engineering judgement, typical small town wastewater treatment |
| | Org P-P | (mg/L) | 1 | Engineering judgement, typical small town wastewater treatment |
| | Dis P-P | (mg/L) | 3 | Engineering judgement, typical small town wastewater treatment |
| | CHL a | (ug/L) | 10 | Engineering judgement, typical small town wastewater treatment |
| Incremental Inflow | Flow | (cfs) | 2 | Engineering judgement |
| | Temp | (°F) | 88.7 | Assumed to be same as headwater |
| | DO | (mg/L) | 5.95 | Assumed to be same as headwater |
| | CBODu | (mg/L) | 2.8 | Assumed to be same as headwater |
| | Org N-N | (mg/L) | 0.484 | Assumed to be same as headwater |
| | NH3-N | (mg/L) | 0.05 | Assumed to be same as headwater |
| | NO3 | (mg/L) | 0.4 | Assumed to be same as headwater |
| | NO2 | (mg/L) | 0.1 | Assumed to be same as headwater |
| | Org P-P | (mg/L) | 0.07 | Assumed to be same as headwater |
| | Dis P-P | (mg/L) | 0.04 | Assumed to be same as headwater |
| | CHL a | (ug/L) | 0 | Engineering judgement |

NOTES:
1) Supporting documentation presented in Appendix 3.
2) Supporting documentation presented in Appendix 2.

TABLE 3-6. SUMMARY OF MODEL INPUTS
OUACHITA RIVER NEAR CROSSETT, ARKANSAS CALIBRATED QUAL2E MODEL
AUGUST 27, 1998 CALIBRATION MODEL
RATES AND COEFFICIENTS

| PARAMETER | UNITS | VALUE PER REACH | | | | | | | | SOURCE OF DATA |
|---|---|---|---|---|---|---|---|---|---|---|
| | | REACH 1 | REACH 2 | REACH 3 | REACH 4 | REACH 5 | REACH 6 | REACH 7 | REACH 8 | |
| **Hydraulic data** | | | | | | | | | | |
| Dispersion Constant | unitless | 38 | 38 | 22 | 21 | 10 | 17 | 7 | 7 | Calculated value |
| V=aQ^b, a | unitless | 0.00046 | 0.00046 | 0.00046 | 0.00046 | 0.00028 | 0.00028 | 0.0002 | 0.0002 | Hydroqual, 1992, p. 4-7 |
| V=aQ^b, b | unitless | 0.897 | 0.897 | 0.897 | 0.897 | 0.946 | 0.946 | 0.93 | 0.93 | Hydroqual, 1992, p. 4-7 |
| D=cQ^d, c | unitless | 7.17 | 7.17 | 7.17 | 8 | 12 | 12 | 15.03 | 15.03 | Hydroqual, 1992, p. 4-7 |
| D=cQ^d, d | unitless | 0.05 | 0.05 | 0.05 | 0.05 | 0.018 | 0.018 | 0.011 | 0.011 | Hydroqual, 1992, p. 4-7 |
| Manning's n | unitless | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | Chow, 1959 |
| **BOD/DO Reaction Rates** | | | | | | | | | | |
| BOD Decay Rate, k1 | 1/day | 0.05 | 0.075 | 0.075 | 0.075 | 0.05 | 0.05 | 0.05 | 0.05 | Hydroqual, 1992, p. 5-16<br>NCASI, 1982<br>Engineering judgement |
| Reaeration Rate, k2 (1) | 1/day | - | - | - | - | - | - | - | - | Hydroqual, 1992, p. 5-2 |
| BOD Settling Rate | 1/day | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Engineering judgement |
| SOD | g/ft^2-day | 0.051 | 0.051 | 0.051 | 0.071 | 0.071 | 0.071 | 0.051 | 0.051 | Hydroqual, 1992, p. 5-47 |
| **N, P, and Algae Coefficients** | | | | | | | | | | |
| Org-N Hydrolosis Rate | 1/day | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | Engineering judgement |
| Org-N Settling Rate | 1/day | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Engineering judgement |
| NH3 Oxidation Rate | 1/day | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | NCASI, 1982<br>Engineering judgement |
| NH3 Benthos Rate | 1/day | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Engineering judgement |
| NO2 Oxidation Rate | 1/day | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | NCASI, 1982<br>Engineering judgement |
| Org-P Decay Rate | 1/day | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 | 0.05 | 0.05 | Engineering judgement |
| Org-P Settling Rate | 1/day | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Engineering judgement |
| Dis-P Benthos Rate | 1/day | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Engineering judgement |
| Chloro-a/Algae Ratio | µgChla/mgA | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | Standard Methods 10200I |
| Algal Settling Rate | ft/day | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | Bowie et al., 1985, p. 353 |
| Non-Algal Light Extinction | 1/ft | 0.57 | 0.9 | 0.6 | 0.72 | 0.77 | 0.71 | 0.5 | 0.5 | Secchi disc measurements<br>August 27, 1998<br>Engineering judgement |

TABLE 3-7. SUMMARY OF MODEL INPUTS
OUACHITA RIVER NEAR CROSSETT, ARKANSAS CALIBRATED QUAL2E MODEL
AUGUST 27, 1998 CALIBRATION MODEL
GLOBAL PARAMETERS

| PARAMETER | UNITS | VALUE | SOURCE |
|---|---|---|---|
| O Uptake by NH3 Oxidation | mg O/mg N | 3.43 | QUAL2E manual (2), p. 54-55; Bowie et al., 1985 (1), p. 158 |
| O Uptake by NO2 Oxidation | mg O/mg N | 1.14 | QUAL2E manual, p. 54-55; Bowie et al., 1985, p. 158 |
| O Production per Unit Algae | mg O/mg A | 1.8 | QUAL2E manual, p. 54-55 |
| O Uptake per Unit Algae Resp. | mg O/ mg A | 2 | QUAL2E manual, p. 54-55 |
| N Content of Algae | mg N/mg A | 0.085 | Bowie et al., 1985, p. 286-287 |
| P Content of Algae | mg P/mg A | 0.015 | Bowie et al., 1985, p. 286-287 |
| Algal Max Specific Growth Rate | 1/day | 2.5 | QUAL2E manual, p. 54-55; Bowie et al., 1985, p. 291-293 |
| Algae Respiration Rate | 1/day | 0.05 | QUAL2E manual, p. 54-55; Bowie et al., 1985, p. 291-293 |
| N Half Saturation Constant | mg/L | 0.2 | Bowie et al., 1985, p. 327-328 |
| P Half Saturation Constant | mg/L | 0.01 | QUAL2E manual; Personal comm. with B. Ambrose, USEPA |
| Linear Algal Shading Coefficient | 1/ft-µCha/L | 0.0027 | QUAL2E manual, p. 54-55 |
| Non-linear Algal Shading Coeff. | 1/ft-µCha/L^2/3 | 0.0165 | QUAL2E manual, p. 54-55 |
| Light Function Option | - | 2 | Eng. judgement; QUAL2E manual, p. 28 |
| Light Saturation Coefficient | (BTU/ft^2-min) | 0.1 | Bowie et al., 1985, p. 321-322 |
| Daily Averaging Option | - | 2 | Eng. judgement; QUAL2E manual, p. 30 |
| Light Averaging Factor | - | 0.92 | QUAL2E manual, p. 32 |
| Number of Daylight Hours | hours | 13 | Engineering judgement |
| Total Daily Solar Radiation | BTU/ft^2 | 754 | National Solar Radiation Database |
| Algae Growth Calculation Option | - | 1 | Eng. judgement; QUAL2E manual, p. 100 |
| Algal Preference for NH3 | - | 0.5 | QUAL2E manual, p. 100 |
| Nitrification Inhibition Factor | - | 10 | QUAL2E manual, p. 101 |

NOTES:

1) Bowie, et. al. 1985
2) Brown and Barnwell, 1987

## MODEL RESULTS

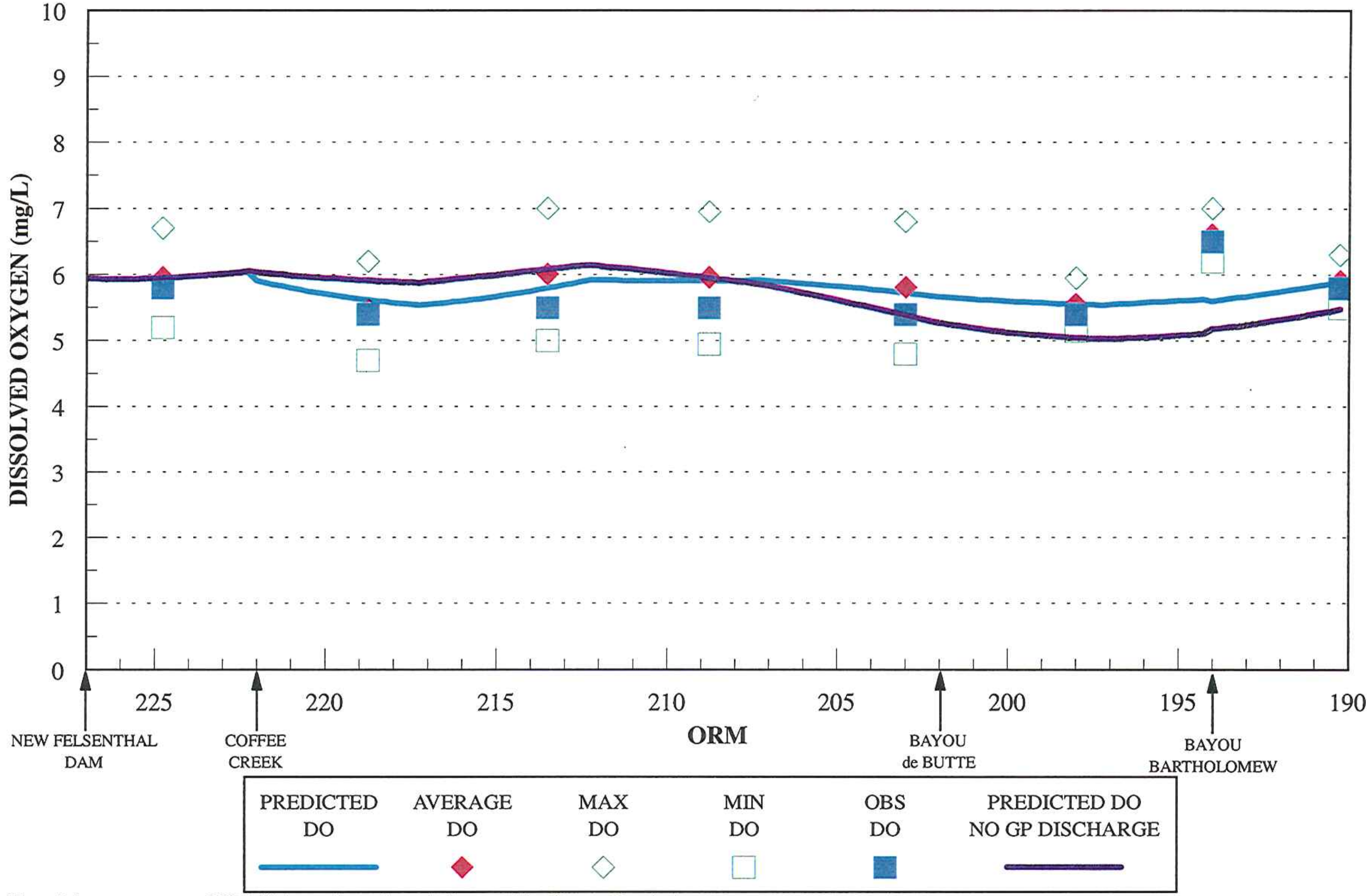
The model was calibrated against DO concentrations measured during the August 27, 1998 synoptic water quality data collection. As mentioned earlier, the target DO was the average DO concentration adjusted for diurnal variation. The model prediction for DO is illustrated in Figure 3-3 along with observed DO, and the predicted maximum, minimum, and mean DOs. In general, the QUAL2E model calibrated to observed DO measurements and reasonably predicted $CBOD_u$ and nitrogen parameters, based on values monitored during the November 1998 study. Therefore, the calibration to observed conditions and a good prediction for most parameters indicates that a calibrated QUAL2E model has been successfully constructed for the Ouachita River near Crossett, Arkansas. The model prediction with the Coffee Creek (Georgia-Pacific) discharge removed is also presented in Figure 3-3. Georgia-Pacific provides nutrients to the Ouachita River system. As shown in Figure 3-3, the lack of nutrients in the River system when the Georgia-Pacific discharge is removed causes the model to predict a decrease in River DO from approximately ORM 207 through ORM 190. The calibration model prediction, when the effects of algae are removed from the system, is presented in Figure 3-4. This model prediction demonstrates the importance of algae to the Ouachita River system.

During the model calibration, it was observed that the significant point source impacts to the Ouachita River include: **1)** Coffee Creek (ORM 222); **2)** the Bean Field (Bayou de Butte, ORM 203); and **3)** Bayou Bartholomew (ORM 194). Coffee Creek is the location of the Georgia-Pacific discharge. As shown in Figure 3-3, the impact from the Georgia-Pacific discharge occurs from approximately ORM 222 to ORM 212 (within about three days travel time). The Bean Field is a 19,000-acre diked soybean field whose drainage is believed to be discharged to Bayou de Butte and

# FIGURE 3-3

## AUGUST 27, 1998 CALIBRATION MODEL

### OUACHITA RIVER NEAR CROSSETT, AR

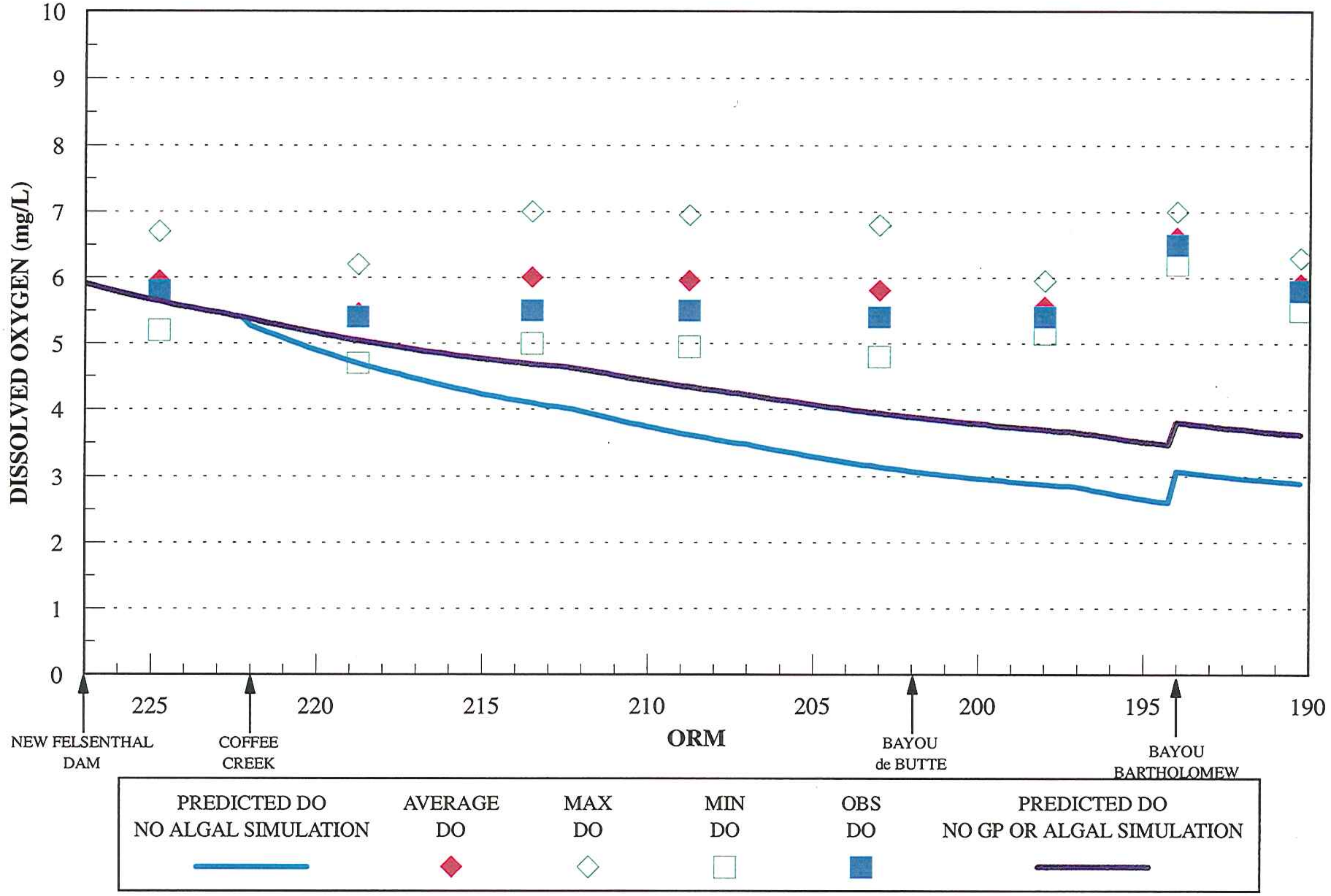


Note: Measurement at ORM 194 may have been influenced by Bayou Bartholomew.

# FIGURE 3-4

## AUGUST 27, 1998 CALIBRATION MODEL

### OUACHITA RIVER NEAR CROSSETT, AR



then to the Ouachita River. The Bean Field most likely provides a source of nutrients and BOD to the River when discharges occur from this area. Bayou Bartholomew is the third significant point source into the River. Bayou Bartholomew can impact the River in both a positive and a negative fashion. The dissolved oxygen near the Bayou's confluence with the Ouachita River has been observed to decrease during high flows; conversely, during low flows, the Bayou may increase the DO levels observed in the River.

The calibration model was adjusted to represent June 25, 1998 temperature and flow conditions and was compared to target DO values measured during a June 25, 1998 synoptic water quality data collection trip performed by Georgia-Pacific, as presented in Table 3-8 and Figure 3-5. The June 25, 1998 target DO values were adjusted for diurnal DO variations to an average daily DO. As shown in Figure 3-5, the calibration model predicts the June 25, 1998 target DO values well. The same process was followed for July 21, 1998 data, as presented in Figure 3-6. The predicted DO (1) line is the calibration model prediction, whereas the predicted DO (2) line is the calibration model prediction with the light extinction coefficient in Reaches 5 through 8 adjusted to 0.9/ft. Intense localized rainfall in the study area (as shown by the Coffee Creek flow increase from 48.8 cfs and 42.1 cfs in June and August, respectively, to a value of 110 cfs in July) was believed to have caused increased flows and non-point source runoff into the River on or around July 21, 1998. It is believed that increased turbidity in the River may have contributed to the lower DO values in the lower reaches of the River by causing the light extinction coefficient to increase.

The calibration model was also compared to the July 1987 DO data set presented in the 1992 HydroQual study, as presented in Figure 3-7. Please note that this data set includes the maximum, minimum, and average observed DO values from five independent days of measurements during

TABLE 3-8. INPUTS FOR CALIBRATION MODEL COMPARISONS
OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| DATE | RIVER STAGE (feet) (1) | RIVER FLOW (cfs) (1) | RIVER TEMP (°F / °C) (2) | RIVER DO (mg/L) (3) | COFFEE CREEK FLOW (cfs / MGD) | COFFEE CREEK TEMP (°F / °C) | COFFEE CREEK DO (mg/L) | COFFEE CREEK CBODu (mg/L) (4) | COFFEE CREEK CBOD5 (mg/L) (4) | COFFEE CREEK CBODu (lbs) (4) | COFFEE CREEK CBOD5 (lbs) (4) | BAYOU BARTHOLOMEW FLOW (cfs / MGD) (5) | BAYOU BARTHOLOMEW TEMP (°F / °C) | BAYOU BARTHOLOMEW DO (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| July 1987 (8) | 52.6 - 52.8 | 892 | 86.0 / 30.0 | 5.10 | 57.1/36.9 | 84.2 / 29 | 3.5 | 44.2 | 11.1 | 13,602 | 3,400 | 222 (6, 7) | 82.4 / 28 | 5.56 |
| 25-Jun-98 | 52.7 | 1,128 | 89.0 / 31.6 | 5.05 | 50.4 / 32.6 | 84.2 / 29.0 | 3.5 | 53.2 | 13.3 | 14,464 | 3,616 | 192 (6) | 85.4 / 29.7 | 5.4 |
| 21-Jul-98 | 52.8 | 1,353 | 90.5 / 32.5 | 5.50 | 100.5 / 65.0 | 84.2 / 29.0 | 3.5 | 32.0 | 8.0 | 17,348 | 4,337 | 241 (6) | 86.9 / 30.5 | 5.4 |
| 27-Aug-98 | 52.6 | 980 | 88.7 / 31.5 | 5.95 | 42.1 / 27.2 | 86.9 / 30.5 | 3.5 | 48.8 | 12.2 | 11,072 | 2,768 | 222 (6, 7) | 86.0 /30.0 | 5.4 |

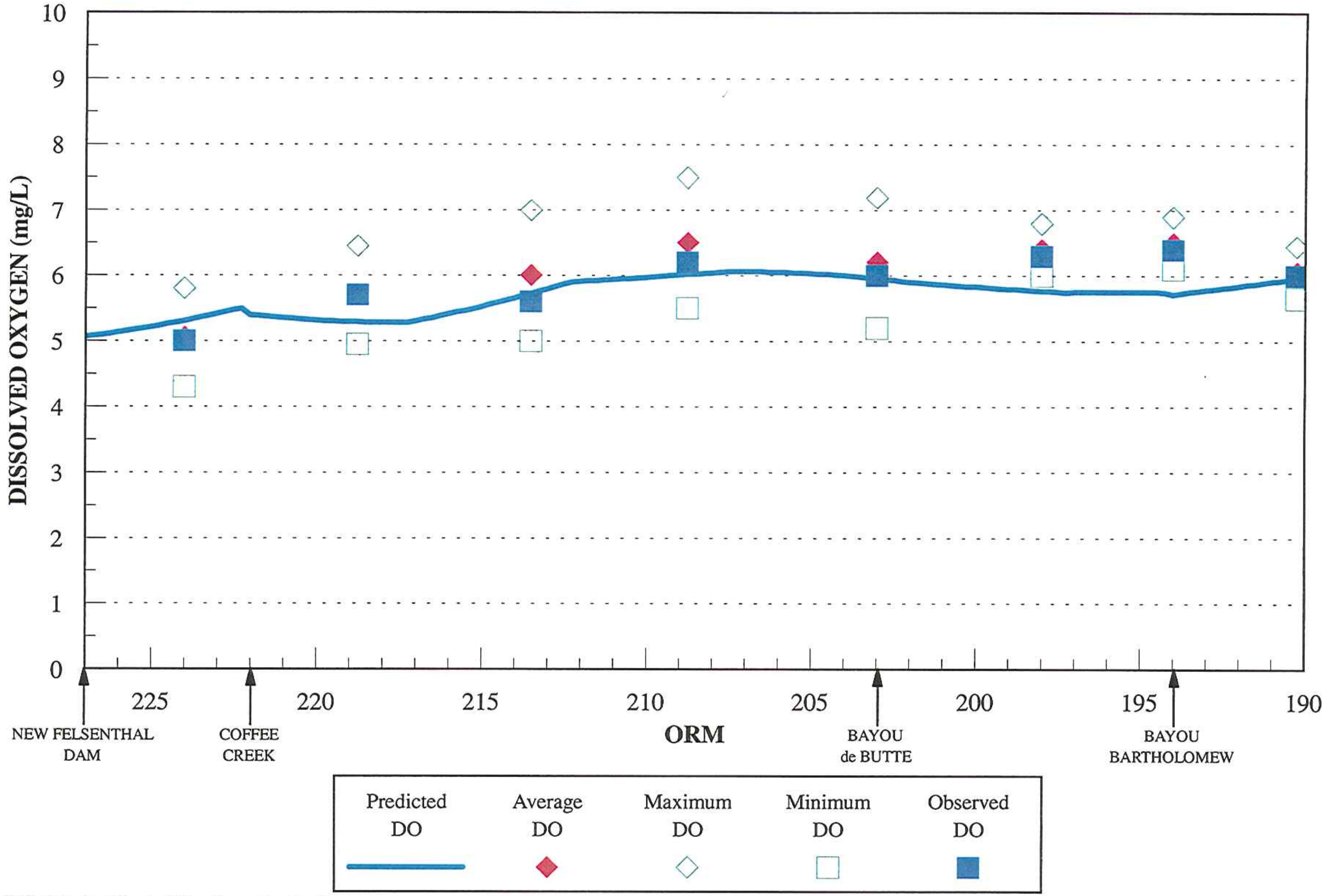
NOTE:

1) Average value for day of measurement plus one-week preceding measurement. River flows are not available on weekends and holidays.
2) Average temperature from ORM 224 to ORM 194. 1998 data measured at a depth of 5 feet.
3) With the exception of July 1987, DO adjusted for diurnal impacts. 1998 DO measured at a depth of 5 feet.
4) CBODu:CBOD5 = 4.
5) One-day flow measured by USGS near Jones, LA.
6) Provisional data.
7) Most recent flow available - measured August 16, 1998.
8) July 1987 data from Hydroqual (1992a).
9) August 27, 1998 data set used as the calibration model. Calibration model comparisons completed for July 1987, June 25, 1998, and July 12, 1998.

# FIGURE 3-5

## CALIBRATION MODEL COMPARISON TO JUNE 25, 1998 DATA

### OUACHITA RIVER NEAR CROSSETT, AR

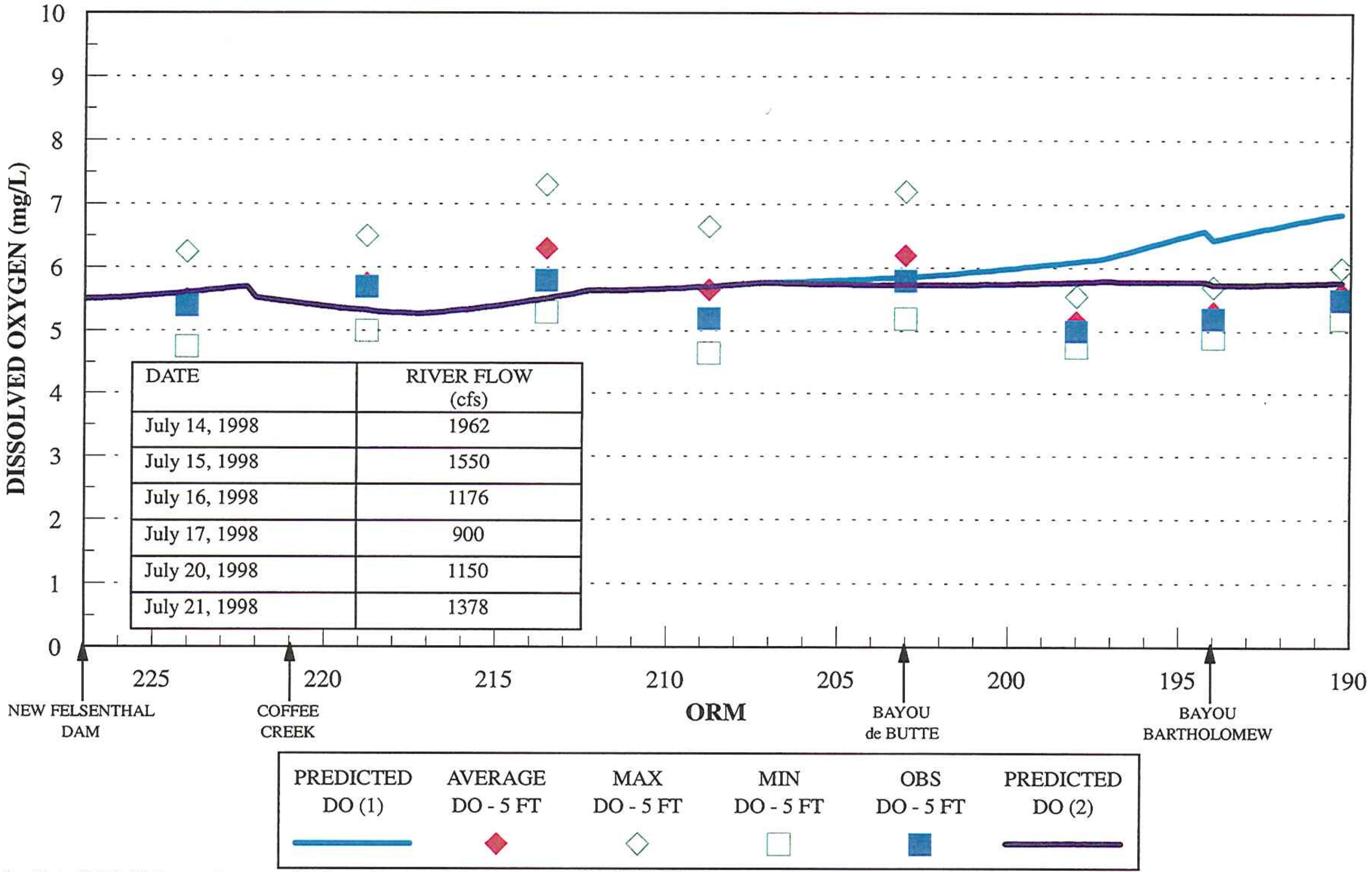


DO data is adjusted for diurnal activity.

## FIGURE 3-6

## CALIBRATION MODEL COMPARISON TO JULY 21, 1998 DATA

### OUACHITA RIVER NEAR CROSSETT, AR



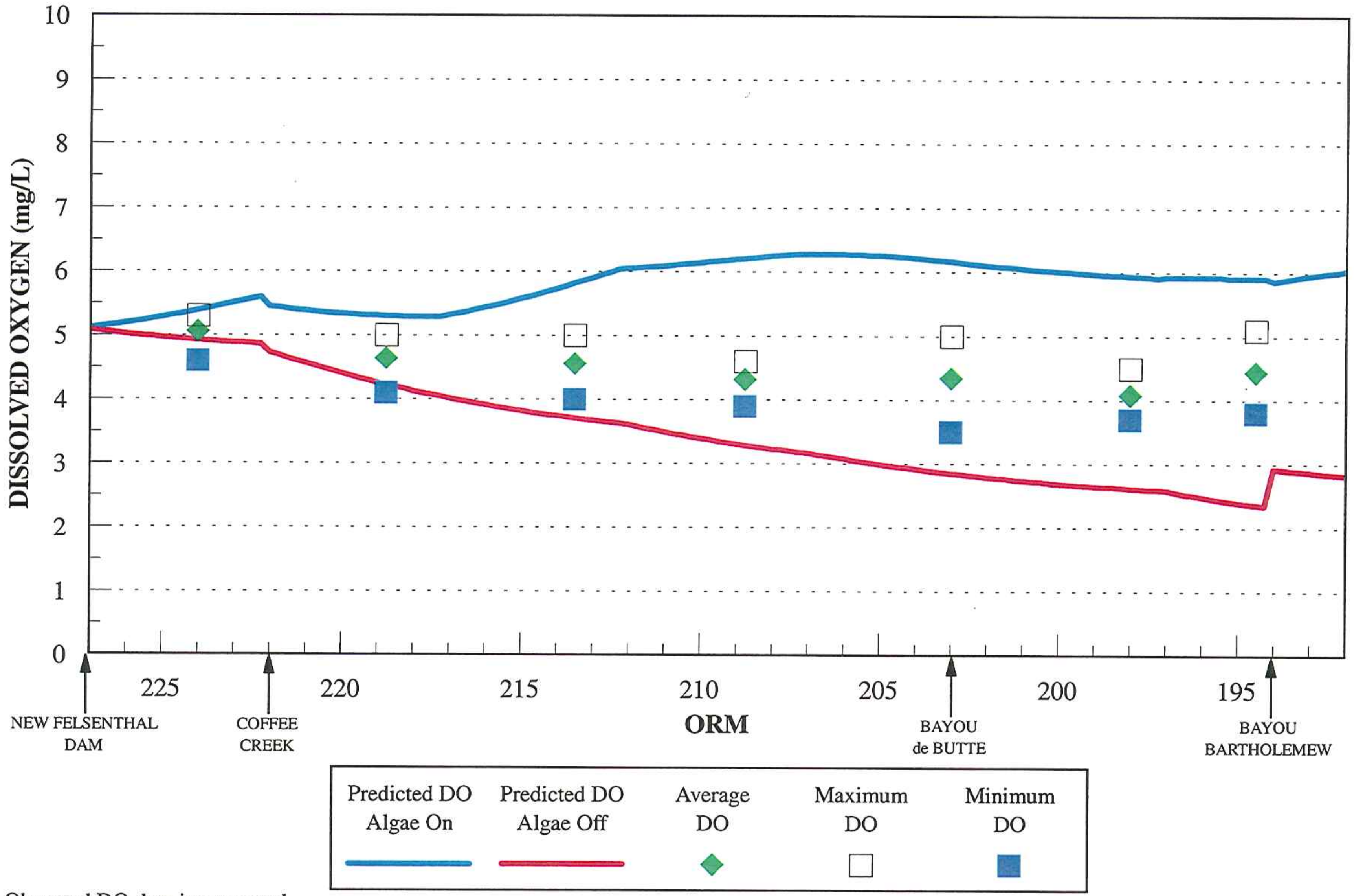
| DATE | RIVER FLOW (cfs) |
|---|---|
| July 14, 1998 | 1962 |
| July 15, 1998 | 1550 |
| July 16, 1998 | 1176 |
| July 17, 1998 | 900 |
| July 20, 1998 | 1150 |
| July 21, 1998 | 1378 |

Predicted DO (2) has an increased light extinction factor.
DO data is adjusted for diurnal activity.

# FIGURE 3-7

## CALIBRATION MODEL COMPARISON TO JULY 1987 DATA

### OUACHITA RIVER NEAR CROSSETT, AR



Observed DO data is presented.

Maximum, minimum, and average observed DO are taken from July 2, July 9, July 16, July 23, and July 30, 1987 data.

July 1987. Diurnal DO adjustments were not performed on the 1987 data. These diurnal adjustments were not made primarily because only water was being released over the Dam for the 1998 calibration data set, while water was only released as a bottom release from the Dam for the 1987 data set. The bottom waters from Felsenthal most likely had low DOs and did not contain any substantial algal population to feed the downstream River waters. An active algal population, as confirmed during the November 1998 study, is being introduced over the Dam during the current discharge scenario, which causes increased algal activity in the River downstream from New Felsenthal Dam. In 1987, these algae were not being introduced over the Dam, and the algal population was required to gradually build in the River. As can be seen in Figure 3-7, the calibration model overpredicts the DO in the River when the model algal simulation is on and underpredicts the DO when the algal simulation is off. Therefore, the 1987 data set falls in between the 1998 calibration model predictions with algae (the current conditions) and the model predictions without algae. Hence, the 1987 data set no longer represents current conditions in the River.

Another change that may be occurring is a point brought up a few years ago by Mr. Bill Keith of ADPC&E, who stated that a change in the low-flow BOD from the reservoir would decrease as the reservoir aged and the standing forests and vegetation left in the reservoir had substantially decayed. This would result in the DO increasing downstream from the Dam.

As previously presented in Table 2-7, chlorophyll *a* concentrations at ORM 229, just upstream from Felsenthal Lock and Dam, and at ORM 224, downstream from Felsenthal Lock and Dam, are similar. This indicates that algae are not destroyed as they travel over the Dam. In a conversation with Mr. Dennis Baxter, a biologist with the Tennessee Valley Authority (TVA), he stated that suspended algae were not killed as they traveled over the spillway of a dam. In addition, Dr. Chris Dickens and Mr. Mark Graham, of Umgeni Water, South Africa, presented a paper called, "The Rupture of Algae During Abstraction from A Reservoir and the Effects on Water Quality" (Journal Aqua, 1995). Dr. Dickens and Mr. Graham stated that they would predict little algal loss spilling over a dam, and that pressures equivalent to 200 meters of head were required to break up predominately blue-green algae.

Both the River flow and water temperature carry about the same importance in determining the self-purification or assimilative capacity potential of the stream. In addition, due to the slow velocities of the Ouachita River in the study reaches, algal influences have a large impact on the DO resources of the River. The critical low-flow estimate used for predictive modeling must be combined with an appropriate River water temperature. Monthly 7Q10 flows combined with the mean and 90th percentile monthly temperatures, as presented in Section 4, are used to determine the wasteload allocation for the study reaches of the Ouachita River under various conditions.

## SENSITIVITY ANALYSIS

Model sensitivity was examined by varying specific input parameters and using the calibration model conditions to check the model calibration with algae contribution to dissolved oxygen turned "on" in the model, as presented in Table 3-9. Separate runs were made first to determine first the effect of no algae in the system (algae turned off in the model runs) and second to determine the effect of algae alone contributing to the oxygen balance with no reaeration. Additionally, a run was made with no Georgia-Pacific loading to the River.

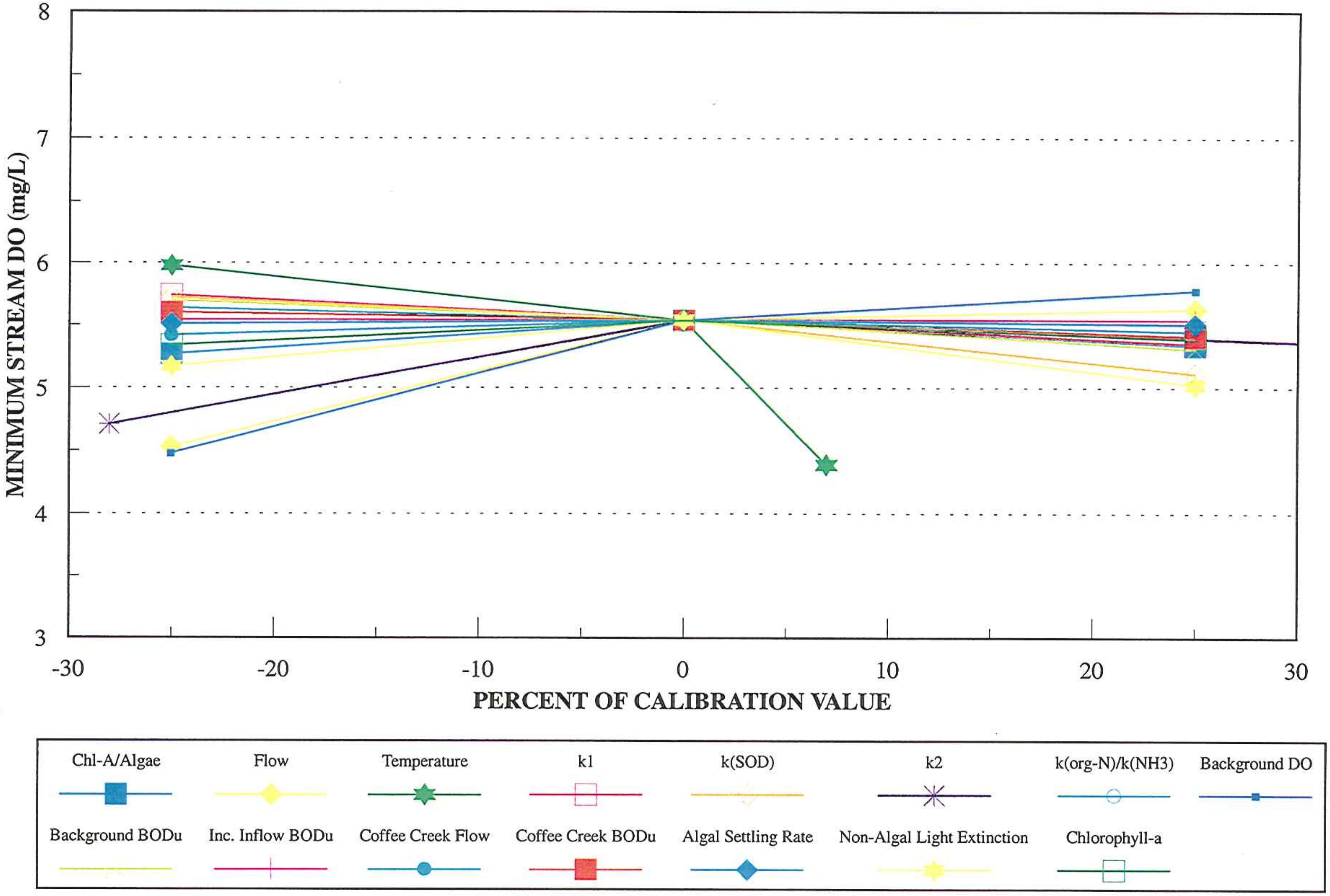
As presented in Table 3-9 and Figure 3-8, the chosen parameters were varied one at a time, in general, by 25 percent above and below the calibration value. The exception to the 25 percent

## TABLE 3-9. SENSITIVITY ANALYSIS FOR ALGAE CONTRIBUTION ON IN MODEL QUAL2E CALIBRATION MODEL, AUGUST 27, 1998

| PARAMETER | UNITS | CALIBRATION INPUT VALUE | CHANGE IN INPUT VALUE (%) | REVISED VALUE | ALGAL CONTRIBUTION (ON/OFF) | MIN DO (mg/L) | CHANGE IN MIN DO (%) | SENSITIVITY RATIO (1) | NORMALIZED SENSITIVITY RATIO (2) (0 TO 1) |
|---|---|---|---|---|---|---|---|---|---|
| Algal Contribution | - | - | - | - | ON | 5.54 | - | - | - |
| | - | - | - | - | OFF | 2.60 | -53.1% | - | - |
| k1 | (1/day) | 0.05/0.075 | 25% | 0.063/0.094 | ON | 5.35 | -3.4% | 0.14 | 0.05 |
| | (1/day) | 0.05/0.075 | -25% | 0.038/0.056 | ON | 5.74 | 3.6% | 0.14 | 0.05 |
| k(SOD) | (g/ft^2/day) | 0.051/0.071 | 25% | 0.064/0.089 | ON | 5.11 | -7.8% | 0.31 | 0.11 |
| | (g/ft^2/day) | 0.051/0.071 | -25% | 0.038/0.053 | ON | 5.72 | 3.2% | 0.13 | 0.04 |
| k(org-N)/k(NH3) | (1/day) | 0.1/0.1 | 25% | 0.125/0.125 | ON | 5.39 | -2.7% | 0.11 | 0.04 |
| | (1/day) | 0.1/0.1 | -25% | 0.075/0.075 | ON | 5.64 | 1.8% | 0.07 | 0.02 |
| Background Flow | (cfs) | 980 | 25% | 1,225 | ON | 5.63 | 1.6% | 0.06 | 0.02 |
| | (cfs) | 980 | -25% | 735 | ON | 4.53 | -18.2% | 0.73 | 0.25 |
| Background Temp (3) | (°F) | 88.7 | 7% | 95 | ON | 4.39 | -20.8% | 2.92 | 1.00 |
| | (°F) | 88.7 | -25% | 66.53 | ON | 5.98 | 7.9% | 0.32 | 0.11 |
| Background DO | (mg/L) | 5.95 | 25% | 7.44 | ON | 5.78 | 4.3% | 0.17 | 0.06 |
| | (mg/L) | 5.95 | -25% | 4.46 | ON | 4.48 | -19.1% | 0.77 | 0.26 |
| Background BODu | (mg/L) | 3.75 | 25% | 4.69 | ON | 5.31 | -4.2% | 0.17 | 0.06 |
| | (mg/L) | 3.75 | -25% | 2.81 | ON | 5.70 | 2.9% | 0.12 | 0.04 |
| Incremental Inflow BODu | (mg/L) | 2.8 | 25% | 3.5 | ON | 5.54 | 0.0% | 0.00 | 0.00 |
| | (mg/L) | 2.8 | -25% | 2.1 | ON | 5.54 | 0.0% | 0.00 | 0.00 |
| Coffee Creek Flow | (cfs) | 42.1 | 25% | 52.63 | ON | 5.45 | -1.6% | 0.06 | 0.02 |
| | (cfs) | 42.1 | -100% | 0 | ON | 5.03 | -9.2% | 0.09 | 0.03 |
| | (cfs) | 42.1 | -100% | 0 | OFF | 3.47 | -37.4% | 0.37 | 0.13 |
| | (cfs) | 42.1 | -25% | 31.58 | ON | 5.42 | -2.2% | 0.09 | 0.03 |
| Coffee Creek DO | (mg/L) | 3.5 | 25% | 4.4 | ON | 5.55 | 0.2% | 0.01 | 0.00 |
| | (mg/L) | 3.5 | -25% | 2.6 | ON | 5.51 | -0.5% | 0.02 | 0.01 |
| Coffee Creek BODu | (mg/L) | 48.8 | 25% | 61 | ON | 5.41 | -2.3% | 0.09 | 0.03 |
| | (mg/L) | 48.8 | -25% | 36.6 | ON | 5.60 | 1.1% | 0.04 | 0.01 |
| Algal Settling Rate | (ft/day) | 0.8 | 25% | 1.0 | ON | 5.51 | -0.5% | 0.02 | 0.01 |
| | (ft/day) | 0.8 | -25% | 0.6 | ON | 5.51 | -0.5% | 0.02 | 0.01 |
| Non-Algal Light Extinction | (1/ft) | 0.57/0.90/0.60/0.72/0.77/0.71/0.5 | 25% | 0.71/1.13/0.75/0.90/0.96/0.89/0.63 | ON | 5.02 | -9.4% | 0.38 | 0.13 |
| | (1/ft) | 0.57/0.90/0.60/0.72/0.77/0.71/0.5 | -25% | 0.43/0.68/0.45/0.54/0.58/0.53/0.38 | ON | 5.17 | -6.7% | 0.27 | 0.09 |
| Chloro-a/Algae Ratio | (ug/L/mg/L) | 15 | 25% | 18.8 | ON | 5.34 | -3.6% | 0.14 | 0.05 |
| | (ug/L/mg/L) | 15 | -25% | 11.3 | ON | 5.27 | -4.9% | 0.19 | 0.07 |
| Chlorophyll a | (ug/L) | 8.4 | 25% | 10.5 | ON | 5.39 | -2.7% | 0.11 | 0.04 |
| | (ug/L) | 8.4 | -25% | 6.3 | ON | 5.34 | -3.6% | 0.14 | 0.05 |
| Reaeration Rate (k2) (5) | (1/day) | 0.25 | 25% | 0.31 | ON | 5.72 | 3.2% | 0.13 | 0.04 |
| | (1/day) | 0.25 | -25% | 0.19 | ON | 5.15 | -7.0% | 0.28 | 0.10 |
| | (1/day) | 0.25 | -100% | 0 | ON | 2.65 | -52.2% | 0.52 | 0.18 |

1) Sensitivity Ratio = Absolute Value[(Percent Change in Minimum DO)/(Percent Change in Input Value)]
2) Normalized Sensitivity Ratio = [(Sensitivity Ratio)/(Maximum of All Sensitivity Ratios)]
3) Temperature is limited to a upper boundary of 95 °F.
4) When Algal Contribution is deactivated, algal parameters will no longer contribute to the output minimum DO.
5) The reaeration rate varies for each reach. The values shown are for the first reach.

# FIGURE 3-8
## CALIBRATION MODEL SENSITIVITY ANALYSIS
### ALGAL CONTRIBUTION ON



variation above and below the calibration value was the calibration of temperature, which was set to a maximum value of 95 °F (35 °C). The reaeration rate was varied by inputting the calculated reaeration value at plus and minus 25 percent from the value calculated from the O'Connor-Dobbins equation. This was done since allowing the model to calculate this rate would require changing both the depth and the velocity equations to change the reaeration rate by plus or minus 25 percent. These changes would also change other rate functions in the model and not give an accurate reflection of just the effect of the reaeration rate on the model.

The model was run for each of the altered parameters, and the minimum calculated DO and the resulting percent change from the calibration minimum DO were recorded. A sensitivity ratio was calculated by dividing the absolute value of the percent change in the minimum DO by the percent change in the input value. A low sensitivity ratio indicates that a change in the input parameter has little or no effect on the calculated minimum DO, whereas a high ratio indicates that a change in the parameter has a significant effect on the minimum DO. Normalized sensitivity ratios were calculated by dividing each ratio by the maximum observed ratio, resulting in a range of values from zero to one. This normalization has the result of displaying the relative effects of the sensitivity ratios.

In general, the sensitivity analysis has demonstrated that water temperature, the algae contribution to DO, the reaeration rate, and the SOD rate are the most important parameters in the model. As expected, algae and physical reaeration each contribute about 50 percent of the oxygen resources to the River, and each plays a very important role in the DO resources of this river-lake system. Flows less than about 1,000 cfs have a much larger effect on the allocation than increasing the flows from about 1,000 to 1,600 cfs due to the oxygen sag moving further downstream at higher flows (to around ORM 208.8). The Georgia-Pacific discharge results in about a 0.5 mg/L impact to the minimum DO in the River at the calibration conditions, but the resultant DO at Sterlington is improved with the Georgia-Pacific discharge primarily due to the nutrient addition which aids the algae production of oxygen.

# SECTION 4

# WASTELOAD ALLOCATION PROJECTIONS

The assimilative capacity of the Ouachita River near Crossett, Arkansas has been modeled using the calibrated QUAL2E model presented in Section 3 of this report. The assimilative capacity allows for safely receiving effluent discharges while maintaining the regulatorily-required water quality standards, specifically DO. The assimilative capacity of the Ouachita River actually varies daily due to changes in flow and water temperature, but the regulations require that the DO standards be met during the critical 7Q10 flow at a representative water temperature for the low flow period. The most critical period on the Ouachita River occurs during August and September when the combination of low flows and high temperatures result in minimum assimilative capacity. NPDES dischargers must also meet certain technology treatment standards in order to receive an allocation of this assimilative capacity. For the Georgia-Pacific Crossett Mill, the effluent limits are determined by effluent limit guidelines (ELG) contained in 40 CFR 430.20 and by water quality limits.

The water quality limits require Georgia-Pacific to meet during the summer months a maximum effluent $BOD_5$ discharge of 8,000 lbs/day as a monthly average and 12,000 lbs/day as a daily maximum.

Since the last permit was issued, Ouachita River water quality limit for DO in the River for both Arkansas and Louisiana are as follows:

a. DO = 3 mg/L June and July;
b. DO = 4.5 mg/L August; and
c. DO = 5 mg/L September through May;

The Arkansas and Louisiana regulations also state that, "these seasonal criteria may be unattainable during or following naturally occurring high flows, (i.e., river stage above 65 feet measured at the lower gauge at the Felsenthal Lock and Dam, Station No. 89-o, and also for the two weeks following the recession of flood waters below 65 feet), which occurs from May through August. Naturally occurring conditions which fail to meet criteria should not be interpreted as violations of these criteria."

## CRITICAL RIVER FLOW AND TEMPERATURE

The critical 7Q10 flow for the Ouachita River was reported in the HydroQual (1992a) Report, as presented in Table 4-1. These flows were presented in the Georgia-Pacific UAA (Taylor, et. al. 1993) using a drainage area extrapolation method to determine the 7Q10 flows. The drainage area extrapolation method was recommended for establishing wasteload allocations since direct probability-based method calculations at the Arkansas-Louisiana state line were inconsistent with upstream measurements at the Camden, Arkansas gauge. The additional flow between Camden and the state line was projected from free-flowing, gaged tributaries in the basin. The lowest monthly 7Q10 flow at the state line was projected to be 802 cfs for the month of August. The 7Q10 event is a 90th percentile event.

HydroQual prepared a temperature analysis on the Ouachita River presenting mean, 90th percentile, and 95th percentile monthly temperatures (HydroQual, 1992b), as presented in Table 4-2. The temperatures presented are based on a probability analysis which determines the average temperature for the month with the 7Q10 flow for a given month. The use of the 7Q10 flow in conjunction with the actual temperatures at the time these flows occur results in a combination of

## TABLE 4-1. MONTHLY 7Q10 FLOW ANALYSIS
## OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| MONTH | OUACHITA RIVER 7Q10 FLOW AT CROSSETT, ARKANSAS (cfs) |
|---|---|
| January | 2,658 |
| February | 5,269 |
| March | 4,037 |
| April | 2,436 |
| May | 1,591 |
| June | 1,049 |
| July | 894 |
| August | 802 |
| September | 829 |
| October | 822 |
| November | 1,231 |
| December | 2,059 |

Source: Taylor, et.al. (1993)

**TABLE 4-2. MONTHLY TEMPERATURE ANALYSIS (HYDROQUAL, OCTOBER 12, 1992)**
**OUACHITA RIVER NEAR CROSSETT, ARKANSAS**

| MONTH | MEAN TEMPERATURE (°C) | 90TH PERCENTILE TEMPERATURE (°C) |
|---|---|---|
| May | 22.7 | 26.5 |
| June | 27 (26.9) | 31.0 |
| July | 30 (29.5) | 31.9 |
| August | 30 (29.5) | 31.6 |
| September | 27 (26.5) | 29.8 |
| October | 21.3 | 25.1 |

**NOTE:**
The mean temperature value in parentheses was reported by HydroQual,
the number not in parentheses was used in the predictive modeling.

conditions which has a recurrence frequency of once in 10 years for each individual month. HydroQual (1992b) analysis showed that the 7Q10 flow and temperature were not well correlated in the Ouachita River, which is often the case with regulated streams. Based on this lack of correlation, the occurrence of the once in 10 year flow in conjunction with the 90th or 95th percentile temperature is expected to have a low probability (i.e., greater than the 90th percentile occurrence). HydroQual states that, "the average of the daily data for the entire month is expected to provide a better estimate of the average temperature, given the larger sample size, and it is therefore recommended for use." The wasteload allocation projections in this report have been performed for both the mean and the 90th percentile temperatures reported. There is not a good database available for river temperature measurements since the USACOE has begun operation of the hinge crest gates. The use of the 90th percentile flow with the 90th percentile water temperature is typically very conservative for regulated streams.

## OUACHITA RIVER AVAILABLE ASSIMILATIVE CAPACITY

The calibrated QUAL2E model was used to project assimilative capacity of the Ouachita River near Crossett, Arkansas for each of the months of June through September, as presented in Tables 4-3 and 4-4 and in Figures 4-1 through 4-8. The model was run to predict the maximum capacity available for discharging $CBOD_u$ for each of the months at the 7Q10 flow conditions during each summer month at both the mean and 90th percentile temperatures. The background DO for the predictions was 82 percent of saturation, as presented in Table 4-5. The percent saturation was calculated from available temperature and DO measurements collected by Georgia-Pacific since the initiation of the program to release water over the hinge crest gates of the Felsenthal Lock and Dam.

## TABLE 4-3. MAXIMUM CAPACITY WASTELOAD ALLOCATION (WLA) PROJECTIONS
## OUACHITA RIVER NEAR CROSSETT, ARKANSAS
## MEAN TEMPERATURES

| MONTH (1) | TEMP. (°F/°C) | MONTHLY Q7-10 FLOW (cfs) | DO SAT (mg/L) | OUACHITA HEADWATER DO (mg/L) (1) | WLA CBODu (mg/L) (2) | WLA CBODu (lbs/day) (2) | 5-DAY BOD (mg/L) (3) | 5-DAY BOD (lbs/day) (3) | 5-DAY BOD 10% SF (lbs/day) (3) | DO STANDARD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| June | 80.6 / 27 | 1049 | 7.97 | 6.53 | 322 | 120,847 | 81 | 30,212 | 27,190 | 3 |
| July | 86 / 30 | 894 | 7.56 | 6.20 | 211 | 79,188 | 53 | 19,797 | 17,817 | 3 |
| August | 86 / 30 | 802 | 7.56 | 6.20 | 118 | 44,285 | 30 | 11,071 | 9,964 | 4.5 |
| September | 80.6 / 27 | 829 | 7.97 | 6.53 | 87 | 32,651 | 22 | 8,163 | 7,346 | 5 |

**NOTES:**

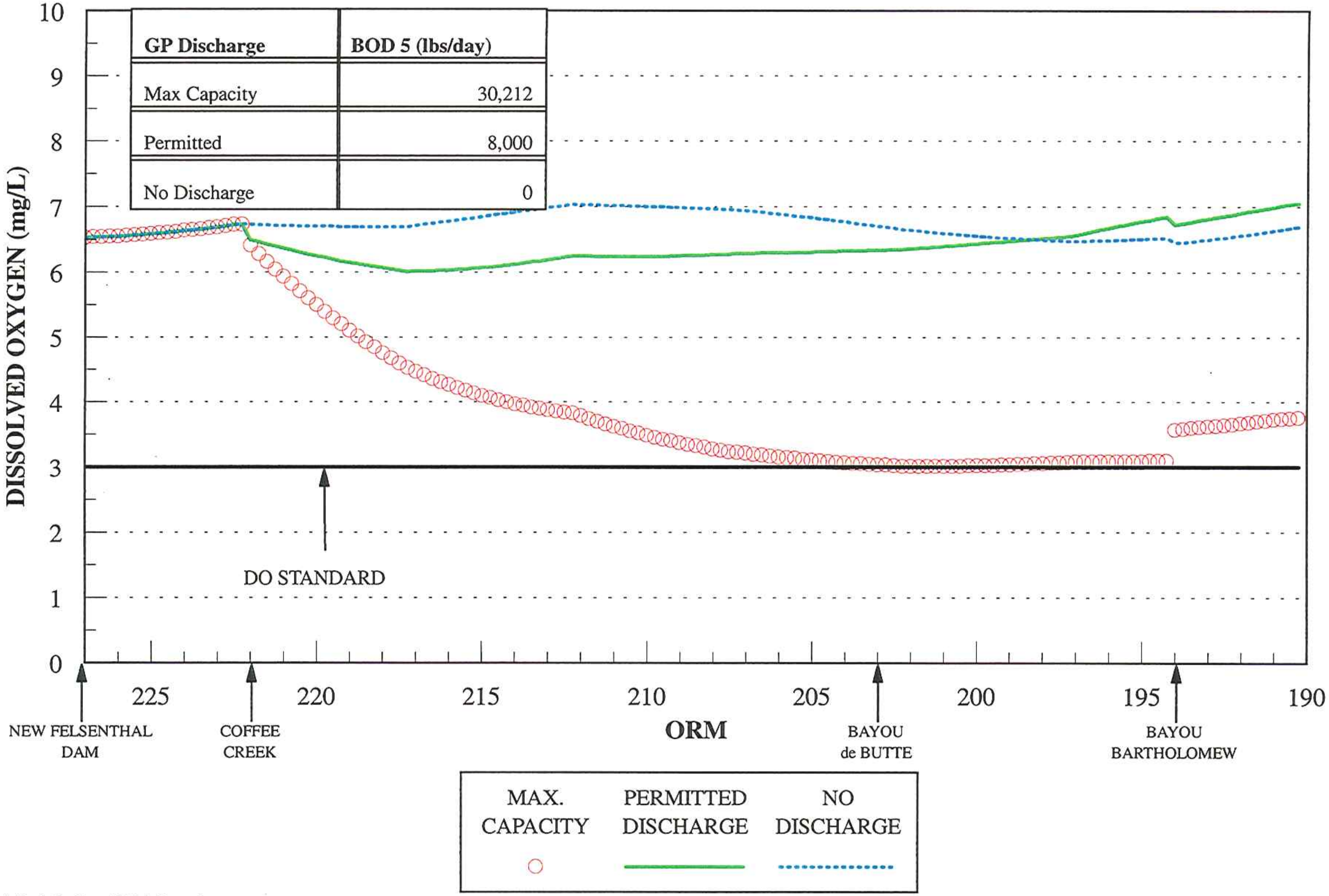
1) Ouachita River headwater DO equals 82 percent of saturation.
2) Values determined at Georgia-Pacific flow = 45 mgd.
3) Assume CBODu:CBOD5 = 4.

## TABLE 4-4. MAXIMUM CAPACITY WASTELOAD ALLOCATION (WLA) PROJECTIONS
OUACHITA RIVER NEAR CROSSETT, ARKANSAS
90TH PERCENTILE TEMPERATURES

| MONTH (1) | TEMP. (°F/°C) | MONTHLY Q7-10 FLOW (cfs) | DO SAT (mg/L) | OUACHITA HEADWATER DO (mg/L) (1) | WLA CBODu (mg/L) (2) | WLA CBODu (lbs/day) (2) | 5-DAY BOD (mg/L) (3) | 5-DAY BOD (lbs/day) (3) | 5-DAY BOD 10% SF (lbs/day) (3) | DO STANDARD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| June | 87.8 / 31 | 1049 | 7.43 | 6.09 | 242 | 90,823 | 61 | 22,706 | 20,435 | 3 |
| July | 89.4 / 31.9 | 894 | 7.32 | 6.00 | 167 | 64,913 | 42 | 16,228 | 14,605 | 3 |
| August | 88.9 / 31.6 | 802 | 7.36 | 6.03 | 86 | 32,276 | 22 | 8,069 | 7,262 | 4.5 |
| September | 85.6 / 29.8 | 829 | 7.59 | 6.22 | 70 | 26,271 | 18 | 6,568 | 5,911 | 5 |

NOTES:
1) Ouachita River headwater DO equals 82 percent of saturation.
2) Values determined at Georgia-Pacific flow = 45 mgd.
3) Assume CBODu:CBOD5 = 4.

# FIGURE 4-1
## JUNE PREDICTED DO - MEAN TEMPERATURE
### OUACHITA RIVER NEAR CROSSETT, AR



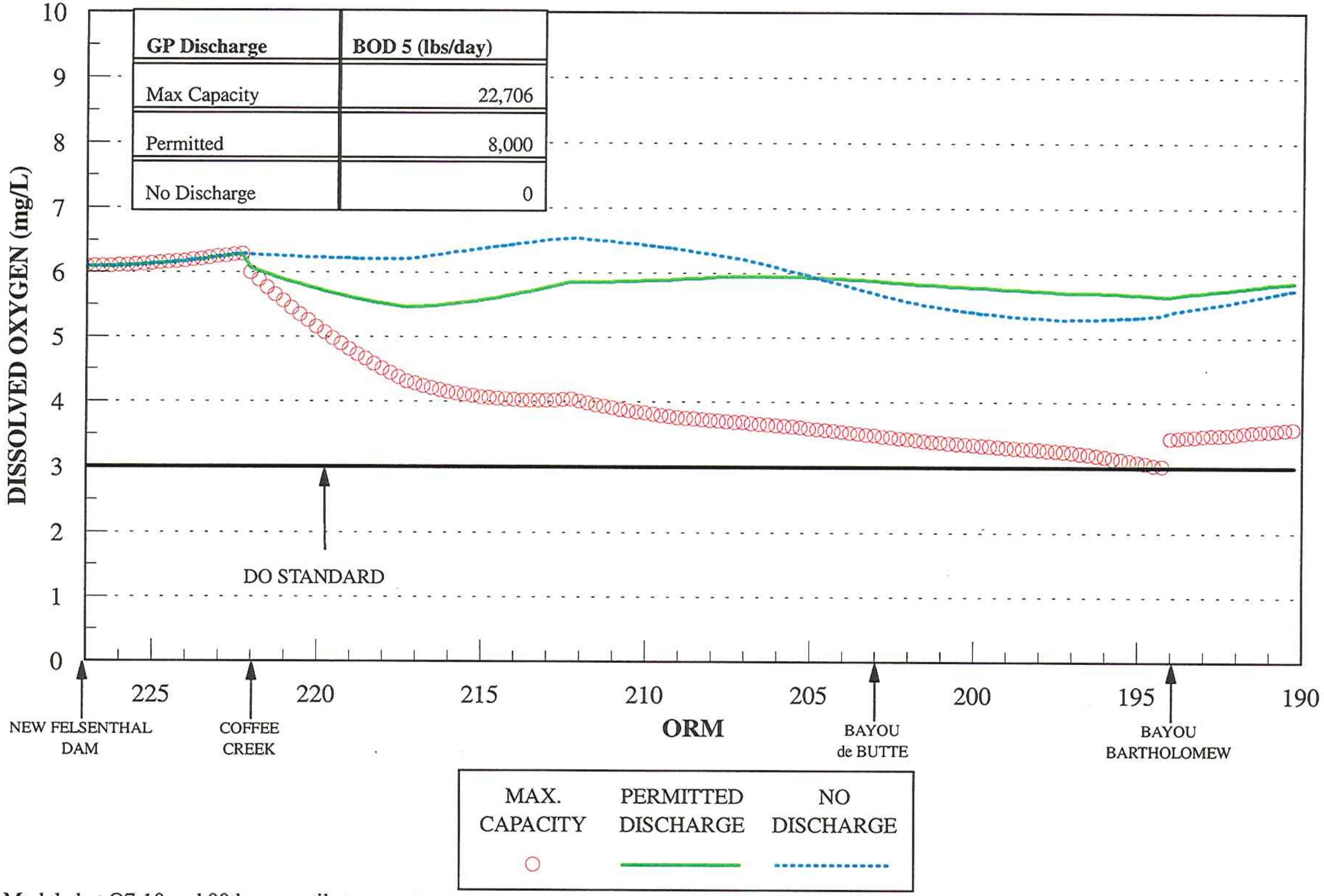
| GP Discharge | BOD 5 (lbs/day) |
|---|---|
| Max Capacity | 30,212 |
| Permitted | 8,000 |
| No Discharge | 0 |

Modeled at Q7-10 and mean temperature.
Q7-10 = 1049 cfs; T = 27°C

## FIGURE 4-2

## JUNE PREDICTED DO - 90TH PERCENTILE TEMPERATURE

### OUACHITA RIVER NEAR CROSSETT, AR



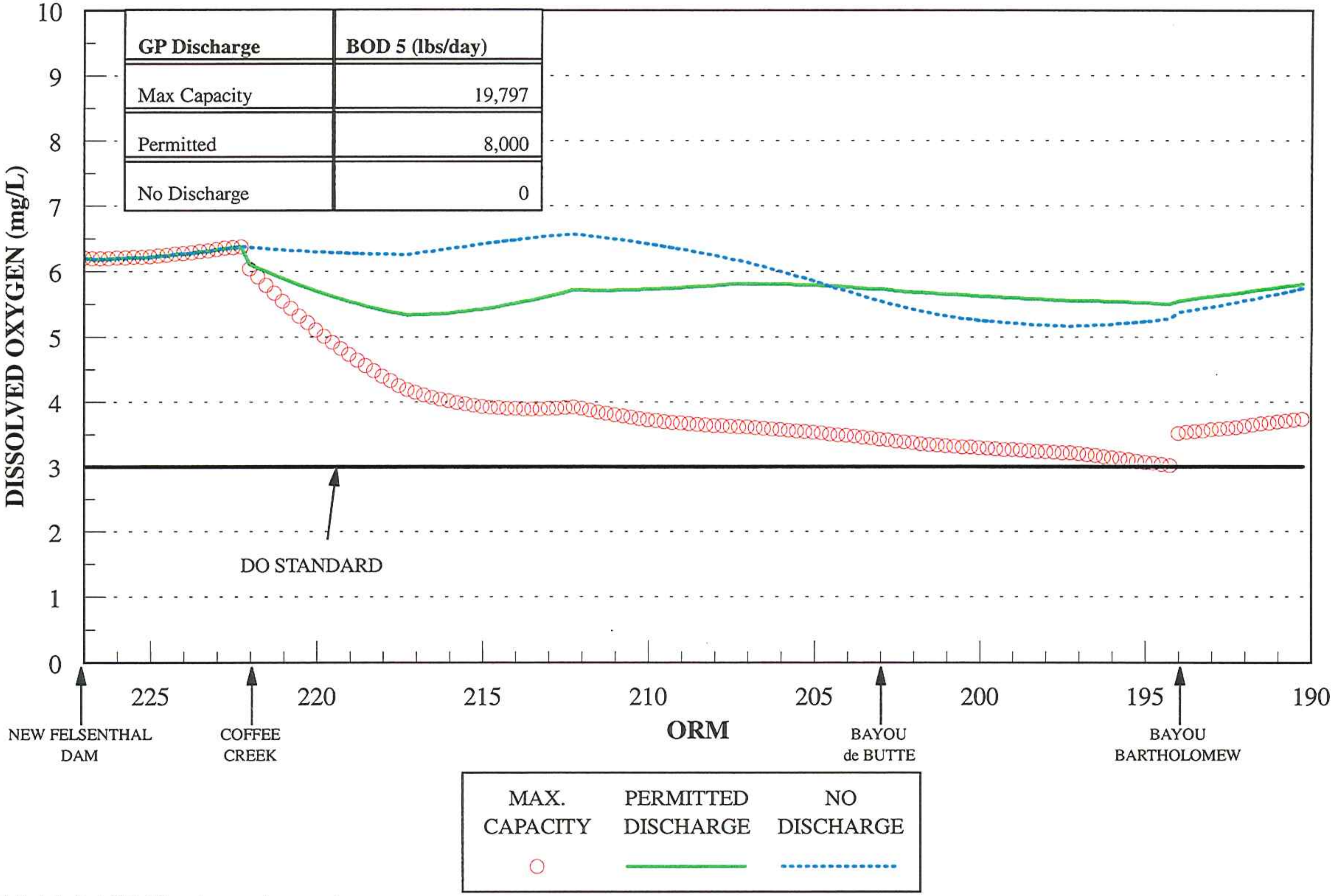
| GP Discharge | BOD 5 (lbs/day) |
|---|---|
| Max Capacity | 22,706 |
| Permitted | 8,000 |
| No Discharge | 0 |

Modeled at Q7-10 and 90th percentile temperature.
Q7-10 = 1049 cfs; T = 31°C

## FIGURE 4-3

## JULY PREDICTED - MEAN TEMPERATURE

### OUACHITA RIVER NEAR CROSSETT, AR



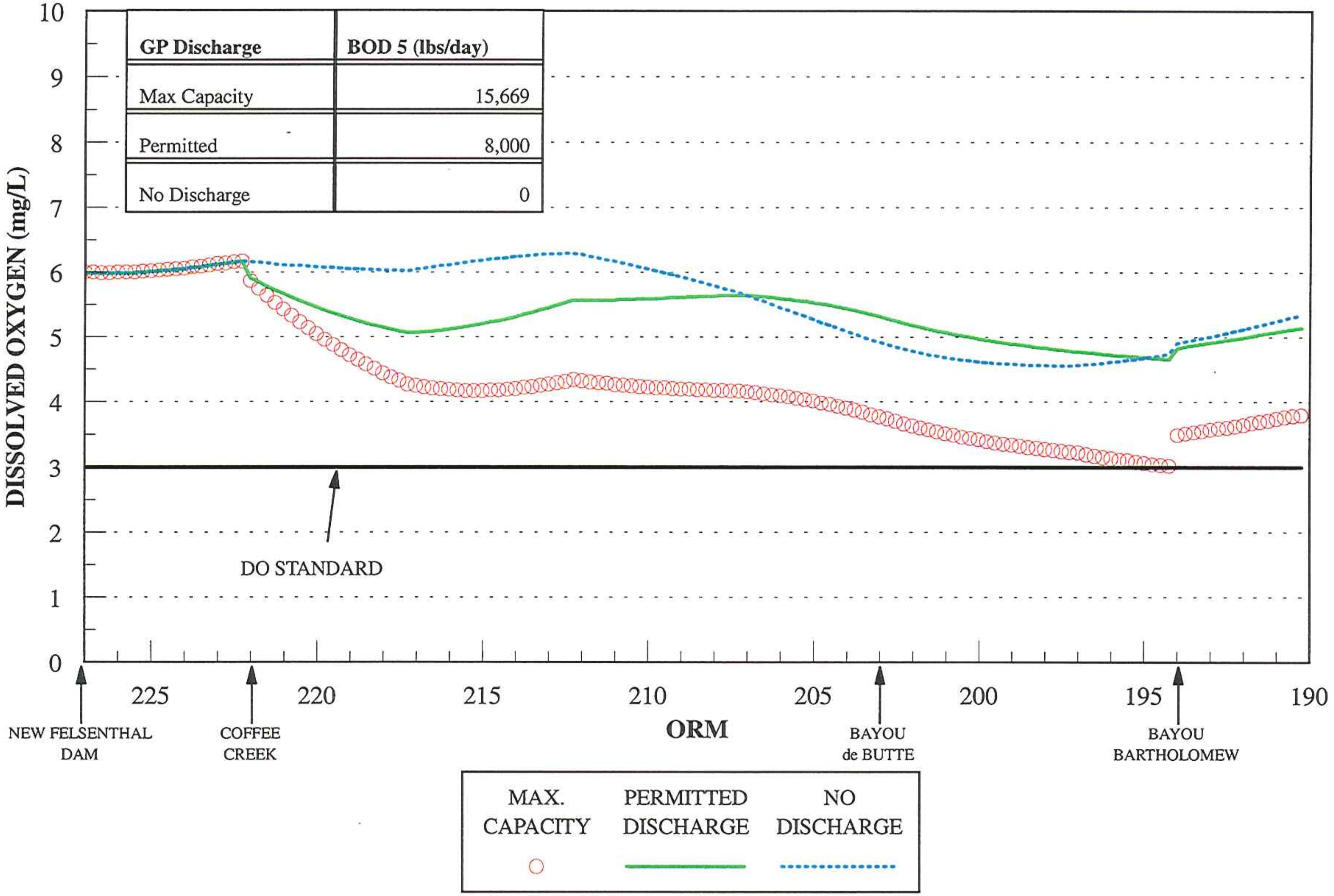
| GP Discharge | BOD 5 (lbs/day) |
|---|---|
| Max Capacity | 19,797 |
| Permitted | 8,000 |
| No Discharge | 0 |

Modeled at Q7-10 and mean temperature.
Q7-10 = 894 cfs; T = 30°C

# FIGURE 4-4

## JULY PREDICTED - 90TH PERCENTILE TEMPERATURE

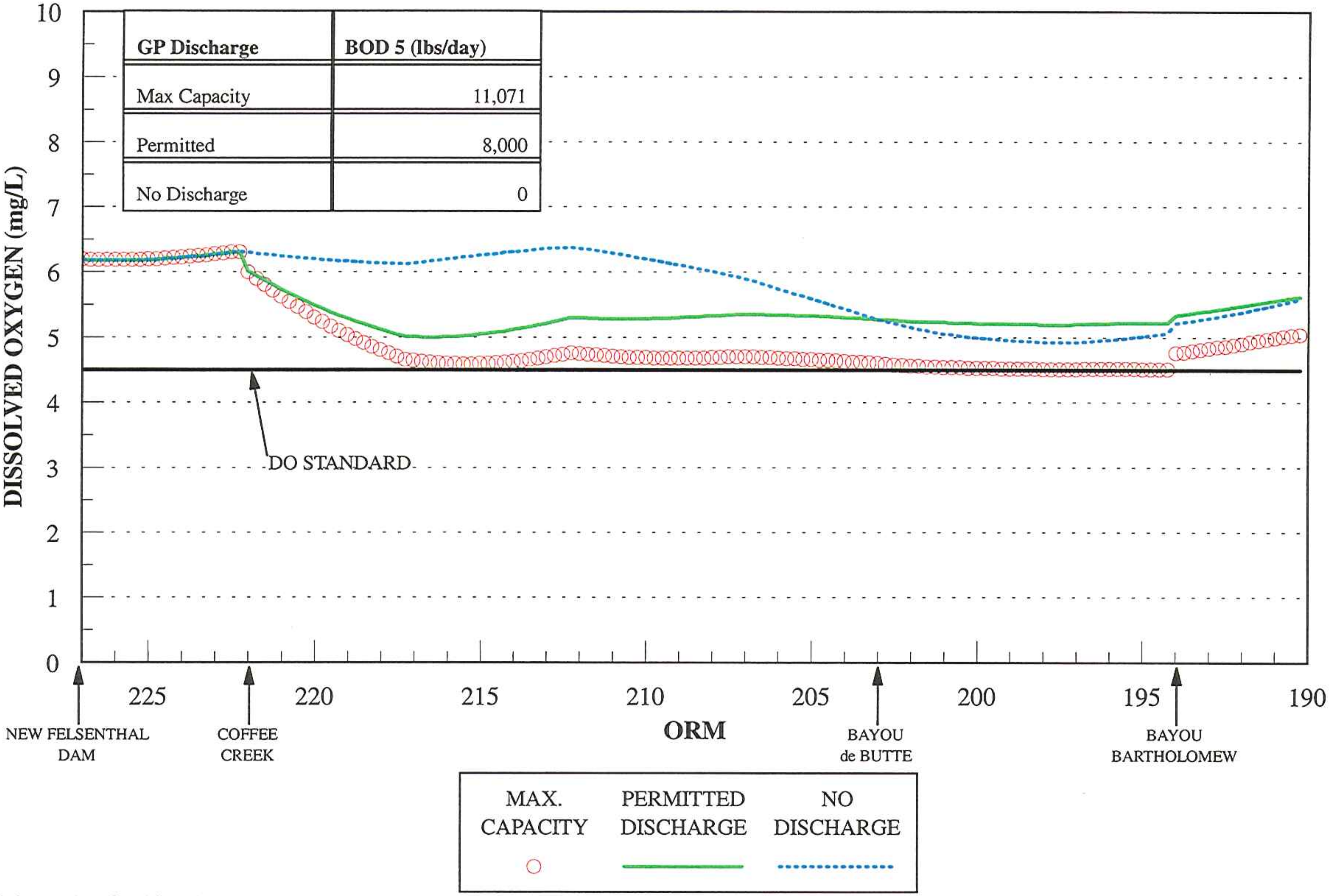
OUACHITA RIVER NEAR CROSSETT, AR



| GP Discharge | BOD 5 (lbs/day) |
|---|---|
| Max Capacity | 15,669 |
| Permitted | 8,000 |
| No Discharge | 0 |

Modeled at Q7-10 and 90th percentile temperature.
Q7-10 = 894 cfs; T = 31.9°C

# FIGURE 4-5
## AUGUST PREDICTED DO - MEAN TEMPERATURE
### OUACHITA RIVER NEAR CROSSETT, AR



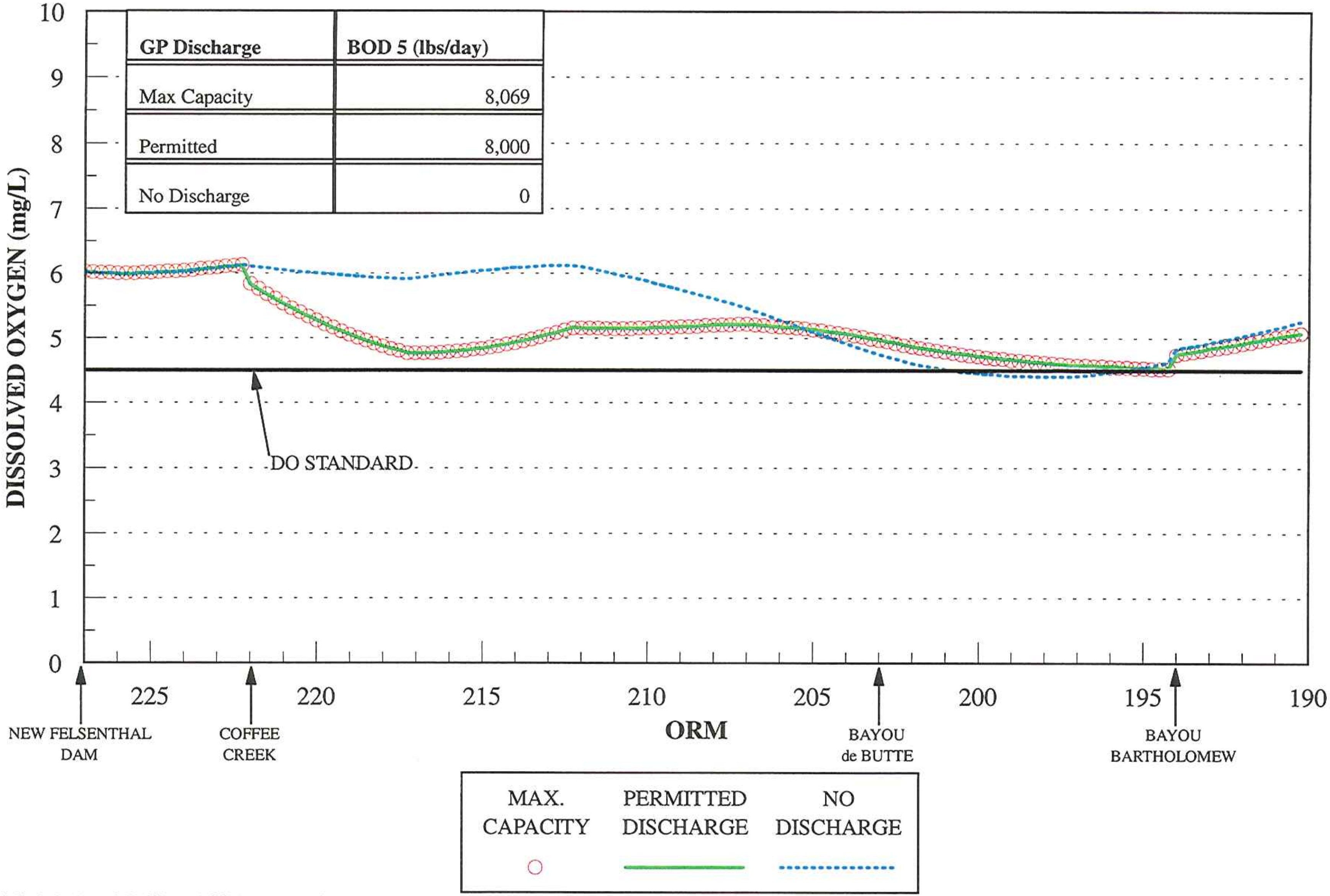
| GP Discharge | BOD 5 (lbs/day) |
|---|---|
| Max Capacity | 11,071 |
| Permitted | 8,000 |
| No Discharge | 0 |

Modeled at Q7-10 and mean temperature.
Q7-10 = 802 cfs; T = 30°C

## FIGURE 4-6

### AUGUST PREDICTED DO - 90TH PERCENTILE TEMPERATURE

OUACHITA RIVER NEAR CROSSETT, AR

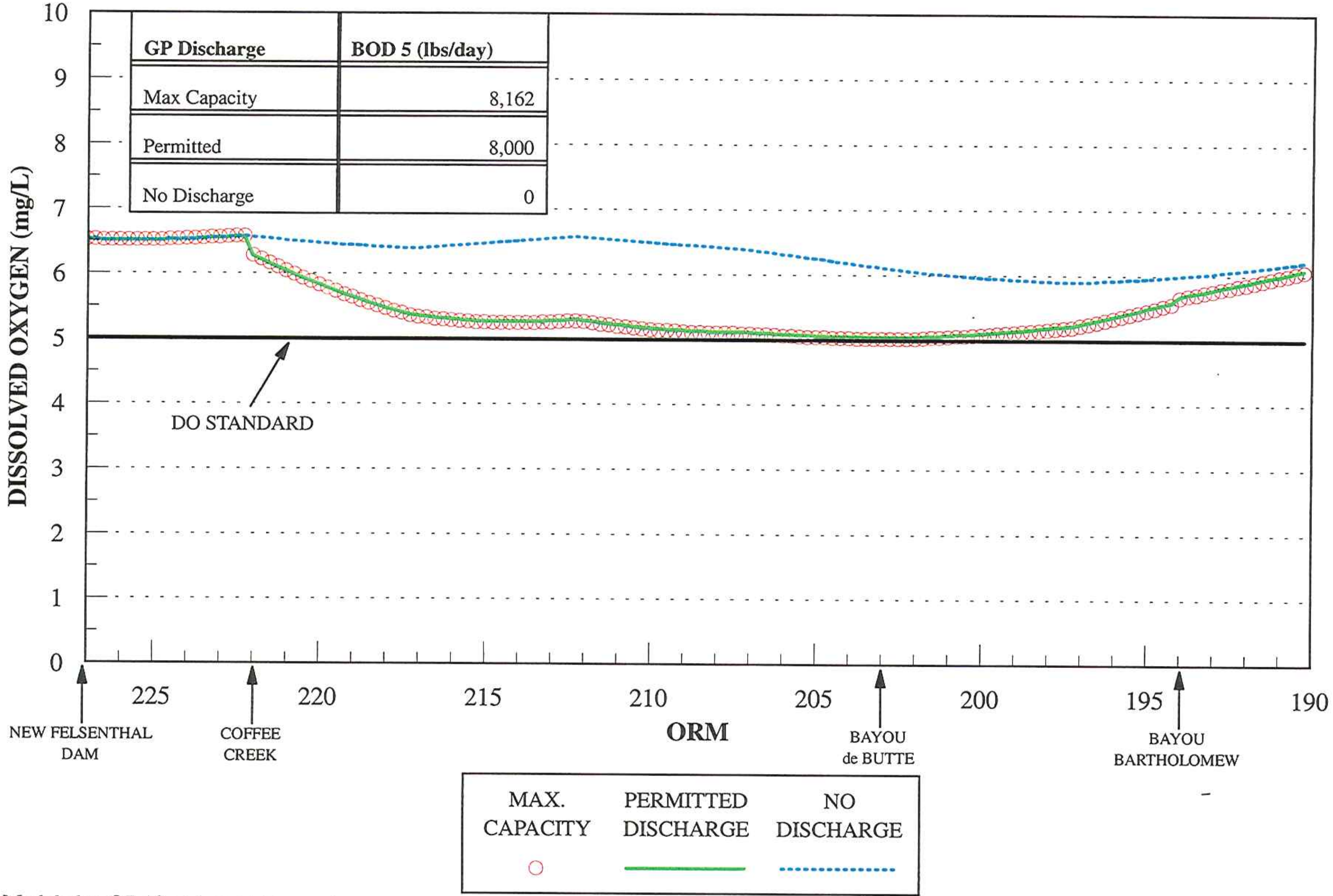


Modeled at Q7-10 and 90th percentile temperature.
Q7-10 = 802 cfs; T = 31.6°C

# FIGURE 4-7

## SEPTEMBER PREDICTED DO - MEAN TEMPERATURE

OUACHITA RIVER NEAR CROSSETT, AR



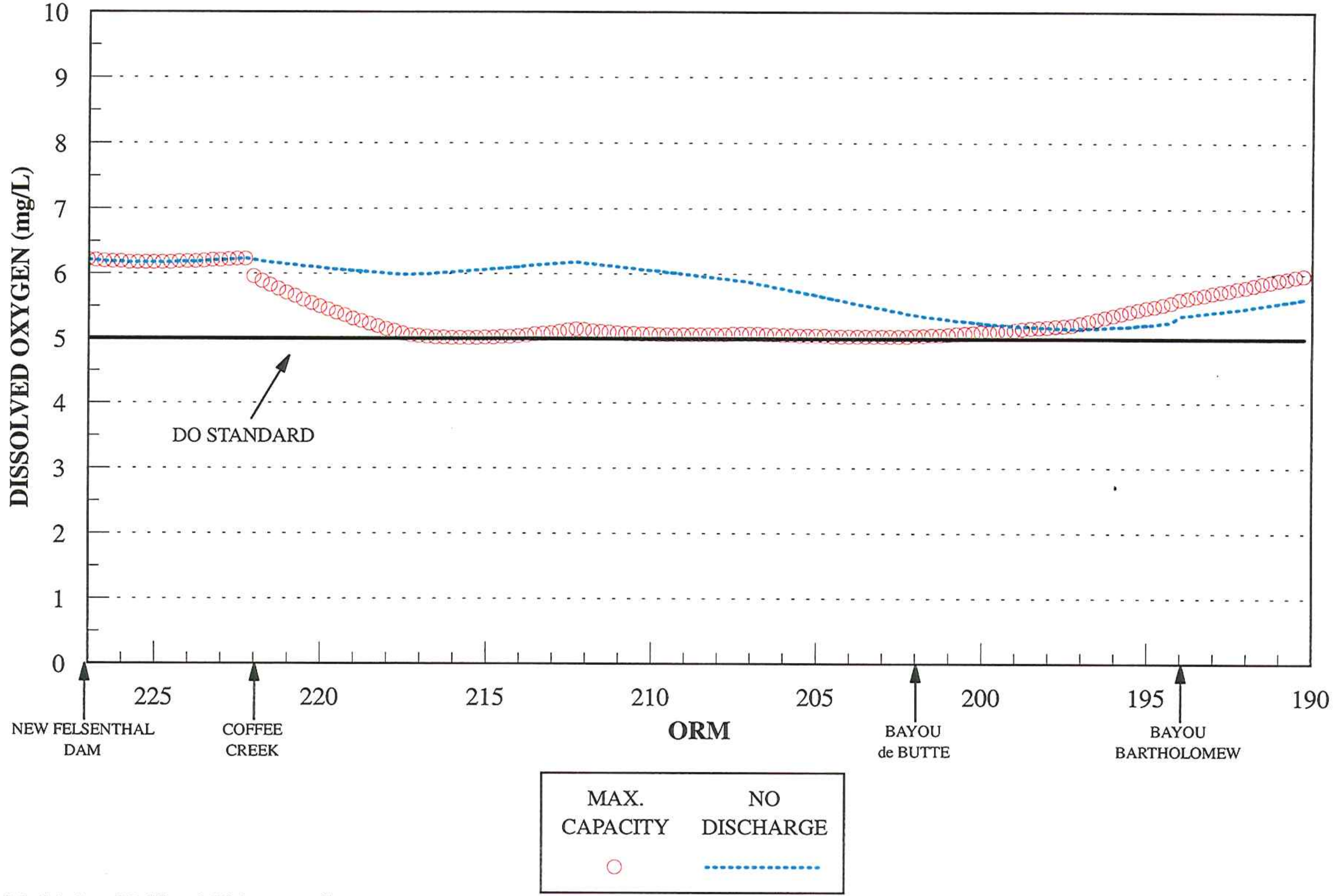
| GP Discharge | BOD 5 (lbs/day) |
|---|---|
| Max Capacity | 8,162 |
| Permitted | 8,000 |
| No Discharge | 0 |

Modeled at Q7-10 and mean temperature.
Q7-10 = 829 cfs; T = 27°C

# FIGURE 4-8

## SEPTEMBER PREDICTED DO - 90TH PERCENTILE TEMPERATURE

OUACHITA RIVER NEAR CROSSETT, AR



Modeled at Q7-10 and 90th percentile temperature.
Q7-10 = 829 cfs; T = 29.8°C

TABLE 4-5. DISSOLVED OXYGEN PERCENT SATURATION
OUACHITA RIVER NEAR CROSSETT, ARKANSAS

| MONTH | DATE | ORM | LOCATION | TEMP (°C) | MEASURED DO (mg/L) | SATURATION DO (mg/L) | DO % SATURATION |
|---|---|---|---|---|---|---|---|
| June | 25-Jun-98 | 224 | 3 mi. downstream of dam | 31.5 | 5 | 7.4 | 68% |
| July | 16-Jul-96 | 224 | 3 mi. downstream of dam | 29.8 | 6.7 | 7.6 | 88% |
|  | 21-Jul-98 | 224 | 3 mi. downstream of dam | 32 | 5.4 | 7.3 | 74% |
| August | 05-Aug-97 | 224 | 3 mi. downstream of dam | 30.6 | 6.9 | 7.5 | 92% |
|  | 27-Aug-98 | 224 | 3 mi. downstream of dam | 31.5 | 5.8 | 7.4 | 79% |
| September | 18-Sep-96 | 224 | 3 mi. downstream of dam | 27 | 6.5 | 8.0 | 82% |
|  | 16-Sep-97 | 224 | 3 mi. downstream of dam | 28.4 | 7.6 | 7.8 | 98% |
|  | 18-Sep-98 | 224 | 3 mi. downstream of dam | 27.5 | 5.9 | 7.9 | 75% |
| AVG. % SAT |  |  |  |  |  |  | 82% |

As discussed previously, the River conditions have changed significantly since the initiation of releasing water over the Dam. Therefore, an analysis of DO percent saturation from 1996 to the present is appropriate. It is also important to point out that the average percent saturation is based on measurements from both low-flow events and high stage or substantial nonpoint source inflows into the Ouachita River. The Arkansas and Louisiana DO standard for each month was also used in the analyses.

The minimum assimilative capacity available for wasteload allocation occurred during 7Q10 conditions in September. The current Georgia-Pacific Crossett Mill permitted discharge of 8,000 lbs/day $BOD_5$ was also input in to the model for the months of June through October, as presented in Figures 4-1 through 4-8 to show the impact of that loading on the stream. The permitted loading was not input into the model for the month of September due to the maximum capacity loading equaling less than 8,000 lbs/day $BOD_5$. In addition, the model was run with no Georgia-Pacific discharge to show the effects in the lower reaches of the stream, due to a nutrient deficiency when the Georgia-Pacific discharge is removed.

The maximum capacity $BOD_5$ projections in Tables 4-3 and 4-4 are also shown with a 10 percent safety factor reduction. This safety factor was agreed upon by USEPA, LDEQ, and ADPC&E during a November 4, 1998 conference call between those parties, Georgia-Pacific, and **AquAeTer**. With the 10 percent safety factor, the minimum $BOD_5$ loading available, using the mean temperature scenario, is predicted to be 7,346 lbs/day $BOD_5$ during the month of September. When the 90th percentile flow event, the 90th percentile temperature, and the 10 percent safety factor are used, the minimum $BOD_5$ loading available is predicted to be 5,911 lbs/day $BOD_5$ during the month of September.

The calibration model output and the inputs/outputs for the production run for September WLAs for both the average temperature and the 90th percentile temperature are presented in Appendix 11. Two disks containing the version of the QUAL2E model and the input/output files for the calibration model and WLA models for both the average and 90th percentile temperatures for June, July, August, and September are included in Appendix 11.

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