BRAZOS RIVER AUTHORITY OF TEXAS

Report on

Lakes Belton and Stillhouse Hollow

WATER QUALITY EVALUATION

PREPARED BY:

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SUMMARY OF WATER QUALITY EVALUATION

This report presents the results of Task II of the Brazos River Authority's Water Quality and Regional Facility Planning Study. This task included the evaluation of water quality objectives, collection of water quality data, calculation of point and nonpoint source loads, and the development and use of stream and lake water quality models for the following water bodies.

1. Lake Stillhouse Hollow
2. Lake Belton
3. Leon River Above Lake Belton
4. Leon River below Lake Belton
5. Sulphur Creek
6. Clear Creek
7. Lampasas River above Lake Stillhouse Hollow
8. Lampasas River below Lake Stillhouse Hollow
9. Nolan Creek (used model already developed by the Texas Water Commission)
10. House Creek
11. Turkey Run Creek

The following conclusions and recommendations have been made on the basis of the above work.

CONCLUSIONS

Lakes Belton and Stillhouse Hollow have been classified by the Texas Water Commission as two of the cleanest lakes in the State based on Carlson's Trophic State Index parameters set in the State of Texas Water Quality Inventory, 8th Edition, 1986. However, water quality data indicate that Lake Stillhouse Hollow water quality in terms of algae growth (as measured by chlorophyll 'a') is increasing with time. Sampling data collected for this study for both lakes showed higher levels of algae than the historical data. Lake Belton has what could be termed as excessive levels in the Leon River arm of the lake. These increased levels of algae may be due to the continuing point and nonpoint discharges and accumulation of nutrients (i.e., nitrogen and phosphorous) into the lakes. Much of the nutrient load entering the lakes settles to the bottom with soil particles or dead algae and can be recycled back into the water column to contribute to future increases in algae population. Some of the differences in algae population could be attributed to differences in climate conditions.

Water quality collected in this study show annual average chlorophyll 'a' values of about 11 ug/l at the dam of each lake. Based on this existing water quality and expected year to year variations, which are essentially uncontrollable, an annual average chlorophyll 'a' of between 10 and 15 ug/l at the dam of each lake should be used as an indicator of good water quality. In other words we suggest that existing annual average chlorophyll 'a' values would provide an appropriate target.

Results of preliminary water quality modeling indicate that Lake Stillhouse Hollow would be adversely impacted by point source nutrient loads unless advanced waste treatment is required to reduce these loads. As shown in Chapter IV, discharges of year 2030 point sources without advanced waste treatment would increase chlorophyll 'a' values at the dam. The projected values would be above existing chlorophyll 'a' concentrations and the projected values would be above the 10 to 15 ug/l target for Lake Stillhouse Hollow.

As further indicated in Chapter IV, chlorophyll 'a' concentrations at the dam in Lake Belton would not be significantly affected by projected point source discharges. Therefore the existing chlorophyll 'a' concentrations would be essentially unchanged. However, as shown in Figure II-13 for sites 9 and 10, chlorophyll 'a' in the upper arm of Lake Belton is frequently in excess of 100 ug/l. This concentration is above any reasonable criteria.

Modeling along with the water quality data reflect that the sediments in both lakes serve as a sink and source of nutrients. In the context of this report a sink is a place within the lake such as the lake bottom where nutrients are deposited and can accumulate. A source is a place where nutrients originate. Under certain conditions, lake sediments can become a source by releasing accumulated nutrients into the water column. In this way a sink can become a source.

RECOMMENDATIONS

Based on the above conclusions the following recommendations are made relative to Lakes Belton and Stillhouse Hollow:

1. The discharges into the lakes from point sources should be strongly discouraged in order to reduce nutrient loadings to the lakes.

2. Discharges into the lakes, if allowed, should be subject to the following conditions:

   - Treatment plants should be operated by an operator with at least a Class B certification.
   - Treatment plants should include effluent filters.
   - Treatment plants should be monitored in accordance with the requirements of the Texas Water Commission rules and regulations at a minimum frequency of once per week using a 24-hour composite sample.
   - Treatment plants should be constructed in a manner which will facilitate future addition of facilities to reduce nitrogen and phosphorus, if necessary.
   - Before a permit is granted an analysis should be required to determine the localized water quality impact of the discharge on cove and/or backwater areas.

3. An ongoing water quality monitoring program of each of the lakes should be implemented. Additionally, an annual water quality assessment report should be prepared and the lake water quality models used in this study should be verified.

Based on the stream water quality modeling performed in this study, a number of wastewater treatment plants in the study area may have more stringent permit limits imposed on their effluent discharges in the future. This may be observed in Table ES-1, which shows projected effluent limits for wastewater treatment plants discharging into streams modeled in this study. Wastewater treatment plants which may have stricter permit limits imposed in the future include those operated by the City of Gatesville, North Fort Hood, the City of Oglesby, the Temple-Belton Regional Sewerage System, Bell County WCID No. 1, the City of Lampasas (both plants), and the City of Copperas Cove (three plants).

TABLE ES-1

PROJECTED FLOWS AND EFFLUENT REQUIREMENTS
FOR LAKE BELTON AND LAKE STILLHOUSE HOLLOW STUDY AREA

Model	Year	Projected Flows: Gatesville (MGD)	Projected Flows: North Fort Hood (MGD)	Projected Flows: Oglesby (MGD)	Required Effluent Quality: Gatesville	Required Effluent Quality: North Fort Hood	Required Effluent Quality: Oglesby
Leon River above Lake Belton	1990	1.14	0.25	0.05	10/2/6	10/15/2	10/15/2
	2000	1.52	0.33	0.06	10/2/6	10/3/4	10/3/4
	2010	2.02	0.44	0.07	10/2/6	10/3/4	10/3/4
	2020	2.68	0.59	0.07	10/2/6	10/3/4	10/3/4
	2030	3.62	0.79	0.08	10/2/6	10/3/4	10/3/4

Model	Temple-Belton Regional Sewerage System For Permitted Flow of 10 MGD
Leon River Below Lake Belton	10/2/6

Model	Total Flow from Hypothetical WWTP's (MGD)	Required Effluent Quality
Lampasas River Below Lake Stillhouse Hollow	0.65	20/15/2

Note: Effluent Requirements shown in terms of BOD/NH_3-N/DO.

TABLE ES-1

PROJECTED FLOWS AND EFFLUENT REQUIREMENTS
FOR LAKE BELTON AND LAKE STILLHOUSE HOLLOW STUDY AREA
(continued)

Model	Year	Projected Flows: WCID #1 (MGD)	Projected Flows: WCID #1 STP #2 (MGD)	Projected Flows: Harker Heights WCID #4 (MGD)	Projected Flows: WCID #3 (MGD)	Required Effluent Quality: WCID #1	Required Effluent Quality: WCID #1 STP #2	Required Effluent Quality: Harker Heights WCID #4	Required Effluent Quality: WCID #3
					Alternative #1				
Nolan Creek Model	1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
	2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
	2010	17.04	2.12	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
	2020	19.16	3.64	3.00	0.44	7/2/6	7/2/6	10/3/4	10/15/2
	2030	19.16	7.68	3.72	0.56	7/2/6	7/2/6	10/3/4	10/15/2
					Alternative #2				
	1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
	2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
	2010	17.04	2.12	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
	2020	19.16	3.45	3.00	0.44	7/2/6	7/2/6	10/3/4	10/15/2
	2030	19.16	7.11	3.72	0.56	7/2/6	7/2/6	10/3/4	10/15/2
					Alternative #3				
	1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
	2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
	2010	17.04	1.06	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
	2020	19.16	2.22	2.44	0.44	7/2/6	7/2/6	10/3/4	10/15/2
	2030	19.16	4.16	2.70	0.56	7/2/6	7/2/6	10/3/4	10/15/2

Note: Effluent Requirements shown in terms of BOD/NH^3-N/DO.

TABLE ES-1

PROJECTED FLOWS AND EFFLUENT REQUIREMENTS
FOR LAKE BELTON AND LAKE STILLHOUSE HOLLOW STUDY AREA
(continued)

Model	Year	Total Projected Flows For Planning Area (MGD)	Required Effluent Quality
		City of Lampasas Low Flow Scenario	
Sulphur Creek	1990	0.70	10/15/2
	2000	0.90	10/3/4
	2010	1.20	10/3/4
	2020	1.50	10/3/4
	2030	1.80	10/3/4
		City of Lampasas High Flow Scenario	
	1990	0.74	10/15/2
	2000	1.01	10/3/4
	2010	1.42	10/3/4
	2020	1.96	10/3/4
	2030	2.62	10/3/4

Model	Year	Copperas Cove Northeast (MGD)	Copperas Cove Northwest (MGD)	Copperas Cove South (MGD)	Copperas Cove Northeast	Cooperas Cove Northwest	Copperas Cove South
House Creek, Turkey Creek, and Clear Creek	1990	0.92	1.51	0.85	10/3/4	10/3/4	10/3/4
	2000	1.07	1.89	1.37	10/3/4	10/3/4	10/3/4
	2010	1.19	2.04	1.59	10/3/4	10/3/4	10/3/4
	2020	1.29	2.23	1.75	10/3/4	10/3/4	10/3/4
	2030	1.35	2.46	1.93	10/3/4	10/3/4	10/3/4

Note: Effluent requirements shown in terms of BOD/NH_3-N/DO.

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CHAPTER I

WATER QUALITY OBJECTIVES

GENERAL

The purpose of this study is to determine measures required to protect the quality of water in study area streams and lakes so that the intended uses of these water bodies can be maintained. With the possible exception of limits for nutrients and chlorophyll 'a', the April 29, 1988, Texas Surface Water Quality Standards establish criteria and conditions which are adequate to meet the above objective. These standards include general criteria, an antidegradation provision, and limitations on toxic materials, all of which apply to all waters of the State. In addition, the Standards include site-specific uses and numerical criteria applicable to specific water bodies, which are referred to as stream segments. This chapter describes the water quality standards used in evaluating wastewater treatment needs for existing and potential dischargers into various area streams and Lakes Belton and Stillhouse Hollow. Where possible, critical low flows were taken from the April 1988, Texas Surface Water Quality Standards. In cases where no low flow criteria were published an assumed low flow value was used based on field observations and best engineering judgement. A map showing the location of these various water bodies is included as Figure I-1. The lack of criteria for nutrients and recommendations for addressing the nutrient issue are discussed with water quality objectives for Lakes Belton and Stillhouse Hollow.

WATER QUALITY STANDARDS FOR STUDY AREA STREAMS

Water Quality Standards for Classified Stream Segments

The Texas Water Commission has established water uses and numerical criteria on a site-specific basis for a number of stream segments in Texas. Table I-1 lists these uses and criteria for the streams and lakes which

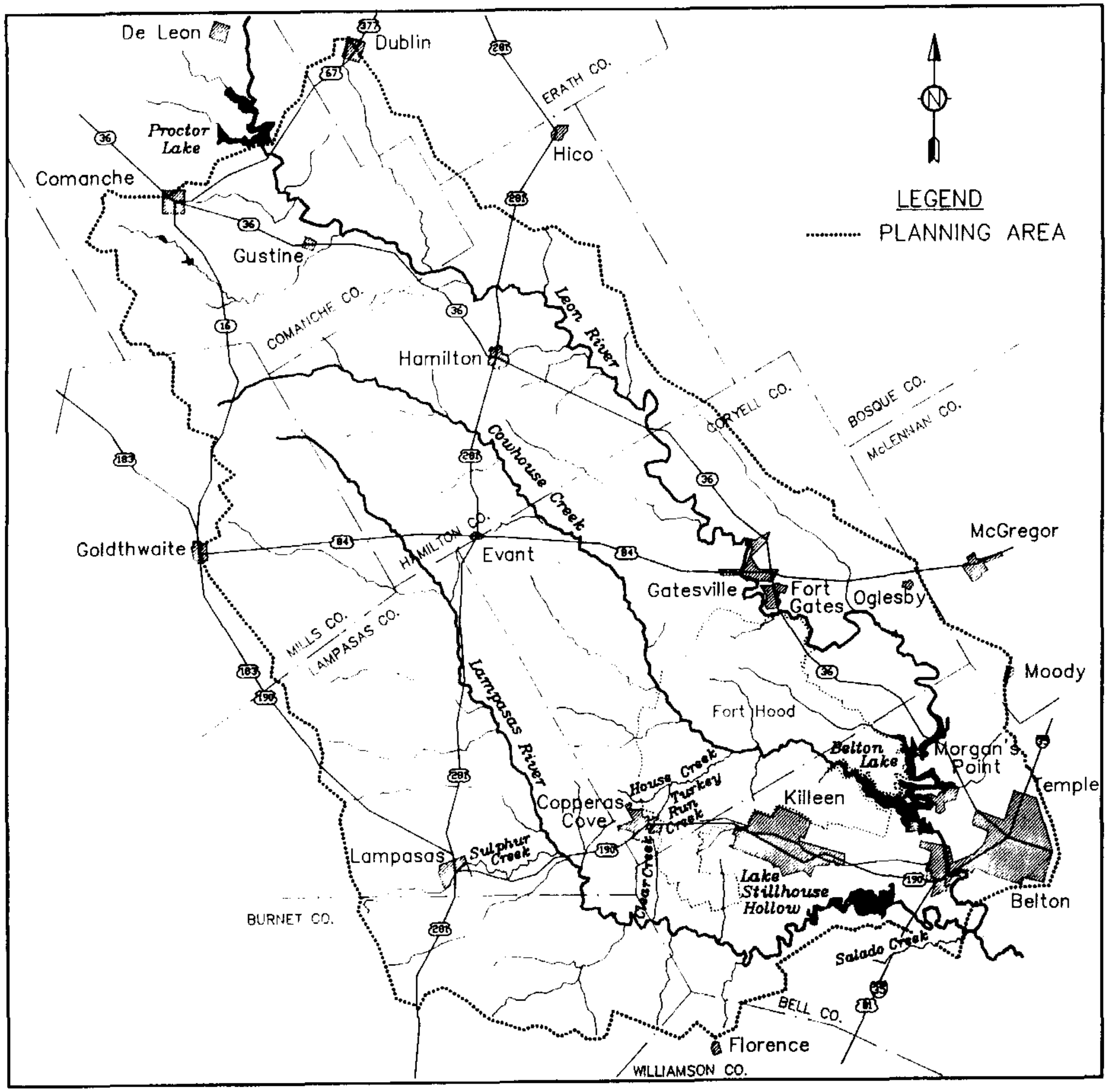


FIGURE I-1
LAKE BELTON AND LAKE
STILLHOUSE HOLLOW STUDY AREA

TABLE I-1

CURRENT TEXAS SURFACE WATER QUALITY STANDARDS
LAKE BELTON AND LAKE STILLHOUSE HOLLOW DRAINAGE AREAS

Segment Number	Segment Name	Water Uses[1] A	B	C	D	CL[2] (mg/l)	SO_4[3] (mg/l)	TDS[4] (mg/l)	DO[5] (mg/l)	pH (S.U.)	Fecal[6] Coliform	Temp[7] (°F)
1215	Lampasas River Below Lake Stillhouse Hollow	CR	H	PS		100	75	500	5.0	6.5-9.0	200	91
1216	Lake Stillhouse Hollow	CR	E	PS		100	75	500	6.0	6.5-9.0	200	93
1217	Lampasas River Above Lake Stillhouse Hollow	CR	H			480	80	840	5.0	6.5-9.0	200	91
1218	Nolan Creek	CR	H	PS		100	75	500	5.0	6.5-9.0	200	93
1219	Leon River Below Lake Belton	CR	H	PS		150	75	500	5.0	6.5-9.0	200	91
1220	Lake Belton	CR	H	PS		100	75	500	5.0	6.5-9.0	200	93
1221	Leon River Below Lake Proctor	CR	H	PS		150	75	500	5.0	6.5-9.0	200	90

Source: Texas Water Commission SURFACE WATER QUALITY STANDARDS, April 1988

[1]Class A: Recreation (CR - Contact Recreation)
Class B: Aquatic Life (H - High Quality, E - Exceptional Quality)
Class C: Domestic Water Supply (PS - Public Water Supply)
Class D: Other

[2]Chlorides: Annual average not to exceed this value.

[3]Sulfate: Annual average not to exceed to this value.

[4]Total Dissolved Solids: Annual average not to exceed this value.

[5]Dissolved Oxygen: Minimum value for 24-hour mean. For thermally stratified impoundments, compliance is measured in the epilimnion.

[6]Fecal Coliform: For contact recreation, fecal coliform content shall not exceed 200 colonies per 100 ml as a geometric mean based on a representative sampling of not less than 5 samples collected over not more than thirty days.

[7]Temperature: Not to exceed this value.

have been classified in this manner within the planning area for this study. The following paragraphs describe each of these classified stream segments.

Leon River Below Lake Proctor. The Leon River Below Proctor Lake (Segment 1221) extends from a point 100 meters upstream of FM 236 in Coryell County to Proctor Dam in Comanche County. The site-specific uses and criteria which apply to Segment 1221 are presented in Table I-1.

Wastewater treatment needs in the Gatesville area were based on a dissolved oxygen limit of 5.0 mg/l, a critical low flow of 2.0 cfs, and a temperature of 27.5°C. The 5.0 mg/l dissolved oxygen limit and 2.0 cfs critical low flow are values specified in the Texas Surface Water Quality Standards for Segment 1221. The temperature of 27.5°C is the maximum summer temperature of water in Segment 1221.

Nolan Creek. Nolan Creek (Segment 1218) extends from the confluence with the Leon River in Bell County to a point 100 meters upstream of the most upstream crossing of US 190 near the intersection of US 190 and Loop 172 in Bell County.

The site-specific uses and criteria which apply to Segment 1218 are shown in Table I-1.

Wastewater treatment needs in the Killeen, Harker Heights, and Nolanville areas were based on a dissolved oxygen limit of 5.0 mg/l, a critical low flow of 0.1 cfs, and a temperature of 29.5°C.

Leon River Below Lake Belton. The Leon River Below Belton Lake (Segment 1219) extends from the confluence with the Lampasas River in Bell County to Belton Dam in Bell County. The site-specific uses and criteria which apply to Segment 1219 are presented in Table I-1.

Wastewater treatment plant effluent requirements for the Temple/Belton Regional Sewerage System were based on a 5.0 mg/l limit for dissolved oxygen, an upstream critical low flow of 0.5 cfs, and a temperature of 24.3°C.

Lampasas River Above Lake Stillhouse Hollow. The Lampasas River Above Lake Stillhouse Hollow (Segment 1217) extends from a point immediately upstream of the confluence of Rock Creek in Bell County to FM 2005 in Hamilton County. The site-specific uses and criteria which apply to Segment 1217 are shown in Table I-1.

There are no point source dischargers which discharge directly into this segment.

Lampasas River Below Lake Stillhouse Hollow. The Lampasas River Below Lake Stillhouse Hollow (Segment 1215) extends from the confluence with the Leon River in Bell County to Stillhouse Hollow Dam in Bell County. The site-specific uses and criteria which apply to Segment 1215 are presented in Table I-1.

Wastewater treatment plant effluent requirements for this segment were based on a 5.0 mg/l limit for dissolved oxygen, a critical low flow of 4.3 cfs, and a temperature of 24.3°C.

Water Quality Standards for Unclassified Stream Segments

Four streams in the study area were evaluated which do not have established water uses and numerical criteria. These are House Creek, Turkey Run Creek, Clear Creek, and Sulphur Creek. Texas Surface Water Quality Standard's General Criteria, Antidegradation Policy and Toxic Materials Criteria all apply to these unclassified stream segments. The above mentioned General Criteria provides that the dissolved oxygen standard for unclassified segments will be based on the aquatic use of the segment (see Table I-2). Where little or no data are available to assess aquatic uses, the stream segment is assumed to have a limited aquatic life use and associated dissolved oxygen criteria. However, this assumption is subject to change when administrative or regulatory action is taken by the TWC which relates to the particular unclassified water body. The following paragraphs describe each of the unclassified stream segments which were evaluated.

House Creek, Turkey Run Creek, and Clear Creek. House, Turkey Run, and Clear Creeks are unclassified streams in Coryell County which respectively receive effluent from each of three Copperas Cove wastewater treatment plants. According to the Texas Surface Water Quality Standards, unclassified waters which are perennial or support perennial aquatic life uses are designated for the specific uses that are existing or characteristic of those waters. In instances where the executive director of the commission determines that little or no information is available to assess those uses, the waters will be preliminarily assumed to have a limited aquatic life use. As no information were found on the aquatic uses of these creeks, they were assumed to have a limited aquatic life use. The dissolved oxygen standard for limited aquatic life use is an average of 3.0 mg/l over a 24 hour period. Water quality modeling to determine wastewater treatment needs for Copperas Cove were based on the 3.0 mg/l dissolved limit, a critical low flow of 0.1 cfs, and a temperature of 29.5°C in each creek.

Sulphur Creek. Sulphur Creek is an unclassified stream in Lampasas County which receives effluent from the City of Lampasas' wastewater treatment plant. No information was found on the aquatic uses for Sulphur Creek. Thus Sulphur Creek was assumed to be a limited aquatic use habitat with a dissolved oxygen standard of 3.0 mg/l. Wastewater treatment plant effluent requirements for the City of Lampasas was based on a 3.0 mg/l limit for

TABLE I-2

CURRENT TEXAS SURFACE
AQUATIC LIFE SUBCATEGORIES

Aquatic Life Use Subcategory	Dissolved Oxygen Criteria, mg/l			Aquatic Life Attributes					
	Freshwater mean/minimum	Freshwater in Spring mean/minimum	Saltwater mean/minimum	Habitat Characteristics	Species Assemblage	Sensitive Species	Diversity	Species Richness	Trophic Structure
Exceptional	6.0/4.0	6.0/5.0	5.0/4.0	Outstanding Natural Variability	Exceptional or Unusual	Abundant	Exceptionally High	Exceptionally High	Balanced
High	5.0/3.0	5.5/4.5	4.0/3.0	Highly Diverse	Unusual Association Expected Species	Present	High	High	Balanced to Slightly Imbalanced
Intermediate	4.0/3.0	5.0/4.0	3.0/2.0	Moderately Diverse	Some Expected Species	Very low in Abundance	Moderate	Moderate	Moderately Imbalanced
Limited	3.0/2.0	4.0/3.0		Uniform	Few Expected Species	Rare	Low	Low	Severely Imbalanced

Dissolved oxygen means are applied as an average over a 24-hour period.

Daily minima are not to extend beyond 8-hours per 24-hour day. Lower dissolved oxygen minima may apply on a site-specific basis, when natural daily fluctuations below the mean are greater than the difference between the mean and minima of the appropriate criteria.

Spring criteria to protect fish spawning periods are applied during that portion of the first half of the year when water temperatures are 63.0°F to 73.0°F.

Aquatic life attributes are preliminary and subject to further refinement pending results of studies being conducted by the commission. Quantitative criteria to support aquatic life attributes are being developed with conjunction with the research.

Dissolved oxygen analyses and computer models to establish effluent limits for permitted discharges will normally be applied to mean criteria at steady-state, critical conditions.

Determination of standards attainment for dissolved oxygen criteria is specified in §307.9(d)(6) (relating to Determination of Standards Attainment).

dissolved oxygen, a critical low flow of 2.0 cfs, and a temperature of 30.0°C.

LAKE WATER QUALITY OBJECTIVES

As previously mentioned, except for nutrients and chlorophyll 'a', the April 19, 1988 Texas Surface Water Quality Standards (see Table I-1) are adequate to support the intended uses of Lakes Belton and Stillhouse Hollow. There are no national or state-wide water quality standards for in-lake concentrations of chlorophyll 'a' or the nutrients nitrogen and phosphorous.

Increases in chlorophyll 'a' concentration over time are one of the measures of lake eutrophication. The State of Texas data bases for Lakes Belton and Stillhouse Hollow, shown in the 1986 State of Texas Water Quality Inventory, published by the Texas Water Commission, are limited with nine chlorophyll 'a' samples available. These samples indicate average chlorophyll 'a' concentrations of 2 and 3 ug/l near the dams in Lakes Stillhouse Hollow and Belton, respectively. There are no other comprehensive data on lake water quality in the State of Texas data base for the two lakes. Based on these data, both lakes are reported to have good water quality when compared to the other lakes in the state which were reported to vary from about 1 ug/l to 70 ug/l chlorophyll 'a'.

The State of Texas data base has been augmented by the sampling program which is a part of the present study. The data from the current program indicates a mean chlorophyll 'a' concentration of slightly in excess of 11 ug/l at the surface for the stations closest to the dams in each of the lakes. This is in contrast to the more limited historical data which indicates average chlorophyll 'a' concentrations, at comparable locations, of approximately 2 and 3 ug/l for Lakes Stillhouse Hollow and Belton respectively.

Comparisons of the average chlorophyll 'a' concentration at the dams for Lakes Belton and Stillhouse Hollow with the information on Texas lakes in the state data base suggests that these lakes are roughly at the average chlorophyll 'a' concentration observed in state lakes. It is difficult to clearly interpret the comparison of the value of the average chlorophyll 'a' obtained from an annual data set with the information in the state data base. The state data base represents more random sampling where some of the lakes are represented by very small data bases and other lakes have been fairly extensively sampled. In this context a water quality objective which limits the chlorophyll 'a' in the main lake near the dam to between 10 and 15 ug/l could be considered. However, this target should be subjected to continued evaluation using data from an ongoing water quality monitoring program which has been recommended for each of these lakes.

In conclusion, the water quality objectives for Lakes Belton and Stillhouse Hollow should be as follows:

1. The Texas Surface Water Quality Standards for segments 1216 (Lake Stillhouse Hollow) and 1220 (Lake Belton); and
2. A chlorophyll 'a' target of between 10 and 15 ug/l in the main lake near the dam in each lake.

CHAPTER II

WATER QUALITY DATA

INTRODUCTION

Water quality monitoring of the lakes and streams in the study area has been conducted for many years by various federal and state agencies. Agencies which have performed water quality monitoring prior to this study include the U.S. Geological Survey (USGS), the Texas Water Commission (TWC), and the Central Texas Council of Governments (CTCOG) for a 1980 report on nonpoint source pollution.

As part of this study, Lakes Stillhouse Hollow and Belton were sampled by the Brazos River Authority twelve times during the course of a year to provide a data base that could be used to develop a model of each lake's water quality. Stream surveys were conducted on seven streams as part of the study to develop water quality models. Sampling was conducted at several points along each stream's course to determine changes in water quality, especially below point source discharges. The sampling sites were visited more than once during the sampling day to provide an indication of diurnal changes in water quality. Nonpoint Source (NPS) sampling was conducted to determine the pollutant concentrations for various landuses. In the following sections, historical water quality monitoring and the water quality monitoring performed by the Brazos River Authority for this study will be described and data from the various monitoring programs will be presented.

HISTORICAL WATER QUALITY MONITORING

Data collected during the period 1978-1988 were used to assess the historical water quality for Lakes Belton and Stillhouse Hollow and for the Leon and Lampasas Rivers immediately upstream and downstream from each lake.

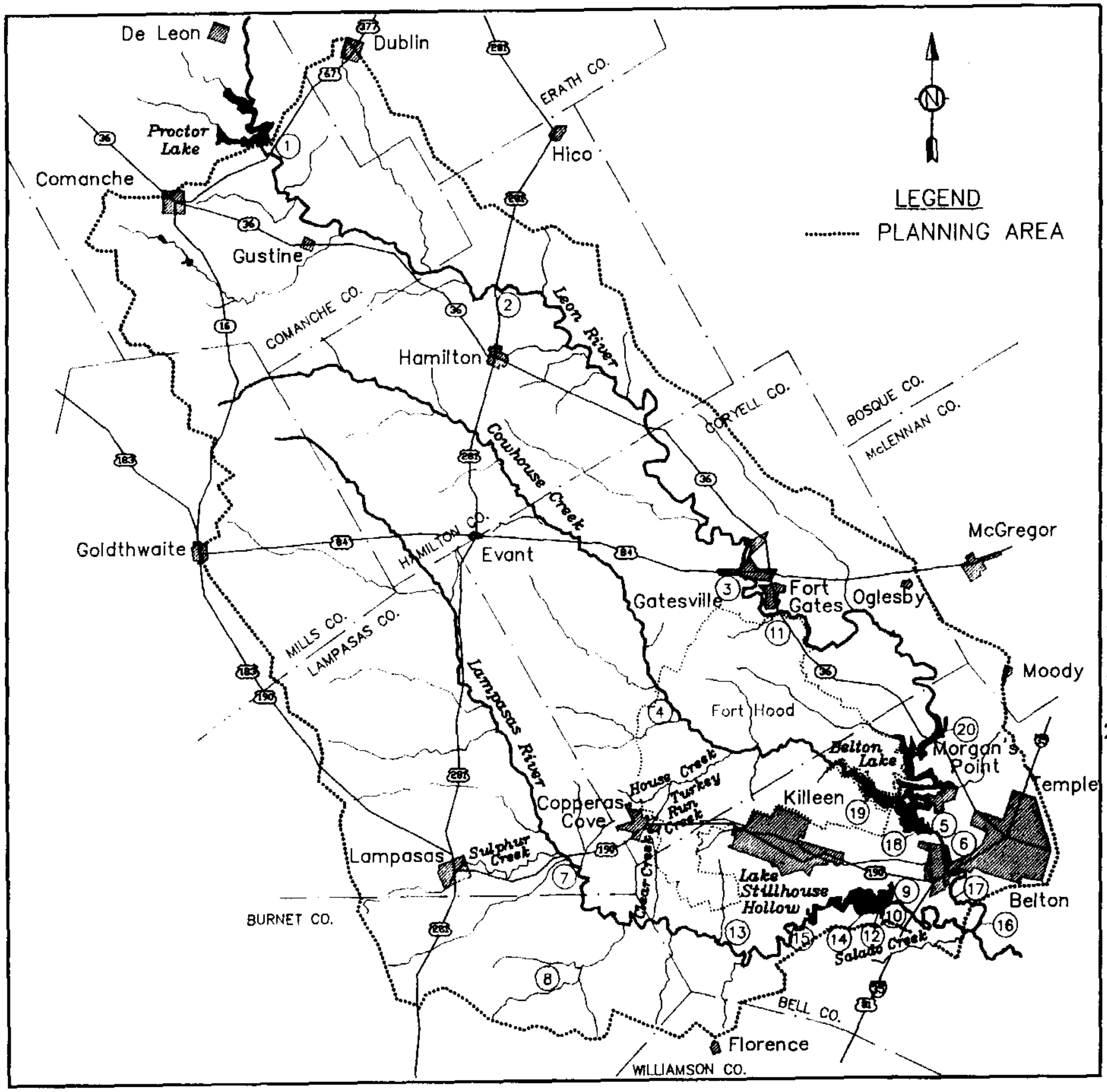
Much of the data used in this historical water quality assessment were collected by the Texas Water Commission (TWC) and the United States Geological Survey (USGS). The TWC and the USGS both operate monitoring stations where data have been periodically collected. Figure II-1 shows the locations of the TWC and USGS monitoring stations. Data collected for this study and the 1980 CTCOG at the TWC and USGS monitoring sites are also included in this section.

The water quality assessment results for both the lakes and rivers are presented using minimum, maximum, average values, and the number of samples collected for each water quality parameter. All samples collected at each site were used in making this determination.

Some of the sampling stations were monitored on a regular basis over the period evaluated, while other stations were sampled infrequently or discontinued during the study period. Data were collected by the Brazos River Authority for this study only in 1987 and 1988, and data were collected by CTCOG only in 1980. The parameters analyzed at the stations varied. However, most sampling stations did include the basic physical and chemical water quality parameters: DO, temperature, chlorophyll 'a', and the nitrogen and phosphorous series. The following presents summaries of the data collected for lakes and streams in the study area.

Streams

The historical water quality data summary for the Leon River immediately upstream and downstream of Lake Belton is presented in Table II-1. The historical water quality data summary for the Lampasas River immediately upstream and downstream of Lake Stillhouse Hollow is presented in Table II-2.



1. DISCHARGE GAGE LEON RIVER NEAR HASSE
2. DISCHARGE GAGE LEON RIVER NEAR HAMILTON
3. DISCHARGE GAGE LEON RIVER AT GATESVILLE
4. DISCHARGE GAGE COWHOUSE CREEK AT PIDCOKE
5. DISCHARGE GAGE BELTON LAKE NEAR BELTON
6. DISCHARGE GAGE LEON RIVER AT FM 817 NEAR BELTON
7. DISCHARGE GAGE LAMPASAS RIVER NEAR KEMPNER
8. MONITORING GAGE SOUTH FORK ROCKY CREEK NEAR BRIGGS
9. DISCHARGE GAGE STILLHOUSE HOLLOW LAKE NEAR BELTON
10. DISCHARGE GAGE LAMPASAS RIVER NEAR BELTON
11. MONITORING GAGE LEON RIVER AT SH 36 SOUTHEAST OF GATESVILLE
12. MONITORING GAGE LAMPASAS RIVER AT INTERSTATE HWY 35 – US HWY 81
13. MONITORING GAGE LAMPASAS RIVER AT FM 440
14. MONITORING GAGE STILLHOUSE HOLLOW RESERVOIR– NEAR DAM
15. MONITORING GAGE STILLHOUSE HOLLOW RESERVOIR– AT HEADWATER
16. MONITORING GAGE LEON RIVER AT FM 436
17. MONITIRING GAGE LEON RIVER AT FM 93 NEAR BELTON
18. MONITORING GAGE LAKE BELTON NEAR DAM NEAR BELTON
19. MONITORING GAGE LAKE BELTON COWHOUSE CREEK ARM
20. MONITORING GAGE LAKE BELTON LEON RIVER ARM

FIGURE II-1
LAKE BELTON AND LAKE STILLHOUSE HOLLOW STUDY AREA MONITORING STATIONS

TABLE II-1

LEON RIVER NEAR LAKE BELTON
HISTORICAL WATER QUALITY DATA SUMMARY

LOCATION: Leon River at Headwater of Lake Belton
REPORTING PERIOD: 2/9/79 through 2/16/87
SOURCES: Texas Water Commission, Central Texas Council of Governments

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.153	0.005	0.010	0.041	0.008	0.050
Maximum	2.411	0.360	2.622	2.320	2.290	105.280
Average	0.685	0.074	0.445	0.434	0.332	9.374
No. of Samples	12	43	44	42	42	39

LOCATION: Leon River Below Lake Belton Dam
REPORTING PERIOD: 3/12/80 through 9/30/80
SOURCES: Central Texas Council of Governments

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.172	0.002	0.029	0.007	0.002	0.590
Maximum	0.561	0.051	0.550	0.188	0.021	67.920
Average	0.292	0.017	0.179	0.053	0.006	16.900
No. of Samples	11	11	11	9	9	8

TABLE II-2

LAMPASAS RIVER NEAR STILLHOUSE HOLLOW RESERVOIR
HISTORICAL WATER QUALITY DATA SUMMARY

LOCATION: Lampasas River at Headwater of Stillhouse Hollow Reservoir
REPORTING PERIOD: 2/12/79 through 2/19/87
SOURCES: Texas Water Commission, Central Texas Council of Governments

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.037	0.005	0.010	0.010	0.002	0.100
Maximum	1.370	0.130	1.160	0.960	0.070	35.700
Average	0.352	0.030	0.151	0.080	0.014	4.478
No. of Samples	13	45	45	44	43	39

LOCATION: Lampasas River Below Stillhouse Hollow Reservoir
REPORTING PERIOD: 3/10/80 through 8/3/82
SOURCES: Central Texas Council of Governments, United States Geological Survey, Brazos River Authority

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.039	0.002	0.050	0.005	0.002	0.510
Maximum	1.133	0.112	1.800	0.214	0.082	13.100
Average	0.327	0.037	0.612	0.050	0.015	5.172
No. of Samples	19	20	21	19	11	10

Lakes

The historical water quality data were available for three sites on Lake Belton: 1) Near the dam; 2) At the Leon River Arm near the headwater; and 3) At the Cowhouse Creek Arm. The summary of the historical water quality data is presented in Table II-3. Higher values for most of the parameters were observed in the Leon River Arm than at other sites.

Historical data at two sites were evaluated for Lake Stillhouse Hollow: 1) Near the dam and 2) Near the Lampasas River headwater. The summary of the historical water quality data for Lake Stillhouse Hollow is presented in Table II-4. Higher values for most of the parameters analyzed were observed near the Lampasas River headwater than near the dam, however higher values of total and orthophosphorous were observed near the dam.

BRAZOS RIVER AUTHORITY MONITORING FOR THIS STUDY

Stream Monitoring

Stream surveys for this study were conducted to develop water quality models that were used to determine effluent requirements for point source dischargers into the stream. Surveys were conducted during periods of moderate to low flow so impacts of current point source discharges could be distinguished. At each sampling site, measurements of temperature, dissolved oxygen, pH, conductance, and discharge were taken. A sample of water for laboratory analysis was also taken. When possible, each site was visited two or more times during the day so diurnal changes could be determined. Samples from each visit at a particular site were composited to determine the average daily water quality. The sample analysis included BOD5, TSS, VSS, ammonia, nitrite, nitrate, organic nitrogen,total phosphorus and orthophosphorus.

TABLE II-3

LAKE BELTON
HISTORICAL WATER QUALITY DATA SUMMARY

LOCATION: Lake Belton Near Dam
REPORTING PERIOD: 3/10/78 through 8/19/88
SOURCES: Texas Water Commission, Brazos River Authority, Central Texas Council of Governments, United States Geological Survey

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.060	0.001	0.002	0.002	0.002	1.462
Maximum	1.370	0.780	0.474	0.720	0.075	37.450
Average	0.453	0.090	0.132	0.056	0.013	9.249
No. of Samples	49	65	63	66	56	32

LOCATION: Lake Belton at Cowhouse Creek Arm
REPORTING PERIOD: 10/10/79 through 8/19/88
SOURCES: Texas Water Commission, Brazos River Authority, Central Texas Council of Governments

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.050	0.004	0.003	0.006	0.002	2.000
Maximum	2.114	0.504	0.295	0.159	0.061	42.060
Average	0.324	0.067	0.087	0.033	0.013	12.629
No. of Samples	21	29	28	28	28	25

TABLE II-3

LAKE BELTON
HISTORICAL WATER QUALITY DATA SUMMARY
(continued)

LOCATION: Lake Belton at Leon River Arm
REPORTING PERIOD: 10/10/79 through 8/19/88
SOURCES: Texas Water Commission, Brazos River Authority, Central Texas Council of Governments

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.090	0.010	0.010	0.010	0.002	3.000
Maximum	5.520	0.510	0.659	0.767	0.129	261.310
Average	0.878	0.144	0.131	0.081	0.021	70.473
No. of Samples	38	47	47	45	46	28

TABLE II-4

LAKE STILLHOUSE HOLLOW
HISTORICAL WATER QUALITY DATA SUMMARY

LOCATION: Lake Stillhouse Hollow Near Dam
REPORTING PERIOD: 10/10/79 through 7/14/88
SOURCES: Texas Water Commission, Brazos River Authority, Central Texas Council of Governments, United States Geological Survey

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.080	0.004	0.009	0.001	0.001	0.100
Maximum	1.319	0.250	0.342	0.380	0.171	26.450
Average	0.326	0.071	0.109	0.037	0.020	7.630
No. of Samples	39	44	51	54	42	30

LOCATION: Lake Stillhouse Hollow Near Lampasas River Headwater
REPORTING PERIOD: 10/10/79 through 7/14/88
SOURCES: Texas Water Commission, Brazos River Authority, Central Texas Council of Governments, United States Geological Survey

	Organic Nitrogen mg/l	Ammonia Nitrogen mg/l	Nitrate and Nitrite Nitrogen mg/l	Total Phosphorous mg/l	Ortho-Phosphorous mg/l	Chlorophyll 'a' ug/l
Minimum	0.040	0.005	0.003	0.005	0.002	0.900
Maximum	2.190	0.495	0.399	0.070	0.048	36.990
Average	0.435	0.083	0.085	0.025	0.013	12.658
No. of Samples	35	40	48	50	40	29

Leon River. The Leon River above Lake Belton was sampled on two occasions, October 13, 1987 and February 16, 1988. Four sites and the Gatesville wastewater treatment plant (WWTP) were sampled on both occasions, and a fifth site was added for the February sampling. Figure II-2 is a map of the sampling sites. The field observations are presented in Table II-5 and Table II-6 for the October and February surveys, respectively. During the February survey each site was only visited once, since a time of travel study was being conducted concurrently. Data presented in the tables indicate that the WWTP had a slight impact on dissolved oxygen downstream of the discharge (site 2) and the stream recovered rapidly.

The results of the chemical analysis of the water samples are also presented in Tables II-5 and II-6. In both surveys the nutrient levels in the stream were elevated below the WWTP. During both surveys the WWTP effluent had high BOD5 ,ammonia and organic nitrogen concentrations. The total nitrogen and total phosphorus levels found during the October survey steadily decreased below the WWTP, while the February survey showed the nitrogen and phosphorus levels to be constant or increasing downstream. The differences could be due to nutrient cycling by plant life. In October the aquatic plant life was probably actively growing, while in February most growth was stopped and some mortality may have occurred which could reintroduce nutrient into the water column.

Sulphur Creek. Sulphur Creek was sampled from just above the two City of Lampasas' WWTPs to just above the confluence with the Lampasas River. Five sites were sampled as well as the two WWTPs. Figure II-3 is a map of the creek and the sampling sites. The field measurements and the analyses of the water samples are shown in Table II-7. The dissolved oxygen measurements show that the WWTP discharges had almost no impact on the stream's dissolved oxygen. This is partially due to the moderate flows in the stream and the low ammonia levels in the effluent. The dissolved oxygen

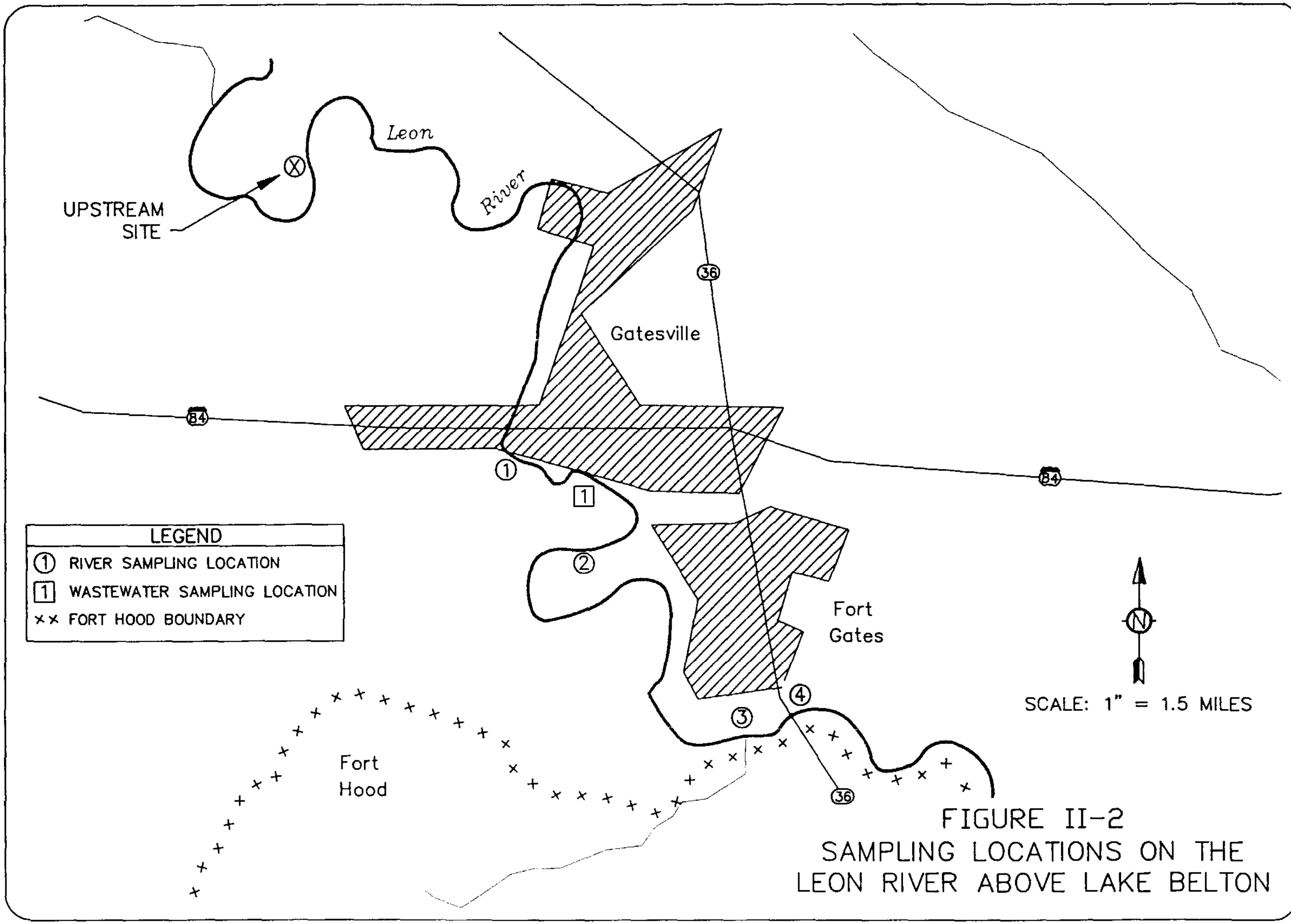


FIGURE II-2
SAMPLING LOCATIONS ON THE
LEON RIVER ABOVE LAKE BELTON

TABLE II-5

RESULTS OF INTENSIVE SURVEY OF LEON RIVER ABOVE LAKE BELTON ON OCTOBER 13, 1987

Field Measurements Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft^2	Average velocity ft/sec	Discharge ft^3/sec
Leon River								
Site 1	11:36 am	17.03	8.15	7.50	856	41.8	0.49	20.4
	3:24 pm	18.15	8.22	7.50	857			
	5:36 pm	18.06	7.72	7.52	860	44.1	0.51	22.5
Gatesville WWTP	11:00 am	23.93	7.60	7.55	2120			
	3:11 pm	24.68	6.57	7.45	2130			
	4:58 pm	25.10	6.60	7.44	2140			
Site 2	1:30 pm	17.53	6.75	7.36	910	53.8	0.46	24.6
Site 3	9:30 am	16.90	6.75	7.33	897	39.9	0.59	23.5
	2:52 pm	18.30	7.26	7.34	887			
	4:20 pm	18.32	7.64	7.41	886	39.9	0.57	22.8
Site 4	7:30 am	16.85	7.60	7.38	883	15.3	1.86	1.86
	2:35 pm	18.02	8.43	7.40	878			
	3:55 pm	17.91	8.0	7.38	883	14.8	1.76	26.1

TABLE II-5

RESULTS OF INTENSIVE SURVEY OF LEON RIVER ABOVE LAKE BELTON ON OCTOBER 13, 1987
(continued)

Laboratory Measurements Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
Leon River									
Site 1	1.5	10.5	3.3	0.06	0.40	0.003	0.13	0.039	0.056
Gatesville WWTP	23.2	68.4	59.0	7.6	3.60	1.170	9.78	5.39	10.45
Site 2	1.5	11.4	0.5	0.25	0.62	0.055	0.38	0.293	0.541
Site 3	1.8	9.6	0.8	0.13	0.65	0.049	0.21	0.277	0.633
Site 4	1.2	19.5	1.0	0.06	0.60	0.023	0.08	0.182	0.353

TABLE II-6

RESULTS OF INTENSIVE SURVEY OF LEON RIVER ABOVE LAKE BELTON ON FEBRUARY 16, 1988

Field Measurements Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft^2	Average velocity ft/sec	Discharge ft^3/sec
Leon River								
Upstream Site	10:35 am	8.03	11.9	7.63	1126	30.7	0.70	21.6
Site 1	8:55 am	8.90	10.66	7.54	1080	73.1	0.28	20.5
Gatesville WWTP	12:10 pm	16.51	8.87	7.33	1277			
Site 2	11:30 am	10.06	9.94	7.51	1082	28.4	0.71	20.1
Site 3	1:45 pm	11.17	13.04	7.73	1059	13.8	1.56	21.5
Site 4	4:20 pm	10.91	12.08	7.67	759	20.3	1.18	24.0

TABLE II-6

RESULTS OF INTENSIVE SURVEY OF LEON RIVER ABOVE LAKE BELTON ON FEBRUARY 16, 1988
(continued)

Laboratory Measurements Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
Leon River									
Upstream Site	1.7	15.6	3.6	0.00	0.07	0.003	0.22	0.006	0.013
Site 1	3.1	11.4	1.1	0.00	0.19	0.003	0.14	0.039	0.048
Gatesville WWTP	37.0	88.3	62.0	12.30	3.40	0.660	13.14	2.763	6.470
Site 2	3.0	14.8	2.0	0.20	0.80	0.041	0.36	0.159	0.233
Site 3	1.8	6.8	1.0	0.02	1.00	0.056	0.47	0.315	0.582
Site 4	4.6	10.8	1.2	0.00	0.70	0.030	0.86	0.231	0.442

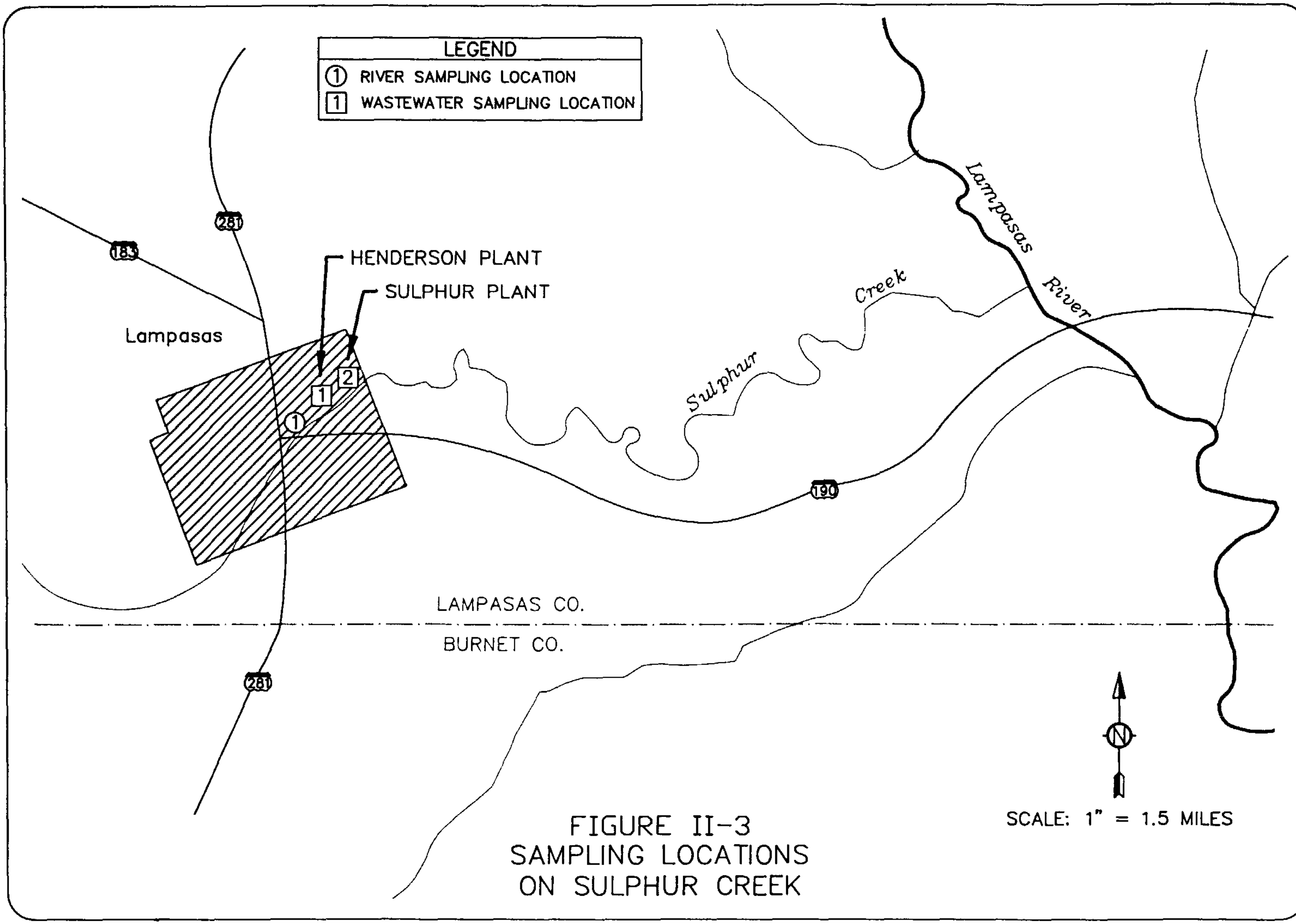


FIGURE II-3
SAMPLING LOCATIONS
ON SULPHUR CREEK

TABLE II-7

RESULTS OF INTENSIVE SURVEY OF SULPHUR CREEK ON OCTOBER 20, 1987

Field Measurements Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft²	Average velocity ft/sec	Discharge ft³/sec
Sulphur Creek								
Site 1	7:57 am	19.77	7.15	7.11	2700	11.9	1.38	16.5
	11:37 am	20.15	8.53	7.15	2870			
	1:17 pm	21.10	9.24	7.22	2880	9.9	1.82	18.0
Henderson WWTP	8:35 am	23.59	7.45	6.89	1121			
	11:44 am	23.90	7.30	6.74	1124			
	1:52 pm	24.27	7.00	6.74	1090			
Sulphur Creek WWTP	8:50 am	23.28	6.36	6.95	1168			
	11:49 am	22.61	6.18	7.02	1380			
	1:59 pm	22.45	6.29	7.08	1315			
Site 2	9:06 am	19.95	7.44	7.25	2280	17.6	1.36	23.9
Site 3	9:45 am	20.12	7.36	7.36	2610	22.9	1.01	23.1
	11:59 am	20.49	8.60	7.34	2390			
	2:15 pm	21.38	10.02	7.45	2300	12.5	1.83	22.9
Site 4	10:17 am	19.58	7.64	7.48	2610	57.2	0.92	52.6
	12:08 pm	19.82	7.99	7.46	2640			
	2:45 pm	20.50	9.45	7.64	2610	14.9	1.86	27.7
Site 5	11:10 am	19.70	9.35	7.60	2390	51.9	0.48	24.9
	12:20 pm	19.74	10.19	7.68	2420			
	3:33 pm	21.94	10.87	7.95	2310	56.4	0.56	31.3

TABLE II-7

RESULTS OF INTENSIVE SURVEY OF SULPHUR CREEK ON OCTOBER 20, 1987
(continued)

Laboratory Measurements Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
Sulphur Creek									
Site 1	1.3	15.7	4.8	0.24	0.06	0.004	0.61	0.012	0.030
Henderson WWTP	3.9	2.6	1.8	0.73	18.0	0.019	4.77	10.1	14.350
Sulphur Creek WWTP	16.6	35.0	33.0	3.21	6.40	0.492	7.46	6.743	9.21
Site 2	5.3	14.0	7.2	0.33	0.09	0.069	0.90	0.413	0.740
Site 3	3.8	15.2	6.0	0.38	0.99	0.053	0.85	0.506	1.130
Site 4	1.3	7.4	3.4	0.14	0.60	0.019	0.42	0.553	1.270
Site 5	1.4	7.0	2.4	0.13	0.42	0.010	0.38	0.372	0.620

levels show a large variation from early morning to late afternoon, indicating that aquatic plant life significantly influences the stream.

The results of the analyses of the water samples indicate there is a slight increase in BOD5 concentration downstream of the two WWTPs (sites 2 and 3). The concentration returns to background levels at site 4. The nutrient concentrations are elevated directly below the WWTP at site 2, and continue to be elevated at site 3. The levels then decline at the two most downstream sites, but are still above the levels at site 1.

Lampasas River. The Lampasas River above Lake Stillhouse Hollow was sampled from just above the junction with Sulphur Creek to just below Rocky Creek. No point source dischargers are located on the Lampasas River in this reach just above the lake. Four sites were sampled on the river as well as Sulphur Creek and Rocky Creek. A map of the Lampasas River showing the sampling sites is presented in Figure II-4. The field and laboratory data are shown in Table II-8. The diurnal variation in dissolved oxygen concentrations measured in Sulphur Creek and the Lampasas River below Sulphur Creek suggest that aquatic plant life may play a major role in the stream chemistry. The laboratory measurements of nutrients in the Lampasas River show that nutrient levels drop below the junction with Sulphur Creek, suggesting that plant life may be utilizing them.

The Lampasas River below Lake Stillhouse Hollow was sampled at four locations and Salado Creek was sampled at one site as shown in Figure II-5. Results of the survey are shown in Table II-9. The field measurements of dissolved oxygen at sites 2 and 4 indicate a diurnal difference, suggesting aquatic plant life may play a significant role in the dissolved oxygen of the river.

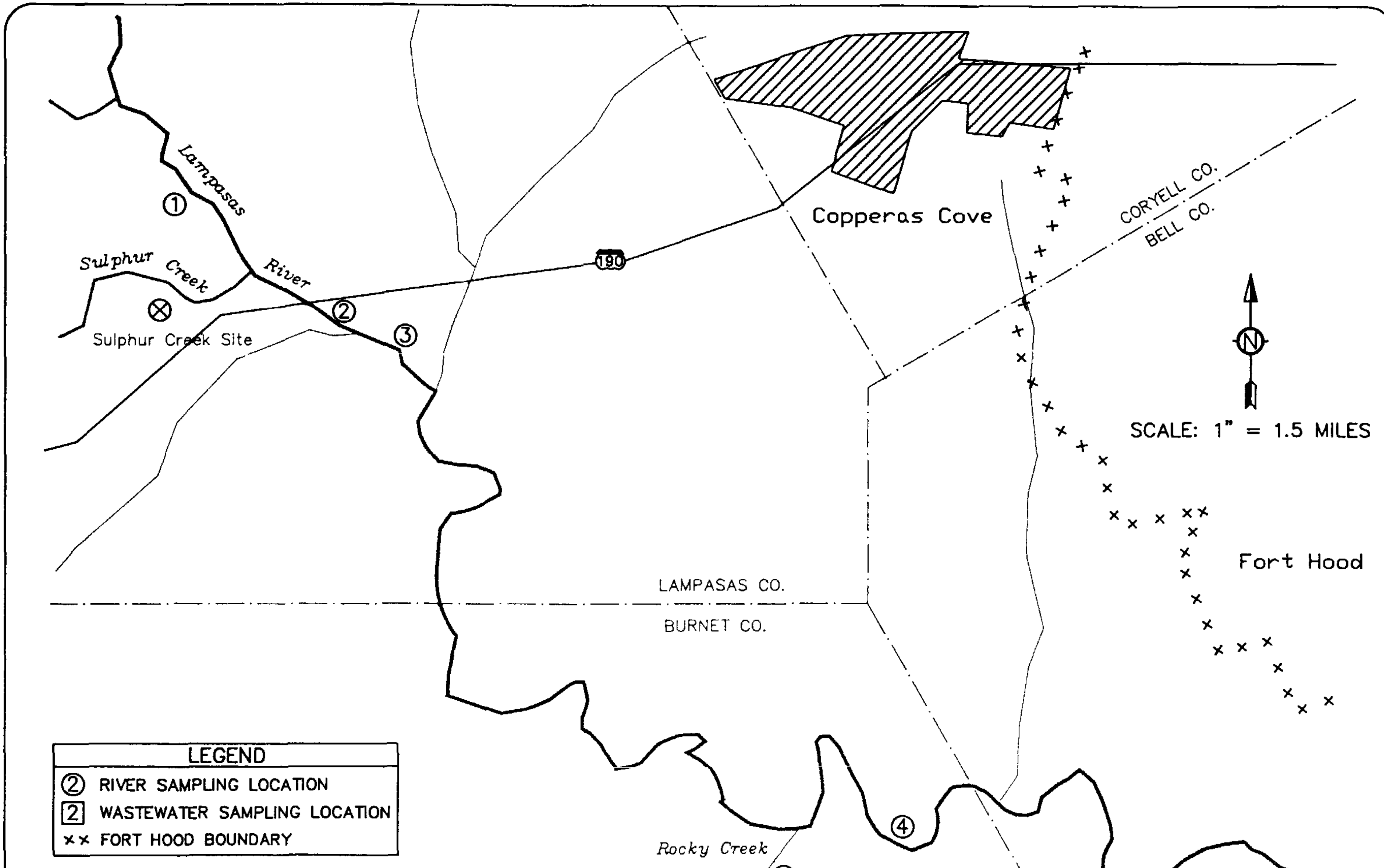


FIGURE II-4
SAMPLING LOCATIONS ON THE LAMPASAS RIVER
ABOVE LAKE STILLHOUSE HOLLOW

TABLE II-8

RESULTS OF INTENSIVE SURVEY OF LAMPASAS RIVER ABOVE LAKE STILLHOUSE HOLLOW ON OCTOBER 16, 1987

Field Measurements Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft^2	Average velocity ft/sec	Discharge ft^3/sec
Lampasas River								
Site 1	10:18 am	20.21	8.57	7.38	614	13.0	0.94	12.2
	3:15 pm	22.23	9.00	7.42	607	13.3	0.97	13.0
Sulphur Creek	11:40 am	21.66	9.37	7.60	2590	69.4	0.33	22.8
	4:37 pm	23.11	15.15	7.90	2550	75.7	0.26	19.8
Site 2	10:52 am	20.80	12.40	7.67	1840	44.7	0.77	34.3
	3:50 pm	23.43	15.87	7.87	1770	42.6	0.74	31.7
Site 3	9:15 am	19.75	7.39	7.38	1770	82.1	0.48	39.4
	2:22 pm	22.41	12.31	7.62	1760	83.4	0.46	38.2
Rocky Creek	8:30 am	20.12	5.90	7.20	465	2.2	0.28	0.6
	1:51 pm	24.55	10.48	7.44	450	2.3	0.27	0.6
Site 4	7:45 am	20.37	7.55	7.44	1590	35.2	1.15	40.7
	1:14 PM	22.96	9.60	7.54	1590	38.0	1.11	42.1

TABLE II-8

RESULTS OF INTENSIVE SURVEY OF LAMPASAS RIVER ABOVE LAKE STILLHOUSE HOLLOW ON OCTOBER 16, 1987
(continued)

Laboratory Measurements Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
Lampasas River									
Site 1	1.3	4.6	0.8	0.03	0.80	0.008	0.10	0.011	0.17
Sulphur Creek	1.4	7.0	0.8	0.04	0.30	0.005	0.10	0.104	0.192
Site 2	1.3	5.2	2.8	0.04	0.29	0.007	0.13	0.032	0.056
Site 3	1.3	4.4	0.6	0.04	0.33	0.008	0.16	0.034	0.058
Rocky Creek	1.4	0.5	0.4	0.03	0.05	0.002	0.09	0.014	0.024
Site 4	1.0	7.4	0.4	0.04	0.09	0.004	0.10	0.022	0.048

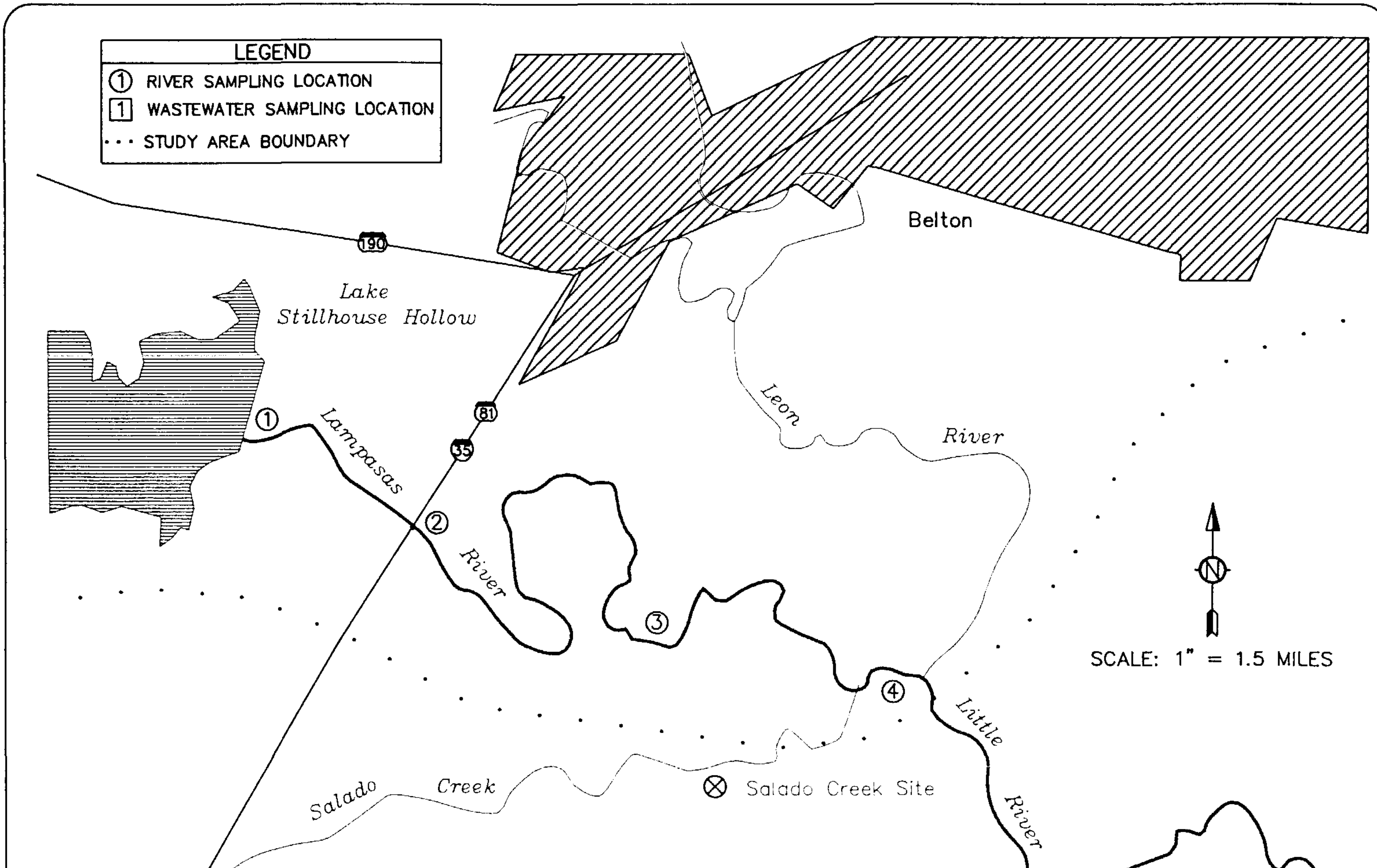


FIGURE II-5
SAMPLING LOCATIONS ON THE
LAMPASAS RIVER BELOW LAKE STILLHOUSE HOLLOW

TABLE II-9

RESULTS OF INTENSIVE SURVEY OF LAMPASAS RIVER BELOW LAKE STILLHOUSE HOLLOW ON OCTOBER 14, 1987

Field Measurements Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft^2	Average velocity ft/sec	Discharge ft^3/sec
Lampasas River								
Site 1	8:40 am	14.52	9.96	8.13	574	6.3	0.20	1.3
	1:30 pm	22.60	9.10	8.40	543	7.1	0.15	1.0
Site 2	9:45 am	15.14	7.05	7.67	538	4.8	0.41	2.0
	2:25 pm	20.71	13.81	8.12	515	4.5	0.41	1.8
Site 3	10:35 am	16.27	7.72	7.74	545	3.6	0.71	2.6
	2:55 pm	17.77	8.90	7.82	540	3.5	0.74	2.6
Salado Creek	11:25 am	18.30	9.54	8.00	437	9.6	0.74	7.1
	3:30 pm	19.43	9.36	8.06	433	9.0	0.83	7.5
Site 4	12:10 pm	17.57	9.42	7.76	462	4.736	2.49	11.8
	4:00 pm	19.47	10.48	7.90	459	7.415	1.37	10.2

TABLE II-9

RESULTS OF INTENSIVE SURVEY OF LAMPASAS RIVER BELOW LAKE STILLHOUSE HOLLOW ON OCTOBER 14, 1987
(continued)

Laboratory Measurements Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
Lampasas River									
Site 1	1.7	5.2	1.2	0.3	0.24	0.007	0.21	0.82	0.214
Site 2	1.9	1.0	0.2	0.06	0.54	0.007	0.68	0.003	0.016
Site 3	2.4	1.0	0.1	0.06	0.17	0.006	0.43	0.085	0.230
Salado Creek	2.3	4.8	0.4	0.06	2.92	0.010	4.17	0.023	0.095
Site 4	2.4	6.4	0.8	0.09	2.0	0.008	2.97	0.07	0.194

<u>Clear Creek</u>. Clear Creek, a small tributary to the Lampasas River which carries effluent from Copperas Cove's Southeast WWTP, was sampled at five locations. The WWTP was also sampled. Figure II-6 is a map showing the location of the sampling points. Results of the survey are presented in Table II-10. The diurnal variation of the dissolved oxygen measurements in the stream below the WWTP suggests that aquatic plant life plays a major role in the stream chemistry. In the lower reaches of the stream, thick mats of algae were observed completely covering the pools in the stream. The chemical analyses of the water samples show that nutrient concentrations declined to background levels at site 5. Nutrient uptake by the plant life was probably the removal mechanism.

<u>Cowhouse Creek Tributaries</u>. Two tributaries of Cowhouse Creek, House Creek and Turkey Run Creek, were also sampled. House Creek receives effluent from Copperas Cove's Northwest WWTP and Turkey Run Creek receives effluent from Copperas Cove's Northeast WWTP. Access was limited for both tributaries, so only one site above and one site below each treatment plant was sampled, along with the treatment plant. Figure II-7 is a map showing the locations of the sample sites. Results of the surveys are shown in Table II-11 and Table II-12. Both WWTPs had good quality effluent during the time of the surveys, and dissolved oxygen at the site below each plant showed no detrimental impact. The laboratory analysis of the water samples showed that the quality of the effluent dominated the stream quality below the WWTP.

Lake Sampling and Testing

Lakes Belton and Stillhouse Hollow were sampled from August 1987 through August 1988 to develop a database that was used to calibrate a water quality model of each lake. Field measurements of dissolved oxygen, pH, specific conductance and temperature were taken at 1.5 meter intervals vertically at each sample site. Measurements of secchi depth and light

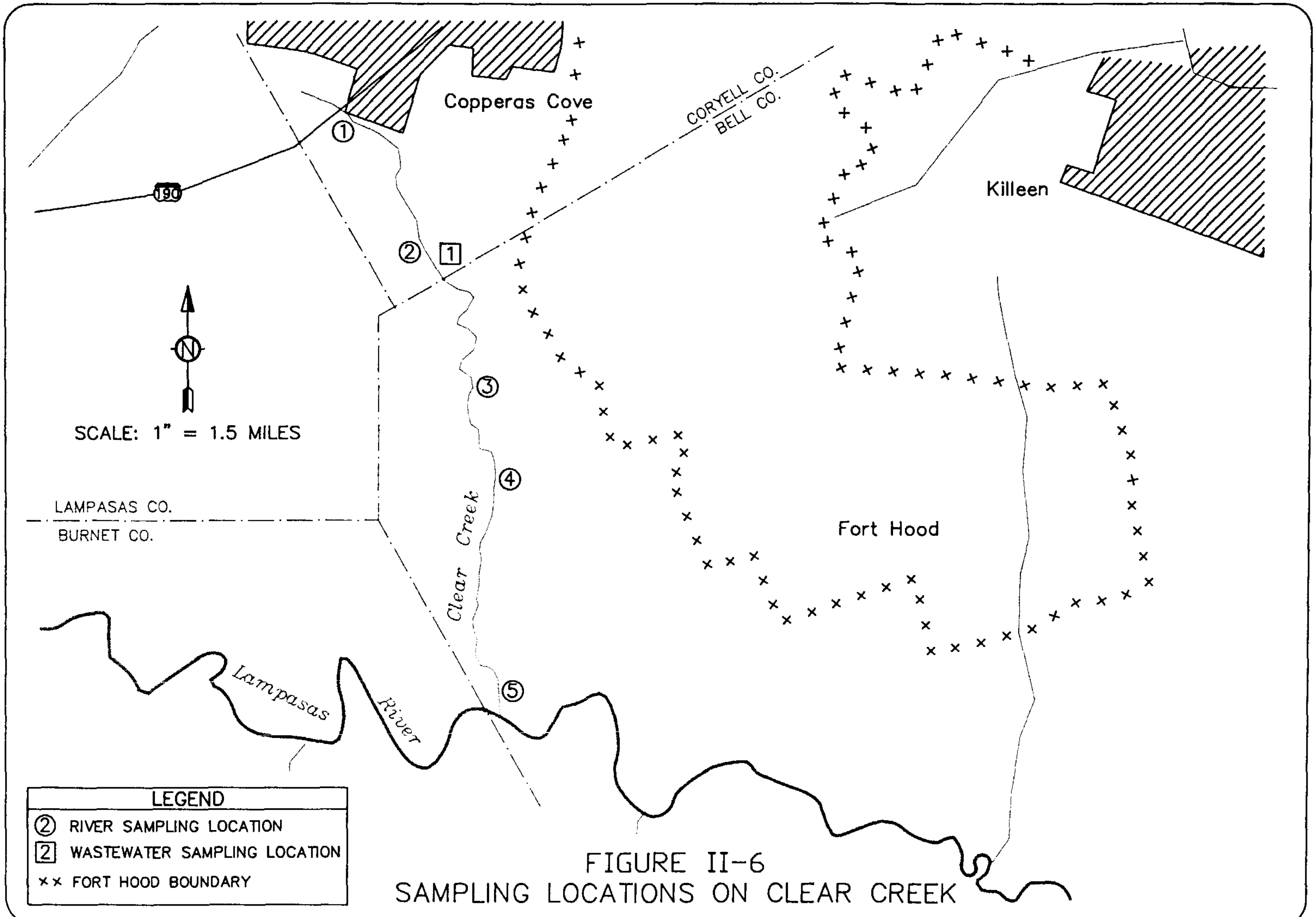


FIGURE II-6
SAMPLING LOCATIONS ON CLEAR CREEK

TABLE II-10

RESULTS OF INTENSIVE SURVEY OF CLEAR CREEK ON SEPTEMBER 10-11, 1987

Field Measurements Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft^2	Average velocity ft/sec	Discharge ft^3/sec
Clear Creek								
Site 1	12:45 pm	23.30	8.93	7.25	505	0.52	0.31	0.16
	7:30 am	21.21	7.62	7.21	543	0.65	0.25	0.17
	10:41 am	21.64	8.40	7.33	542			
	12:26 pm	23.43	8.49	7.44	535			
Copperas Cove SE WWTP	7:54 am	25.38	7.10	6.66	805			
	12:38 pm	26.55	6.80	6.77	803			
Site 2	1:19 pm	24.34	9.09	7.01	744	3.43	0.29	0.99
	8:10 pm	22.48	5.41	6.62	811	2.68	0.14	0.37
	10:48 am	22.94	7.77	7.03	818			
	12:49 pm	24.23	8.19	7.27	774			
Site 3	2:00 pm	25.09	9.65	7.84	7.09	4.4	0.17	0.78
	8:48 pm	23.32	5.91	7.38	778	4.61	0.13	0.61
	11:01 am	23.70	6.31	7.43	776			
	1:02 pm	24.57	7.67	7.63	772			
Site 4	3:06 pm	26.69	13.70	8.53	605	2.45	0.06	0.14
	9:47 am	22.63	5.55	7.42	697	2.50	0.06	0.15
	11:33 am	23.93	9.80	7.87	679			
	1:27 pm	26.33	11.40	8.46	638			
Site 5	2:30 pm	25.85	5.17	7.12	593	3.12	0.07	0.23
	9:23 am	23.57	3.60	7.03	630	2.60	0.10	0.26
	11:14 am	24.84	6.52	7.20	628			
	1:53 pm	27.09	7.80	7.40	619			

TABLE II-10

RESULTS OF INTENSIVE SURVEY OF CLEAR CREEK ON SEPTEMBER 10, 1987
(continued)

Laboratory <u>Measurements</u> Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
<u>Clear Creek</u>									
Site 1	0.8	2.2	--	--	0.94	0.003	0.23	0.203	0.247
Copperas Cove SE WWTP	2.5	7.1	5.8	0.05	16.82	0.001	4.52	6.83	8.073
Site 2	1.0	3.1	1.1	0.05	11.26	0.030	2.14	3.91	6.32
Site 3	0.8	2.8	0.6	0.03	8.63	0.042	3.38	3.093	3.573
Site 4	2.3	1.9	0.6	0.09	1.78	0.030	1.07	0.566	0.687
Site 5	0.4	3.6	0.7	0.03	0.25	0.003	0.45	0.116	0.143

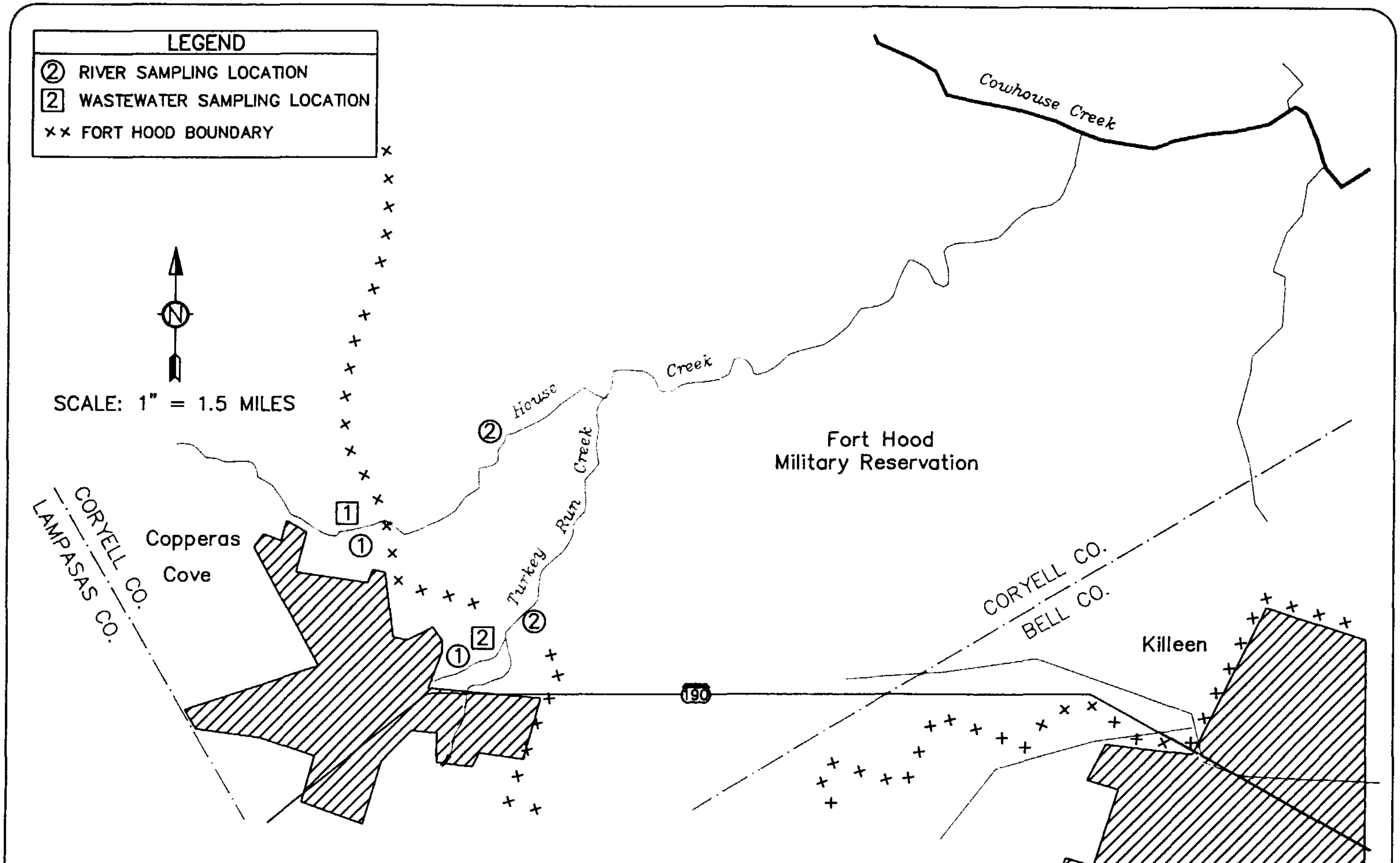


FIGURE II-7
SAMPLING LOCATIONS ON
HOUSE CREEK AND TURKEY RUN CREEK

TABLE II-11

RESULTS OF INTENSIVE SURVEY OF HOUSE CREEK ON NOVEMBER 13, 1987

Field Measurements Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft^2	Average velocity ft/sec	Discharge ft^3/sec
House Creek								
Site 1	8:15 am	8.45	8.91	7.34	564	1.10	0.07	0.08
	11:26 am	10.47	9.57	7.43	570			
	1:20 pm	12.64	7.63	7.52	562	1.24	0.05	0.06
Copperas Cove NW WWTP	8:19 am	16.63	8.02	6.68	804			
	11:22 am	17.45	8.20	6.69	804			
	1:13 pm	18.04	8.05	6.71	795			
Site 2	10:20 am	10.44	10.60	7.40	750	1.22	0.59	0.72
	11:55 am	11.83	10.05	7.39	761			
	2:25 pm	13.33	9.43	7.45	758	0.94	0.84	0.78

TABLE II-11

RESULTS OF INTENSIVE SURVEY OF HOUSE CREEK ON NOVEMBER 13, 1987
(continued)

Laboratory Measurements Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
House Creek									
Site 1	1.5	9.8	1.3	0.08	0.60	0.002	4.78	0.062	0.210
Copperas Cove NW WWTP	4.9	2.8	2.6	0.30	13.10	0.005	21.85	7.305	8.645
Site 2	2.1	33.2	5.6	0.28	11.70	0.002	18.20	5.300	7.834

TABLE II-12

RESULTS OF INTENSIVE SURVEY OF TURKEY RUN CREEK ON NOVEMBER 11, 1987

Field <u>Measurements</u> Site	Time	Water Temp °C	Dissolved Oxygen mg/l	pH std Units	Conductance umhos/cm	x-section area/ft^2	Average velocity ft/sec	Discharge ft^3/sec
<u>Turkey Run Creek</u>								
Site 1	9:18 am	10.37	10.00	7.21	412	0.59	0.40	0.23
	11:45 am	13.21	9.27	7.64	408			
	2:00 pm	14.10	9.40	7.72	410	0.56	0.75	0.42
Copperas Cove NE WWTP	9:40 am	18.35	6.93	6.40	834			
	11:38 am	19.04	6.47	6.40	843			
	1:55 pm	19.52	6.10	6.51	600			
Site 2	11:00 am	14.74	9.43	7.16	723	1.64	0.57	0.91
	12.05 pm	15.63	9.49	7.07	737			
	2:50 pm	16.65	9.07	7.19	728	1.53	0.33	0.50

TABLE II-12

RESULTS OF INTENSIVE SURVEY OF TURKEY RUN CREEK ON NOVEMBER 11, 1987
(continued)

Laboratory Measurements Site	BOD-5 mg/l	TSS mg/l	VSS mg/l	Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Nitrite Nitrogen mg/l	Organics Nitrogen mg/l	Ortho Phosphorous mg/l	Total Phosphorous mg/l
Turkey Run Creek									
Site 1	2.7	23.5	6.5	0.42	2.20	0.029	7.15	4.260	6.485
Copperas Cove NE WWTP	3.9	9.6	8.8	0.36	13.1	0.005	19.63	8.425	9.823
Site 2	2.1	10.0	4.3	0.29	11.10	0.000	13.47	5.22	7.312

decay were taken at each site. Water samples were also collected at one foot below the surface and five feet from the bottom for laboratory analysis. Water samples were analyzed for chlorophyll 'a', BOD, TSS, VSS, ammonia, nitrite, nitrate, organic nitrogen, total phosphorus, orthophosphorus, alkalinity and hardness.

Lake Stillhouse Hollow. Lake Stillhouse Hollow was sampled twelve times at the five locations, shown in Figure II-8. The data collected are presented in the Appendix. Algae populations, as indicated by chlorophyll 'a' concentrations, were highest at sampling sites 3 and 4. Seasonally, algae populations were at their peak in early winter, and declined throughout the summer. Figure II-9 is a plot of the chlorophyll 'a' concentrations observed at the five sites.

Algae growth in lakes is a function of available nutrients, light, temperature, settling, predation, and hydraulic detention time. Experience with Texas lakes indicates that light limitation is normally the major factor limiting phytoplankton growth. Data collected in this study and, as shown in Figure II-10, indicate that nutrient limitations produce between 10 and 20 percent reduction in algae growth rates in Lake Stillhouse Hollow. However, the overall yield of phytoplankton biomass over time can be substantial. In view of this, and that fact that, of the above mentioned variables, nutrients alone are controllable by reasonable measures, it is considered necessary to control nutrient inputs to limit phytoplankton growth. A method known as the Michaelis-Menton relationship has been developed to determine which nutrient, nitrogen or phosphorus, is limiting to algae growth in a lake. This relationship expresses the fraction of optimum ambient growth rate associated with nutrient limitation as follows:

$$Kn = [N]/[N+MMn]$$

where: Kn = fraction of maximum growth

N = concentration of nutrient

MMn = concentration of nutrient that limits growth to 50% of maximum

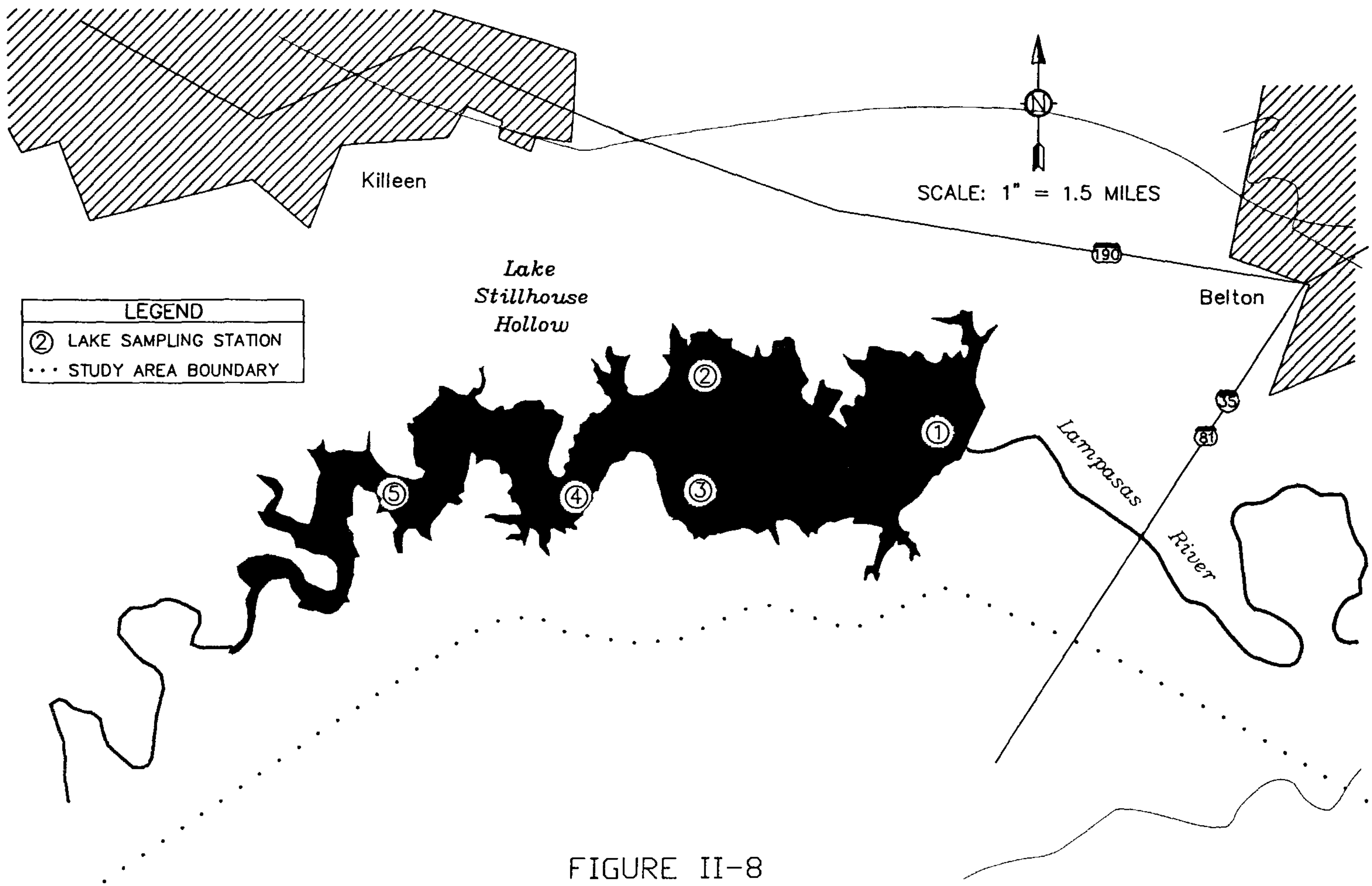


FIGURE II-8
SAMPLING LOCATIONS ON
LAKE STILLHOUSE HOLLOW

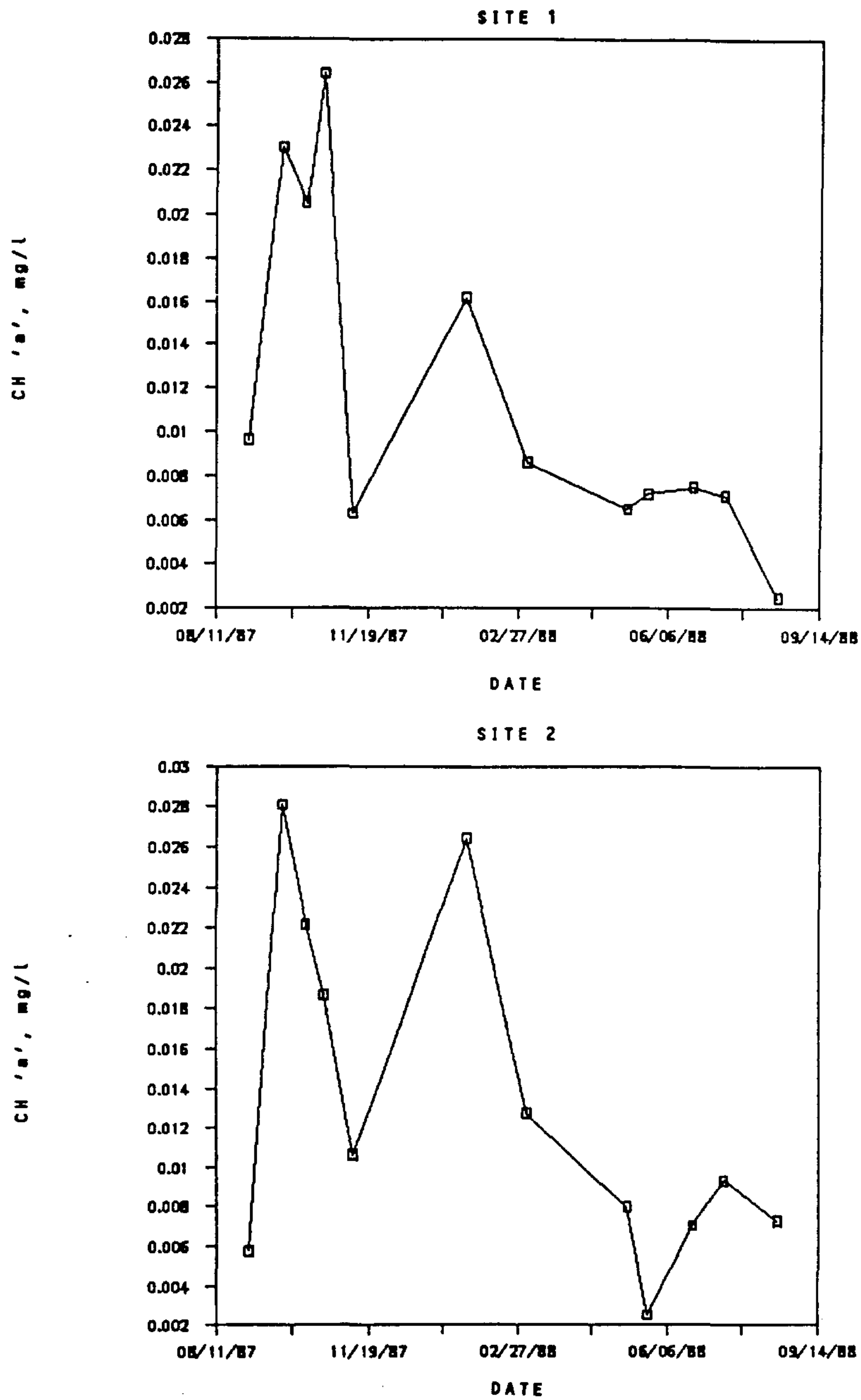
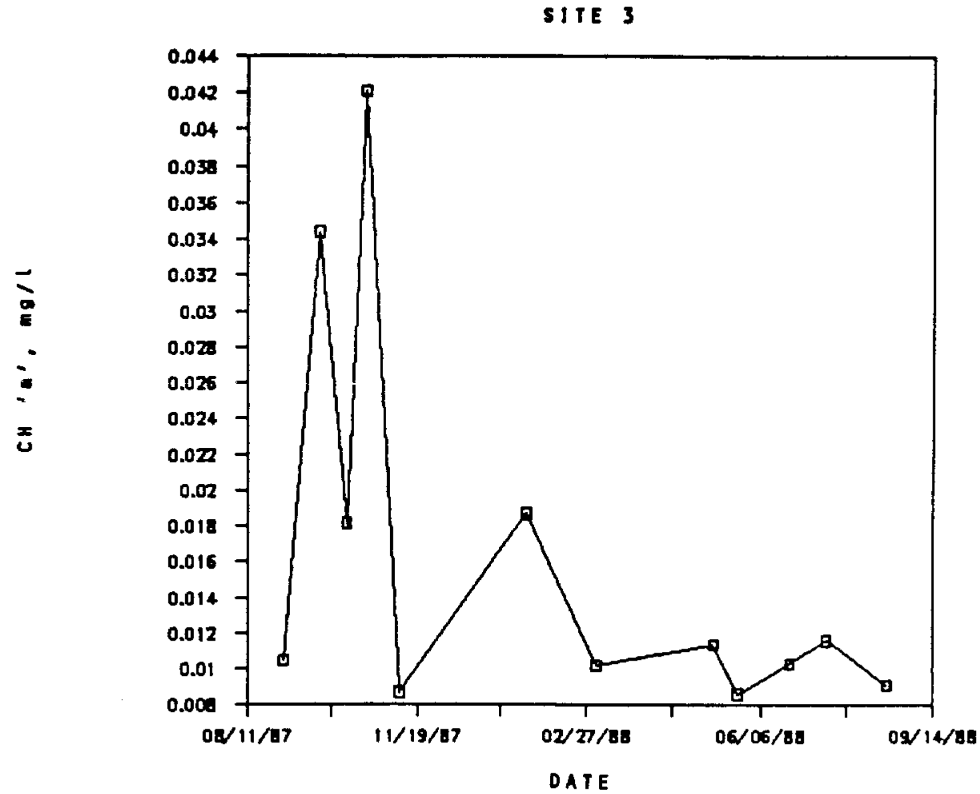


FIGURE II-9

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE STILLHOUSE HOLLOW



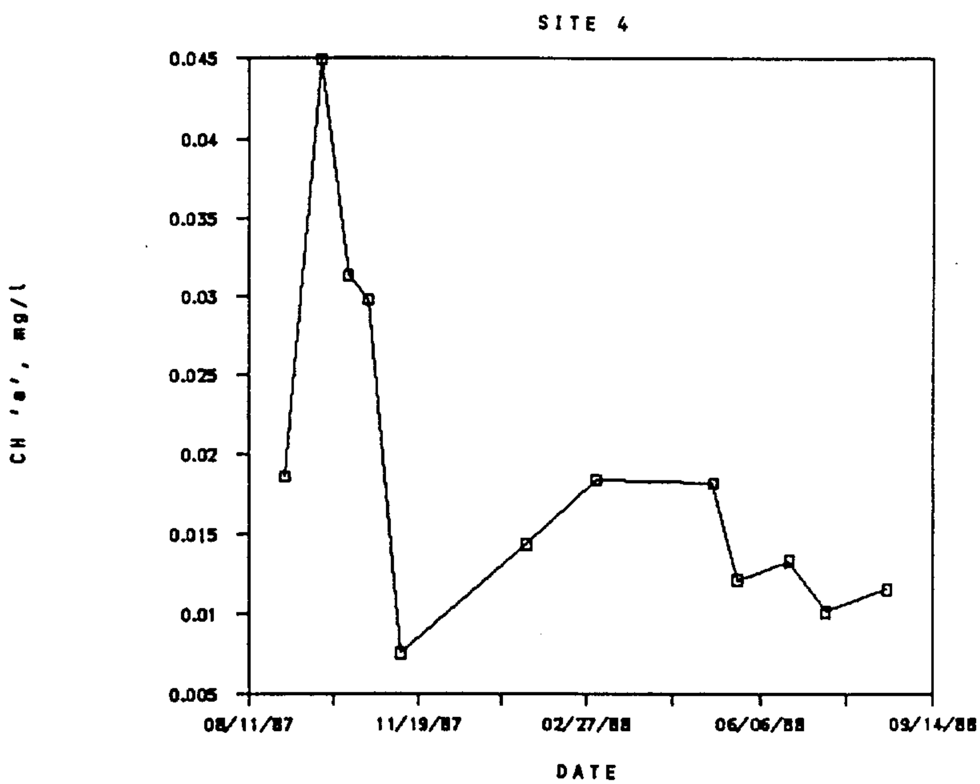


FIGURE II-9

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE STILLHOUSE HOLLOW (continued)

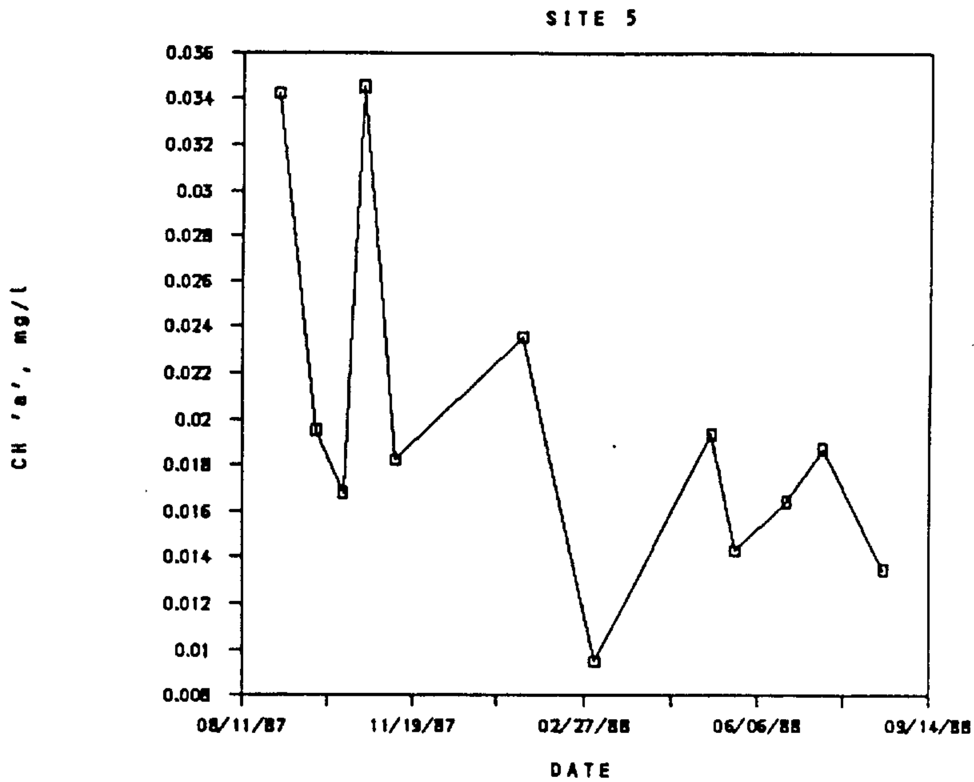


FIGURE II-9

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE STILLHOUSE HOLLOW (continued)

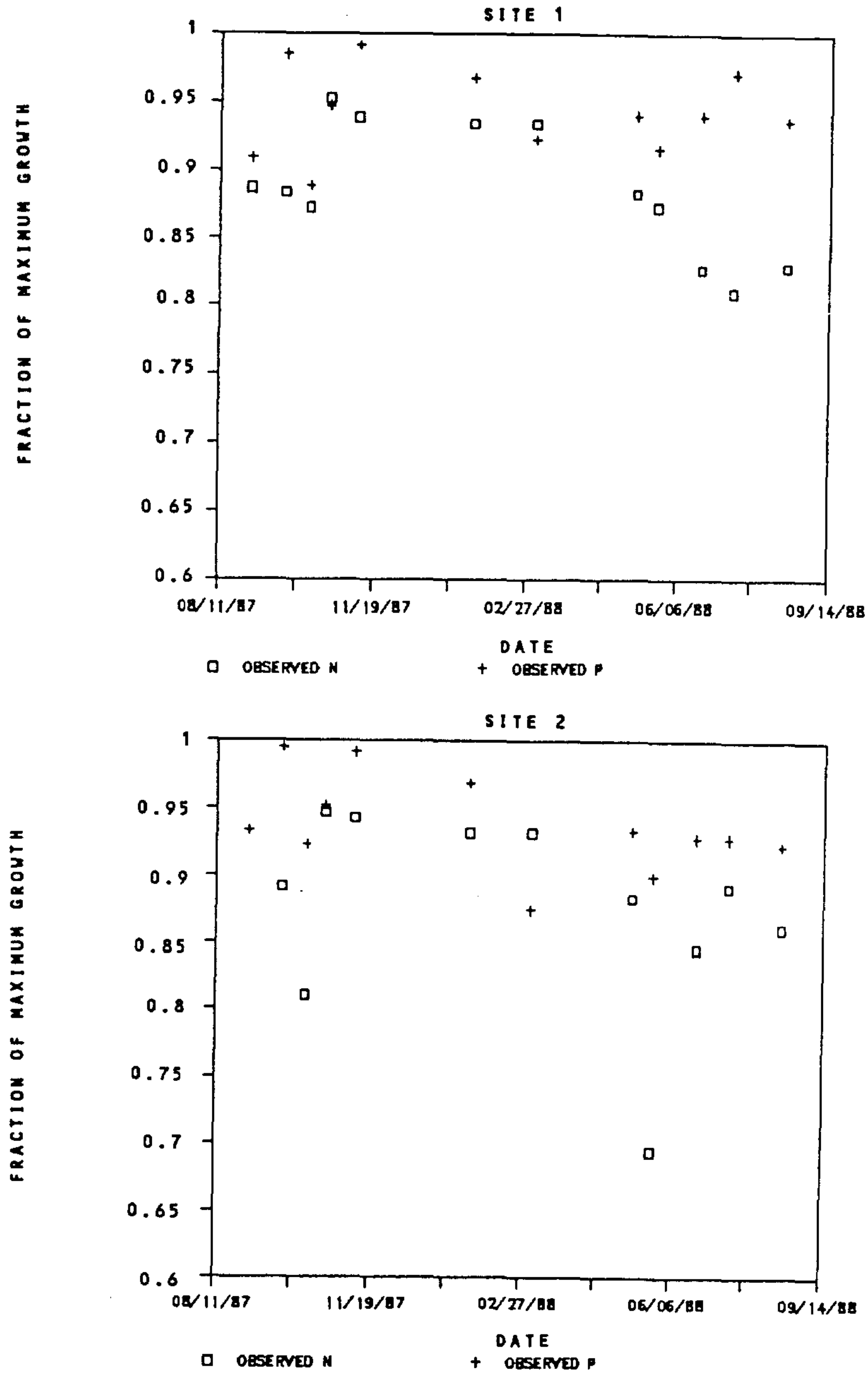
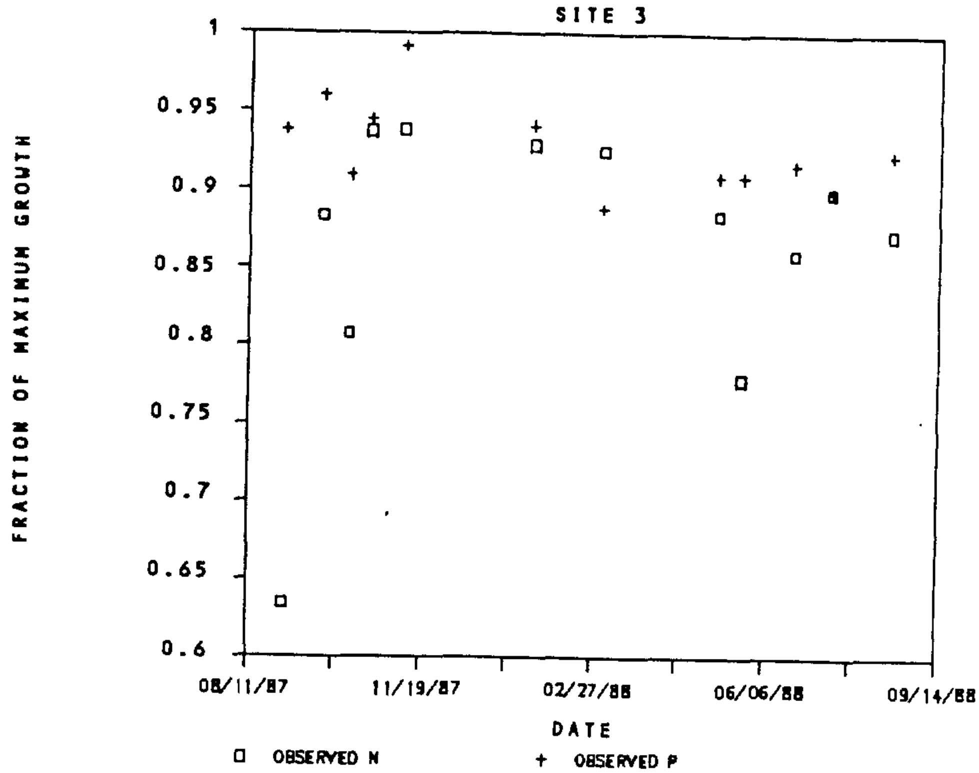


FIGURE II-10

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE NUTRIENTS FROM LAKE STILLHOUSE HOLLOW



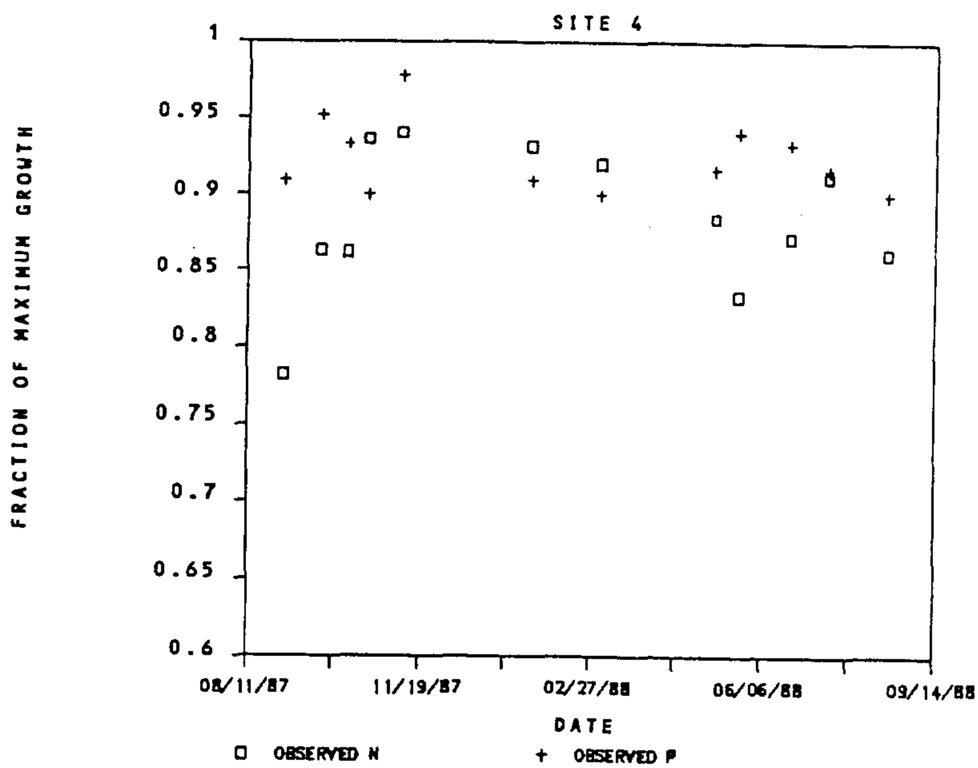


FIGURE II-10

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE NUTRIENTS FROM LAKE STILLHOUSE HOLLOW (continued)

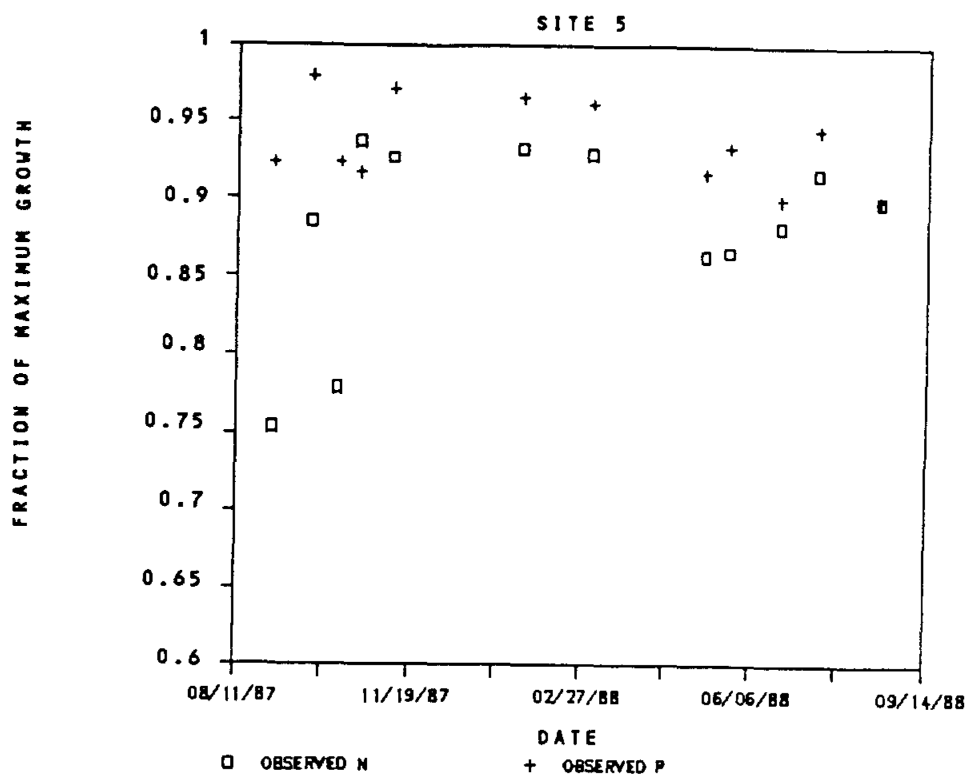


FIGURE II-10

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE NUTRIENTS FROM LAKE STILLHOUSE HOLLOW (continued)

From this equation it can be shown that at a nutrient level of zero, there is no growth since algae requires at least some critical nutrients to stimulate growth. As the nutrient level is increased, growth begins and is very sensitive to the addition of the nutrients. However, as the nutrient levels increase, their effect on the growth rate of the algae is reduced and levels off near a value of 1.0. At this point the nutrient is no longer limiting, because the nutrient concentration is so much greater than the half saturation constant (MMn), and any further increases in the external nutrient supply do not affect the growth.

The limiting nutrient is found by determining which nutrient will produce a lower fraction of maximum growth, in effect, the maximum growth that the organism can achieve assuming that the other available nutrients are in excess supply.

For available nitrogen (ammonia + nitrate + nitrite) MMn was set at 0.015 mg/l, and for orthophosphorus MMn was set at 0.001 mg/l. These are values that have been used in other lake studies in Texas and elsewhere. For each day that Lake Stillhouse Hollow was sampled the growth limitation was determined for each nutrient. Figure II-10 is a plot of the growth limitation over time. Figure II-10 shows a lower fraction of maximum phytoplankton growth associated with nitrogen than with phosphorous for almost all water samples from Lake Stillhouse Hollow, indicating nitrogen to be the limiting nutrient.

The vertical profiles of temperature observed in the lake showed that the lake was at times thermally stratified. Rapid changes in temperature over short vertical distances limit mixing between the upper and lower layers of water in the lake. When this condition occurs the water chemistry of the lower segment may differ from the upper segment. Oxygen, which is replenished through aeration on the surface, may become depleted in the lower layer and create conditions favorable for release of nutrients found in the bottom sediments. Figure II-11 is a plot of the temperature and dissolved oxygen profiles at site 1, the deepest site in the lake. The lake at times stratifies and the dissolved oxygen in the bottom layer becomes depleted. This is a normal occurrence for Texas Lakes.

Lake Belton. Lake Belton was sampled at ten locations at the same frequency as Lake Stillhouse Hollow. Figure II-12 shows the locations of the sampling locations on Lake Belton. The complete data base developed in the sampling program is presented in the Appendix. Figure II-13 is a plot of the chlorophyll 'a' concentrations observed in Lake Belton. The algae populations, as indicated by chlorophyll 'a' concentrations, were highest at the upstream sites.

Lake Belton receives a higher loading of nutrients into the lake than Stillhouse Hollow. This is probably due to a larger drainage area and a greater loading from point source dischargers. Runoff from cultivated agriculture is also thought to contribute significant nutrient loads. The Michaelis-Menton formulations and half saturation constants discussed previously in conjunction with Lake Stillhouse Hollow were employed to assess the limiting nutrient in Lake Belton. The limiting nutrient for algae growth in Lake Belton varies between nitrogen and phosphorus. Figure II-14 plots the growth limitation for the 10 Lake Belton sites over the period the lake was sampled. As can be seen, during the winter the limiting nutrient sometimes becomes phosphorus, whereas nitrogen usually is the limiting nutrient at other times. As can be seen from Figure II-14, nutrient availability appears to produce between a 10 and 20 percent reduction in algae growth rates. However, as illustrated later in this chapter, the overall yield of phytoplankton biomass in Lake Belton can be substantial. In view of this, and the fact that nutrients can be more practically controlled than other variables affecting phytoplankton growth, it is considered necessary to control nutrient inputs to Lake Belton.

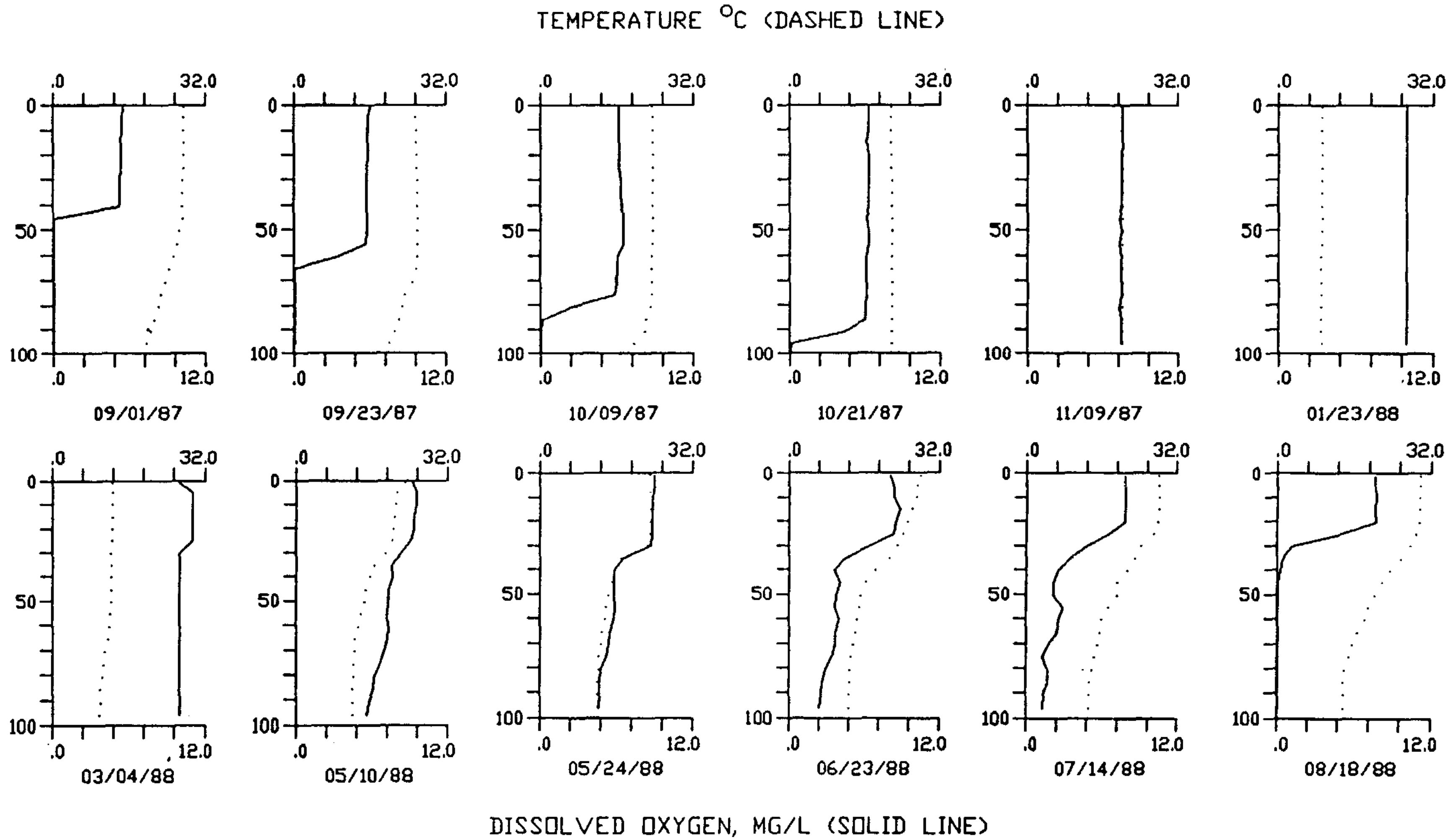


FIGURE II-11

TEMPERATURE DISSOLVED OXYGEN PROFILES
IN LAKE STILLHOUSE HOLLOW

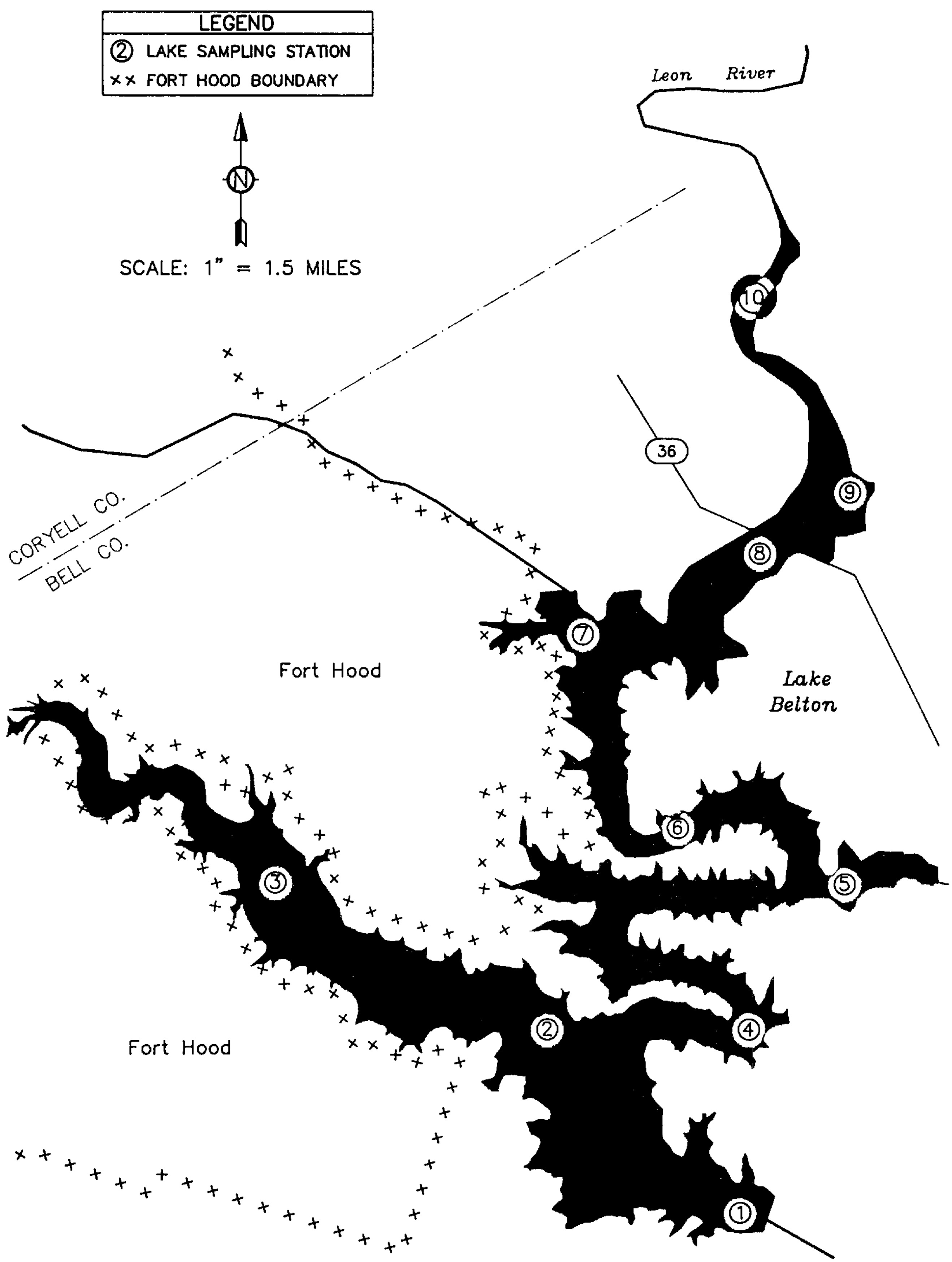
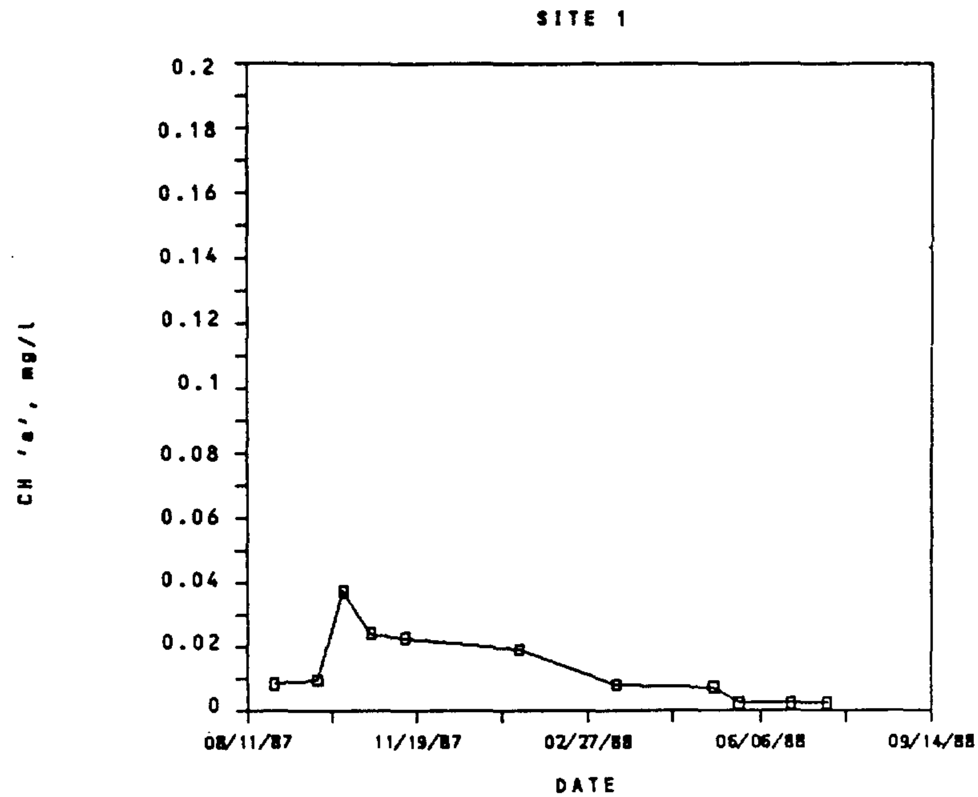


FIGURE II-12
SAMPLING LOCATIONS ON LAKE BELTON



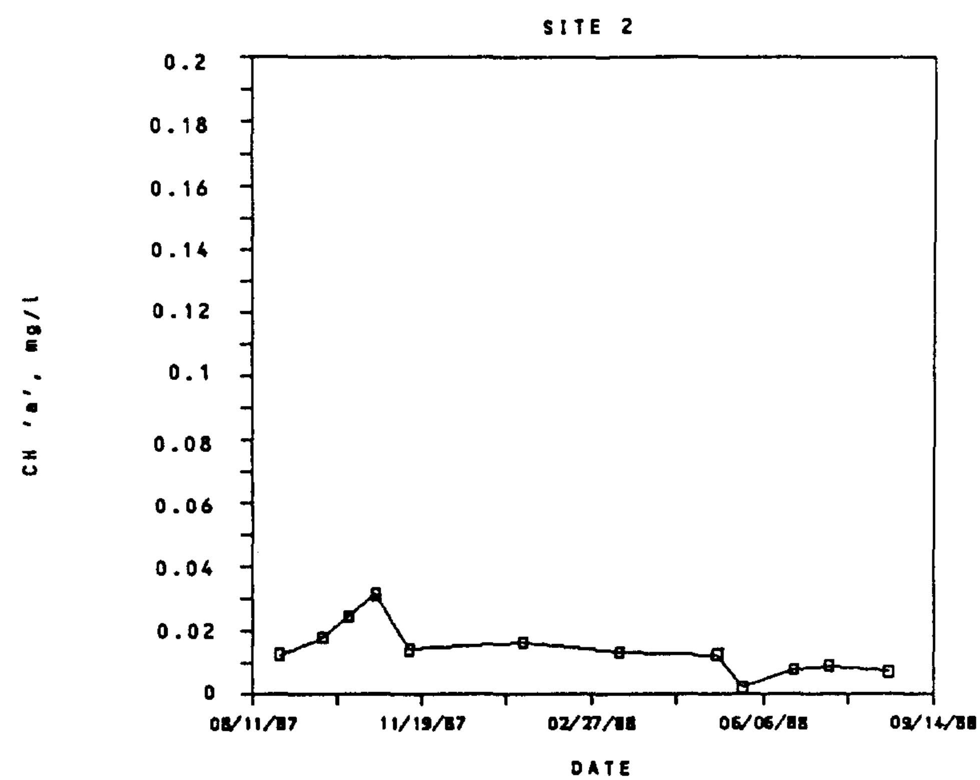
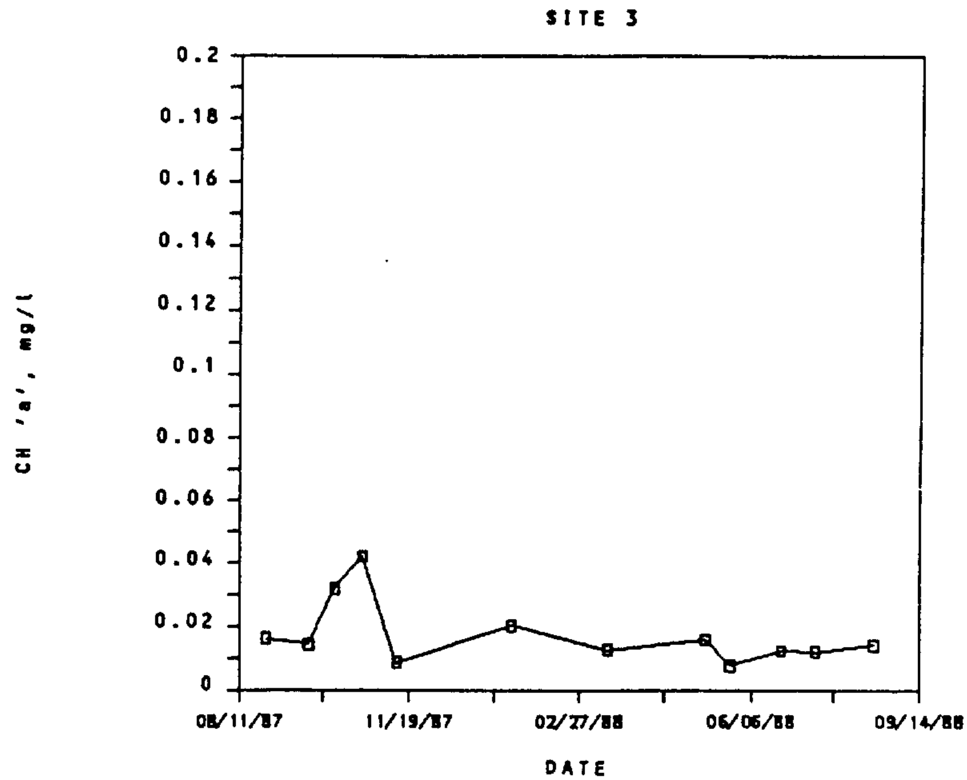


FIGURE II-13

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE BELTON



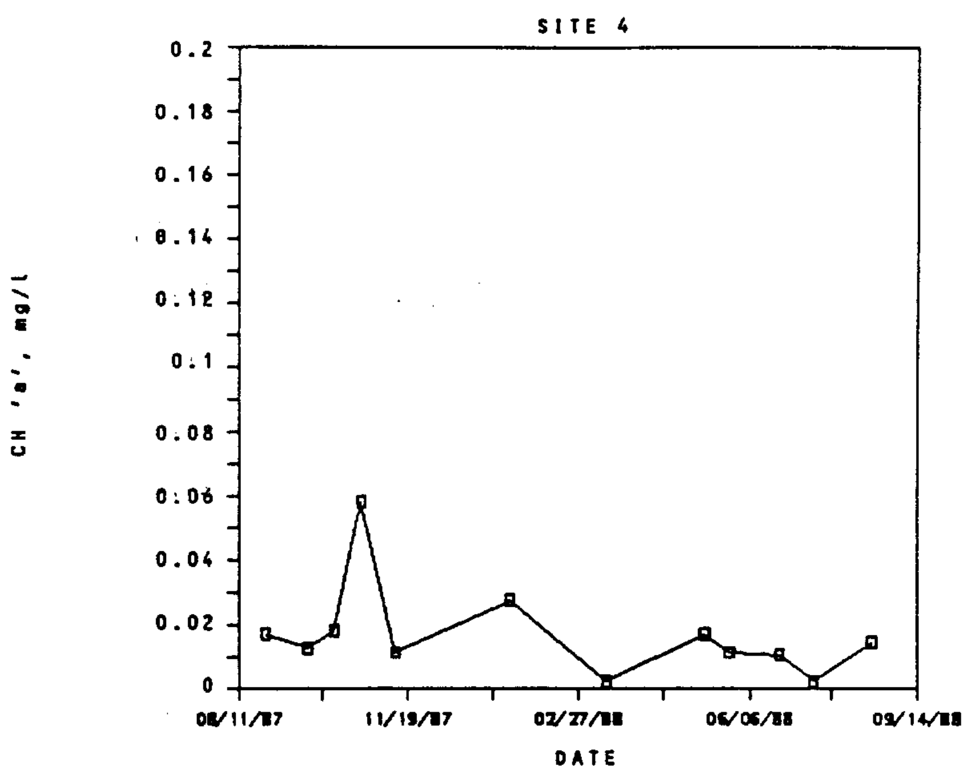
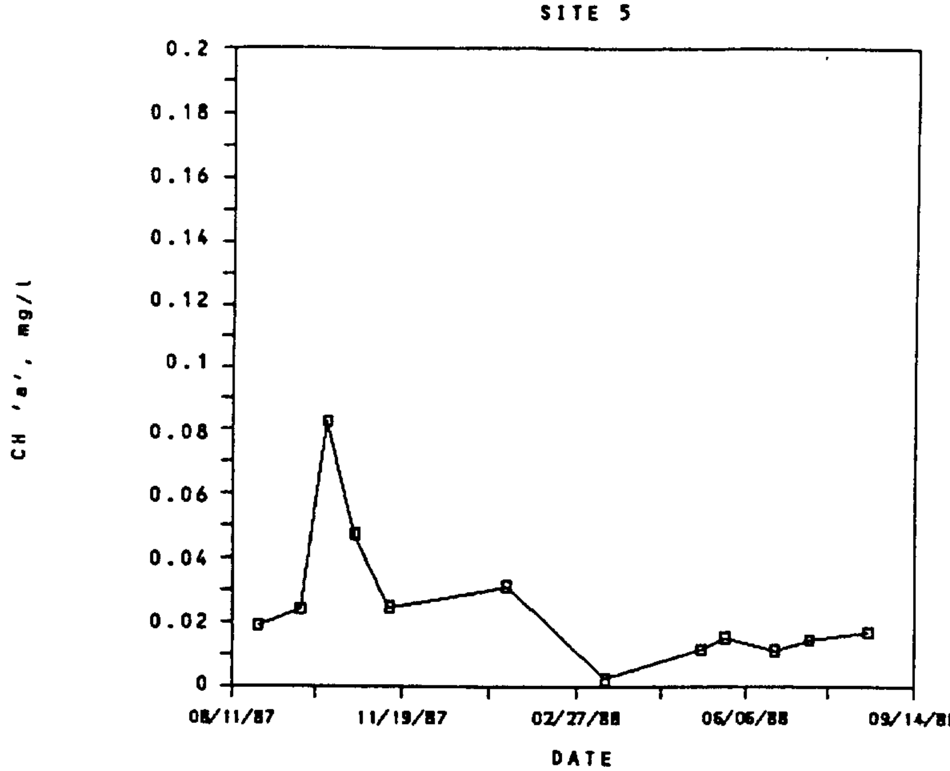


FIGURE II-13

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE BELTON (continued)



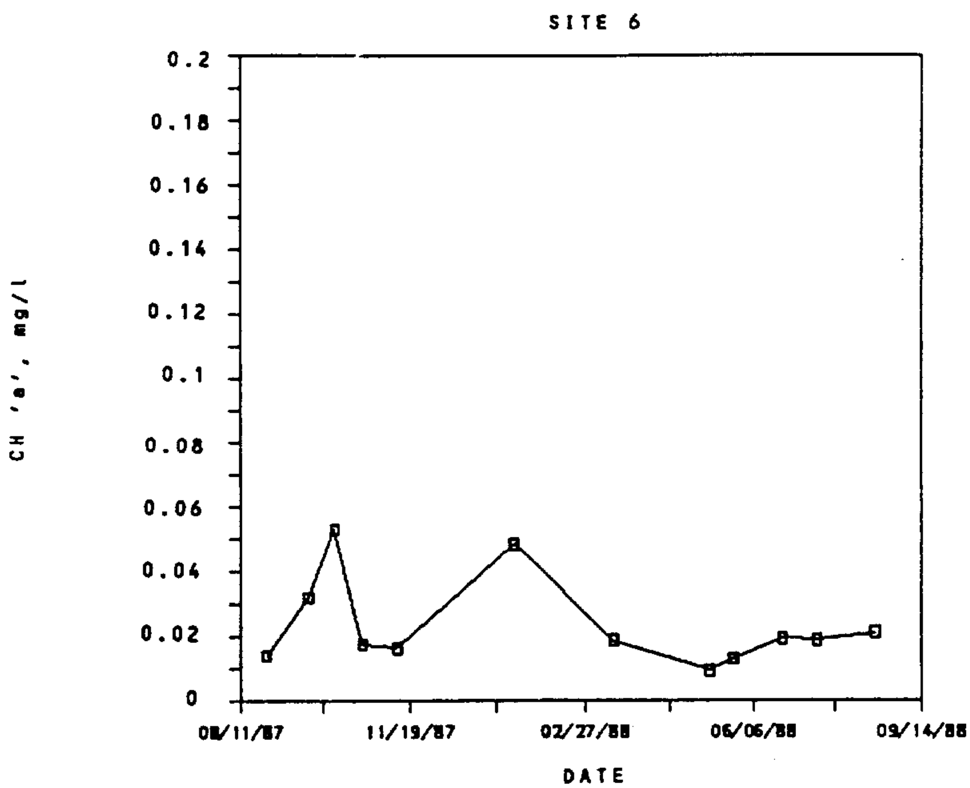
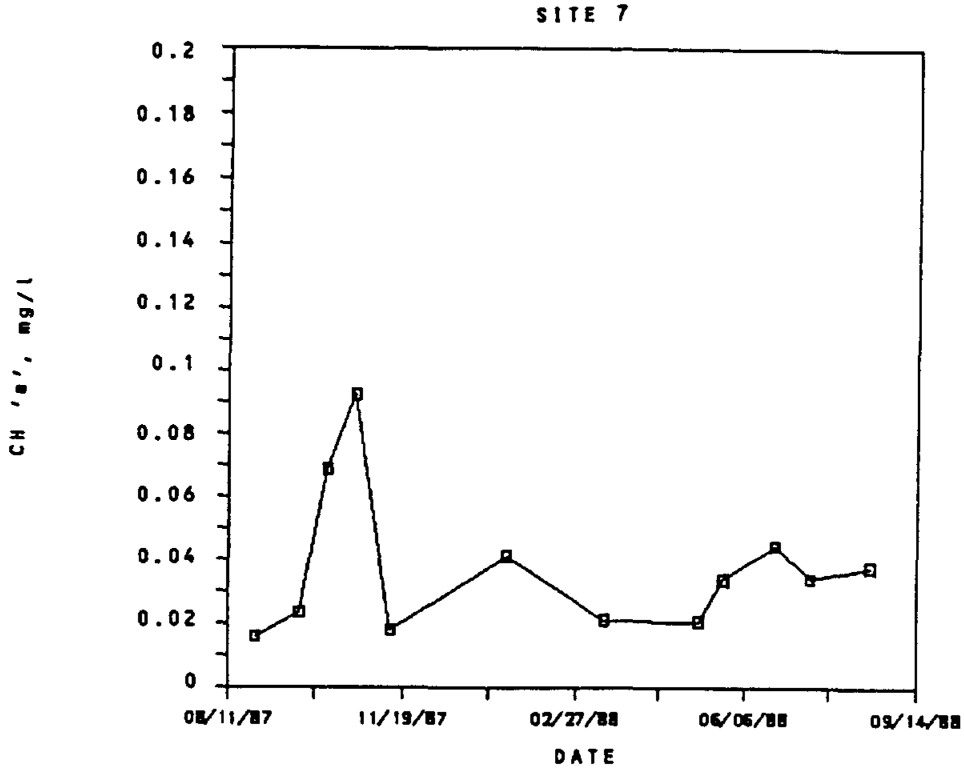


FIGURE II-13

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE BELTON (continued)



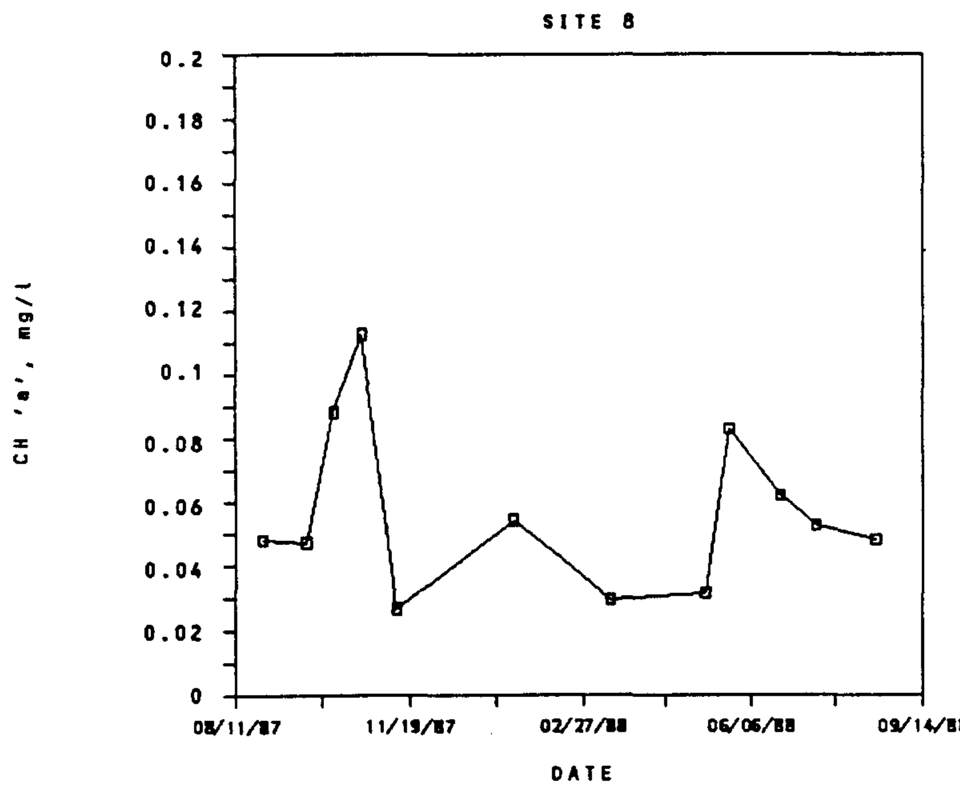
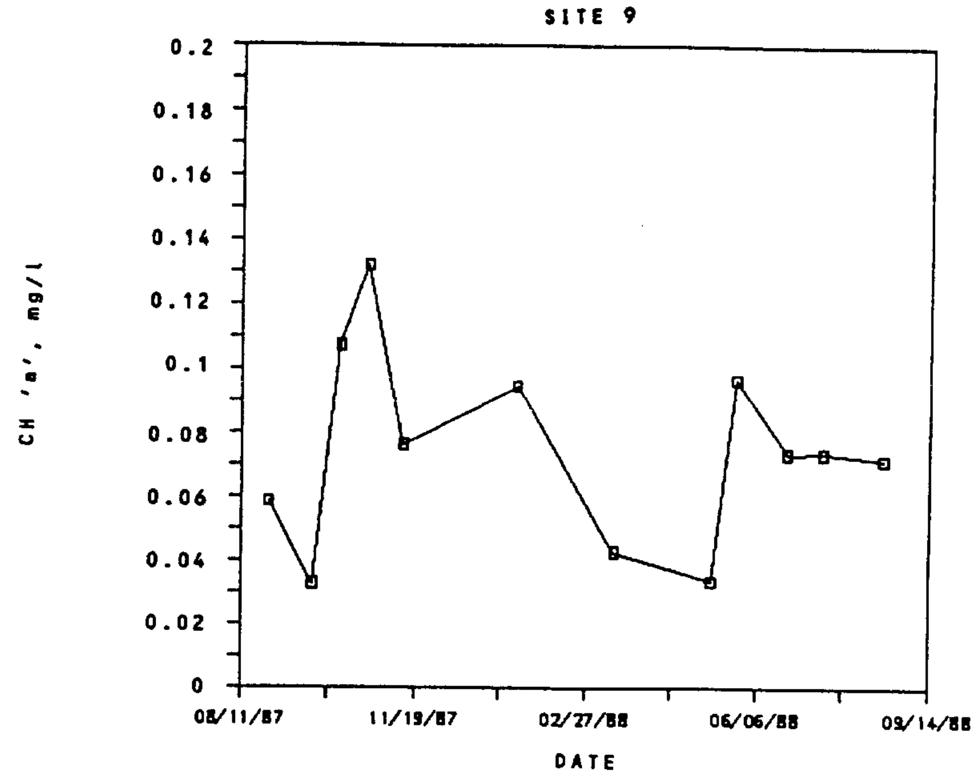


FIGURE II-13

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE BELTON (continued)



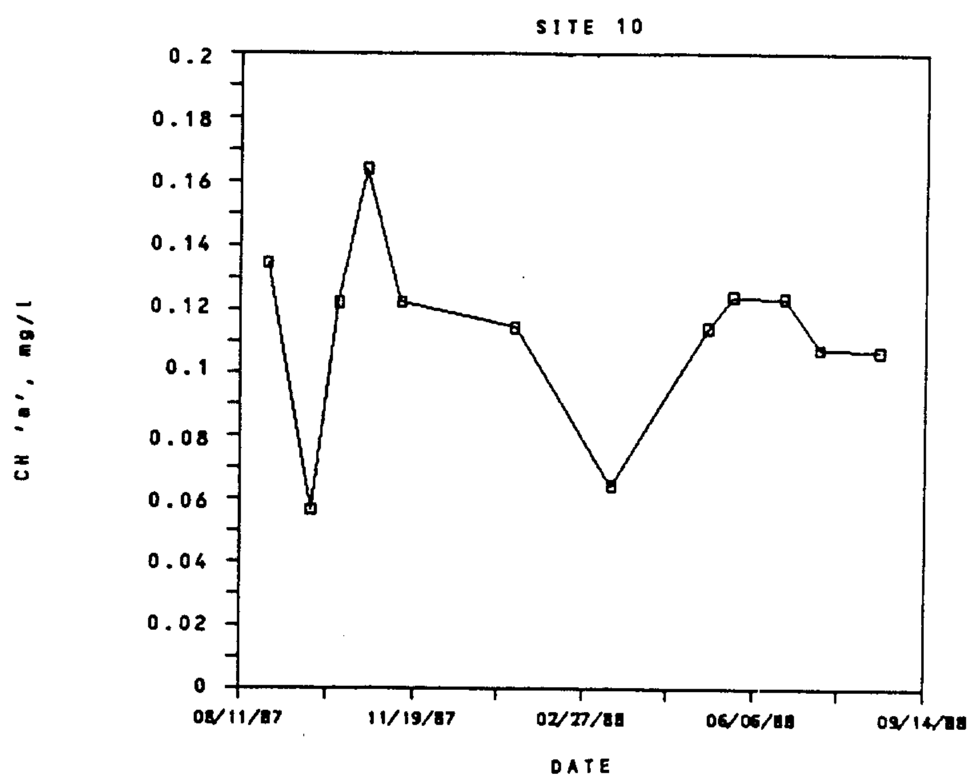


FIGURE II-13

CONCENTRATION OF CHLOROPHYLL 'A' FOR SURFACE SAMPLES FROM LAKE BELTON (continued)

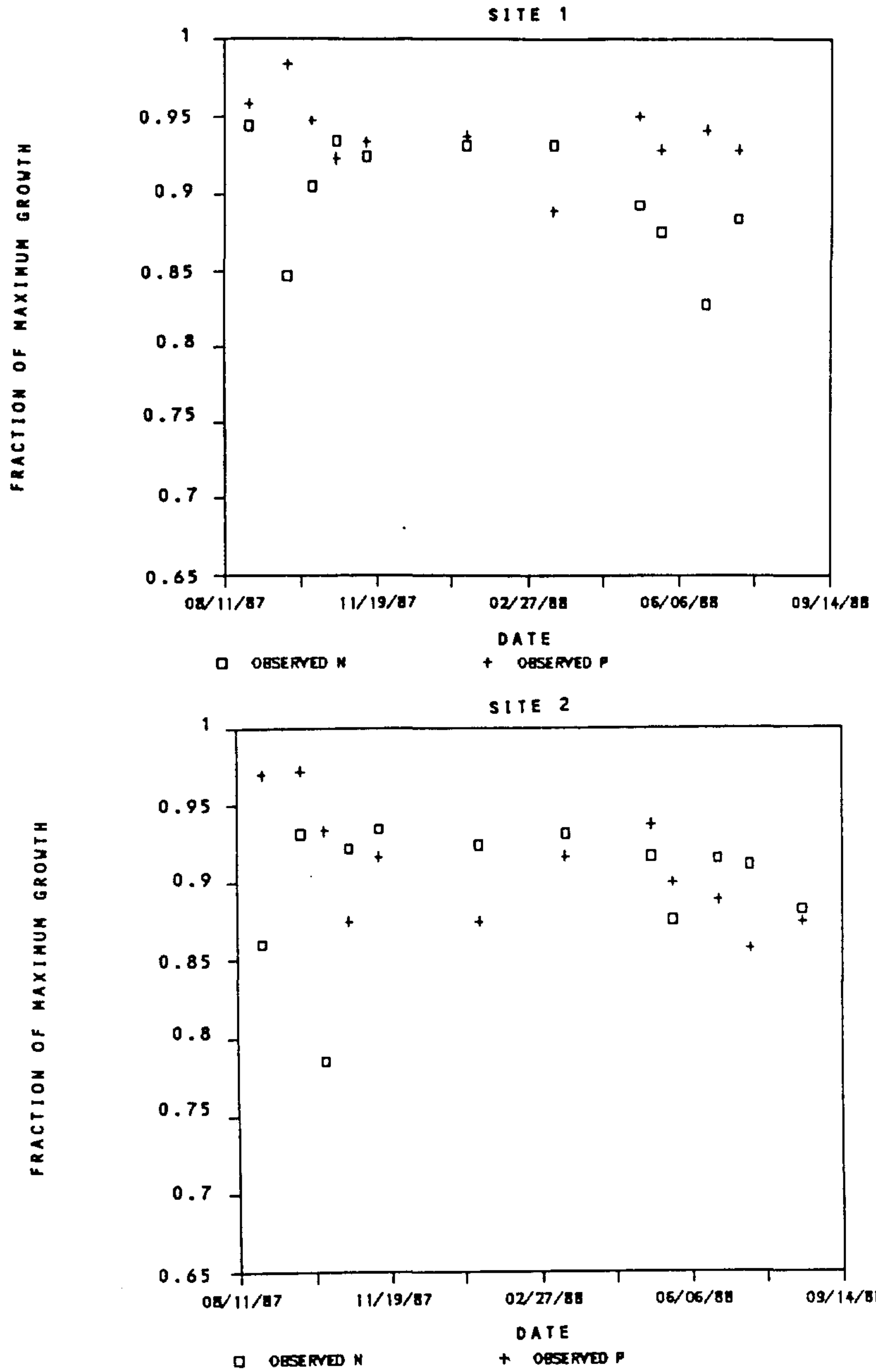


FIGURE II-14

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE NUTRIENTS FROM LAKE BELTON

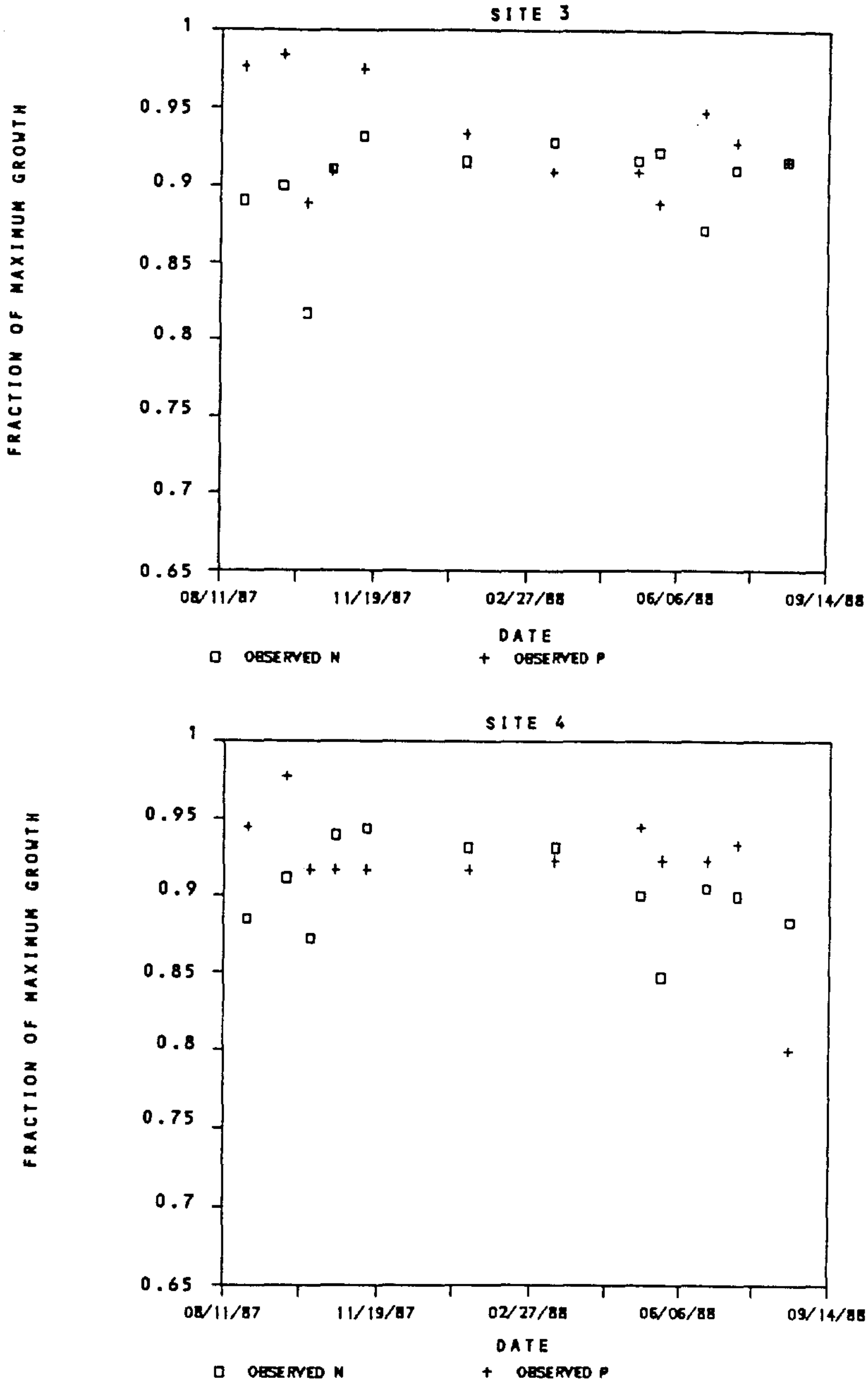
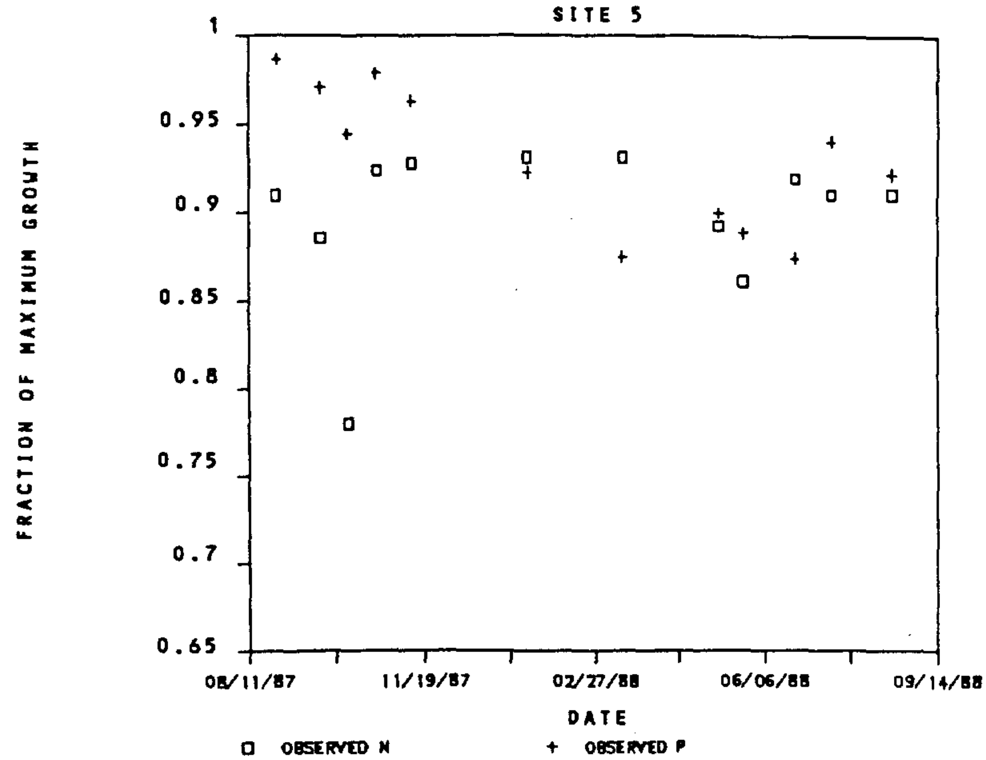


FIGURE II-14

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE NUTRIENTS FROM LAKE BELTON (continued)



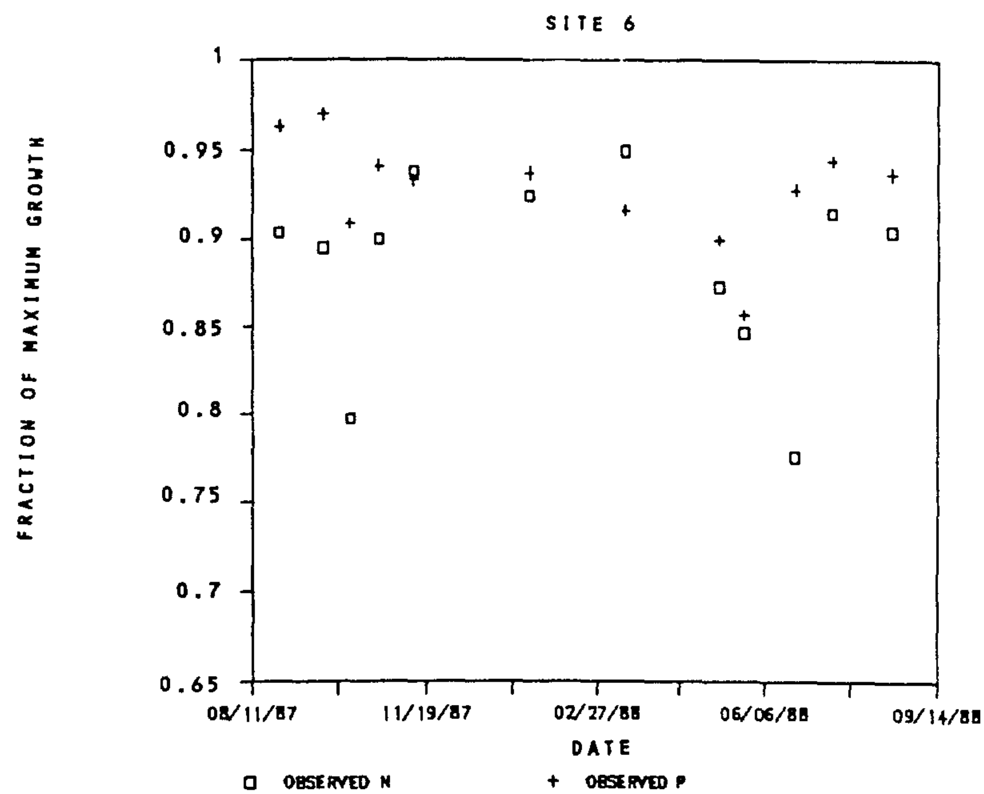
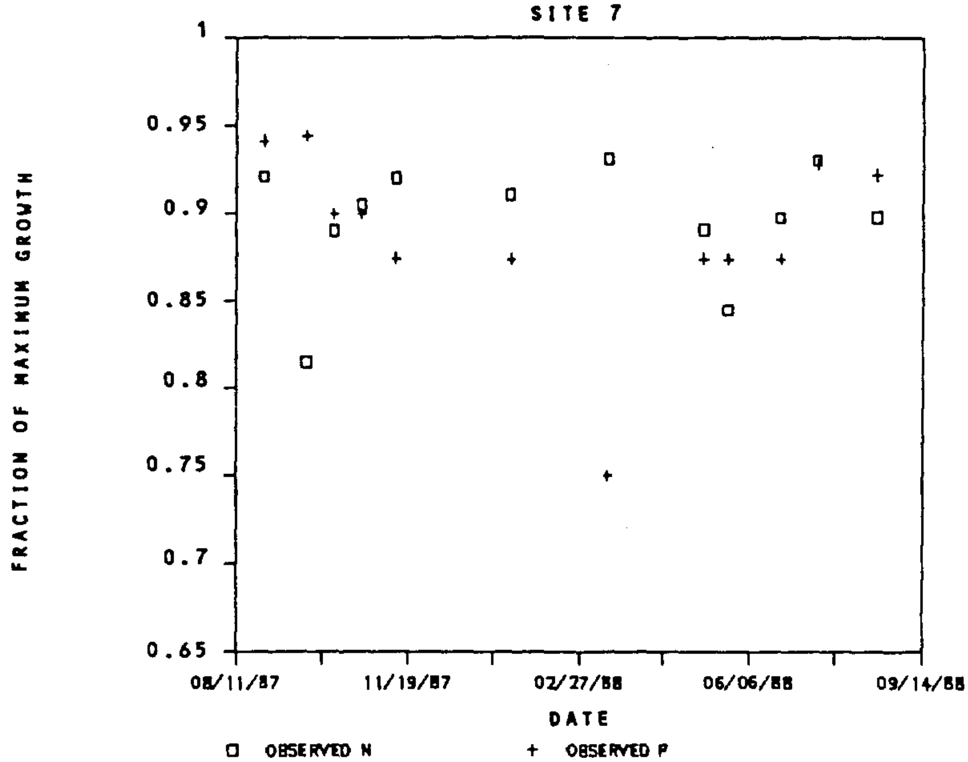


FIGURE II-14

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE NUTRIENTS FROM LAKE BELTON (continued)



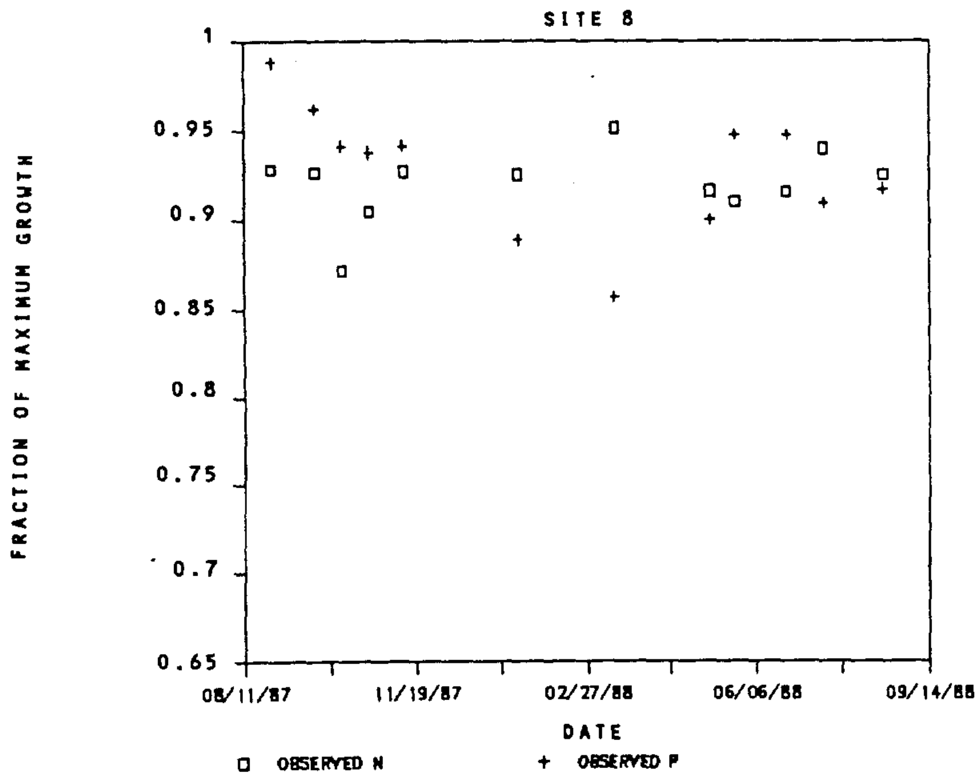
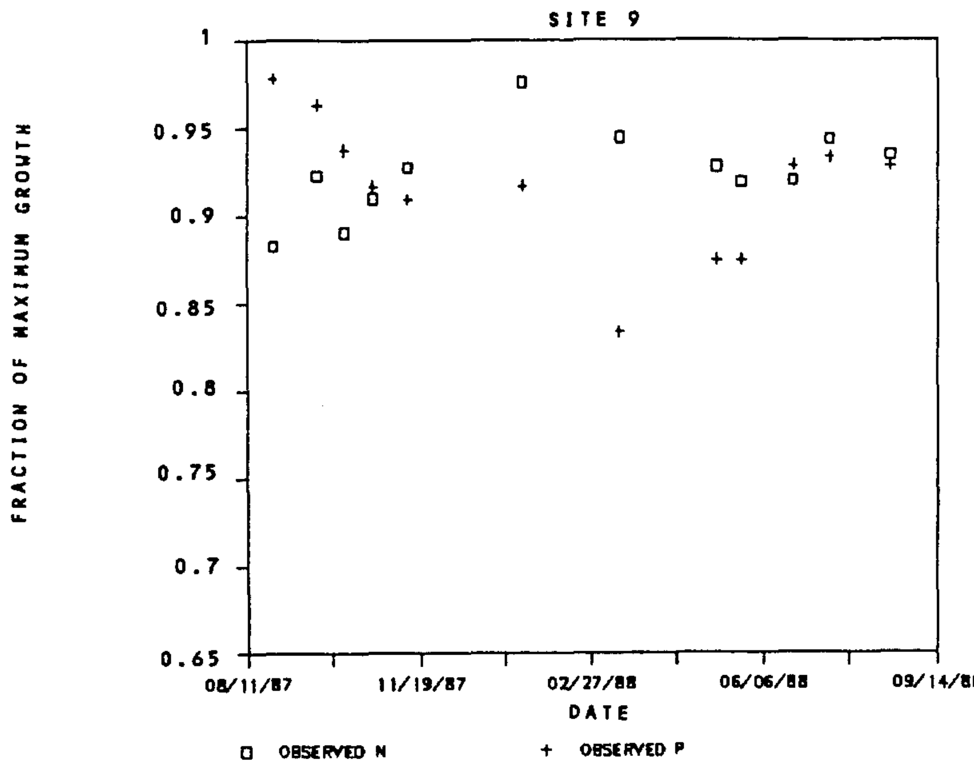


FIGURE II-14

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE
NUTRIENTS FROM LAKE BELTON
(continued)



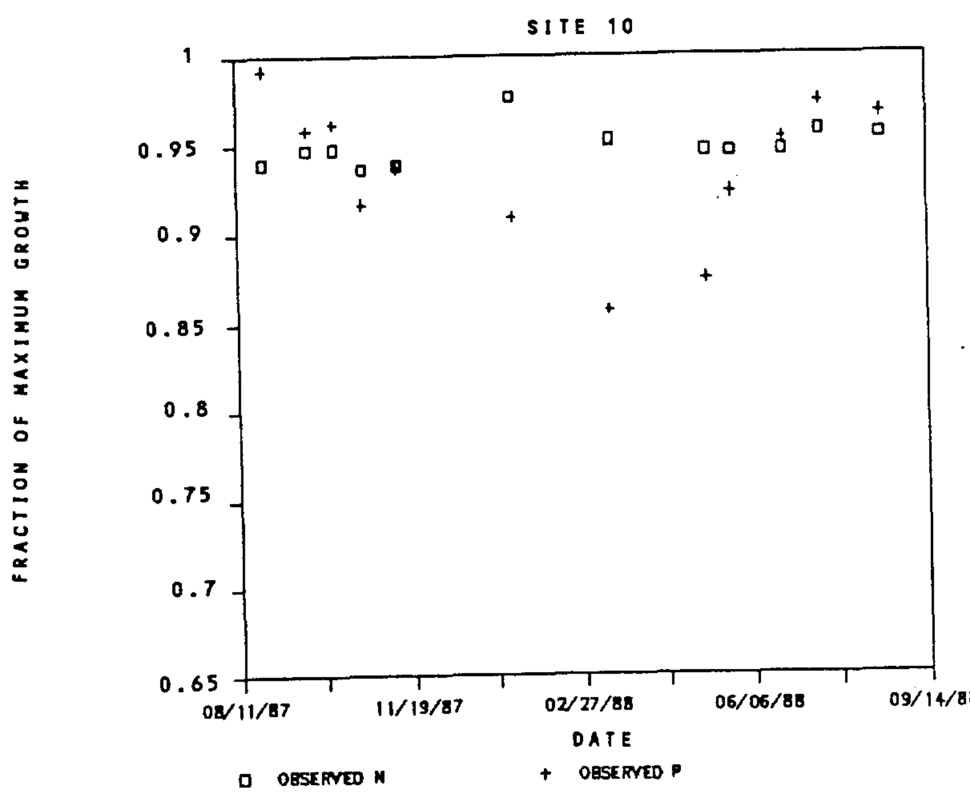


FIGURE II-14

OBSERVED GROWTH LIMITATIONS FOR AVAILABLE
NUTRIENTS FROM LAKE BELTON
(continued)

Figure II-15 is a plot of the temperature and dissolved oxygen profiles at site 1, the deepest site in Lake Belton. As can be seen, the lake at times stratifies and the dissolved oxygen in the bottom layer becomes depleted.

Nonpoint Source Sampling and Testing

A nonpoint source (NPS) sampling program was also developed for this study. NPS sampling provides data that are used to estimate the average concentration of contaminants from stormwater runoff for a variety of landuses. Each sampling site was chosen to represent a single landuse category. For this study, three categories of land use have been used: urban, agricultural, and rangeland. The contaminant concentrations for each landuse were then used to determine the NPS loads from the watersheds entering each lake.

The NPS sampling program produced a very limited data base due to a lack of precipitation during the study period and other constraints. The data which were collected are presented in Table II-13. Because the NPS data base in Table II-13 is very limited, two other existing sources of NPS data from the study area were used in addition to the data collected from the sampling program. These are the 1980 CTCOG study and USGS data from the South Fork Rocky Creek near Briggs station shown on Figure II-1. Together these data sources were used to estimate the NPS loads entering Lakes Belton and Stillhouse Hollow. Use of this expanded data base resulted in the values shown in Table II-14 which were used to calculate NPS loads in the Lake Belton and Lake Stillhouse Hollow watersheds.

APPLICATION OF WATER QUALITY DATA TO THIS STUDY

The primary use of the water quality data presented in this chapter was in the calibration of water quality models and to assess the reasonableness of various input variables. Examination of the available data indicates an

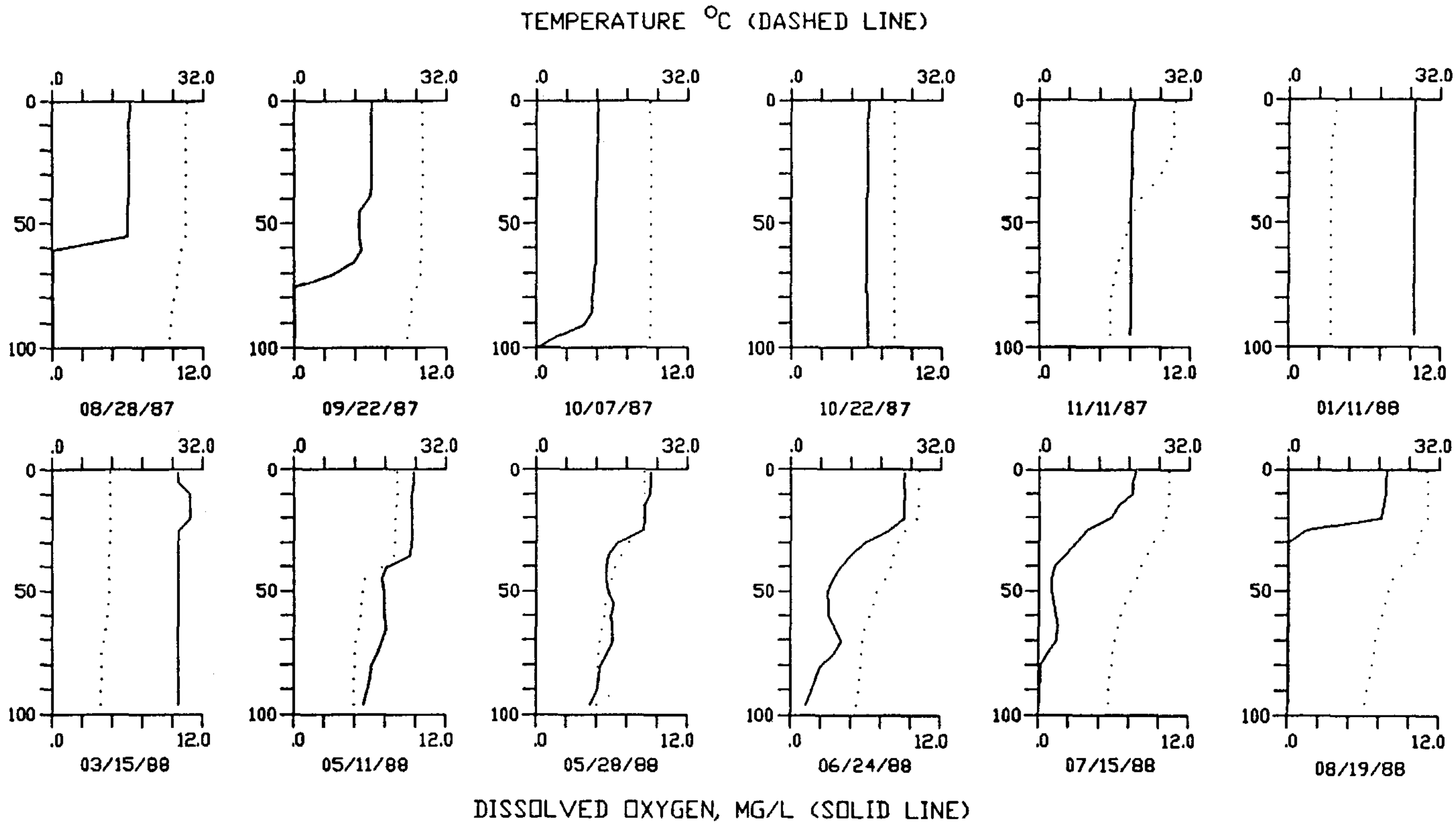


FIGURE II-15

TEMPERATURE - DISSOLVED OXYGEN PROFILES
IN LAKE BELTON

TABLE II-13

NONPOINT SOURCE STORMWATER SAMPLING RESULTS

Site	BOD-5 (mg/l)	TSS (mg/l)	VSS (mg/l)	Ammonia Nitrogen (mg/l)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)	Organic Nitrogen (mg/l)	Ortho Phosphorous (mg/l)	Total Phosphorous (mg/l)
Urban	4.3	270.0	20.0	0.37	0.70	0.014	1.34	0.817	1.428
Agricultural #1	2.9	135.0	10.0	0.60	1.15	0.060	1.55	0.077	0.118
Agricultural #2	6.1	87.5	17.5	0.55	0.14	0.027	0.68	0.855	1.214
Rangeland	3.4	640.0	18.0	0.10	0.32	0.015	1.16	0.099	0.164

TABLE II-14

LAKE BELTON AND STILLHOUSE HOLLOW STUDY
RUNOFF CONSTITUENT CONCENTRATIONS

	LAND USE CATEGORY[1]					
	Mixed	Urban	Agriculture		Rangeland	
Parameter	Mean (mg/l)	CV[2]	Mean (mg/l)	CV[2]	Mean (mg/l)	CV[2]
BOD	0.97	1.15	0.80	1.11	1.01	1.51
TP	0.16	5.11	0.22	1.62	0.08	2.23
PO4-P	0.05	4.24	0.14	2.27	0.03	2.18
NH3-N	0.04	2.11	0.14	4.55	0.07	2.56
NO2-N + NO3-N	1.88	7.14	1.94	11.6	0.24	0.95

(1) Local data base was used
(2) CV-Coefficient of Variation

increase in Chlorophyll 'a' in Lake Stillhouse Hollow over time and excessive levels of Chlorophyll 'a in the Leon River arm of Lake Belton. Chlorophyll 'a' data used in making these observations are shown in Figures II-16 through II-20.

Reference is made to Chapter IV for additional discussion of procedures used in assessing impacts of pollutant loads on existing water quality.

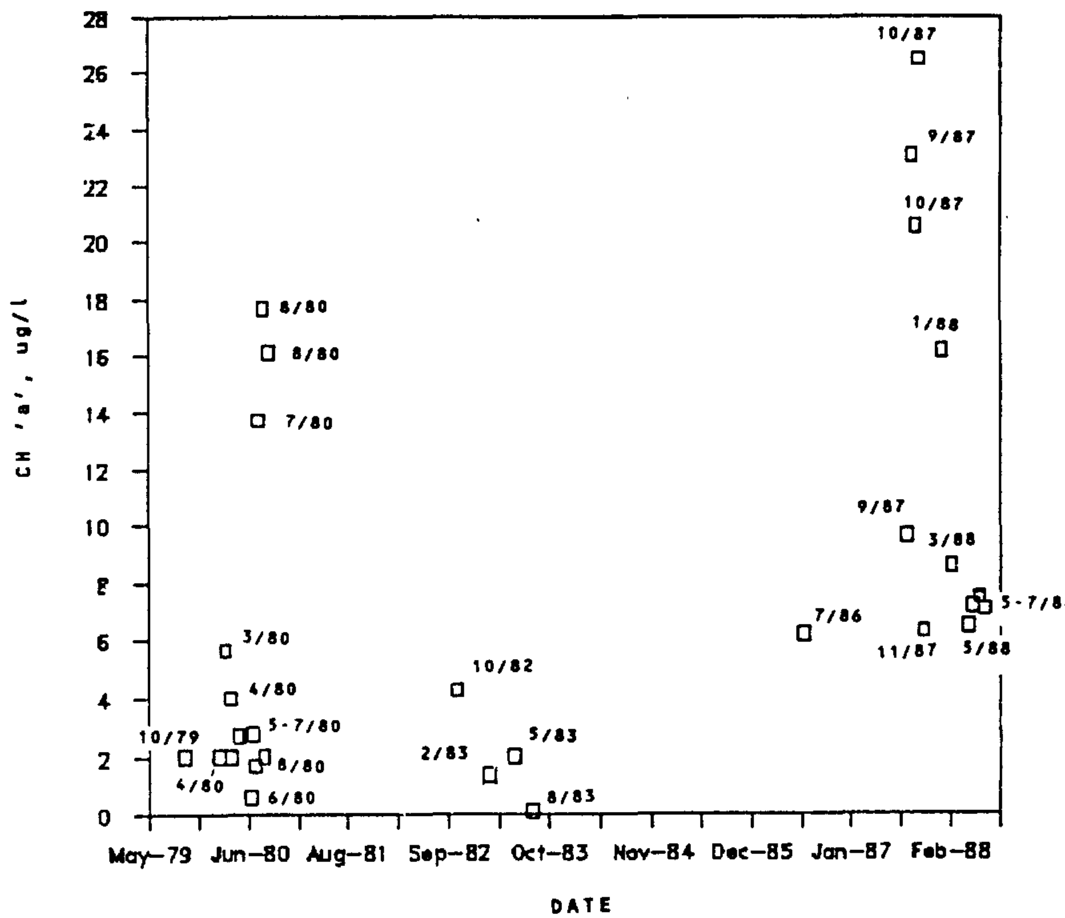


FIGURE II-16

LAKE STILLHOUSE HOLLOW HISTORICAL CHLOROPHYLL 'A' CONCENTRATIONS
(SITE NEAR DAM)

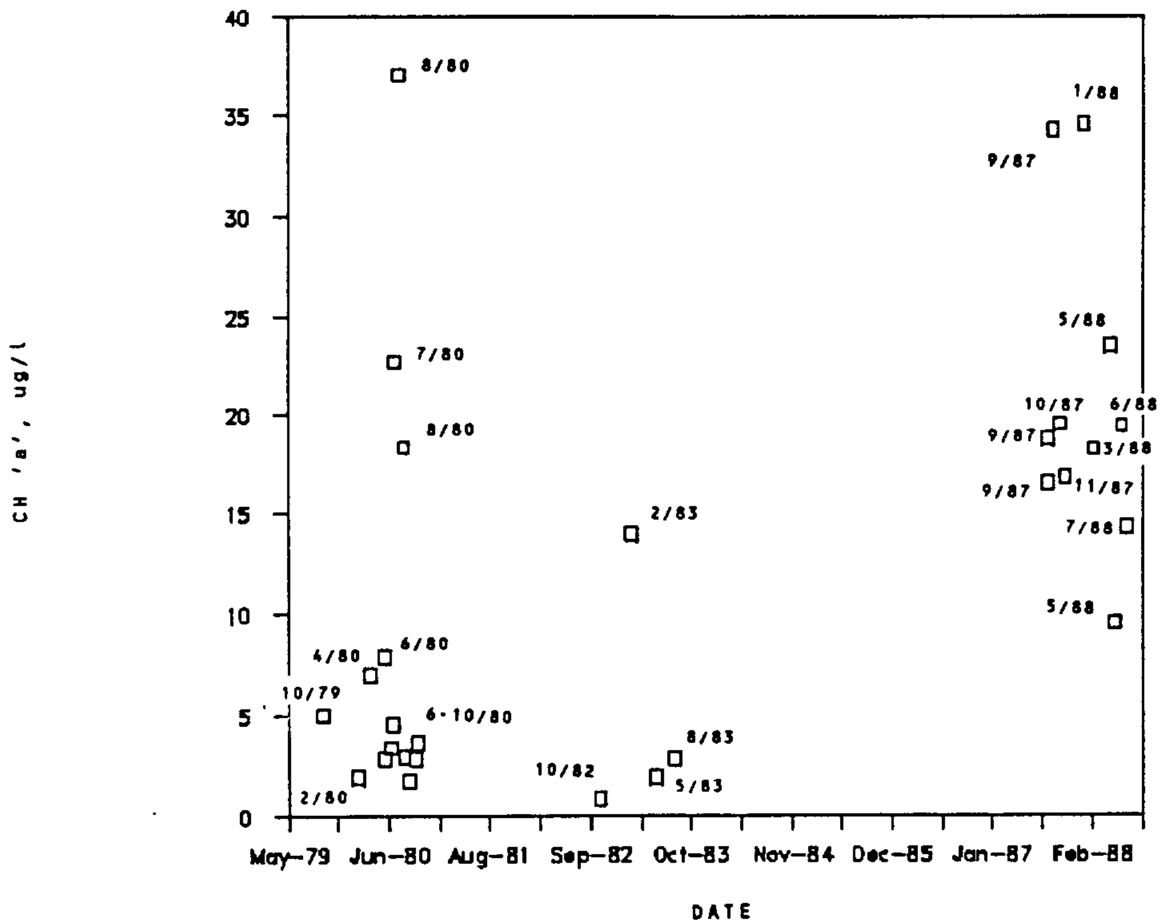


FIGURE II-17

LAKE STILLHOUSE HOLLOW HISTORICAL CHLOROPHYLL 'A' CONCENTRATIONS
(SITE NEAR HEADWATER)

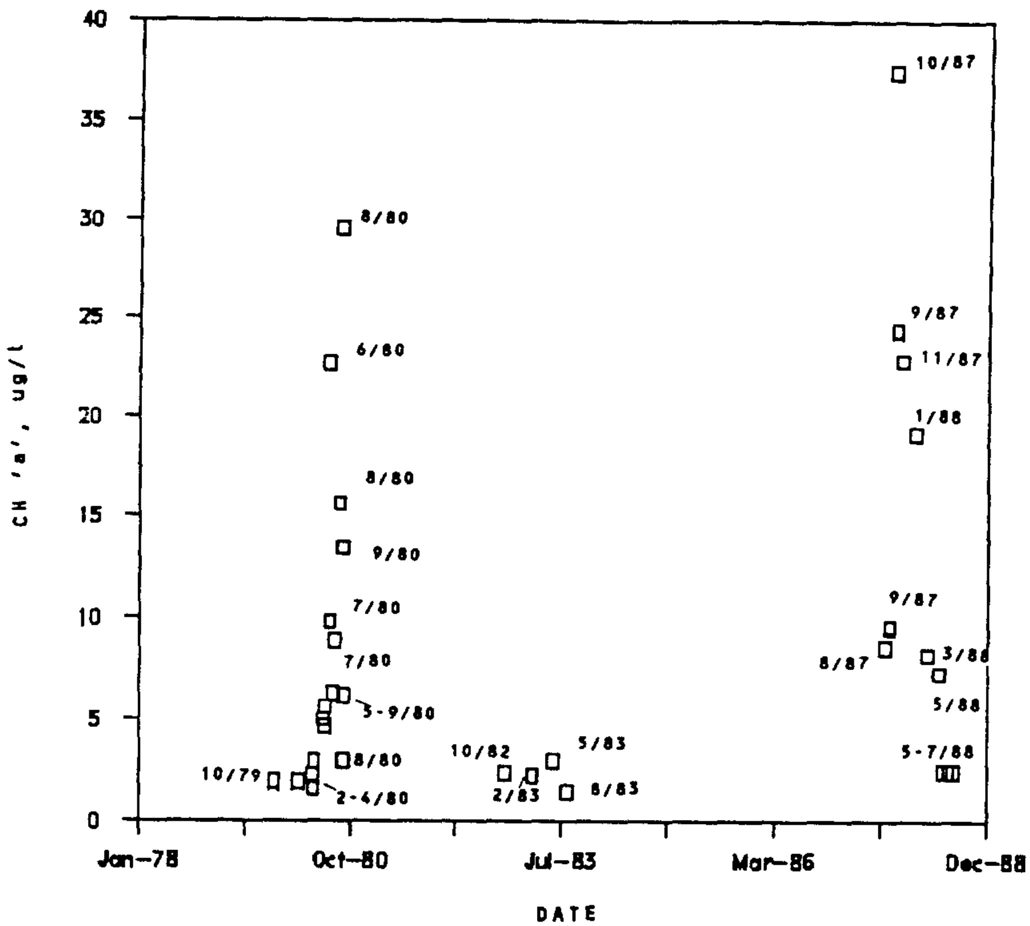


FIGURE II-18

LAKE BELTON HISTORCAL CHLOROPHYLL 'A' CONCENTRATIONS
(SITE NEAR DAM)

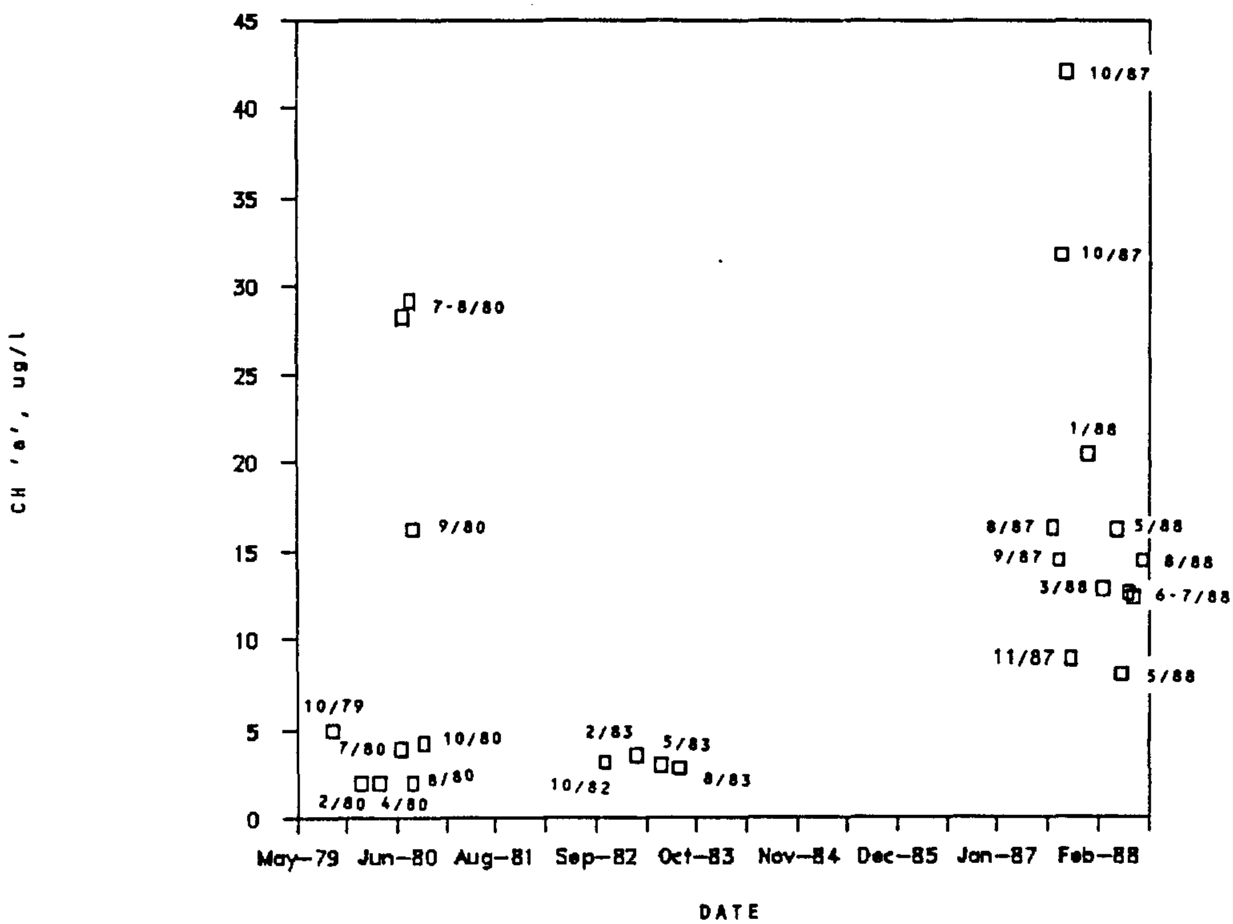


FIGURE II-19

LAKE BELTON HISTORICAL CHLOROPHYLL 'A' CONCENTRATIONS
(COWHOUSE CREEK ARM SITE)

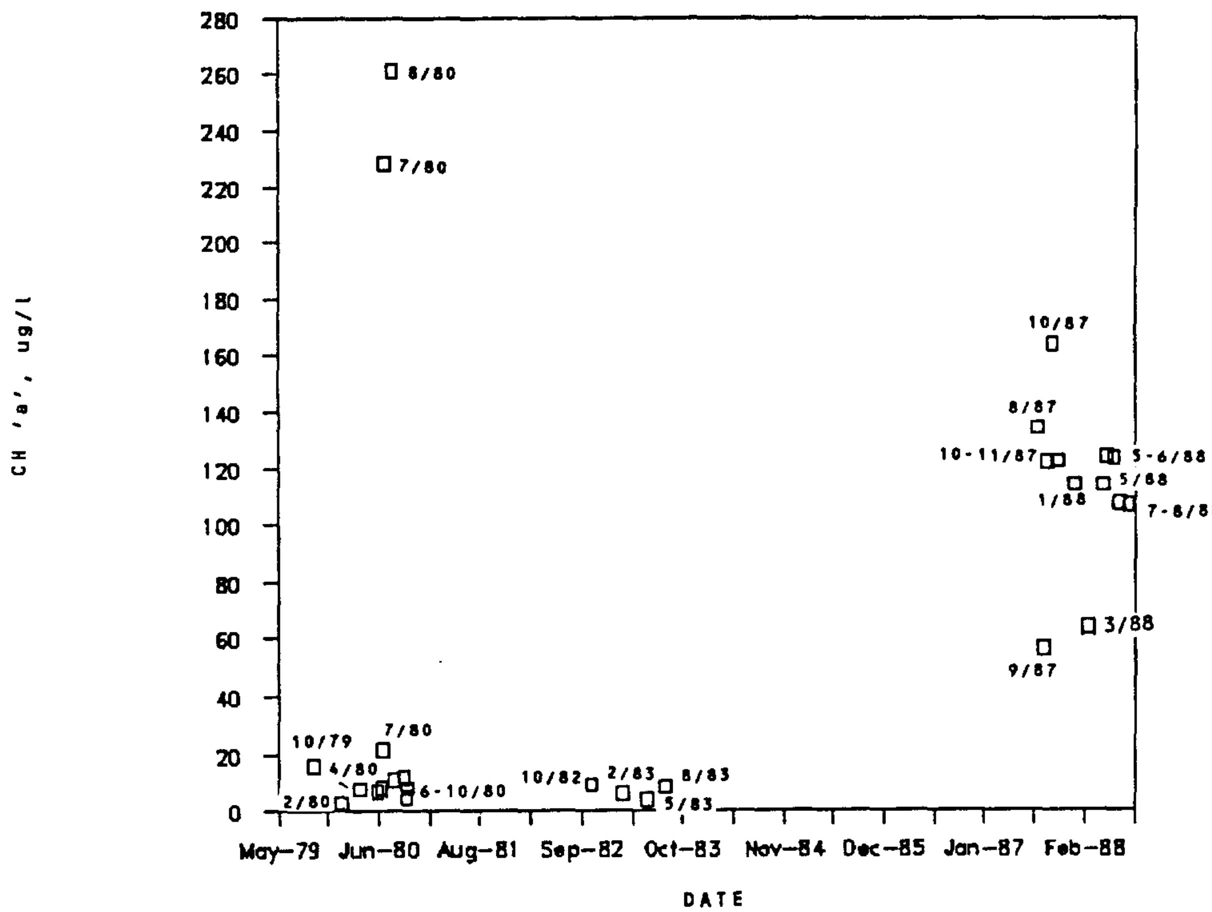


FIGURE II-20

LAKE BELTON HISTORICAL CHLOROPHYLL 'A' CONCENTRATIONS
(LEON RIVER ARM SITE)

CHAPTER III

POINT AND NONPOINT SOURCE LOAD CALCULATIONS

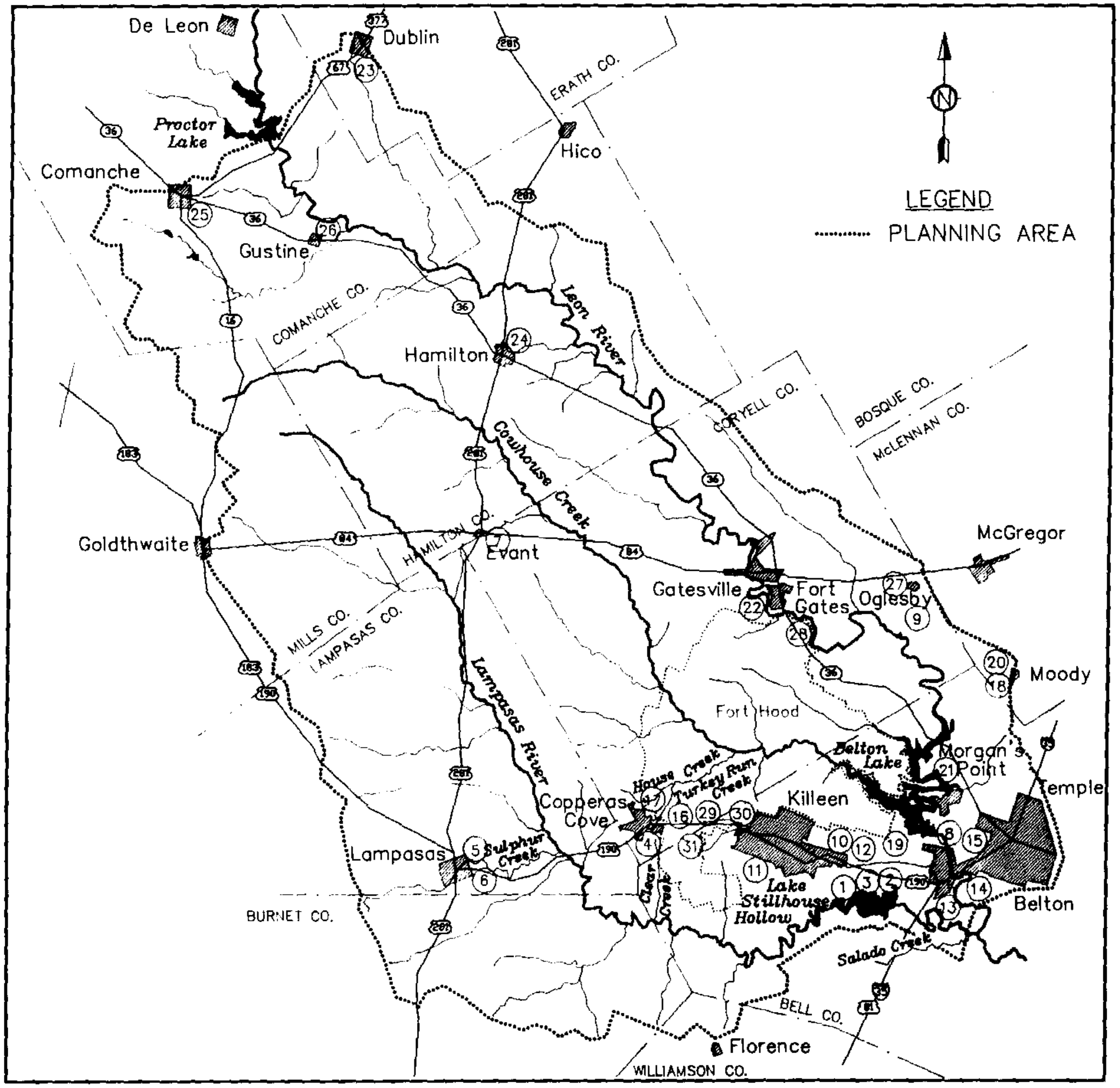
INTRODUCTION

Developing a good estimate of the pollutant loads entering a water body is essential in developing a model of the water quality of that body. Two types of external pollutant loadings are quantified for modelling, point source loadings and nonpoint source loadings. Determining point source loads is fairly straight-forward because all point source dischargers must be permitted by the State and submit regular monthly reports presenting the quality of their effluent. Nonpoint source loadings must be developed from NPS concentrations, land use and the quantity of runoff expected for the basin. The following presents estimates of both point and nonpoint source pollutant loadings.

POINT SOURCE POLLUTANT LOADINGS

There currently are 32 permitted point source dischargers in the study area, seven above Lake Stillhouse Hollow, 21 above Lake Belton, and four in Nolan Creek. Figure III-1 shows the permitted dischargers in the study area. Tables III-1 and III-2 list the dischargers to each lake and their permitted effluent qualities by drainage basin. Also shown in the table are the estimated loads for the sampling period, September 1987 through August, 1988. The estimated loads were based on the TWC's self reporting data reports through July, 1988. The self reporting data does not record values of effluent concentration for total nitrogen and phosphorous, therefore, assumed average values of 20 mg/l and 8 mg/l were used to determine loadings for these constituents.

Future point source loads were based on projected populations for the study area as developed in the Facility Planning Study. Potential locations of new point source dischargers were based on proximity to the user population.



1. COMANCHE UD–FAWN VALLEY STP
2. US CORPS OF ENGINEERS–OTFL 001 STILLHOUSE PARK PLANT
3. US CORPS OF ENGINEERS–OFTL 002 DANA PEAK PARK
4. CITY OF COPPERAS COVE OTFL 003 SOUTH PLANT
5. CITY OF LAMPASAS OTFL 001 SULPHUR PLANT
6. CITY OF LAMPASAS OTFL 002 HENDERSON PLANT
7. EVANT WATER SUPPLY CORPORATION–OTFL 001
8. US CORPS OF ENGINEERS–OFTL 001 BELTON LAKEVIEW PARK
9. US DEPT OF THE NAVY–OFTL 001 NAVAL WEAPONS AREA M
10. BELL CO. WCID 004–OTFL 002 HARKER HEIGHTS
11. BELL CO. WCID 001–OFTL 002 MAIN PLANT AND OFTL 003 NEW PLANT
12. BELL CO. WCID 003–OFTL 001 NOLANVILLE
13. BRA–OTFL 001 TEMPLE–BELTON REGIONAL PLANT
14. BRAZOS ELEC. POWER COOP. OTFL 001 BOB POAGE SES
15. RALPH WILSON PLASTICS CO. OTFL 001
16. CITY OF COPPERAS COVE–OTFL 004 NEW NORTHEAST PLANT
17. CITY OF COPPERAS COVE–OTFL 005 NEW NORTHWEST PLANT
18. CITY OF MOODY–OTFL 001
19. BELL CO. WCID 001–OTFL 001 WATER TREATMENT PLANT
20. GREENBRIER GOLF AND COUNTRY CLUB–OTFL 001
21. CITY OF MORGAN'S POINT RESORT–OTFL 002
22. CITY OF GATESVILLE–OTFL 001
23. CITY OF DUBLIN–OTFL 001
24. CITY OF HAMILTON–OTFL 001
25. CITY OF COMANCHE–OTFL 001
26. CITY OF GUSTINE–OTFL 001
27. CITY OF OGLESBY–OTFL 001
28. US DEPT OF THE ARMY–OFTL 001 & OTFL 003 N. FORT HOOD
29. US DEPT OF THE ARMY–OTFL 006 AND OTFL 007 FORT HOOD CORYELL CO.
30. US DEPT OF THE ARMY–OTFL 001, OTFL 002, OTFL 010, OTFL 004, OTFL 005 FORT HOOD–BELL CO.
31. US DEPT OF THE ARMY–OTFL 001–WEST FORT HOOD

FIGURE III-1
LAKE BELTON AND LAKE STILLHOUSE HOLLOW STUDY AREA
POINT SOURCE DISCHARGERS

TABLE III-1

PERMITTED DISCHARGERS IN STILLHOUSE HOLLOW LAKE WATERSHED

Name	Permit No.	Notes on Permit	Permitted: Avg. Daily Flow (mgd)	Permitted: Avg. Daily BOD (mg/l)	Permitted: Avg. Daily TSS (mg/l)	Permitted: Avg. Daily NH3 (mg/l)	Permitted: Avg. Daily DO (mg/l)	1987 through 1988 data: Avg. Annual Flow (MGD)	1987 through 1988 data: BOD Loading lb/yr	1987 through 1988 data: Nitrogen Loading lb/yr	1987 through 1988 data: Phosphorous Loading lb/yr	State Stream Segment
City of Lampasas Sulphur Plant	10205.001	--	.5	20	20	--	--	.2863	7739	17431	6972	1217
City of Lampasas Henderson Plant	10205.002	--	.5	20	20	--	--	.3531	5331	21496	8599	1217
City of Copperas Cove South Plant	10045.003	--	1.0	20	20	--	--	.457	5980	27813	11125	1217
Comanche UD - Fawn Valley Plant	12016.001	--	.02	10	15	--	--	.0061	232	370	148	1216
US COE - Stillhouse Park Plant	12156.001	--	.008	10	15	--	--	.0003	3.56	20.3	8.1	1216
US COE - Dana Peak Park	12156.002	--	.01	10	15	--	--	.0004	2.5	24.5	9.8	1216
			Total Point Source Loadings						19,288	67,155	26,862	

TABLE III-2

PERMITTED DISCHARGERS IN LAKE BELTON WATERSHED

Name	Permitted							1987 through 1988 data				
	Permit No.	Notes on Permit	Avg. Daily Flow (mgd)	Avg. Daily BOD (mg/l)	Avg. Daily TSS (mg/l)	Avg. Daily NH3 (mg/l)	Avg. Daily DO (mg/l)	Avg. Annual Flow (MGD)	BOD Loading lb/yr	Nitrogen Loading lb/yr	Phosphorous Loading lb/yr	State Stream Segment
US COE - West Fort Hood	2230.001	--	.03	200[1]	30	--	--	.0017	107[2]	43	17	1220
US COE - Fort Hood	2233.003	--	--	200[1]	30	--	--	No Data				
US COE - Fort Hood	2233.004	--	--	200[1]	90	--	--	.145	22958[2]	7981	3193	1220
US COE - Fort Hood	2233.005	--	--	200[1]	90	--	--	1.049	61840[2]	31495	12598	1220
US COE - Fort Hood	2233.006	--	--	200[1]	90	--	--	.0109	6374[2]	491	196	1220
US COE - Fort Hood	2233.007	--	--	200[1]	30	--	--	.0078	3670[2]	156	63	1220
City of Copperas Cove Northeast Plant	10045.004	--	0.8	20.0	20.0	--	--	.5972	8217	36357	14543	1220
City of Copperas Cove Northwest Plant	10045.005	--	1.20	20.0	20.0	--	--	.7781	11372	46991	18796	1220
City of Moody	10225.001	--	0.2	30.0	20.0	--	--	.1273	1486	7752	3101	1220
Greenbrier Golf Club	10888.001	--	.005	20	20	--	--	.0002	3.4	12.2	4.9	1220
Evant Water Supply Corporation	11011.001	--	.03	20	20	--	--	.0201	371	1223	489	1220

TABLE III-2

PERMITTED DISCHARGERS IN LAKE BELTON WATERSHED
(continued)

Name	Permit No.	Notes on Permit	Permitted Avg. Daily Flow (mgd)	Permitted Avg. Daily BOD (mg/l)	Permitted Avg. Daily TSS (mg/l)	Permitted Avg. Daily NH3 (mg/l)	Permitted Avg. Daily DO (mg/l)	1987 through 1988 data Avg. Annual Flow (MGD)	1987 through 1988 data BOD Loading lb/yr	1987 through 1988 data Nitrogen Loading lb/yr	1987 through 1988 data Phosphorous Loading lb/yr	State Stream Segment
US Department of Navy Naval Weapons Plant	2335.001	--	.15	30	--	--	--	.003	156	184	74	1221
City of Gatesville	10176.001	--	1.0	20	20	--	--	.835	25215	50837	20335	1221
City of Dublin	10405.001	--	.25	30	90	--	--	.1529	11753	9309	3724	1221
City of Hamilton	10492.002	--	.25	20	20	--	--	.2933	24705	17857	7143	1221
City of Commanche	10719.001	--	.73	20	20	--	--	.3564	4394	21698	8679	1221
City of Gustin	10841.001	--	.082	20	20	--	--	----------- Not Discharging---------				1221
City of Oglesby	10914.001	--	.025	20	20	--	--	.0258	1290	1571	628	1221
		Total Point Source Loadings							183,911	233,957	93,584	

[1]Daily Maximum Permitted for COD (mg/l)
[2]60 percent of COD concentration used to determine BOD loading

The effluent quality of the future point source flows was varied to determine the impact on the receiving water body. Four effluent quality sets were used to represent treatment levels of secondary treatment, advanced secondary treatment, advanced secondary treatment with nitrification, and tertiary treatment with nutrient removal. Future point source loading was then varied in the projection modelling to determine which treatment alternatives would meet the appropriate state stream standards for dissolved oxygen. The existing point source loads and projected point source loads for 2030 for each watershed are shown in Table III-3. The projected loads for the Lake Stillhouse Hollow watershed include two different loading scenarios from Alternative No. 3 of the Nolan Creek Area Facility Plan (see Chapter IV). The first involves discharges from the Killeen/Harker Heights area which have had advanced secondary treatment with nitrification. The second scenario involves flows from the Killeen/Harker Heights area with advanced waste treatment (tertiary treatment with nutrient removal). In each case, treated wastewater discharged to Stillhouse Hollow would begin with .08 mgd in the year 2010 and increase to 4.54 mgd in the year 2030.

NONPOINT SOURCE LOADINGS

Nonpoint source loadings were developed based on the land use and the concentrations shown in Table II-14 for rainfall runoff from various land uses. Land use in each lake's watershed was determined using satellite imagery, which mapped the reflectance of light from the earth's surface in four wavelength bands. The satellite data were collected for eighty by eighty meter areas, which is about one and one half acres, referred to as pixels. The satellite data were furnished to the U.S. Army at Fort Hood who provided computer and technical assistance in comparing the reflectance of each of the four bands to known reflectance measurements for particular land uses to generate information on the amount of urban, agricultural, and range

TABLE III-3

SUMMARY OF 1988 AND PROJECTED (2030) POINT SOURCE LOADS

Watershed	Total Estimated 1988 Point Source Loads lb/yr BOD	Total Phosphorous	Total Nitrogen
Lake Belton	183,911	93,584	233,957
Lake Stillhouse Hollow	19,288	26,862	67,155

Watershed	Total Projected (2030) Point Source Loads lb/yr BOD	Total Phosphorous	Total Nitrogen
Lake Belton	428,513	218,051	545,120
Lake Stillhouse Hollow	44,941	100,733	251,831
Potential Flows from Killeen/ Harker Heights area to Lake Stillhouse Hollow Watershed[1]			
Without advanced waste treatment	138,202	110,562	276,404
With advanced waste treatment	69,100	13,820	82,921

1. Potential flows from Alternative #3 of Nolan Creek Area Facility Plan.

landuses in the watersheds of Lakes Belton and Stillhouse Hollow. Table III-4 presents the results of the land use analysis.

To estimate nonpoint source loadings the total acreage of each of the three land use types was coupled with the expected average concentration in the runoff shown in Table II-14. The volume of runoff was estimated for each land use group based on the average rainfall in the basin and the observed overall runoff in the basin. The nonpoint source loads under existing conditions were then calculated. The existing nonpoint source loads and projected nonpoint source loads for 2030 for each watershed are shown in Table III-5.

Existing and Projected Pollutant Loads in Lake Watersheds

The total pollutant loads under existing conditions for each watershed are presented in Table III-6. Included in the loads to the Lake Belton watershed are those associated with releases from Lake Proctor. The total projected pollutant loads under 2030 conditions for each watershed are presented in Table III-7. Loads associated with Lake Proctor releases are again included in the projected loads entering the Lake Belton watershed. Projected point source loads to Lake Belton were calculated assuming a continuation of existing secondary treatment practices.

With the exception of the Killeen/Harker Heights area, projected point source loads in the Lake Stillhouse Hollow watershed were also calculated assuming a continuation of existing secondary treatment practices. For the Killeen/Harker Heights area, projected point source loads to Lake Stillhouse Hollow were based on flows projected for Alternative No. 3 of the Nolan

TABLE III-4

LAKE BELTON AND LAKE STILLHOUSE HOLLOW
LAND USE ANALYSIS RESULTS
AS OF NOVEMBER 9, 1988

	Lake Stillhouse Hollow			Lake Belton		
Landuse	Acres	Sq. Miles	% of Total	Acres	Sq. Miles	% of Total
Urban	7,680	12.0	1.0	33,920	53.0	2.4
Agricultural	23,040	36.0	2.7	90,880	142.0	6.3
Rangeland	809,600	1265.0	96.3	1,314,560	2054.0	91.3
Total	840,320 (1)	1313.0 (1)		1,439,360 (2)	2249.0 (2)	

(1) Total drainage area of Lake Stillhouse Hollow
(2) Total drainage area of Lake Belton below Lake Proctor

TABLE III-5

**SUMMARY OF 1988 AND PROJECTED (2030)
NONPOINT SOURCE LOADS**

Watershed	Total Annual Existing Nonpoint Source Loads lb/yr		
	BOD	Total Phosphorous	Total Nitrogen
Lake Belton	549,000	52,800	464,000
Lake Stillhouse Hollow	309,000	26,900	217,000

Watershed	Total Projected (2030) Nonpoint Source Loads lb/yr		
	BOD	Total Phosphorous	Total Nitrogen
Lake Belton	585,234	56,285	494,624
Lake Stillhouse Hollow	329,394	28,675	321,322

TABLE III-6

SUMMARY OF 1988 NONPOINT SOURCE AND POINT SOURCE LOADINGS TO LAKE BELTON AND LAKE STILLHOUSE HOLLOW WATERSHEDS

Lake Belton Watershed	BOD (lb/yr)	Total Phosphorous (lb/yr)	Total Nitrogen (lb/yr)
Total Point Source	183,911	93,584	233,957
Total Nonpoint Source	549,000	52,800	464,000
Loads from Lake Proctor[1]	76,200	7,330	64,400
Total Loads	809,111	153,714	762,357

Lake Stillhouse Hollow Watershed	BOD (lb/yr)	Total Phosphorous (lb/yr)	Total Nitrogen (lb/yr)
Total Point Source	19,288	26,862	67,155
Total Nonpoint Source	309,000	26,900	217,000
Total Loads	328,288	53,762	284,155

1. Loads associated with releases from Lake Proctor entering Lake Belton Watershed.

TABLE III-7

SUMMARY OF PROJECTED (2030) NONPOINT SOURCE AND POINT SOURCE LOADINGS TO LAKE BELTON AND LAKE STILLHOUSE HOLLOW WATERSHEDS

Lake Belton Watershed	BOD (lb/yr)	Total Phosphorous (lb/yr)	Total Nitrogen (lb/yr)
Total Point Source	428,513	218,051	545,120
Total Nonpoint Source	585,234	56,285	494,624
Loads from Lake Proctor[1]	76,200	7,330	64,400
Total Loads	1,089,947	281,666	1,104,144

Lake Stillhouse Hollow Watershed	BOD (lb/yr)	Total Phosphorous (lb/yr)	Total Nitrogen (lb/yr)
Total Point Source	44,941	100,733	251,831
Total Nonpoint Source	329,394	28,675	231,322
Killeen/Harker Heights Flows without advanced waste treatment[2]	138,202	110,562	276,404
Total Loads	512,537	239,970	759,557

Lake Stillhouse Hollow Watershed	BOD (lb/yr)	Total Phosphorous (lb/yr)	Total Nitrogen (lb/yr)
Total Point Source	44,941	100,733	251,831
Total Nonpoint Source	329,394	28,675	231,322
Killeen/Harker Heights Flows with advanced waste treatment[2]	69,100	13,820	82,921
Total Loads	443,435	143,228	566,074

1. Loads associated with releases from Lake Proctor entering Lake Belton watershed.

2. Potential flows from Alternative #3 of the Nolan Creek Facility Planning Area.

Creek Area Facility Plan. These loadings were calculated for two treatment scenarios:

1. BOD5 = 10 mg/l
   Total N = 20 mg/l
   Total P = 8 mg/l
2. BOD5 = 5 mg/l
   Total N = 6 mg/l
   Total P = 1 mg/l

Figure III-2 graphically summarizes the existing and projected total point and nonpoint source loads in the Lake Belton watershed. Figure III-3 graphically summarizes the existing and projected total point and nonpoint source loads in the Lake Stillhouse Hollow watershed including the projected flows from the Killeen/Harker Heights Facility Planning Area with and without advanced waste treatment.

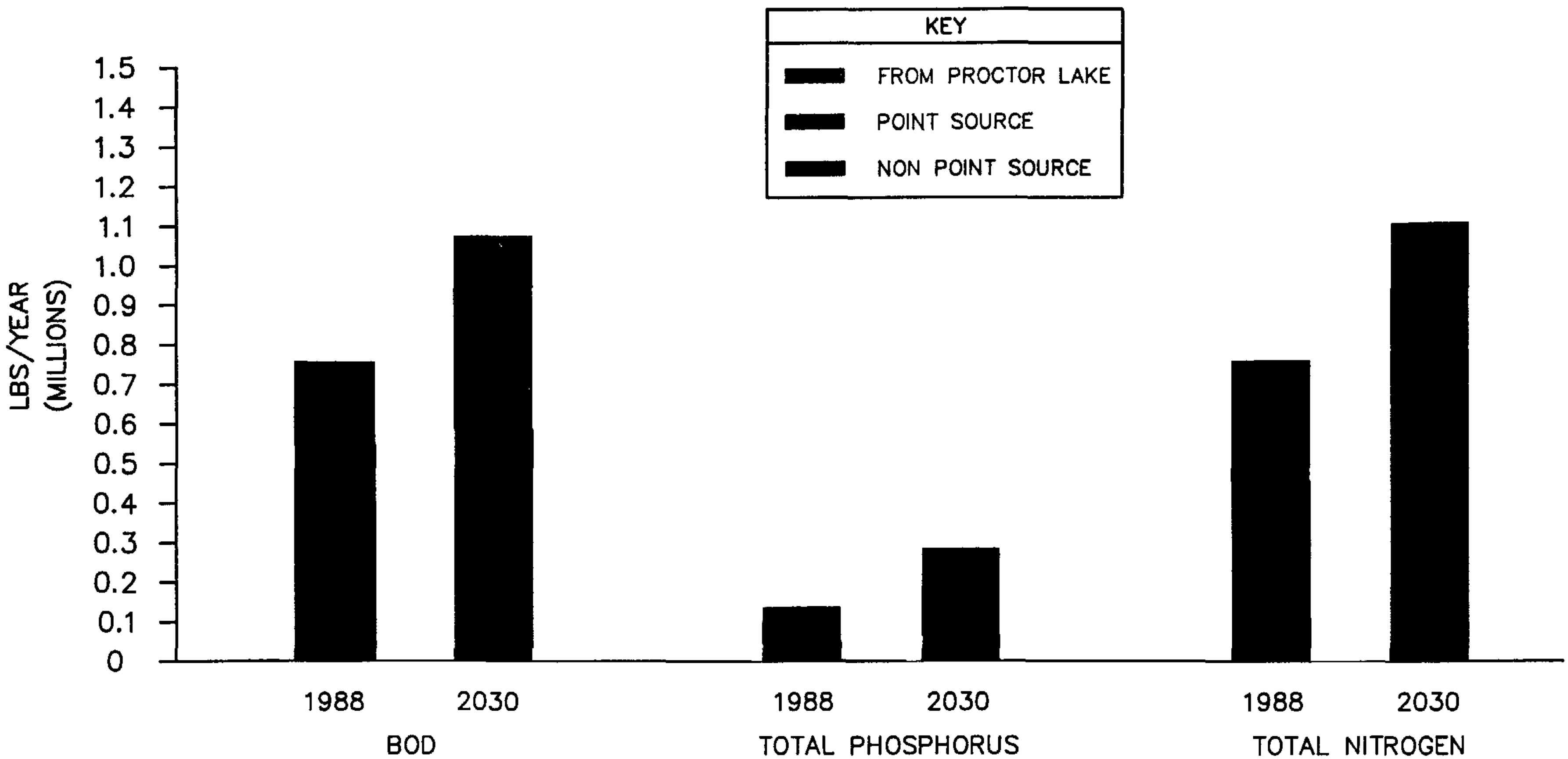


FIGURE III-2
EXISTING AND PROJECTED
POLLUTION LOADINGS
TO LAKE BELTON WATERSHED

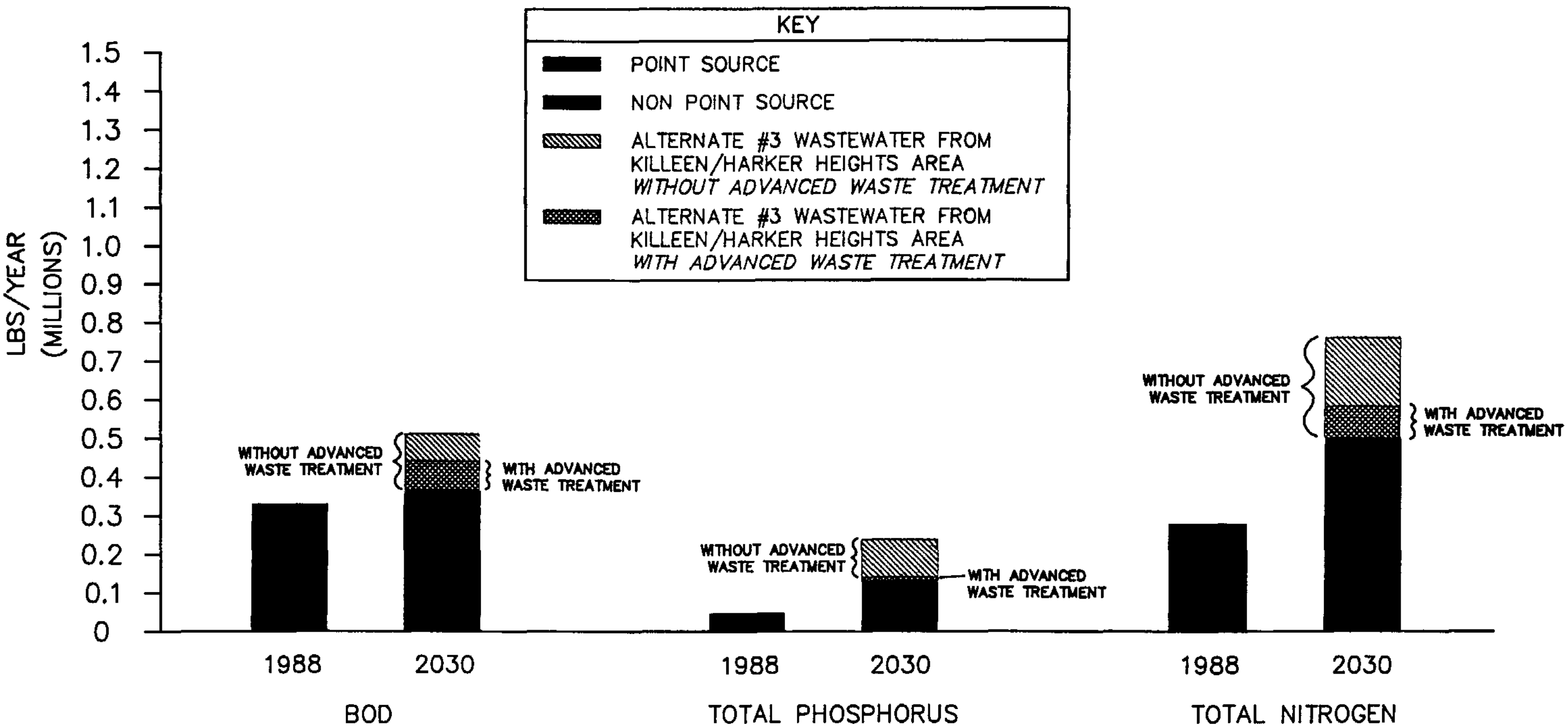


FIGURE III-3
EXISTING AND PROJECTED
POLLUTION LOADINGS TO
LAKE STILLHOUSE HOLLOW WATERSHED

CHAPTER IV

WATER QUALITY MODELLING TO DETERMINE RECOMMENDED EFFLUENT LIMITS

INTRODUCTION

Determining effluent quality limitations requires that the impact of the discharge on the water quality be estimated. This is accomplished by developing a mathematical model. The model is developed using the existing water quality conditions observed in the water body as a basis to estimate the coefficients that describe the processes that influence water quality. These coefficients are adjusted until there is a reasonable comparison between observed water quality parameters and calculated values for those same parameters. At this point the model is said to be calibrated. It is customary to compare model results to a second set of independent water quality observations. If a favorable comparison exists the model is said to be verified. Because of limitations in available data, only two water quality models (Leon River above Lake Belton and Leon River below Lake Belton) were verified in this study. Water quality models developed for this study were used to estimate the impact of projected waste loads. By changing waste load inputs to the model, a waste load can often be determined that meets all regulatory standards developed for the receiving water body. The following discussion presents the techniques used to develop stream and lake models of the water bodies in the study area.

STREAMS

Procedure

As presented in Chapter I, each stream segment in the study area has water quality standards to support the existing usage. To determine the impact of the point source dischargers on the stream, models that simulate dissolved oxygen were developed. Two types of stream models were used in the study.

For House Creek and Turkey Run Creek the Streeter-Phelps dissolved oxygen sag model developed by TWC was used. All other streams were simulated using QUAL-TX, a more complicated model also developed by the TWC.

Both Streeter-Phelps and QUAL-TX are steady state models (that is they assume that the processes and flows represented in the model are unchanging). The Streeter-Phelps model (simplified model) was developed with losses of dissolved oxygen due to BOD decay and nitrification of ammonia and gains in oxygen due to reaeration. The QUAL-TX model adds to that losses due to sediment oxygen demand and can accommodate changes due to the interaction of aquatic plant life. QUAL-TX is written so that the oxygen-dependant BOD oxidation and nitrification rates are used in the model.

The simplified Streeter-Phelps model requires a relatively small data base. Geometry, along with dissolved oxygen, BOD and ammonia concentrations are required to estimate the decay coefficients for BOD and ammonia. This model assumes that the dominant processes regulating the dissolved oxygen concentration are the decay of BOD and the nitrification of ammonia.

QUAL-TX requires a more extensive data base because the interaction of more of the processes affecting dissolved oxygen is simulated. Chapter II discusses the measurements taken and the constituents analyzed in the water samples. Some parameters, such as sediment oxygen demand, were not measured and were estimated using engineering judgement based on experience of the modeler.

QUAL-TX was calibrated using the data that were collected during the stream surveys. These data were presented in Chapter II of this report. The water quality and flow conditions observed at the most upstream site, at the point source dischargers and in tributaries were used as model input (see Figures II-2, II-3, II-4, II-5, II-6 and II-7). The coefficients were then adjusted, within ranges reported in the literature, so that the concentrations of dissolved oxygen, BOD, ammonia, nitrate, and organic nitrogen were in reasonable agreement with the observed values.

As mentioned, the Leon River above Lake Belton model and the Leon River below Lake Belton model were verified during this study. The Nolan Creek model was calibrated and verified by the Texas Water Commission during a previous study. The verification of QUAL-TX is accomplished using data on stream flow, waste loads, and water temperature from a second sampling survey. This second set of input data and coefficients developed during the calibration are used in a "verification run" of the model. The results of the verification run are compared to the water quality observed during the second sampling survey. If the calculated values approximate the observed values, then this verifies that the model describes the process that dominate the water quality.

Once the model is calibrated and, if additional data exists, verified, several parameters are modified to reflect the time when the stream would be most sensitive to point source dischargers, termed the critical period. For most streams this is during the summer when high temperatures and low flows dominate. The flow used in this study was the seven day-two year lowflow (7Q2) and the temperature modelled was the average summertime temperature plus one standard deviation of the data base (if data existed). Other parameters, such as settling rate and sediment oxygen demand were also modified, if necessary, to reflect improved wastewater treatment. The projected wastewater flows were then added to the model and the required effluent determined, based on the model's output and the stream standards.

The following sections describe calibration and verification of stream models used in this study.

Calibration of Stream Water Quality Models Used in This Study

In modeling Sulphur Creek, Clear Creek, and Leon and Lampasas segments above and below Lakes Belton and Stillhouse Hollow it was necessary to calibrate the QUAL-TX model. In modeling Nolan Creek a model previously calibrated by Texas Water Commission was used. Data collected during this study were used to calibrate the models for all of the above streams except Nolan Creek and the Leon River below Lake Belton. For the Leon River below Lake Belton, the TWC provided a data base that included two intensive surveys of the reach. The following sections deal with the calibration of the QUAL-TX model for the Leon River above Lake Belton, the Leon River below Lake Belton, Sulphur Creek, Clear Creek, the Lampasas River above Lake Stillhouse Hollow and the Lampasas River below Stillhouse Hollow Lake.

Leon River Above Lake Belton. The Leon River above Lake Belton was modelled from Gatesville to Lake Belton. The QUAL-TX data set is presented in the appendix. Data were collected from Gatesville to the Highway 36 bridge. Figure IV-1 presents the calculated and observed concentrations from the October sampling. The organic nitrogen and ammonia observations show a rapid downstream decline in concentration below the Gatesville WWTP. Nitrate plus nitrite shows a slower decline. The rapid loss in organic nitrogen was probably due to settling of the solids. As shown in Table II-5 and II-6, the effluent quality of the WWTP was high in solids and organic nitrogen. The organic nitrogen was probably associated with the solids. The decline in ammonia and nitrate was probably due to aquatic plant uptake. The dissolved oxygen showed a well defined sag below the WWTP.

In developing the calibration model it was observed that the poor quality of the effluent from the Gatesville WWTP (see Tables II-5 and II-6) and aquatic plant life observed in the stream could be significant factors affecting water quality. Initial trials of adjusting the BOD5 decay and nitrification

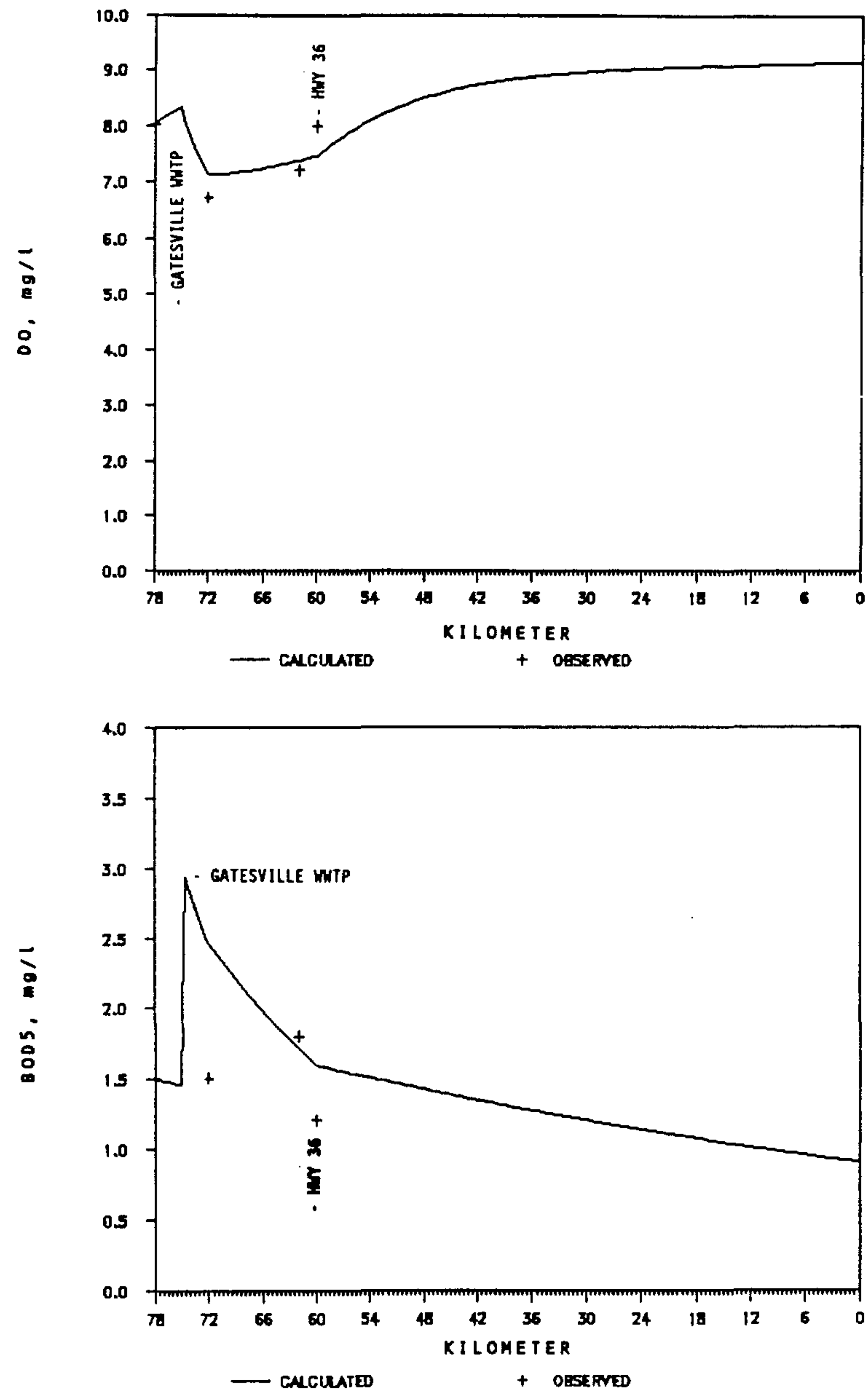
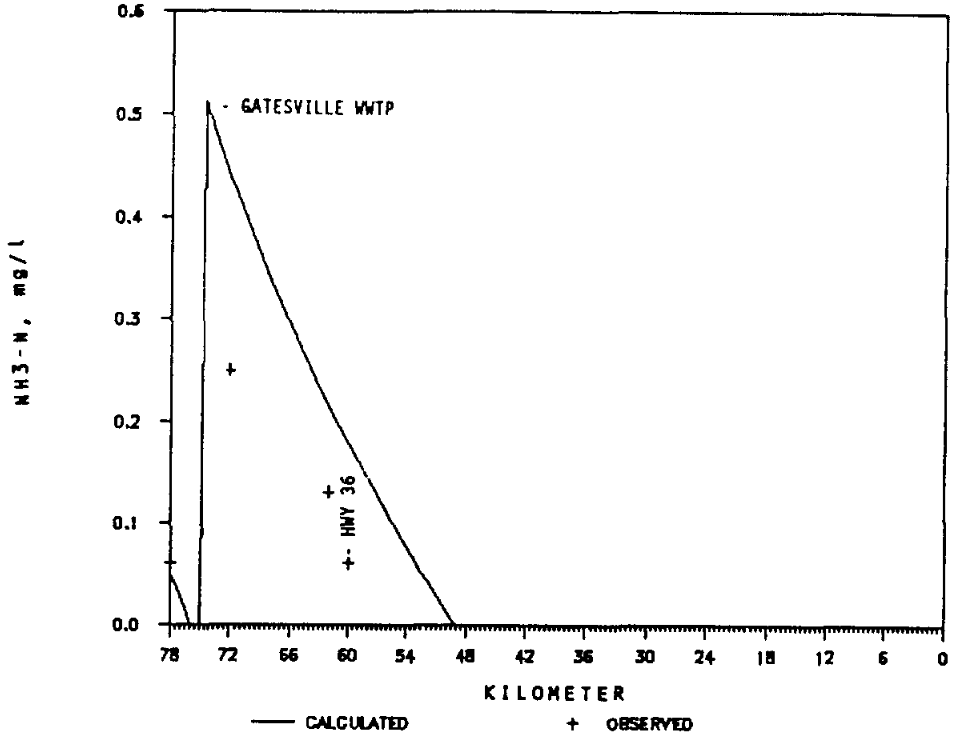


FIGURE IV-1

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 13, 1987 SAMPLING OF THE
LEON RIVER ABOVE LAKE BELTON



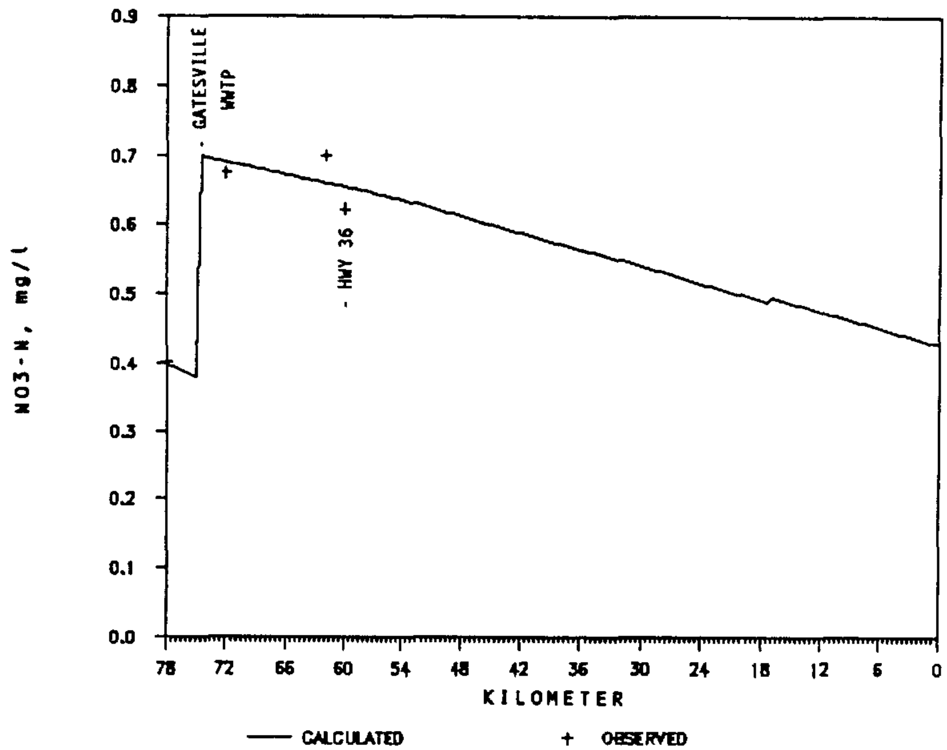


FIGURE IV-1

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 13, 1987 SAMPLING OF THE
LEON RIVER ABOVE LAKE BELTON
(continued)

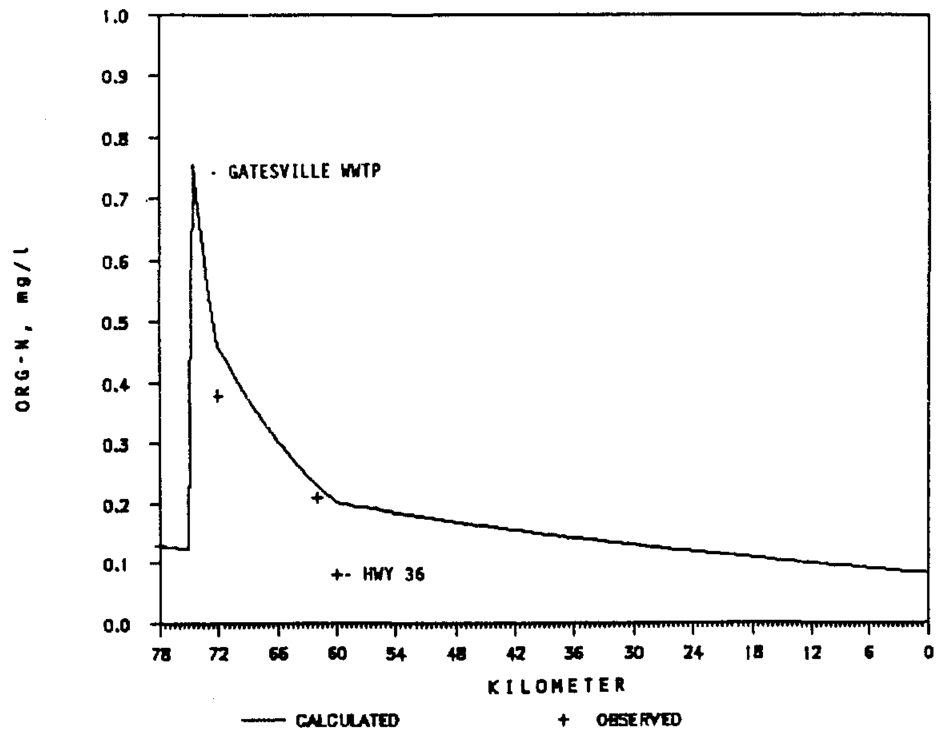


FIGURE IV-1

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 13, 1987 SAMPLING OF THE
LEON RIVER ABOVE LAKE BELTON
(continued)

rates to produce a dissolved oxygen sag similar to the observed values indicated settling of BOD and organic nitrogen, and that sediment oxygen demand and aquatic plant life may all be dominate factors in the dissolved oxygen cycle. Because of the likely influence of these factors, the decay rate for BOD and the nitrification rate could not be independently developed from the field data. Therefore, the decay rate for BOD and the nitrification rate were set to typical values for Texas rivers.

Leon River Below Lake Belton. The Leon River was also modelled from below Lake Belton to the confluence with the Lampasas River. Figure IV-2 presents the calculated and observed values. The observed values used in the model were developed by the TWC. The TWC surveyed the Leon River below the lake in May, 1987 and collected data at five sites along its course, three tributaries and the Brazos River Authority's (BRA) Regional WWTP. The observed values shown in Figure IV-2 suggest that Nolan Creek's flow which includes the BRA Regional plant's discharge just upstream of the Nolan Creek/Leon River confluence impacts the quality of the Leon River. Dissolved oxygen decreases and nutrient levels increase below the confluence with Nolan Creek.

In calibrating the model an increase was observed in the organic nitrogen concentrations in the Leon River below Nolan Creek. This suggests that organic material introduced into the river, either through nonpoint or point source loading, is settling to the bottom, decomposing and being reintroduced into the water column. In addition, there was an observed dissolved oxygen deficit not associated with expected BOD decay and nitrification. This deficit was assigned to sediment oxygen demand. Nitrification appeared to be occurring at a high rate in the Leon River below the confluence with Nolan Creek, based on the rapid disappearance of ammonia and the steady increase in nitrate.

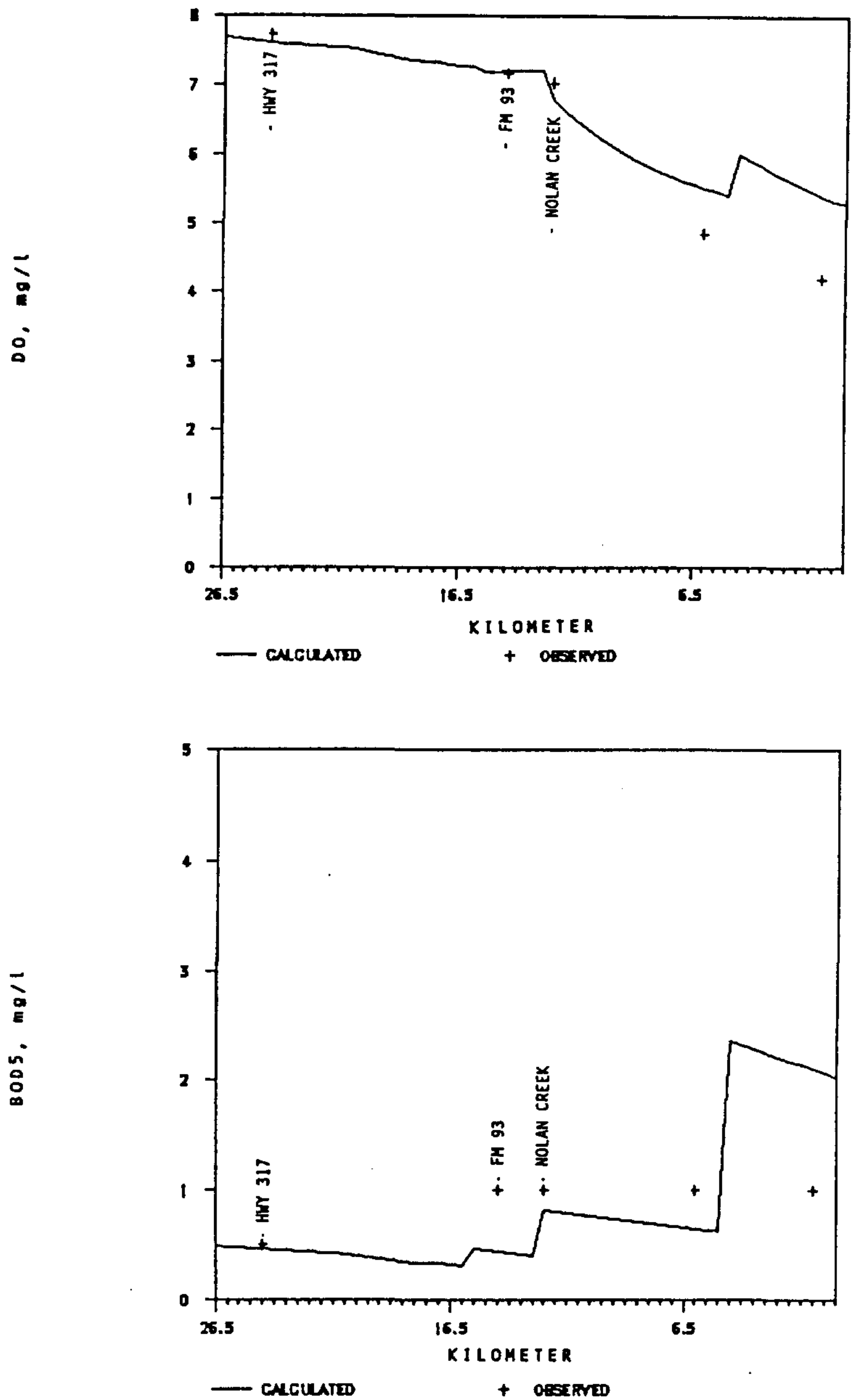
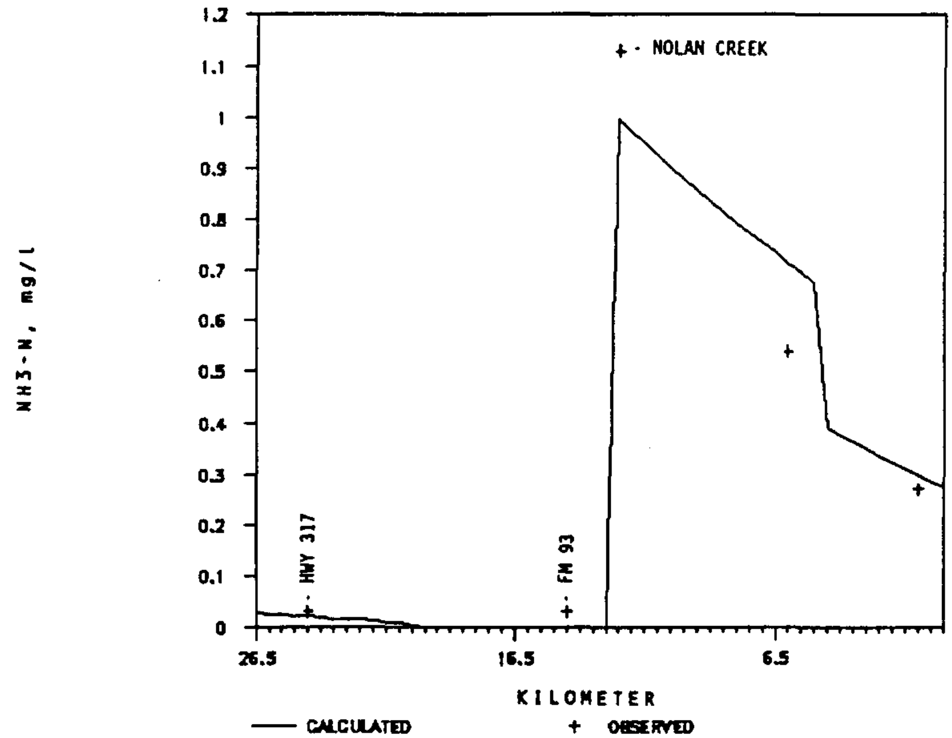


FIGURE IV-2

CALIBRATION MODEL RESULTS AND OBSERVED VALUES FROM THE MAY 19-20, 1987 SAMPLING OF THE LEON RIVER BELOW LAKE BELTON



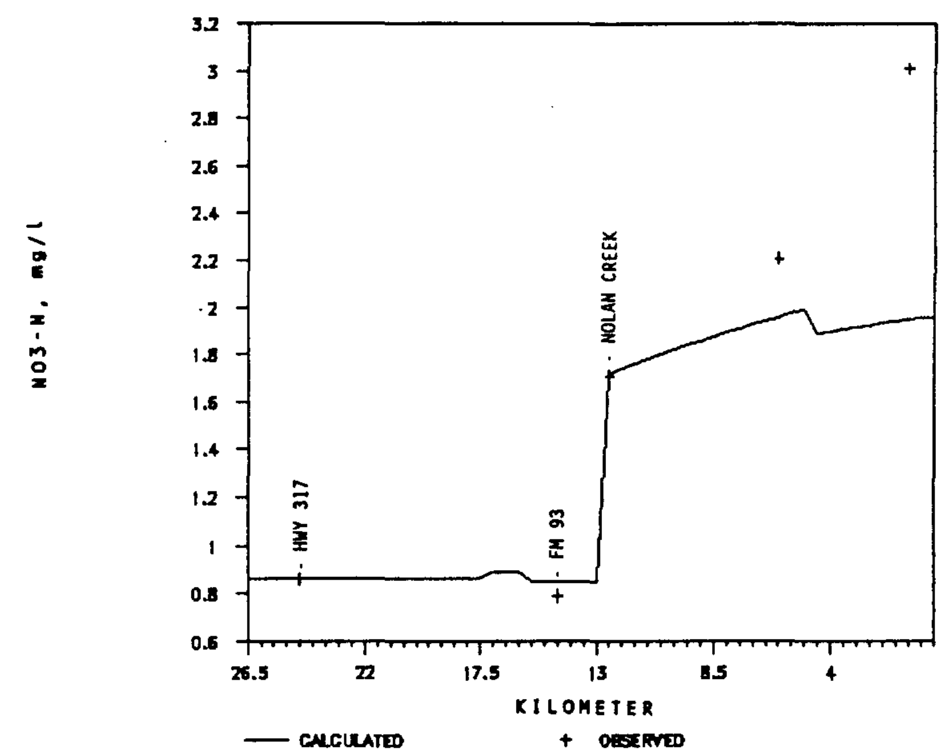


FIGURE IV-2

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE MAY 19-20, 1987 SAMPLING OF THE
LEON RIVER BELOW LAKE BELTON
(continued)

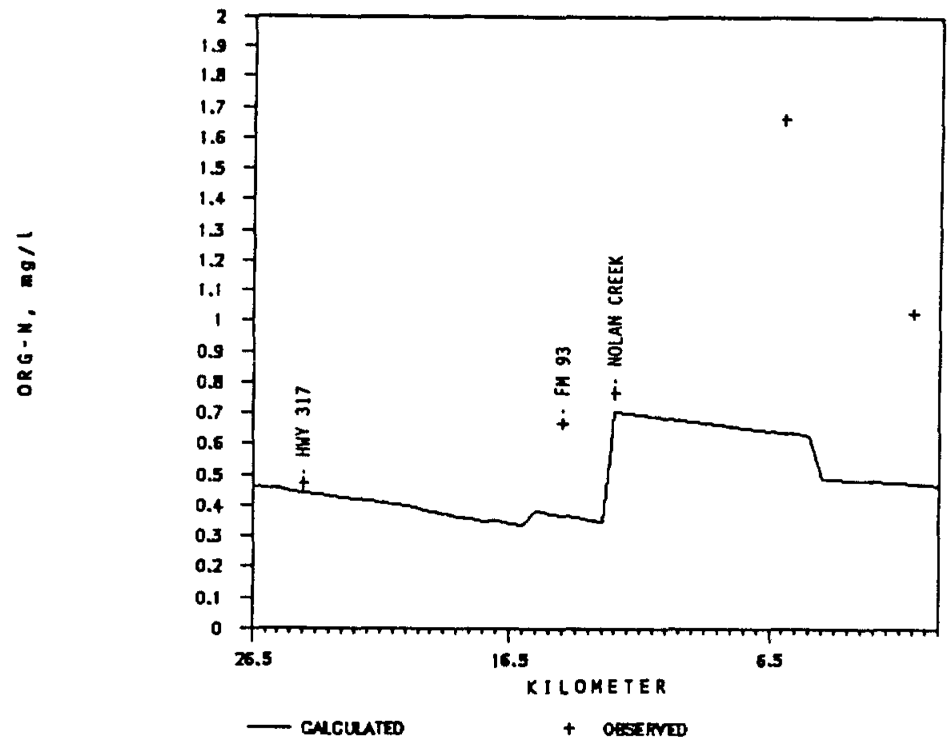


FIGURE IV-2

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE MAY 19-20, 1987 SAMPLING OF THE
LEON RIVER BELOW LAKE BELTON
(continued)

Sulphur Creek. Sulphur Creek, a major tributary of the Lampasas River was modeled from the City of Lampasas to Sulphur Creek/Lampasas River confluence. Two City of Lampasas wastewater treatment plants discharge into the stream. The observed and calculated parameters are shown in Figure IV-3. Based on the average dissolved oxygen measurements, which steadily increase downstream below the WWTP outfalls, and the diurnal change in dissolved oxygen, aquatic plant life was considered to be a major factor affecting water quality.

The observed concentrations of ammonia and nitrate peak well below the discharge of the two WWTPs, indicating some other release of nutrients, probably recycle from organic material on the bottom. This masks the decline of ammonia concentrations due to nitrification and inhibits determination of the nitrification rate. The stream BOD concentration is also higher than would be explained by the WWTP discharge, suggesting that decomposition of settled organic matter may be reintroducing oxygen consuming materials back into the water column. The increased BOD concentrations also inhibit determination of the BOD decay rate. All of these factors contributed to the lack of fit between the calculated and observed water quality shown by Figure IV-3.

Clear Creek. Calibration of the Clear Creek model, based on the survey observations and results, assumed that aquatic plant life would be a dominate process in the stream. Clear Creek was modelled from FM 3046 to the junction with the Lampasas River. The observed and calculated concentrations of the modelled parameters are shown in Figure IV-4. The influence of the extremely high density of plant life observed around kilometer 3 of the stream can be seen in the BOD, DO and ammonia concentrations. BOD and ammonia are both high, probably due to the decomposition of the settled plant life. The DO shows the influence of photosynthesis, where the action of the plant life saturates the water with dissolved oxygen.

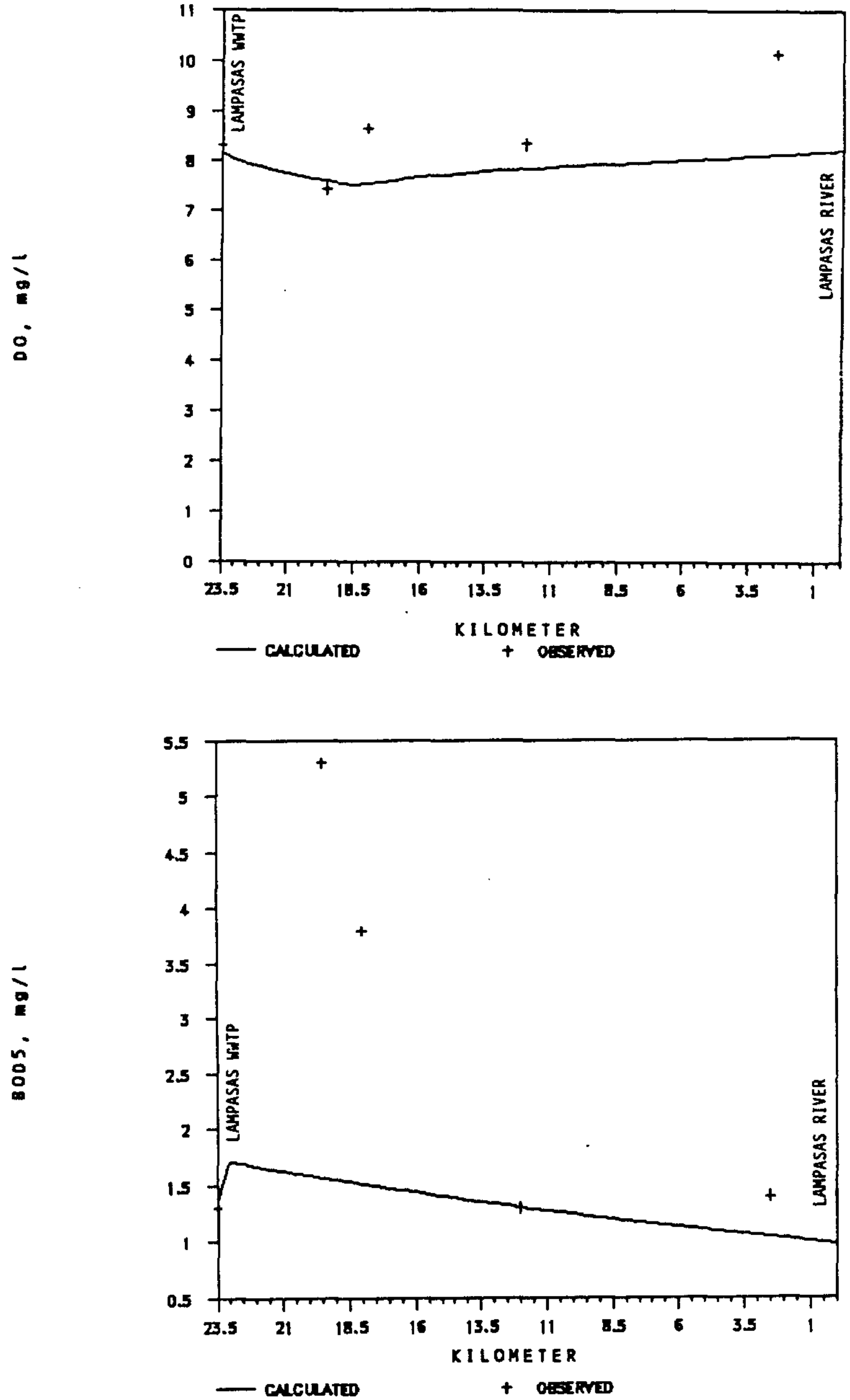


FIGURE IV-3

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 20, 1987 SAMPLING OF
SULPHUR CREEK

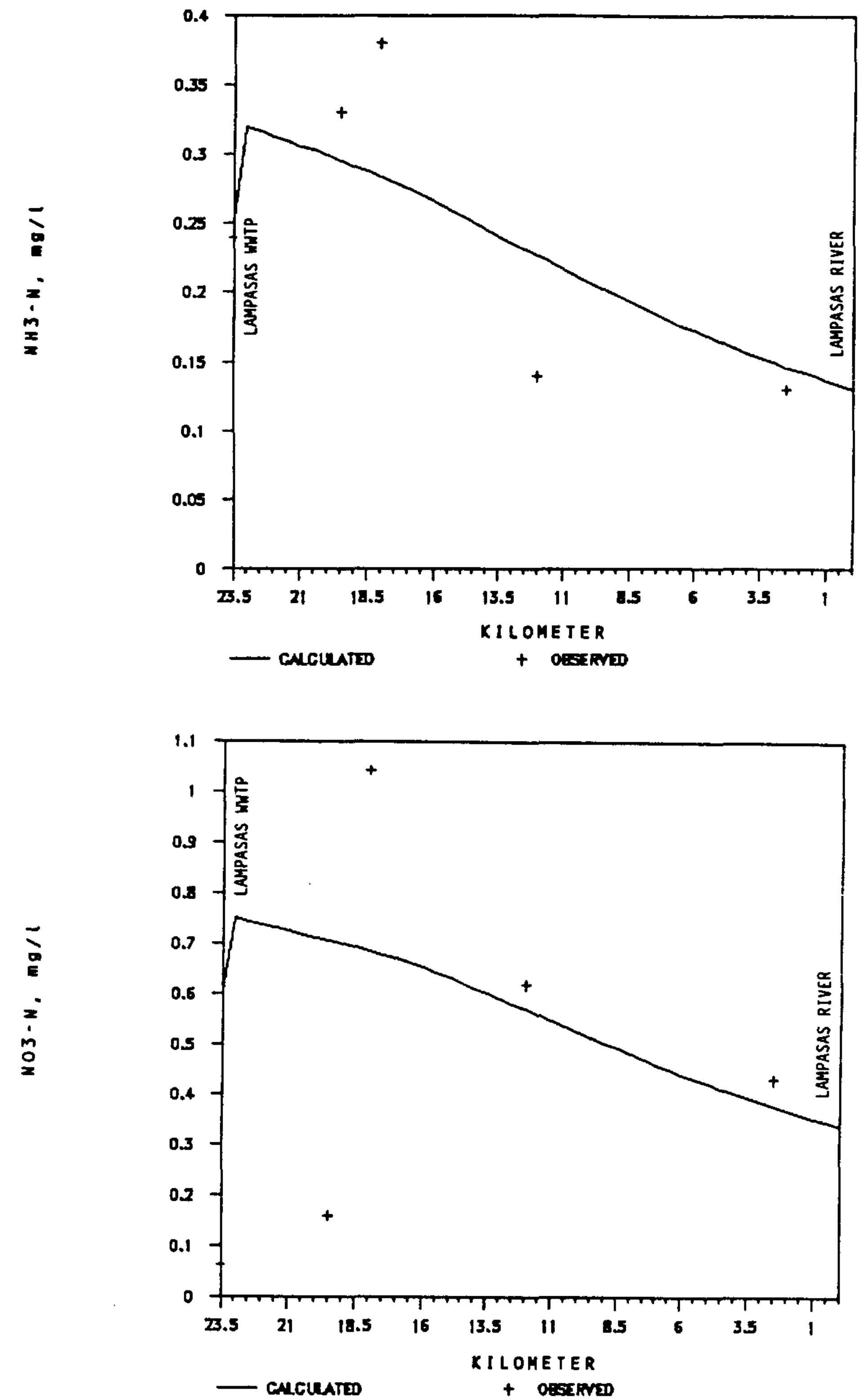


FIGURE IV-3

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 20, 1987 SAMPLING OF
SULPHUR CREEK
(continued)

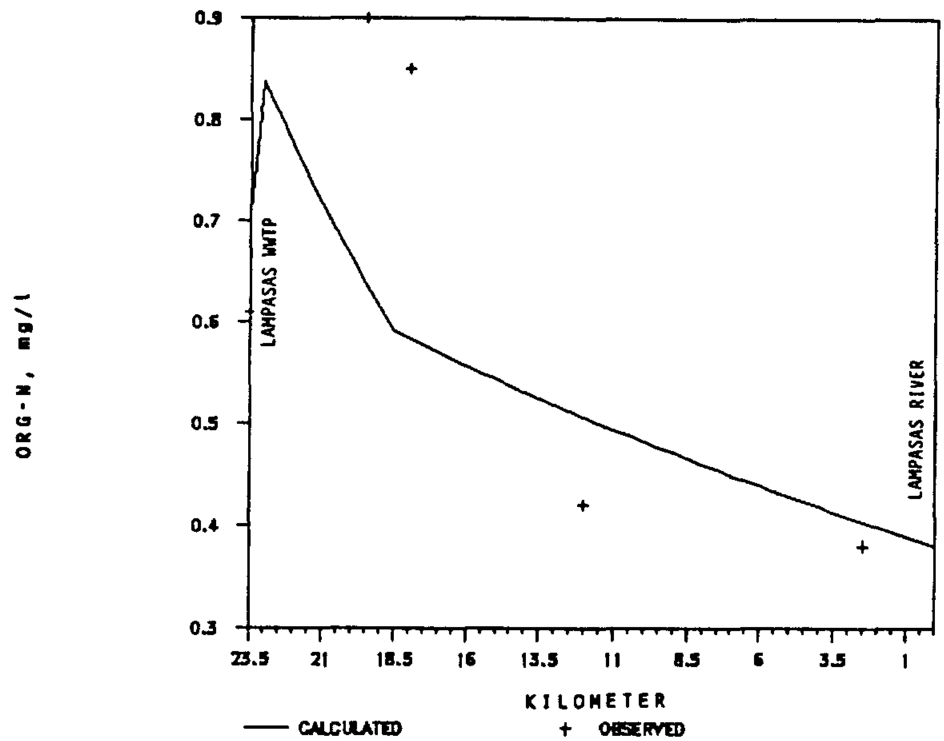


FIGURE IV-3

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 20, 1987 SAMPLING OF
SULPHUR CREEK
(continued)

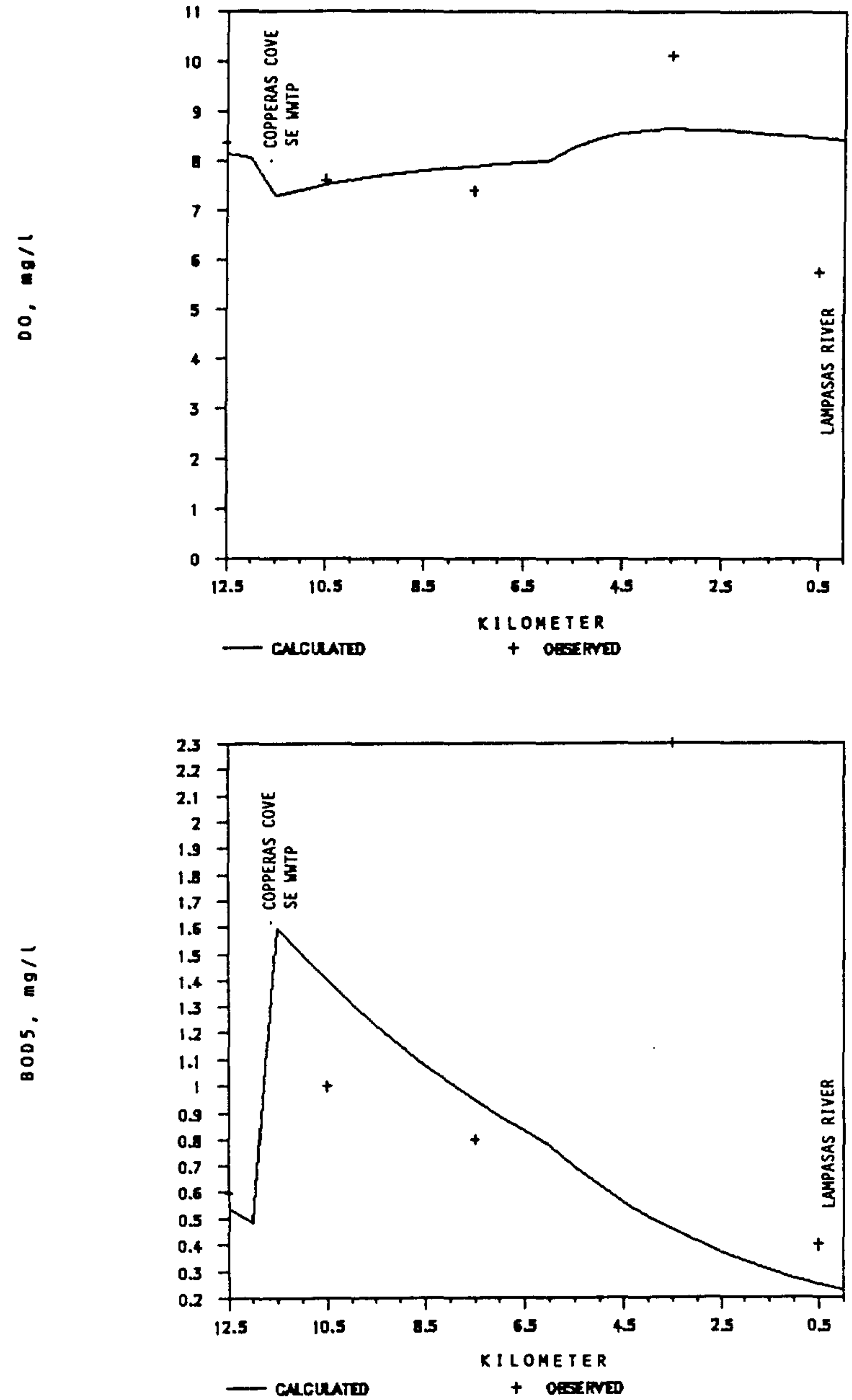


FIGURE IV-4

CALIBRATION MODEL RESULTS AND OBSERVED VALUES FROM THE SEPTEMBER 10-11, 1987 SAMPLING OF CLEAR CREEK

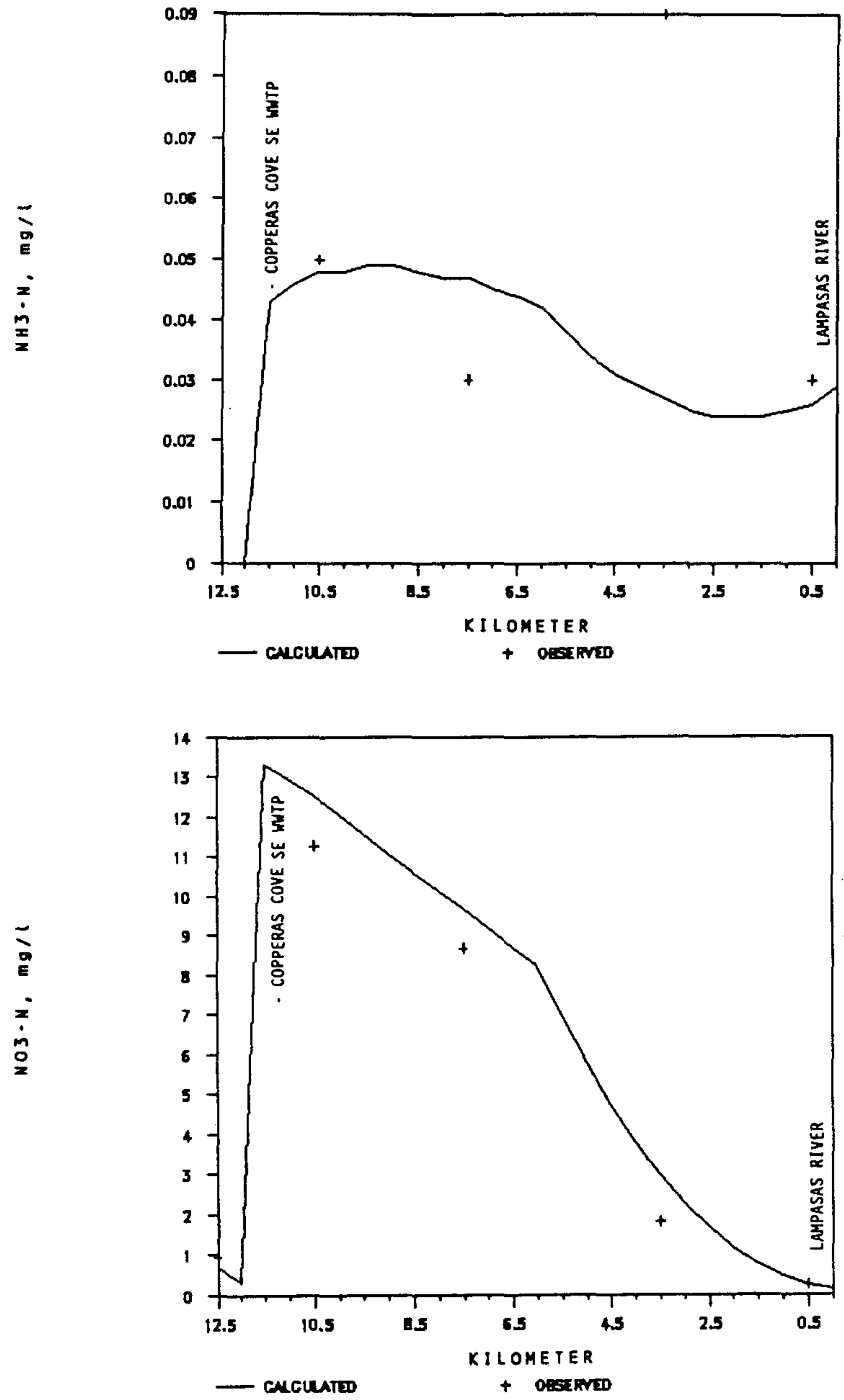


FIGURE IV-4

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE SEPTEMBER 10-11, 1987 SAMPLING OF
CLEAR CREEK
(continued)

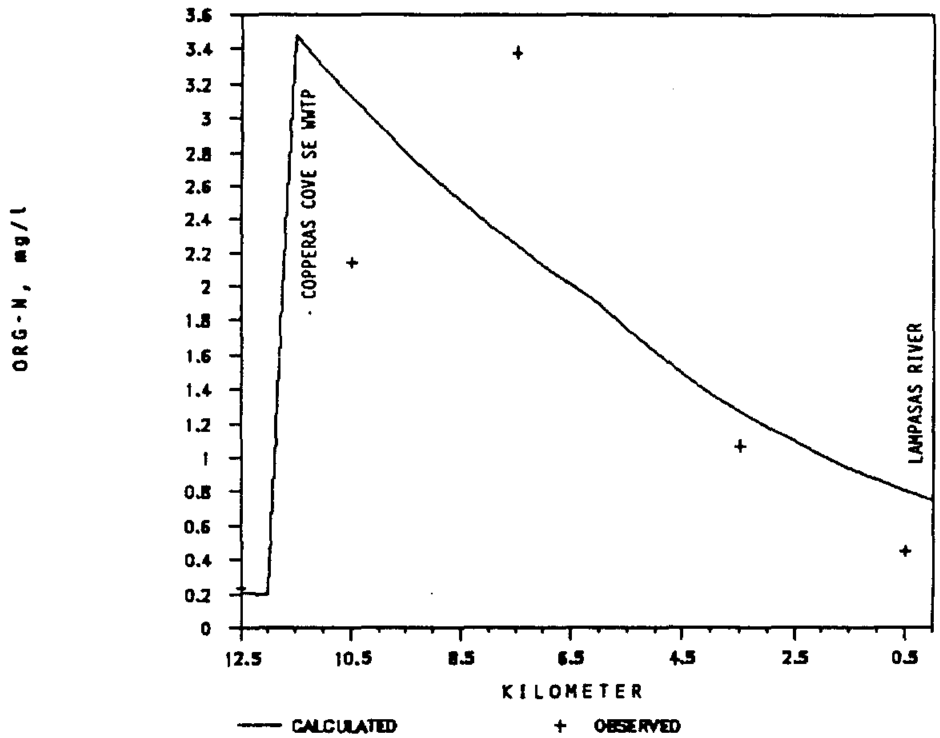


FIGURE IV-4

CALIBRATION MODEL RESULTS AND OBSERVED VALUES FROM THE SEPTEMBER 10-11, 1987 SAMPLING OF CLEAR CREEK (continued)

<u>Lampasas River Above Lake Stillhouse Hollow</u>. The Lampasas River above Lake Stillhouse Hollow was modelled from just above the junction with Sulphur Creek to the headwaters of the lake. No point source dischargers directly discharge into the river in this reach. Figure IV-5 presents the calculated and observed concentrations for the simulated parameters. Based on the survey results shown in Table II-8, which show dissolved oxygen values indicative of aquatic plant activity, aquatic vegetation was assumed to be an important process impacting water quality. The almost constant level of ammonia and the increasing level of organic nitrogen indicated that decay of settled material may also play a role in determining water quality.

<u>Lampasas River Below Lake Stillhouse Hollow</u>. The Lampasas River below Lake Stillhouse Hollow was modelled from the dam to the junction with the Leon River. Dissolved oxygen variations shown in Table II-9 indicate that aquatic plant life influences the water quality of this stream segment. There are no point source dischargers in this reach and water quality does not dramatically change in the reach. However, Salado Creek influences the Lampasas water quality by increasing the BOD, nitrate and organic nitrogen concentrations. Figure IV-6 presents the calculated and observed concentrations of the modelled parameters.

Verification of Stream Water Quality Models Used in This Study

Models of the Leon River above and below Lake Belton were subjected to verification procedures. The results of the verification models of the Leon River above and below Lake Belton are shown in Figures IV-7 and IV-8. The results show that the model of the Leon River below Lake Belton approximates the observed values adequately, while the model of the Leon River above Lake Belton does not approximate the observed values. As explained in the previous section on model calibration the controlling processes in the lower Leon appear to be sediment oxygen demand and nitrification, while in the upper Leon aquatic plant life exhibits a greater

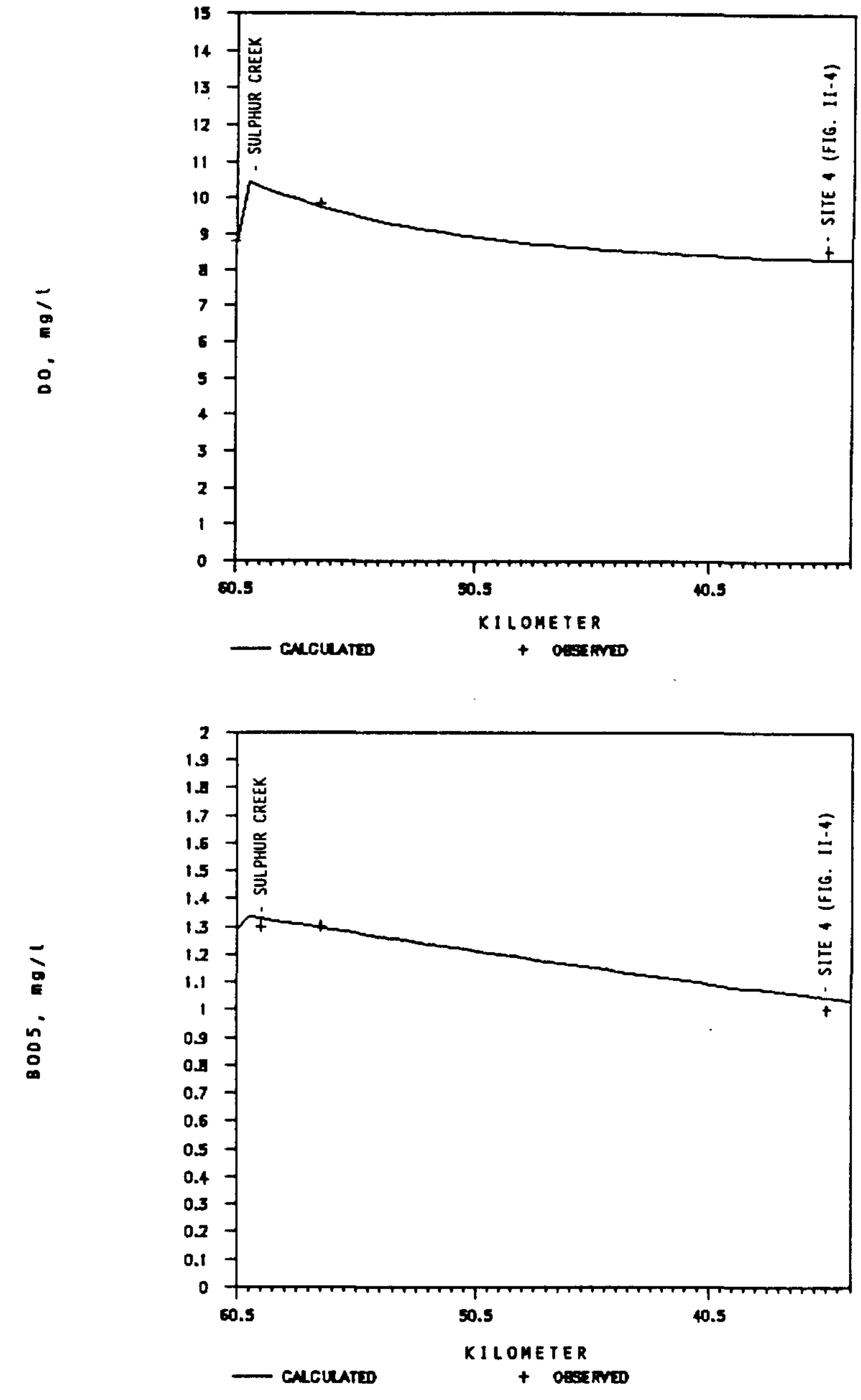
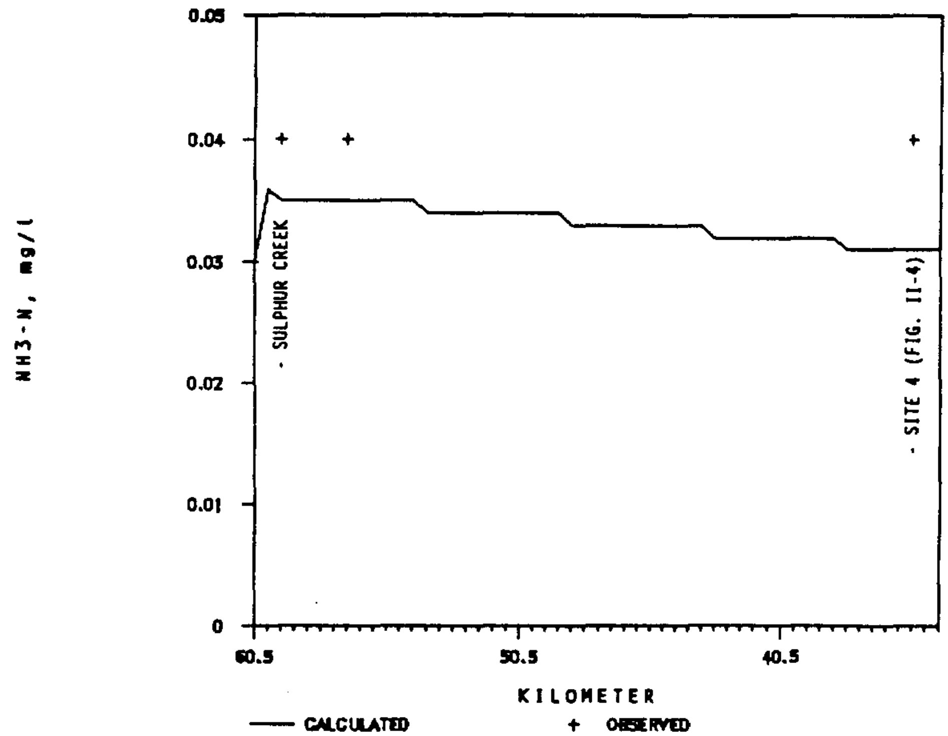


FIGURE IV-5

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 16, 1987 SAMPLING OF
THE LAMPASAS RIVER ABOVE LAKE STILLHOUSE HOLLOW



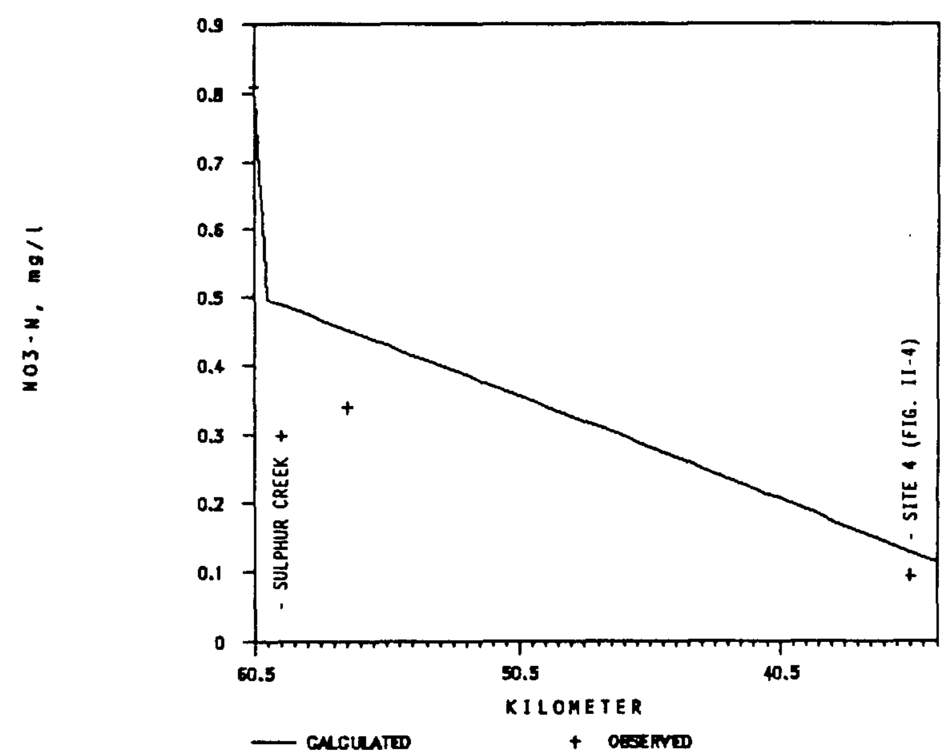


FIGURE IV-5

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 16, 1987 SAMPLING OF
THE LAMPASAS RIVER ABOVE LAKE STILLHOUSE HOLLOW
(continued)

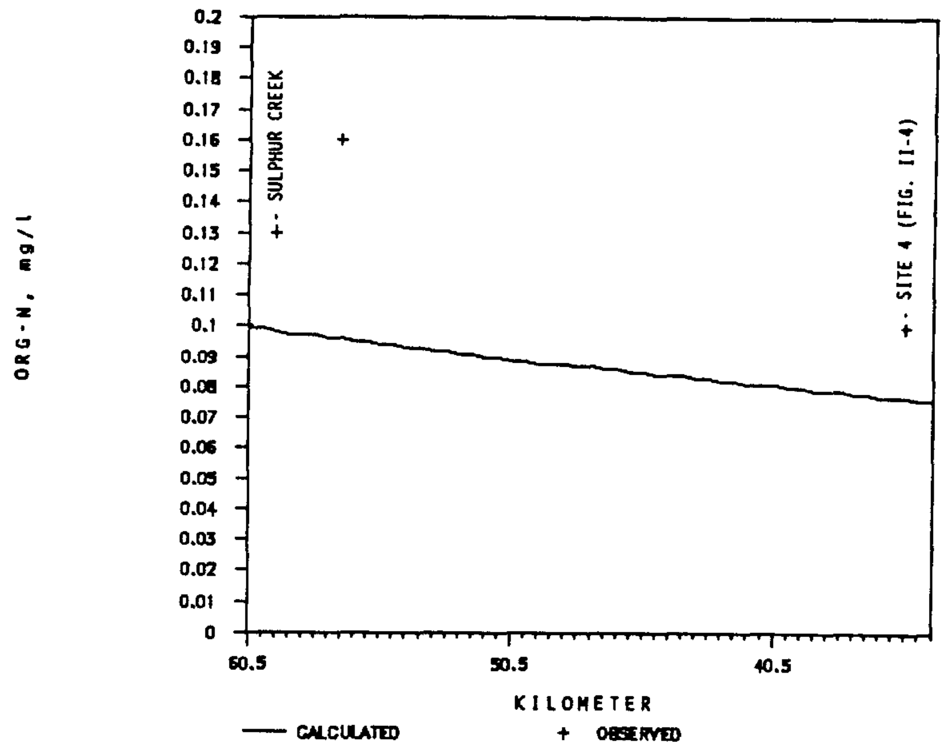


FIGURE IV-5

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 16, 1987 SAMPLING OF
THE LAMPASAS RIVER ABOVE LAKE STILLHOUSE HOLLOW
(continued)

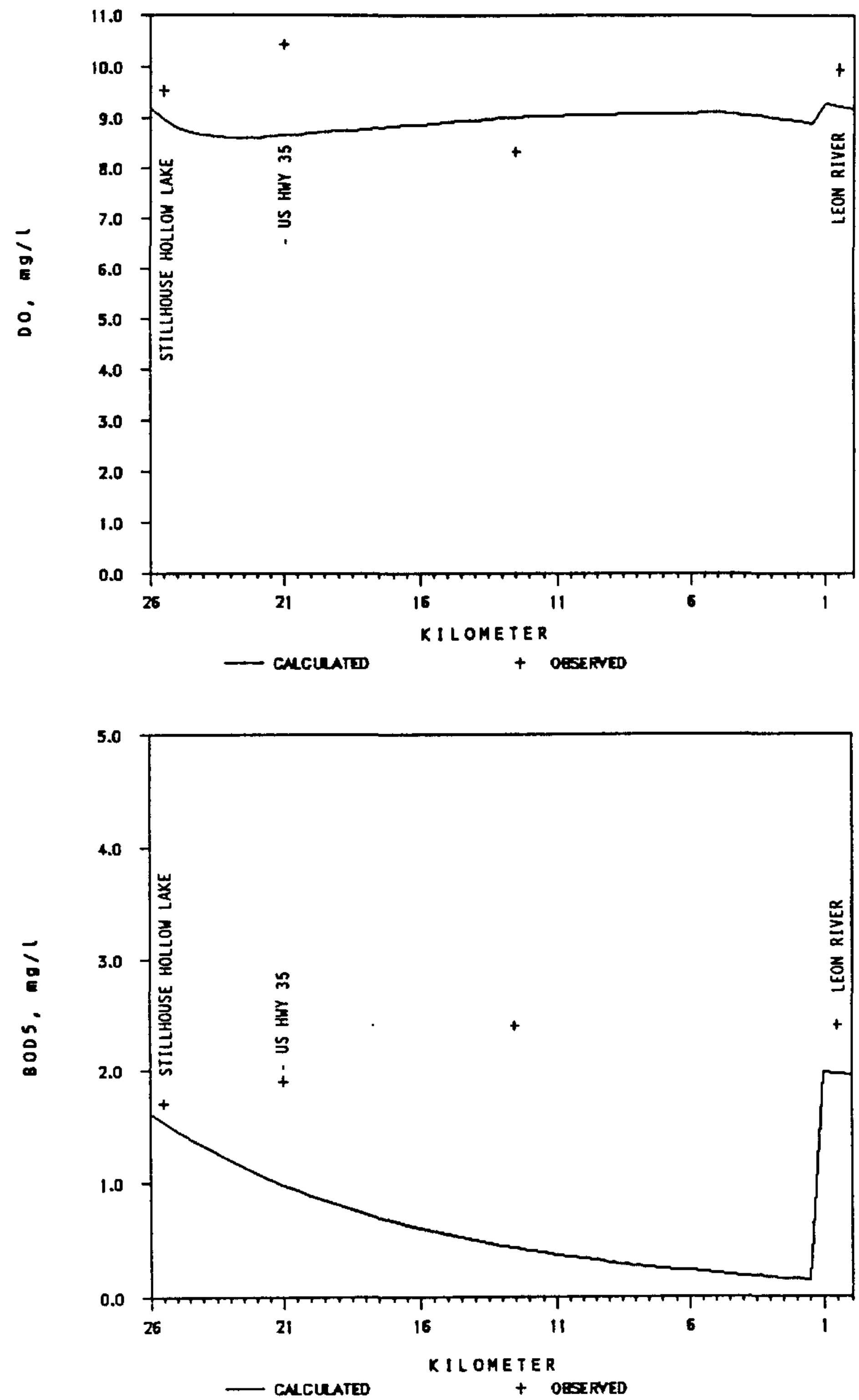
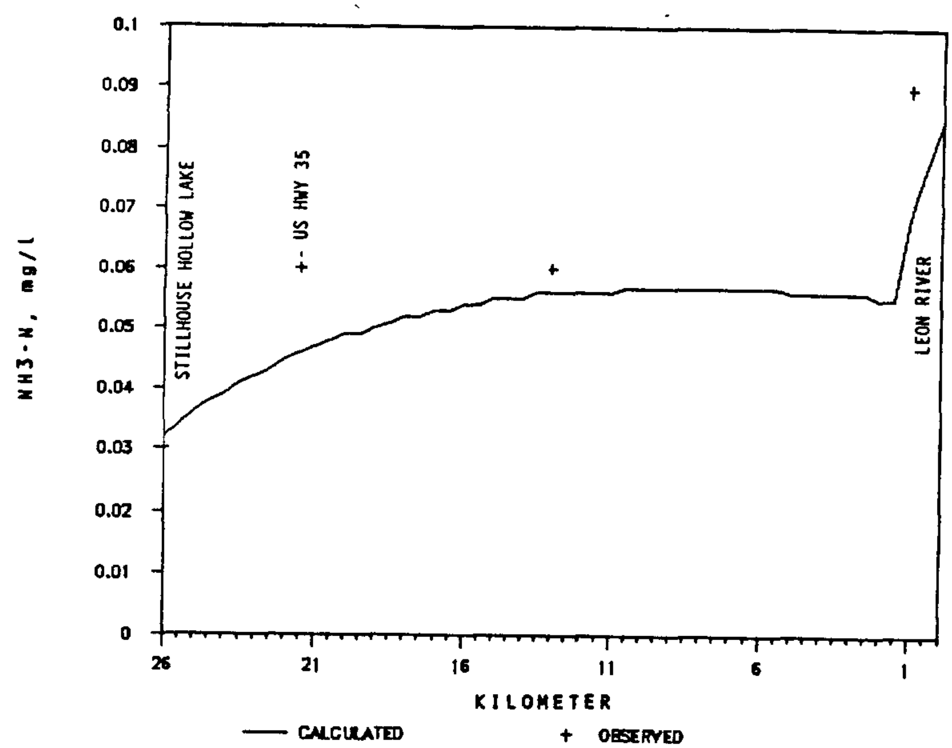


FIGURE IV-6

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 14, 1987 SAMPLING OF
THE LAMPASAS RIVER BELOW LAKE STILLHOUSE HOLLOW



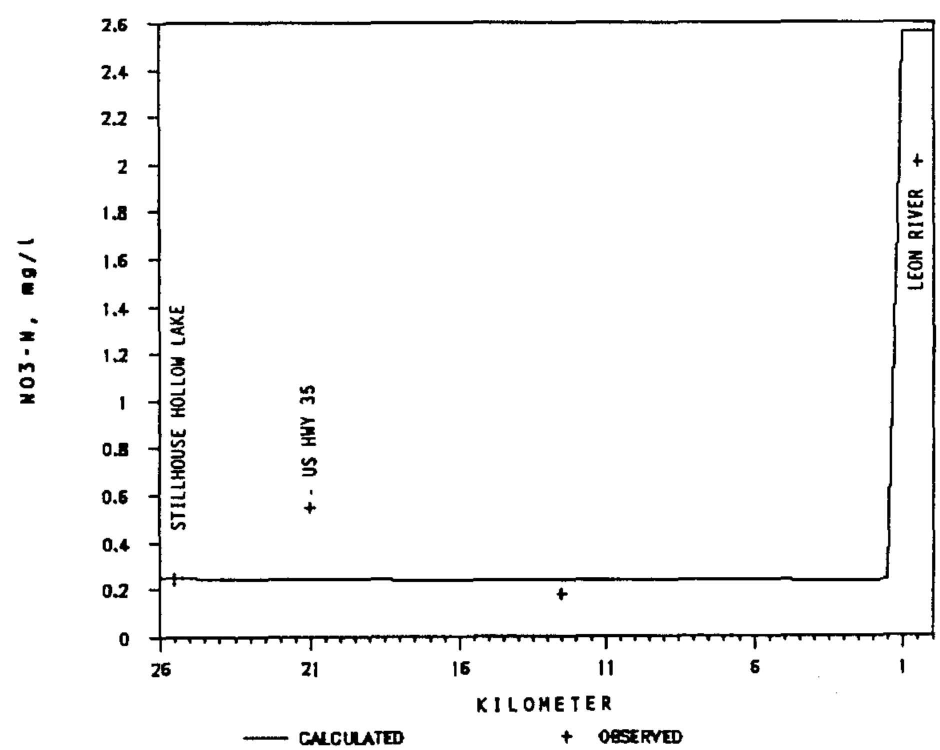


FIGURE IV-6

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 14, 1987 SAMPLING OF
THE LAMPASAS RIVER BELOW LAKE STILLHOUSE HOLLOW
(continued)

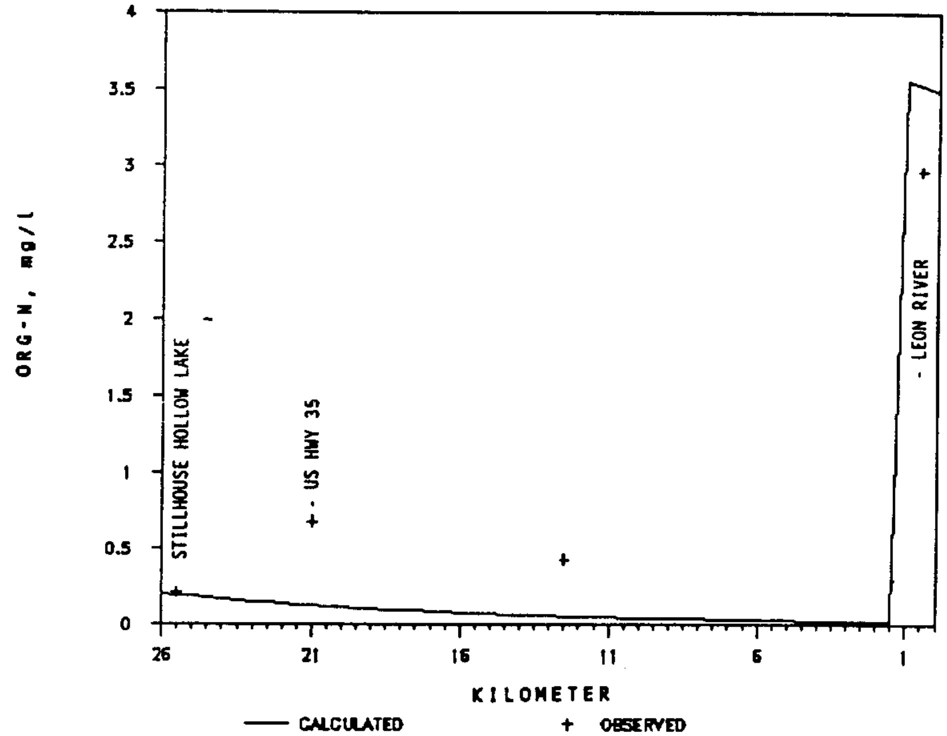


FIGURE IV-6

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FROM THE OCTOBER 14, 1987 SAMPLING OF
THE LAMPASAS RIVER BELOW LAKE STILLHOUSE HOLLOW
(continued)

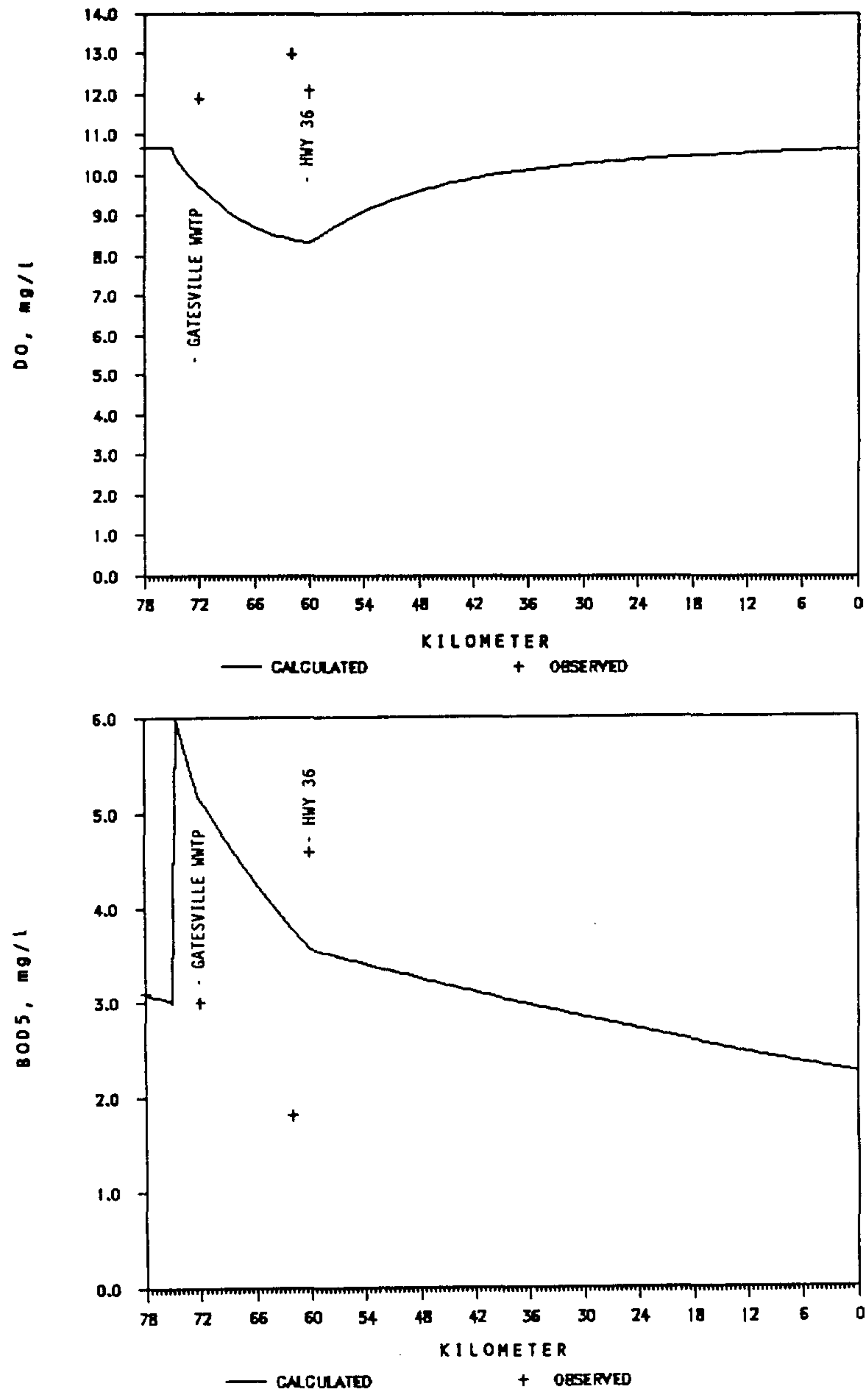
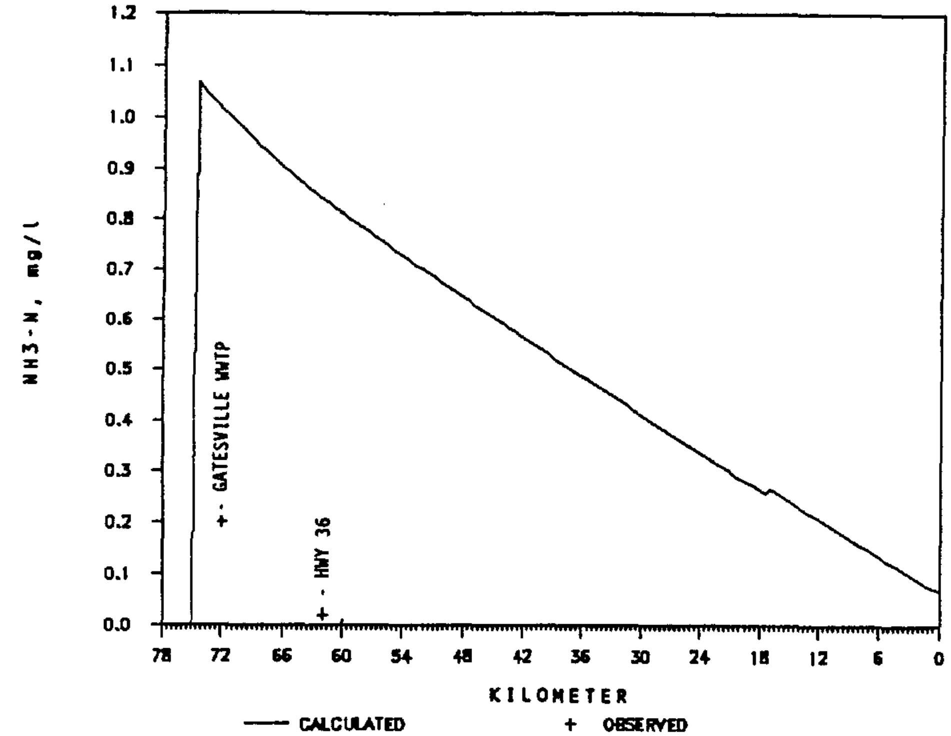


FIGURE IV-7

VERIFICATION MODEL RESULTS AND OBSERVED VALUES
FROM THE FEBRUARY 16, 1988 SAMPLING OF
THE LEON RIVER ABOVE LAKE BELTON



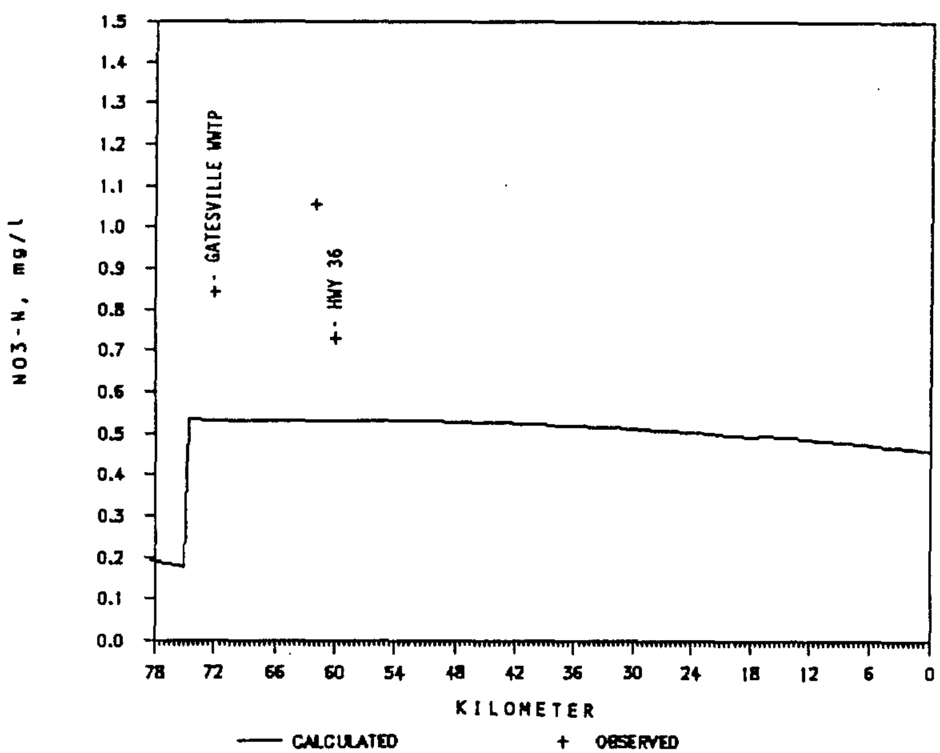


FIGURE IV-7

VERIFICATION MODEL RESULTS AND OBSERVED VALUES
FROM THE FEBRUARY 16, 1988 SAMPLING OF
THE LEON RIVER ABOVE LAKE BELTON
(continued)

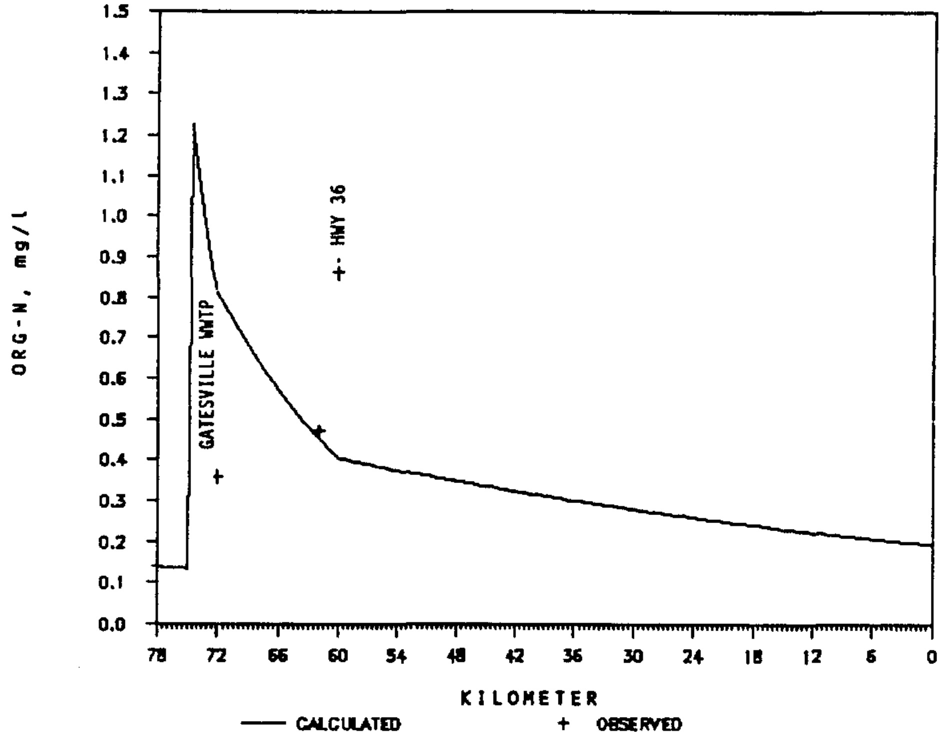


FIGURE IV-7

VERIFICATION MODEL RESULTS AND OBSERVED VALUES
FROM THE FEBRUARY 16, 1988 SAMPLING OF
THE LEON RIVER ABOVE LAKE BELTON
(continued)

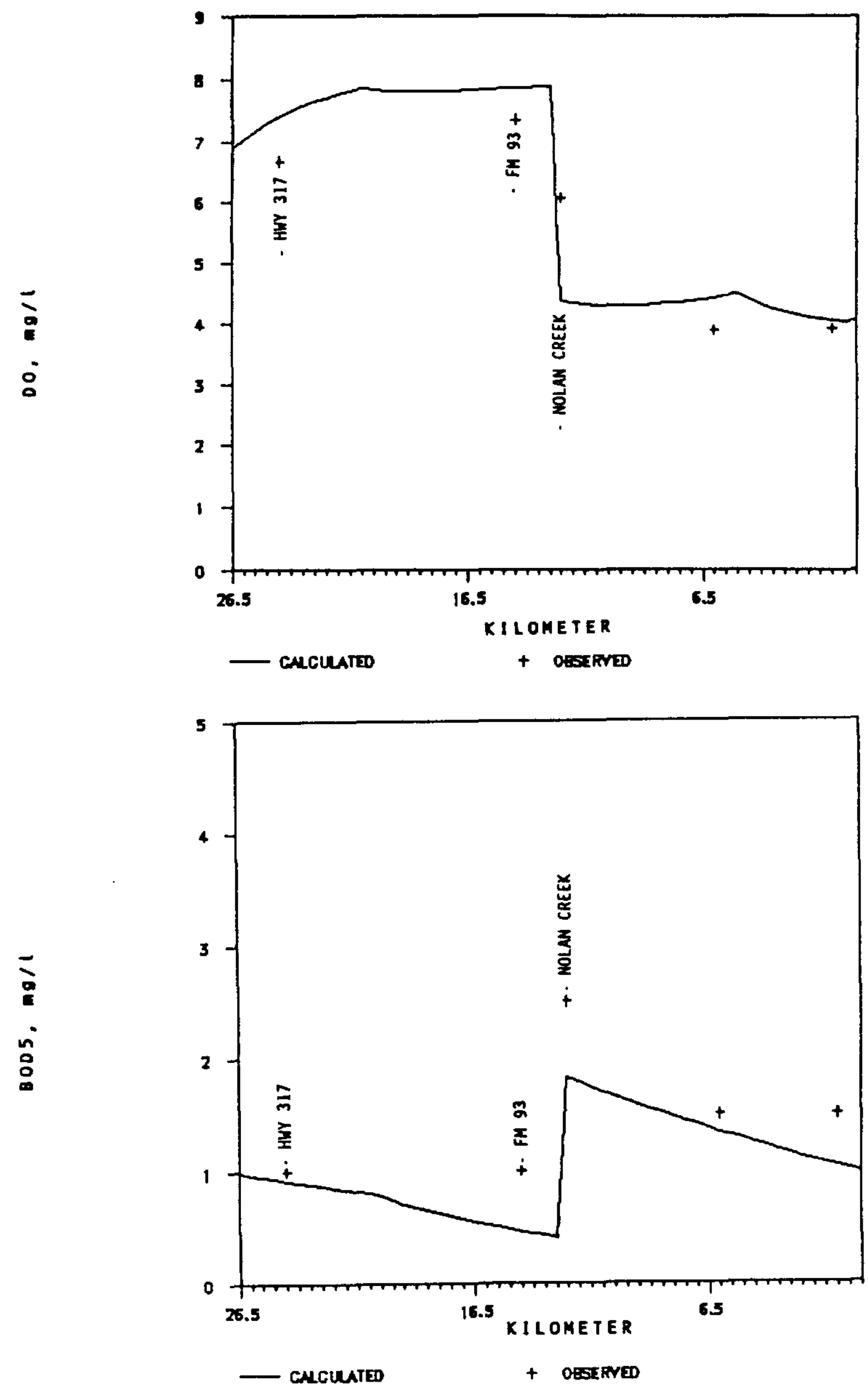
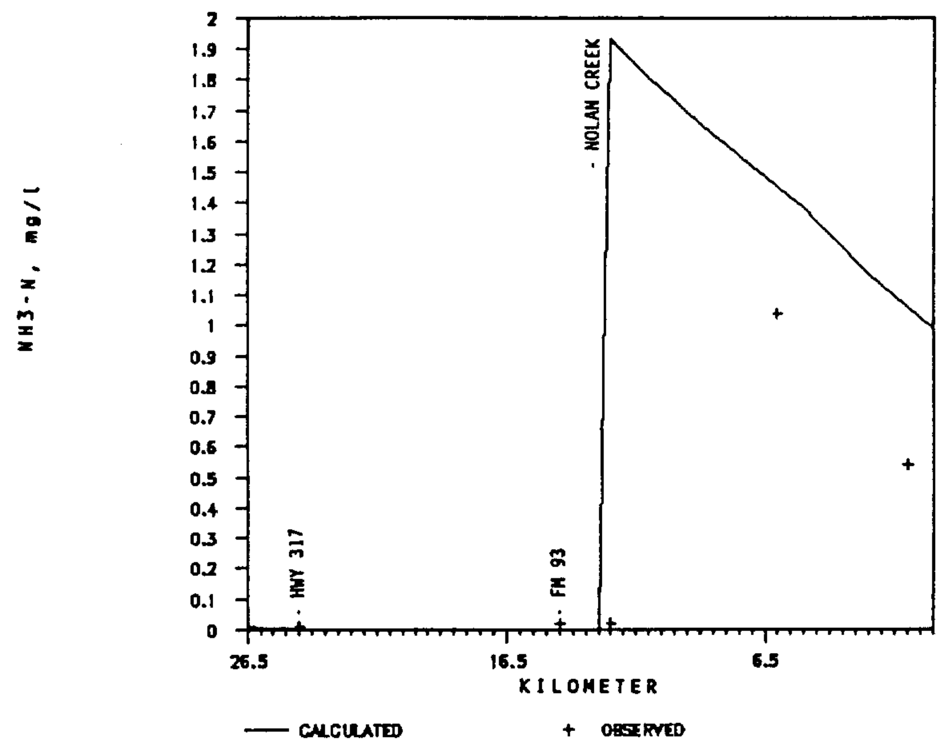


FIGURE IV-8

VERIFICATION MODEL RESULTS AND OBSERVED VALUES
FROM THE NOVEMBER 3-4, 1987 SAMPLING OF THE
LEON RIVER BELOW LAKE BELTON



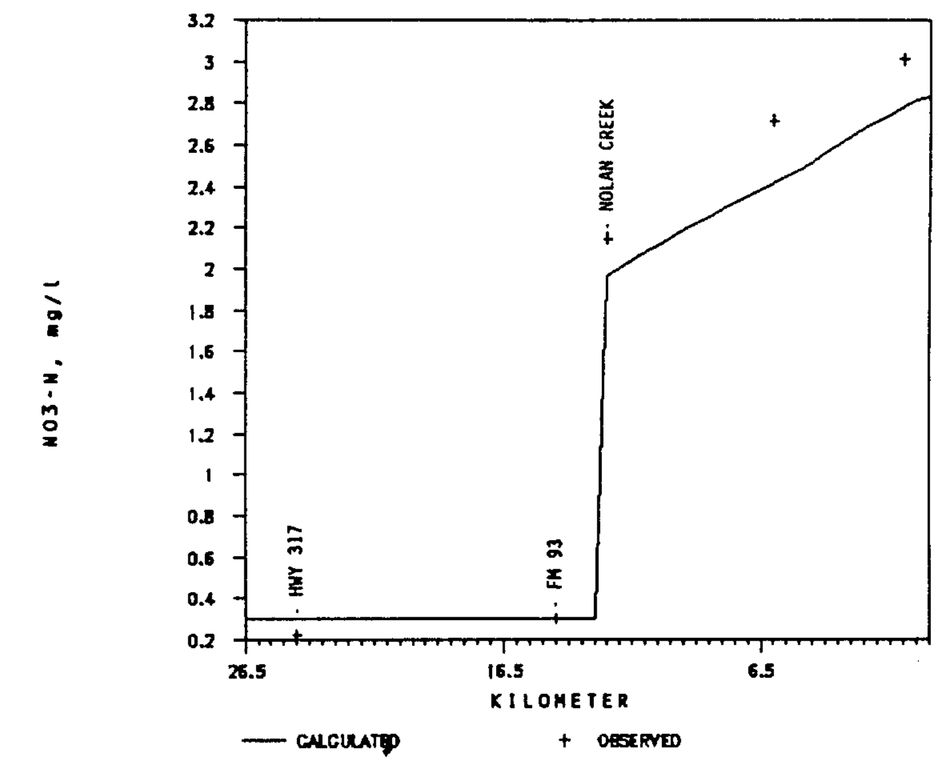


FIGURE IV-8

VERIFICATION MODEL RESULTS AND OBSERVED VALUES
FROM THE NOVEMBER 3-4, 1987 SAMPLING OF THE
LEON RIVER BELOW LAKE BELTON
(continued)

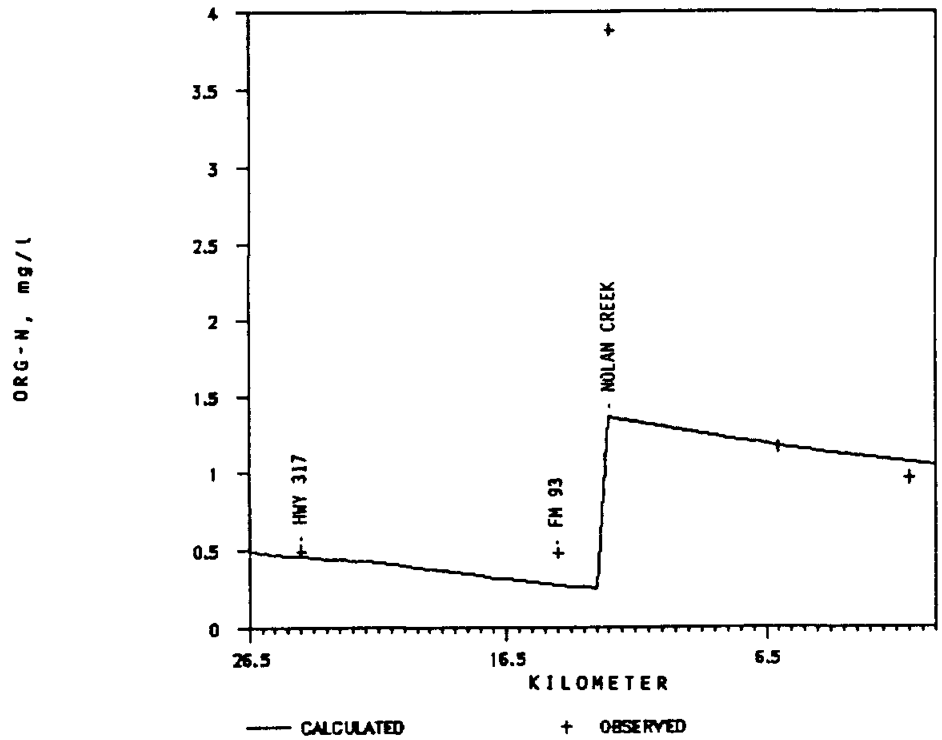


FIGURE IV-8

VERIFICATION MODEL RESULTS AND OBSERVED VALUES
FROM THE NOVEMBER 3-4, 1987 SAMPLING OF THE
LEON RIVER BELOW LAKE BELTON
(continued)

impact. The variability of the water quality in a stream where the processes influencing water quality are dominated by plant life is much greater than a stream where the dominating processes are nitrification and sediment processes.

Application of Stream Models

The stream water quality models described in the previous sections were used to determine effluent requirements associated with projected flows. In making these determinations, the following effluent criteria were used for screening purposes:

1. Secondary Treatment:
   BOD5 = 20 mg/l
   NH3-N = 15 mg/l
   Dissolved Oxygen = 2 mg/l

2. Advanced Secondary Treatment:
   BOD5 = 10 mg/l
   NH3-N = 15 mg/l
   Dissolved Oxygen = 2 mg/l

3. Advanced secondary treatment with nitrification
   BOD5 = 10 mg/l
   NH3-N = 3 mg/l
   Dissolved Oxygen = 4 mg/l

4. Tertiary Treatment:
   BOD5 = 5 mg/l
   NH3-N = 2 mg/l
   Dissolved Oxygen = 5 mg/l

These criteria were based on professional judgement and the Texas Water Commission's Effluent Standards for Domestic Wastewater Treatment Plants (see 31 TAC 309.2, Table 1, 1986). BOD5 concentrations for effluent conditions 1, 2 and 3, above, were based on Texas Water Commission Effluent Standards as were dissolved oxygen concentrations for conditions 2 and 3 and the NH3-N concentration for condition 3. Other values such as the NH3-N concentration of 15 mg/l for conditions 1 and 2 were based on professional judgement.

As mentioned, the above criteria were used for screening purposes. In modeling some of the streams in the study area, additional criteria (e.g., BOD5 = 10 mg/l, NH_3-N = 2 mg/l, and Dissolved Oxygen = 6 mg/l) were tested and found appropriate for meeting stream dissolved oxygen standards.

The following paragraphs describe the application of the stream models in projecting wastewater treatment plant effluent requirements in the study area.

<u>Leon River Above Lake Belton</u>. The Leon River above Lake Belton receives effluent from three municipal WWTP's in the modelled reach. The projected flows, by decade, are:

Location	1990 Flow,MGD	2000 Flow,MGD	2010 Flow,MGD	2020 Flow,MGD	2030 Flow,MGD
Gatesville	1.14	1.52	2.02	2.68	3.62
North Fort Hood	0.25	0.33	0.44	0.59	0.79
Oglesby	0.05	0.06	0.07	0.07	0.08

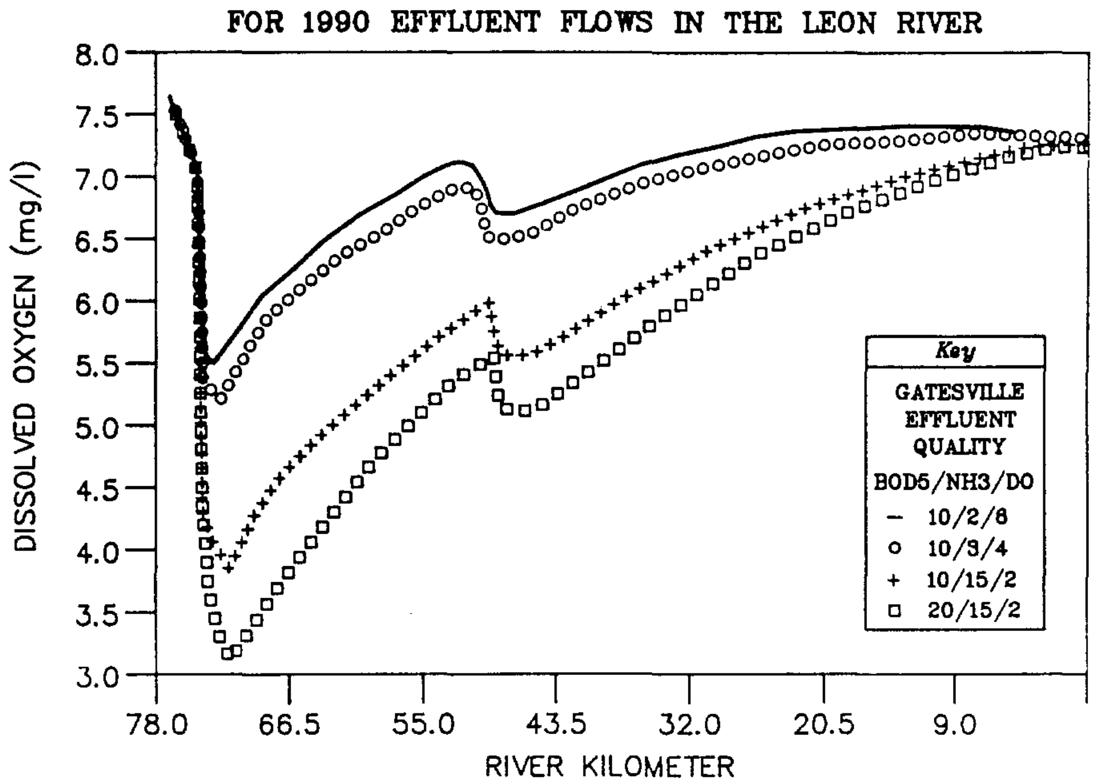
In using the model to reflect expected future conditions, the settling rates were reduced to reflect the lower solids in the effluent associated with higher treatment levels. Similarly, the sediment oxygen demand was reduced to reflect the lower organic solids from the effluent that would settle and decompose. The temperature was set at 27.5°, based on the average of TWC's data for August temperatures plus one standard deviation for years 1979, 1981, 1982, 1983, 1985 and 1986. The headwater flow was set to the 7Q2 flow of 2.0 cfs based on information in the Texas Surface Water Quality Standards. These conditions were meant to represent the critical conditions of the stream.

In order to determine the effluent requirements needed to meet a stream dissolved oxygen standard of 5.0 mg/l numerous effluent quality conditions were tested using the QUAL-TX model. The effluent conditions evaluated and the dissolved oxygen response to each effluent condition are shown in Figure IV-9 for the years 1990, 2000, 2010, 2020, and 2030.

As can be seen from Figure IV-9, the 1990 effluent flows would meet the stream dissolved oxygen standard of 5.0 mg/l with Gatesville discharging at the advanced secondary level with nitrification (10/3/4) and the other two dischargers at the advanced secondary level (10/15/2). The flows in 2000 using the same effluent quality would produce dissolved oxygen levels just below the standard, and as effluent flows increase in the succeeding decades, the dissolved oxygen will be further suppressed. Accordingly, tertiary treatment (5/2/6) was tested for the year 2030 and found to be more than adequate in meeting the stream dissolved oxygen standard. Following questions by the City of Gatesville concerning the appropriateness of tertiary treatment, an additional effluent set (Gatesville BOD5 = 10 mg/l, NH3-N = 2 mg/l, Dissolved Oxygen = 6 mg/l) was tested which predicted dissolved oxygen levels above the dissolved oxygen standard for all scenarios. Based on the above, the following effluent requirements are recommended.

	Projected Flows			Required Effluent Quality		
Year	Gatesville (MGD)	North Fort Hood (MGD)	North Oglesby (MGD)	Gatesville	Fort Hood	Oglesby
1990	1.14	0.25	0.05	10/2/6	10/15/2	10/15/2
2000	1.52	0.33	0.06	10/2/6	10/3/4	10/3/4
2010	2.02	0.44	0.07	10/2/6	10/3/4	10/3/4
2020	2.68	0.59	0.07	10/2/6	10/3/4	10/3/4
2030	3.62	0.79	0.08	10/2/6	10/3/4	10/3/4

Note: Effluent Requirements Shown in Terms of BOD/NH3-N/DO.



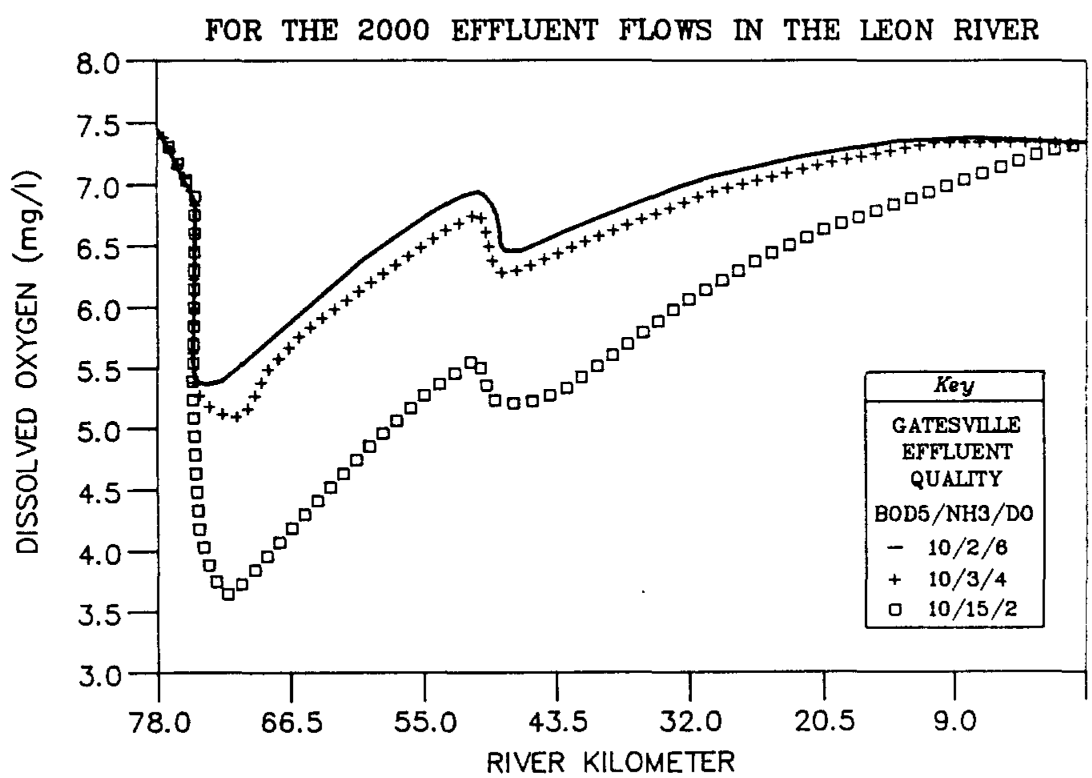
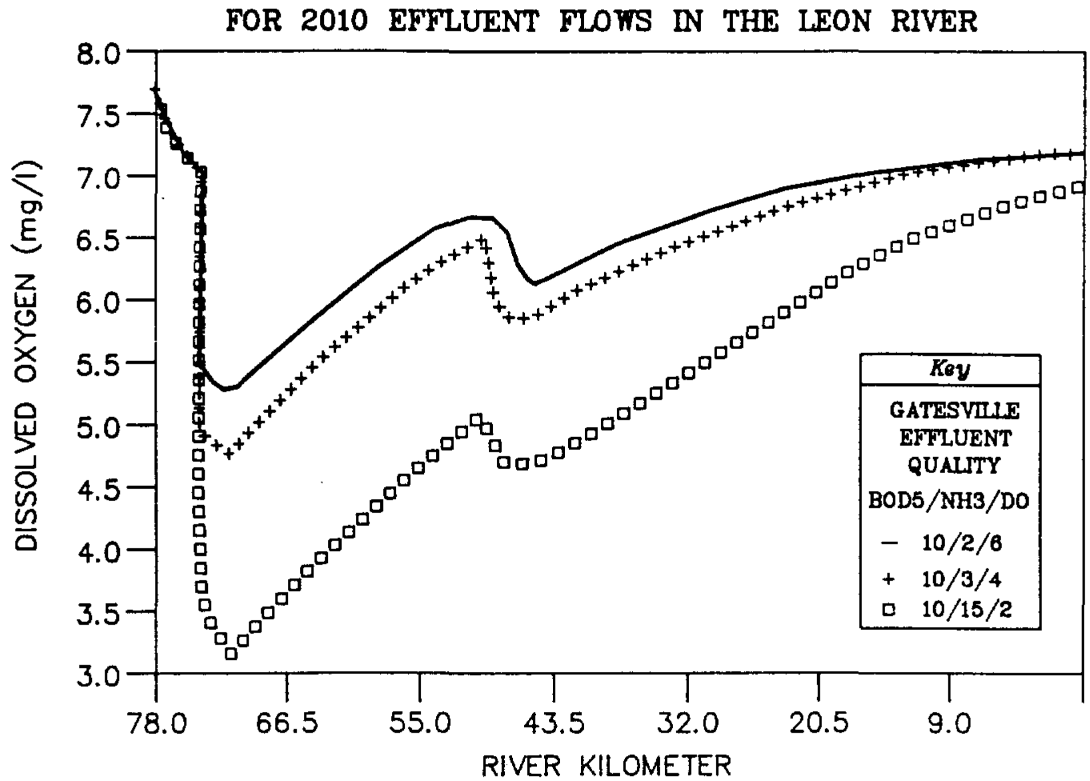


FIGURE IV-9
PROJECTED DISSOLVED OXYGEN CONCENTRATIONS
FOR LEON RIVER ABOVE LAKE BELTON



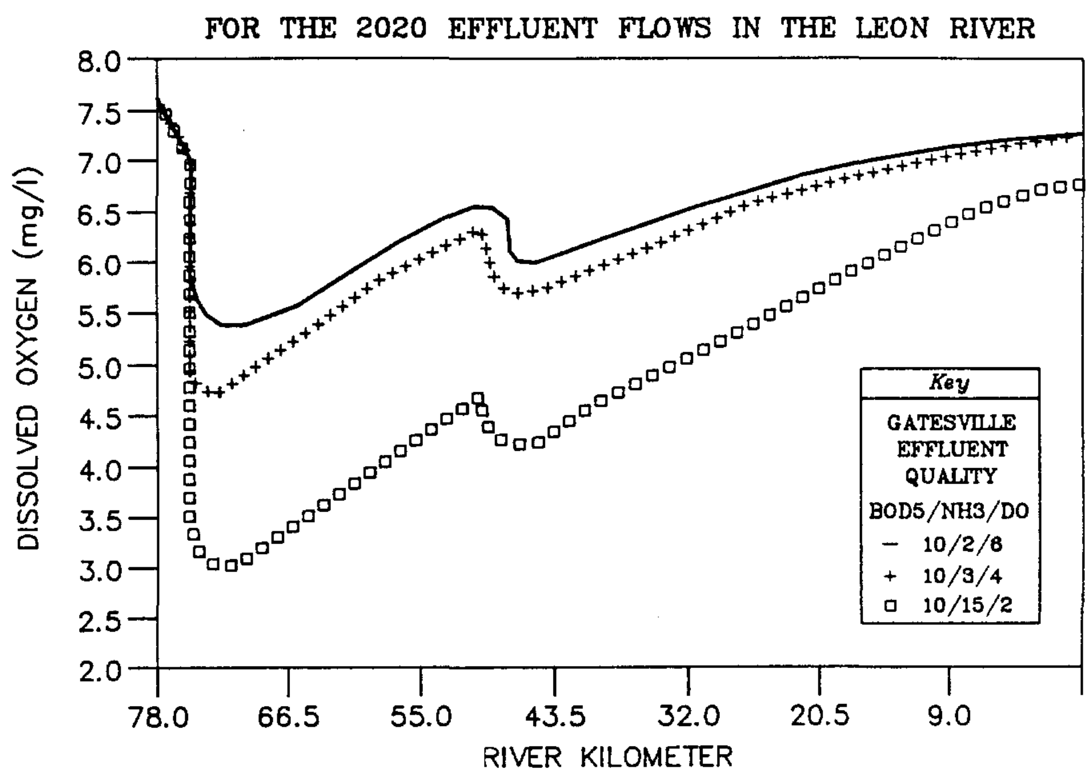


FIGURE IV–9
PROJECTED DISSOLVED OXYGEN CONCENTRATIONS
FOR LEON RIVER ABOVE LAKE BELTON
(CONTINUED)

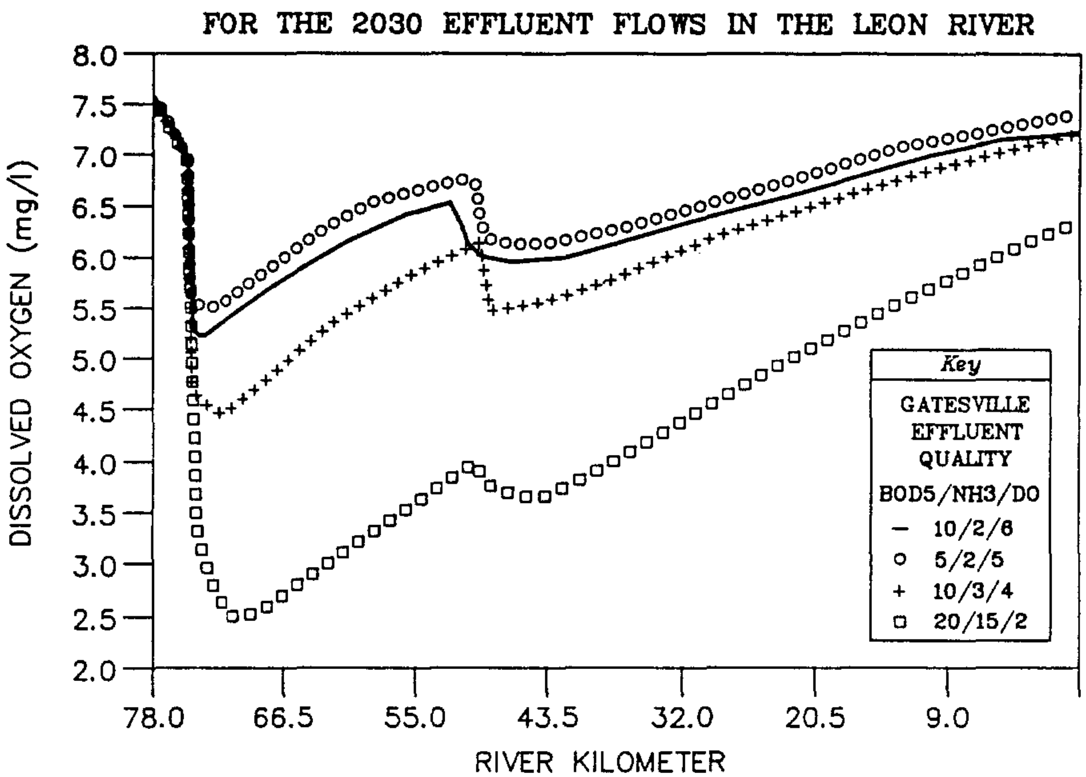


FIGURE IV–9
PROJECTED DISSOLVED OXYGEN CONCENTRATIONS
FOR LEON RIVER ABOVE LAKE BELTON
(CONTINUED)

Nolan Creek. Projected wastewater flows discharged into Nolan Creek were modelled using the TWC's Draft Wasteload Evaluation for Nolan Creek published June 2, 1986. Three scenarios were developed for the projected wastewater flows and treatment in the Kileen-Harker Heights-Nolanville planning area. The first alternative assumed that all wastewater flows would be treated and discharged into Nolan Creek (no point discharge into Lake Stillhouse Hollow) using the existing WWTPs and constructing a new plant for the year 2010 just downstream of Bell County WCID #1.

The second alternative assumes that the majority of wastewater flows are to be discharged into Nolan Creek and flows generated from the Onion Creek WWTP (built in 2020) and other selected areas near the lakeside will discharge into Lake Stillhouse Hollow. This would reduce flows from the WCID #1 STP #2 plant in the year 2020 to 3.45 MGD and in the year 2030 to 7.11 MGD. The Onion Creek WWTP would discharge 0.25 MGD in the year 2020 and 0.63 in the year 2030.

The third alternative for the planning area involved building a treatment plant in the year 2020 that would discharge into Lake Stillhouse Hollow via plants on Trimmier Creek and Onion Creek. Some of the flows generated in the earlier growth areas would be diverted to this plant.
Results of the Nolan Creek model showed that the effluent quality for all four plants discharging into Nolan Creek was essentially the same for all three alternatives. The projected plant flows for each alternative and the required effluent quality to maintain the standard of 5.0 mg/l dissolved oxygen in Nolan Creek are shown below.

Year	Projected Flows WCID #1 (MGD)	WCID #1 STP #2 (MGD)	Harker Heights WCID #4 (MGD)	WCID #3 (MGD)	Required Effluent Quality WCID #1	WCID #1 STP #2	Harker Heights WCID #4	WCID #3
				Alternative #1				
1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
2010	17.04	2.12	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
2020	19.16	3.64	3.00	0.44	7/2/6	7/2/6	10/3/4	10/15/2
2030	19.16	7.68	3.72	0.56	7/2/6	7/2/6	10/3/4	10/15/2
				Alternative #2				
1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
2010	17.04	2.12	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
2020	19.16	3.45	3.00	0.44	7/2/6	7/2/6	10/3/4	10/15/2
2030	19.16	7.11	3.72	0.56	7/2/6	7/2/6	10/3/4	10/15/2
				Alternative #3				
1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
2010	17.04	1.06	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
2020	19.16	2.22	2.44	0.44	7/2/6	7/2/6	10/3/4	10/15/2
2030	19.16	4.16	2.70	0.56	7/2/6	7/2/6	10/3/4	10/15/2

Note: Effluent Requirements shown in terms of BOD/NH3-N/DO.

House Creek, Turkey Run Creek, Clear Creek. For the Copperas Cove planning area, flows were projected for the three existing WWTPs. To simulate the impacts of the projected flows, the House Creek, Turkey Run Creek, and Clear Creek models were used. The projected flows, by decade, are:

WWTP	1990 MGD	2000 MGD	2010 MGD	2020 MGD	2030 MGD
NE	0.92	1.07	1.19	1.29	1.35
NW	1.51	1.89	2.04	2.23	2.46
S	0.85	1.37	1.59	1.75	1.93

The stream standards for all three receiving streams require maintaining a 3.0 mg/l dissolved oxygen concentration. To simulate the critical conditions, the headwater flow was set to 0.1 cfs based on the Texas Water Commission policy for assuming minimum background flows. The water temperature set to 29.5°C. This is the average summer temperature plus one standard deviation. The projection models showed that, to meet the stream standards for all three streams and all projected effluent flows, the required effluent quality is advanced secondary treatment with nitrification (10 mg/l BOD5, 3 mg/l ammonia nitrogen, and 4 mg/l dissolved oxygen).

Sulphur Creek. The Sulphur Creek model was used to determine the impact and the required effluent quality for the City of Lampasas' two wastewater treatment plants to maintain the 3.0 mg/l dissolved oxygen standard in the stream. For the Lampasas planning area, two population projections were developed that bracketed the future population. The two existing WWTPs, which are located adjacent to one another were assumed to be used to treat all projected flows. The total projected flows were:

Projection	1990 MGD	2000 MGD	2010 MGD	2020 MGD	2030 MGD
Low	0.70	0.90	1.20	1.50	1.80
High	0.74	1.01	1.42	1.96	2.62

The model was modified to reflect critical conditions by using a headwater flow of 2.0 cfs and a water temperature of 30.0°C. The results of the modelling showed that for both the low and high projections for the year 1990 the required effluent quality is advanced secondary treatment (10 mg/l BOD, 15 mg/l ammonia nitrogen, and 2 mg/l dissolved oxygen). For all other years for both the high and low projections, the required effluent quality is advanced secondary treatment with nitrification (10 mg/l BOD5, 3 mg/l ammonia nitrogen, and 4 mg/l dissolved oxygen).

Leon River Below Lake Belton. The Leon River below Lake Belton model was used to explore the impact of the expansion of the BRA Regional WWTP, located on Nolan Creek just upstream of the confluence with the Leon River. The model was modified to reflect expected future conditions and critical conditions. The Leon River flow below the dam was set at 0.5 cfs (the 7Q2 flow) and the water temperature set at 24.3°C. The SOD, BOD, and NH3 reaction rates were reduced to reflect the improved effluent characteristics. Two flows from the BRA WWTP were used, 5 MGD and 10 MGD. All other flows in Nolan Creek were assumed to be at the 1995 projections and required quality as specified in the TWC wasteload allocation report for Nolan Creek. The modeling results showed that for a permitted flow of 10 MGD the required effluent quality to meet the stream standard of 5 mg/l for dissolved oxygen is 10 mg/l BOD5, 2 mg/l ammonia nitrogen, and 6 mg/l dissolved oxygen.

Lampasas River Below Lake Stillhouse Hollow. The Lampasas River below Lake Stillhouse Hollow was modelled to receive 0.65 MGD from three small hypothetical plants from lakeshore developments. These plants represented a possible scenario of development around the lake. The results of the model showed that a secondary treatment level, 20 mg/l BOD, 15 mg/l ammonia, and 2 mg/l dissolved oxygen would be sufficient for the Lampasas River to meet the stream standard of 5 mg/l dissolved oxygen.

Discussion of Observations During Model Use

For the Leon River above Lake Belton, Sulphur Creek, Clear Creek, the Lampasas River above Lake Stillhouse Hollow, and the Lampasas River below Lake Stillhouse Hollow, the impact and interaction of aquatic plant life appears to affect water quality. This is pointed out because QUAL-TX and the simplified Streeter-Phelps model used in this study are both steady state models with fixed reaction and process rates that are not time variable, whereas, growth and death of aquatic plant life follows seasonal cycles, where, if the process rates were to be quantified, they would be time variable.

During the period defined as critical, the streams are characterized by low flow and warm water temperatures and aquatic plant life is generally growing at its maximum rate. Nutrient uptake and oxygen production are generally at their peaks. Calibration data sets were collected from September through November, so growth rates and uptake rates were probably below the maximum. The projection model may then be conservative on the uptake rates of nutrients by plant life.

Using dissolved oxygen is generally a good indicator of a impact of the discharge on a stream's quality. Both the Streeter-Phelps and QUAL-TX models simulate the major processes influencing dissolved oxygen. As previously explained, in using these models, adjustments were made that reflect the expected future conditions of the stream being modelled. For example, a reduction in settling was assumed to account for lower future effluent TSS concentrations. After these adjustments were made, the projection models provided a good conservative estimate of the impact of the future point sources on stream dissolved oxygen.

Other impacts to receiving streams may not be identified using dissolved oxygen models. Based on observations made during the stream surveys, aquatic plant life may be adversely impacted by dischargers. For example, based on visual observations in the field, Clear Creek is severely impacted by nutrients from the WWTP discharge. The stream has broad very slow moving pools, that are now completely blanketed in filamentous algae, with a mat well over six inches thick. The nutrient levels observed in the stream reflect plant nutrient uptake.

LAKES

Introduction

This study used chlorophyll 'a', a constituent of algae cells, as a measurement of lake water quality. All lakes age naturally and algae populations eventually increase. The extent of the algae population, and associated water quality indicate a measure of aging called eutrophication. Very clean lakes are referred to as oligotrophic where low algae and nutrient concentrations are found. Lakes with slightly higher concentrations are referred to as mesotrophic, and lakes with high concentrations of nutrients and algae are eutrophic. Texas lakes are usually either mesotrophic or eutrophic due to the rich inflow of nutrients washed into the lake with eroded soil and other material associated with point and nonpoint sources. High concentrations of algae can cause changes in visual appearance. Depressions of dissolved oxygen can also occur because of the high organic load associated with the algae as it dies and settles to the lake bottom. In the context of this report a sink is a place within the lake such as the lake bottom where nutrients are deposited and can accumulate. A source is a place where nutrients originate. Under certain conditions, lake sediments can become a source by releasing accumulated nutrients into the water column. Taste and odor problems in drinking water can result from high algae concentrations and/or depressed dissolved oxygen.

As indicated in the discussion of lake water quality objectives; Lakes Belton and Stillhouse Hollow are ranked among the least eutrophic lakes in Texas based on chlorophyll 'a' measurements in a state-wide lake water quality data base (State of Texas Water Quality Inventory, 1986). However, examination of the average annual chlorophyll 'a' data collected during the year's sampling associated with this project, indicates that these lakes have average annual chlorophyll 'a' concentrations closer to the average for all lakes in the state water quality data base than originally believed.

The extensive annual sampling information developed in the current study is a realistic assessment of water quality for both Lakes Belton and

Stillhouse Hollow. It is probable that the low historical chlorophyll 'a' values previously reported are probably a result of the small number of intermittent samples included in the state data base. Also it appears that the state-wide data base may not include results of earlier local studies such as that by CTCOG (1980) for Lakes Belton and Stillhouse Hollow. In any case, the recent data suggests that annual average chlorophyll 'a' values are on the order of 11 ug/l at main lake stations close to the dams.

Calibration

Both Lakes Belton and Stillhouse Hollow were modelled using WASP, an EPA program that simulates water quality changes over both time and space. The kinetic subroutine used in WASP is developed by the user, and the main WASP program simulates the transport. Application of the model requires an extensive data base, such as that developed from the sampling program in this study. The analysis considers the change in the concentration of chlorophyll 'a', ammonia, nitrate, organic nitrogen, orthophosphorus, unavailable phosphorus (unavailable for uptake by algae), BOD5 and dissolved oxygen.

Algae concentrations represented by chlorophyll 'a' growth are related to light availability, ammonia and nitrate concentrations, orthophosphate, and temperature. Algae removal in the WASP model is associated with settling, predation, respiration, and nonpredatory death. Losses of algae result in BOD, organic nitrogen and unavailable phosphorus that can be reintroduced back into the water column. Growth of algae adds dissolved oxygen to the water column while death and respiration remove oxygen.

WASP simulates nitrogen in three compounds, organic nitrogen, ammonia, and nitrate. Organic nitrogen is a breakdown product of algae, is subject to settling and can be transformed biologically to ammonia. Ammonia, in addition to being a product of organic nitrogen, is also released from the bottom sediments. Ammonia is subject to uptake by algae and nitrification, which transforms it into nitrate. Nitrate is subject to uptake by algae.

Phosphorus is simulated in two compounds, orthophosphorus and unavailable phosphorus. Unavailable phosphorus is the fraction of total phosphorus that cannot be used by algae. Unavailable phosphorus is the product of algae death and is subject to settling and microbiological transformation to orthophosphorus. Orthophosphorus is also released from the bottom and is taken up by algae growth.

Dissolved oxygen is a function of reaeration from the surface, BOD oxidation, nitrification, bottom demand, and production or uses by algae. Reaeration is based on windspeed. Nitrification, BOD decay, and bottom releases of nutrients and sediment oxygen demand is a function of the dissolved oxygen in the bottom layers.

For a further discussion of the WASP model, the reader is referred to WASP 3 (Water Quality Analysis Program), a Hydrodynamic and Water Quality Model - Model Theory, Users Manual and Programmer's Guide, U.S. EPA, September 1986.

In using WASP for this project, data collected from September 1987 through August 1988 were used to calibrate water quality models for Lakes Belton and Lake Stillhouse Hollow. The calibration procedure included developing flow and water volume balances for each lake. The data were employed in a sequential manner to adjust the model coefficients so that the calculated water quality was generally similar to the observed data. The sequence of comparisons of model output to observed data for coefficient adjustment was generally:

1. Conductivity and temperature
2. Total nitrogen and total phosphorus
3. The individual chemical species of nitrogen and phosphorus

4. Chlorophyll 'a'
5. BOD and dissolved oxygen

The resultant model coefficients for each Lake are presented in Table IV-1 and are within the range normally used in water quality modeling of this nature (Technical Guidance Manual for Performing Waste Load Allocations, Book IV Lakes and Impoundments, Chapter 2 Eutrophication, U.S. EPA, August 1983, Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition), U.S. EPA, June 1985, WASP 3 (Water Quality Analysis Program), a Hydrodynamic and Water Quality Model - Model Theory, Users Manual and Programmer's Guide, U.S. EPA, September 1986). These coefficients are the same for each section of a lake and were not varied from segment to segment or from time period to time period except for temperature adjustments. The kinetics used in the model are summarized in the Appendix.

Lake Stillhouse Hollow Model Calibration. Figure IV-10 is a sketch of Lake Stillhouse showing model segmentation and sampling locations. Figures IV-11, IV-12, IV-13 and IV-14 illustrate the comparison between calculated and measured total nitrogen, total phosphorous, chlorophyll a, and dissolved oxygen for the three segments in Lake Stillhouse Hollow adjacent to the dam. The comparisons are typical of those normally obtained in this type of analysis and are representative of the order of comparisons between calculated and observed profiles for all of the Lake Stillhouse Hollow segments. The complete set of figures comparing calculated and observed water quality for each individual variable and each model segment in Lake Stillhouse Hollow are contained in the Appendix.

It should also be noted that the model and observed data are not in agreement with respect to the factors that are limiting phytoplankton growth. The model contains phytoplankton inorganic nitrogen growth limitations, for some periods of the year, which are larger than reflected

TABLE IV-1

MODEL COEFFICIENTS FOR LAKES BELTON AND STILLHOUSE HOLLOW

Number	Constant	Description	Units	Belton	Stillhouse
1	XKN	Ammonia Decay @ 20°C	1/day	.12	.1
2	XKON	Organic N Conversion to NH^3 @ 20°C	1/day	.15	.07
3	XKSEDN	Bottom release of NH_3	$mg/ft^2/day$	17	12
4	SETTON	Settling rate of organic nitrogen (usually=w)	ft/day	.492	.328
5	XDENIT	Denitrification rate	1/day	.01	.01
6	ALGN	Nitrogen to carbon ratio in algae	mg N/mg C	.15	.15
7	KAP	Phosphorous to carbon ratio in algae	mg P/mg C	.01	.01
8	XKNP	Nonavailable P conversions to available P	1/day	.15	.08
9	NONPSET	Nonavailable P settling (usually=w)	ft/day	.492	.328
10	XKPSED	Bottom release of available P	mg $P/ft^2/day$	.80	.75
11	Is	Optimal light intensity	Ly/day	250	250
12	XKPT	Maximum algae growth rate @ 20°C	1/day	2.5	2.5
13	KALD	Nonpreditory algae death rate @ 20°C	1/day	.01	.05
14	KALGRES	Algae respiration @ 20°C	1/day	.09	.05
15	KALGEAT	Algae predation rate @ 20°C	1/day	.04	.04
16	W	Algae settling rate	ft/day	.492	.328
17	KTIN	Michaelis-Menton Nitrogen half-saturation constant	mg/l	.015	.015
18	KPO_4	Michaelis-Menton Phosphorous half-saturation constant	mg/l	.001	.001
19	XKD	BOD_5 decay @ 20°c	1/day	.05	.05
20	XBOTDMD	Sediment oxygen demand @ 20°C	$mg/ft^2/day$	75	110
21	ALGBOD	BOD_5 to carbon ratio in algae	mg BOD_5/mg C	1.57	1.57
22	ALGDO	Dissolved oxygen to carbon ratio for algae use	mg DO/mg C	2.67	2.67
23	XBODSET	BOD_5 settling rate	ft/day	.492	.328
24	KBDN	DO constant for detrification	mg/l	2.	3.

TABLE IV-1

MODEL COEFFICIENTS FOR LAKES BELTON AND STILLHOUSE HOLLOW
(continued)

Number	Constant	Description	Units	Belton	Stillhouse
25	KBPR	DO constant for bottom phosphorous release	mg/l	2.	3.
26	SEDDNIT	Bottom denitrification	$mg/ft^2/day$	.002	.002
27	THNH4	Temperature conversion for NH_3 decay		1.083	1.083
28	THON	Temperature conversion for ON-NH_3 conversion		1.083	1.083
29	THSEDN	Temperature conversion for bottom release of nitrogen		1.083	1.083
30	THNONP	Temperature conversion for nonavailable P to available P		1.083	1.083
31	THRP	Temperature conversion for bottom release of phosphorous		1.083	1.083
32	THALG	Temperature conversion for algae growth, grazing and respiration		1.068	1.068
33	THALD	Temperature conversion for algae growth		1.045	1.045
34	THBOD	Temperature conversion for BOD_5 decay		1.045	1.045
35	THDO	Temperature conversion for sediment oxygen demand		1.045	1.045
36	THDENIT	Temperature conversion for denitrification		1.047	1.047

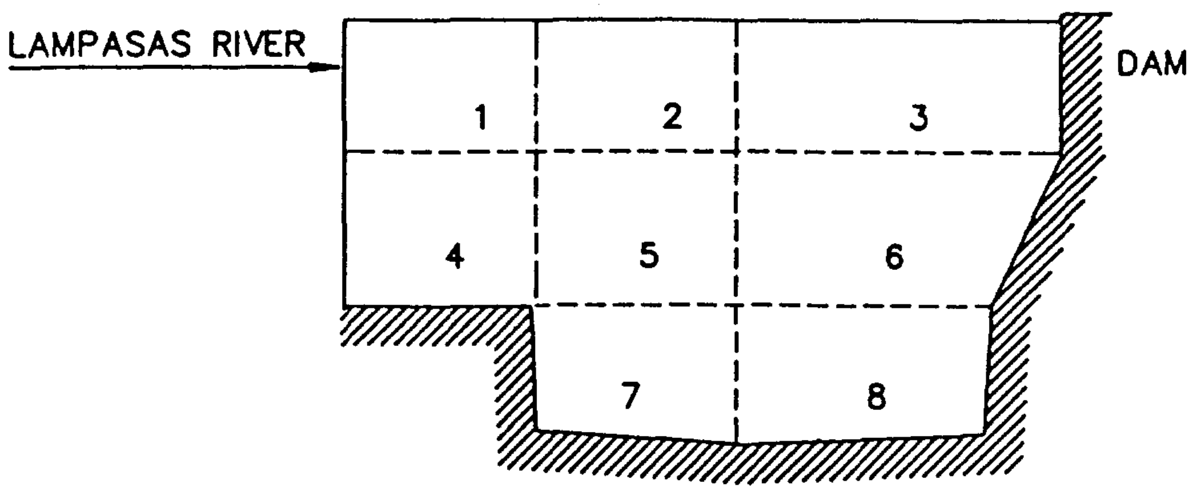


FIGURE IV-10

WATER QUALITY MODEL SEGMENTATION FOR
STILLHOUSE HOLLOW RESERVOIR

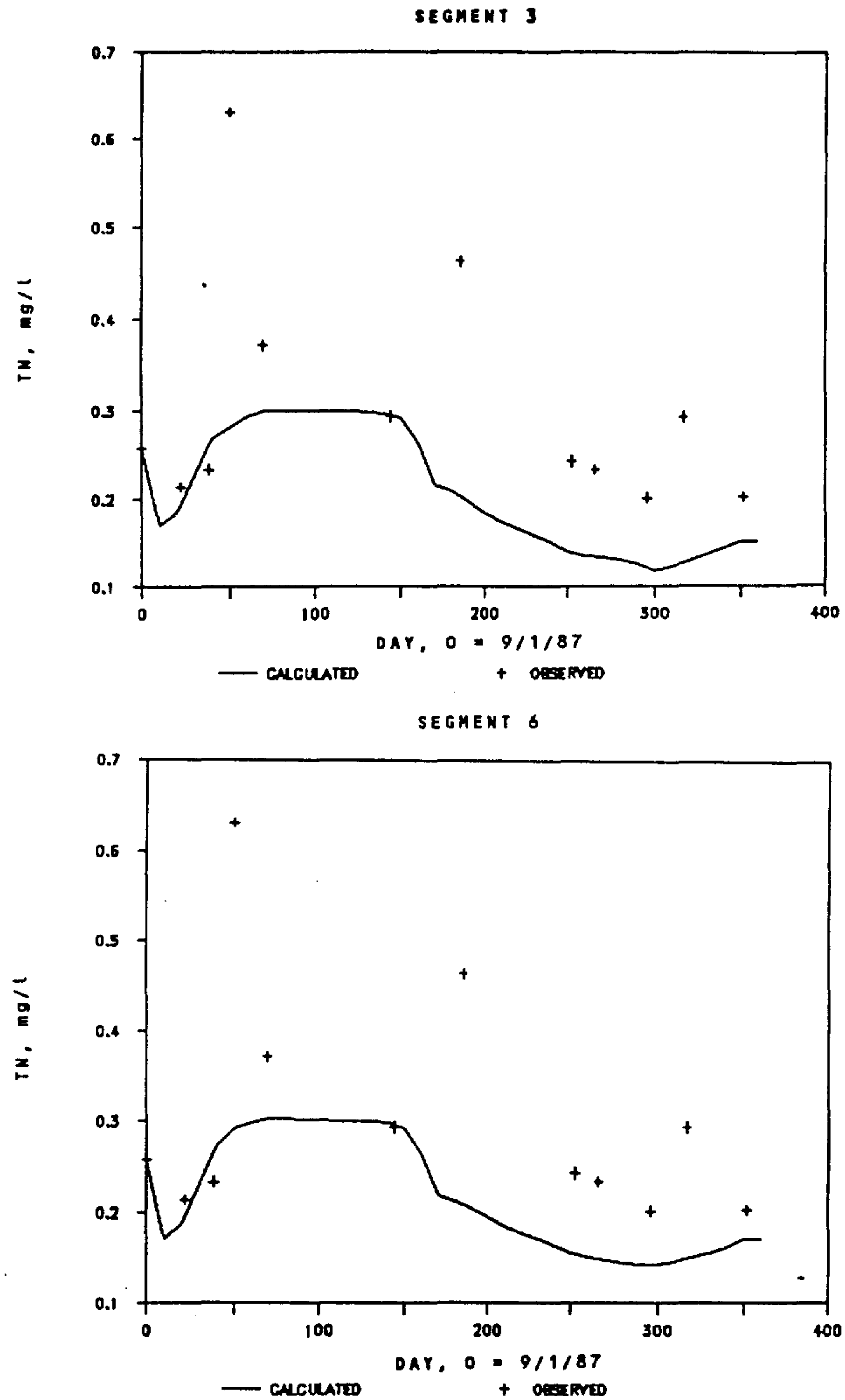


FIGURE IV-11

CALIBRATION MODEL RESULTS AND OBSERVED VALUES FOR TOTAL NITROGEN IN LAKE STILLHOUSE HOLLOW

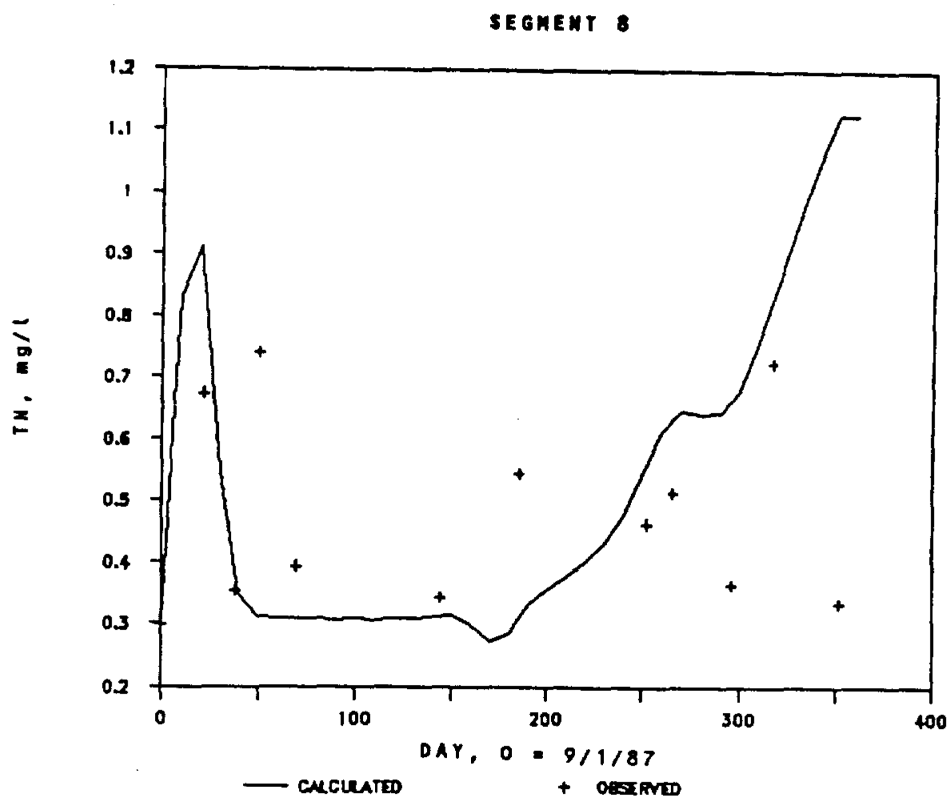


FIGURE IV-11

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FOR TOTAL NITROGEN IN LAKE STILLHOUSE HOLLOW
(continued)

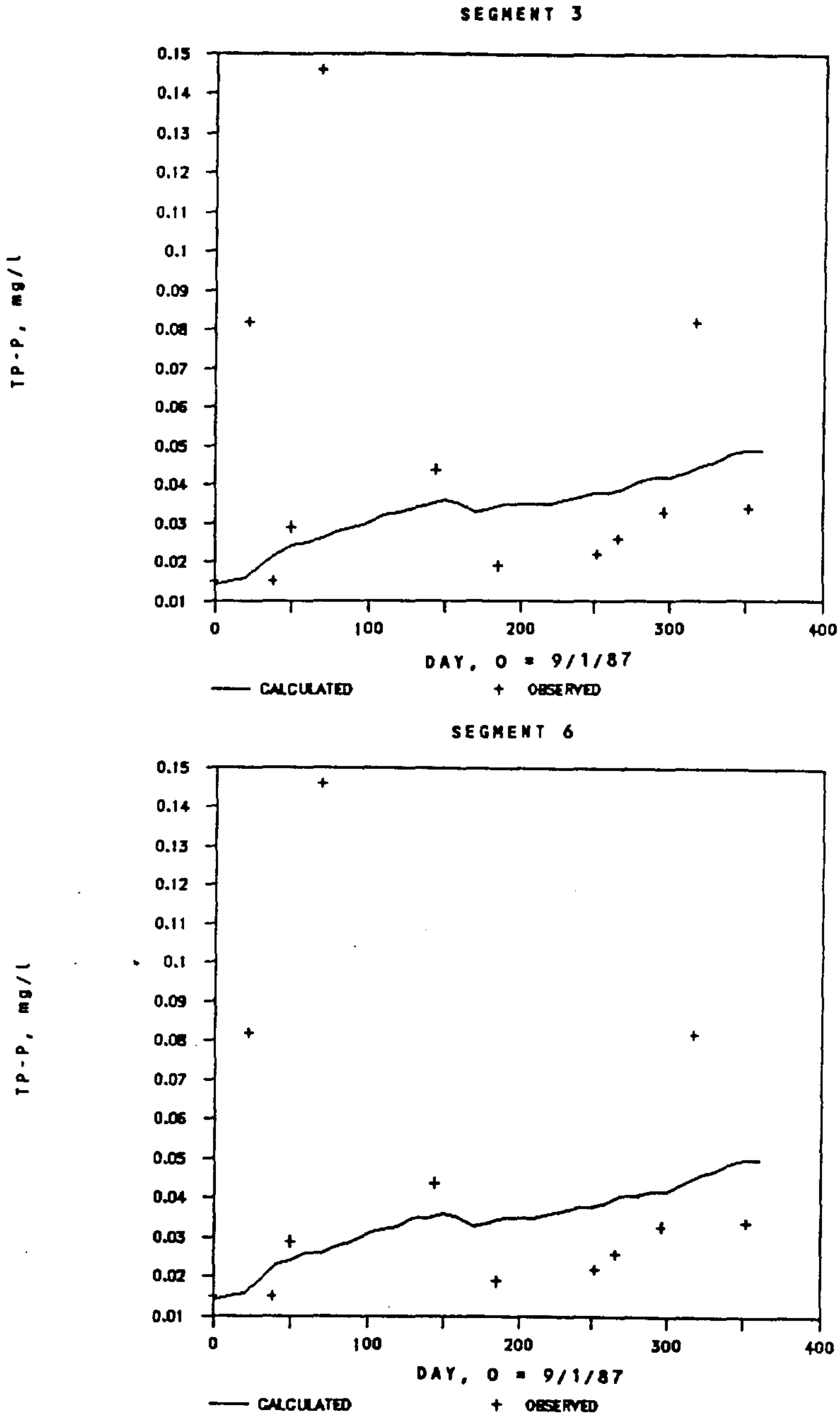


FIGURE IV-12

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FOR TOTAL PHOSPHOROUS IN LAKE STILLHOUSE HOLLOW

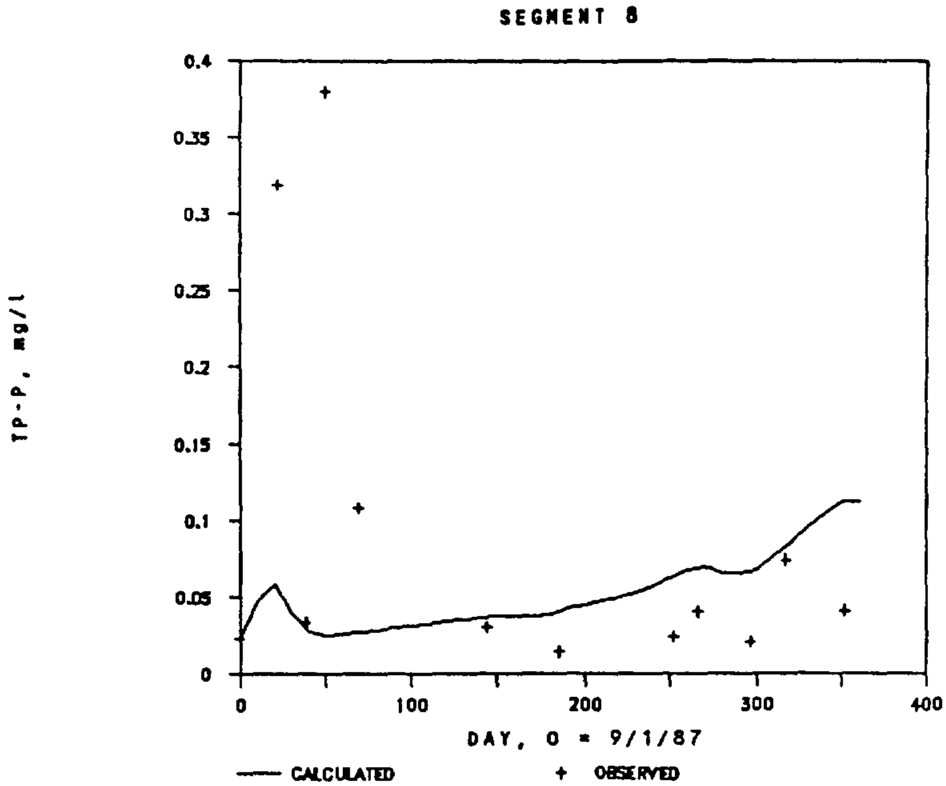


FIGURE IV-12

CALIBRATION MODEL RESULTS AND OBSERVED VALUES FOR TOTAL PHOSPHOROUS IN LAKE STILLHOUSE HOLLOW (continued)

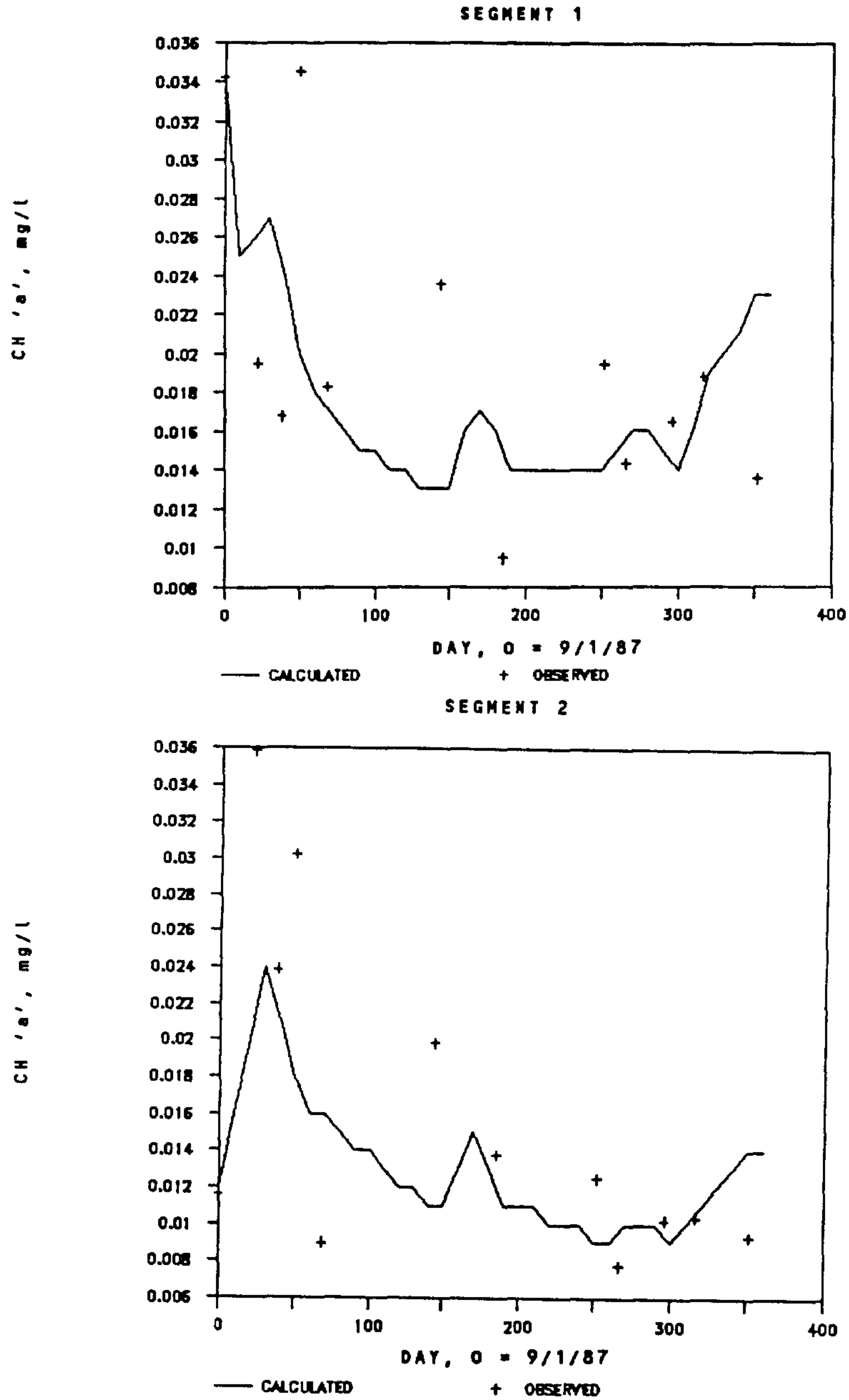


FIGURE IV-13

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FOR CHLOROPHYLL 'A' IN LAKE STILLHOUSE HOLLOW

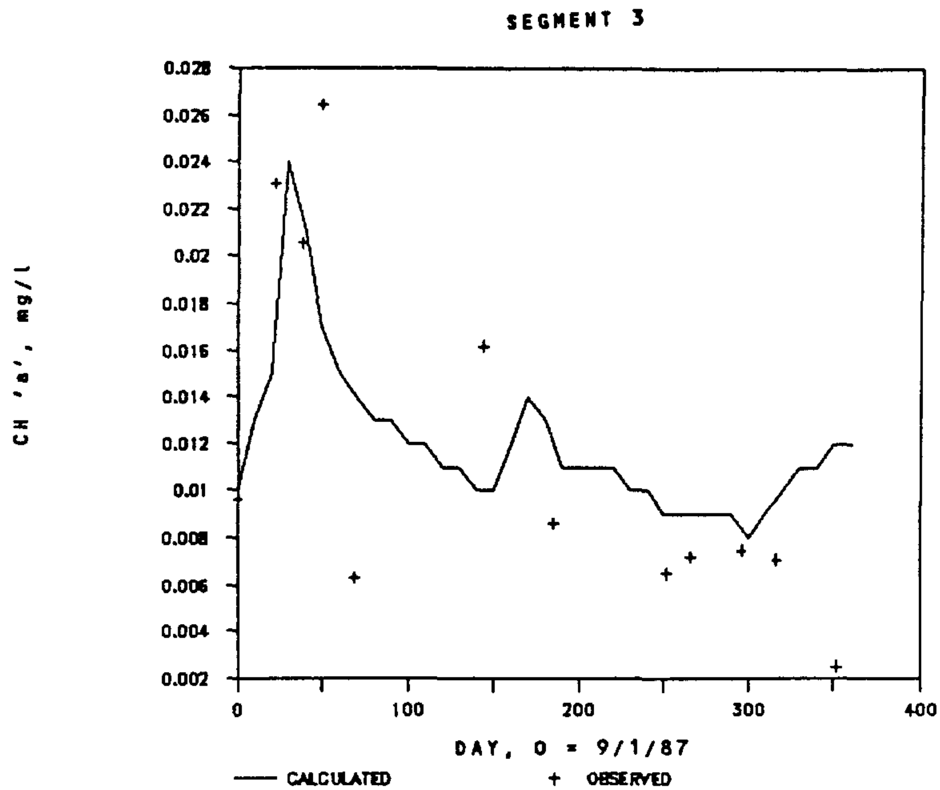
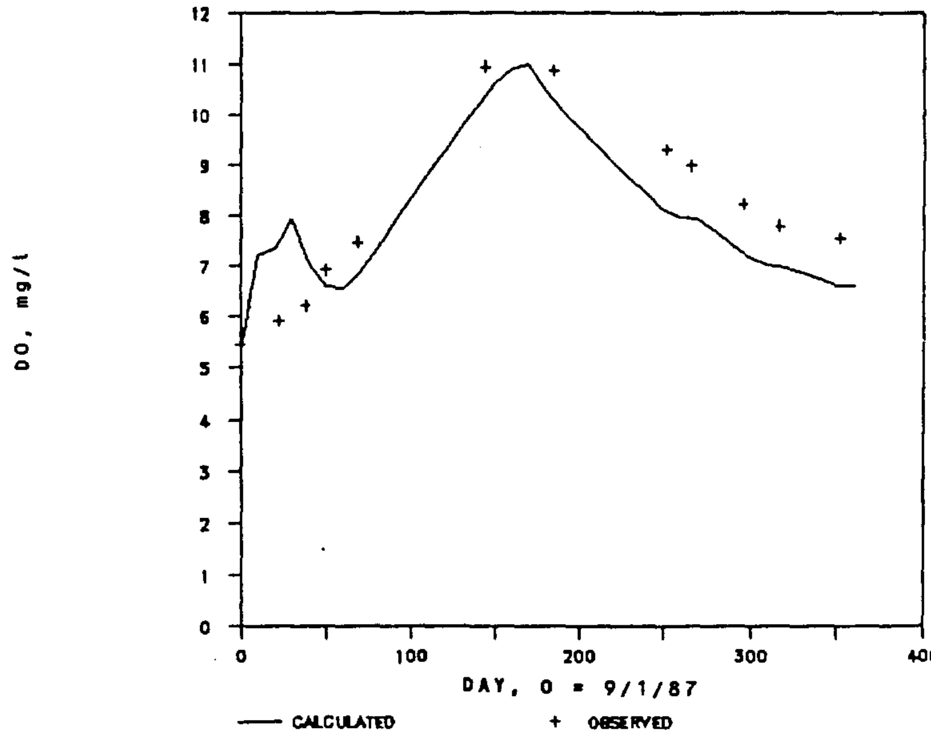


FIGURE IV-13

CALIBRATION MODEL RESULTS AND OBSERVED VALUES FOR CHLOROPHYLL 'A' IN LAKE STILLHOUSE HOLLOW (continued)

SEGMENT 3



SEGMENT 6

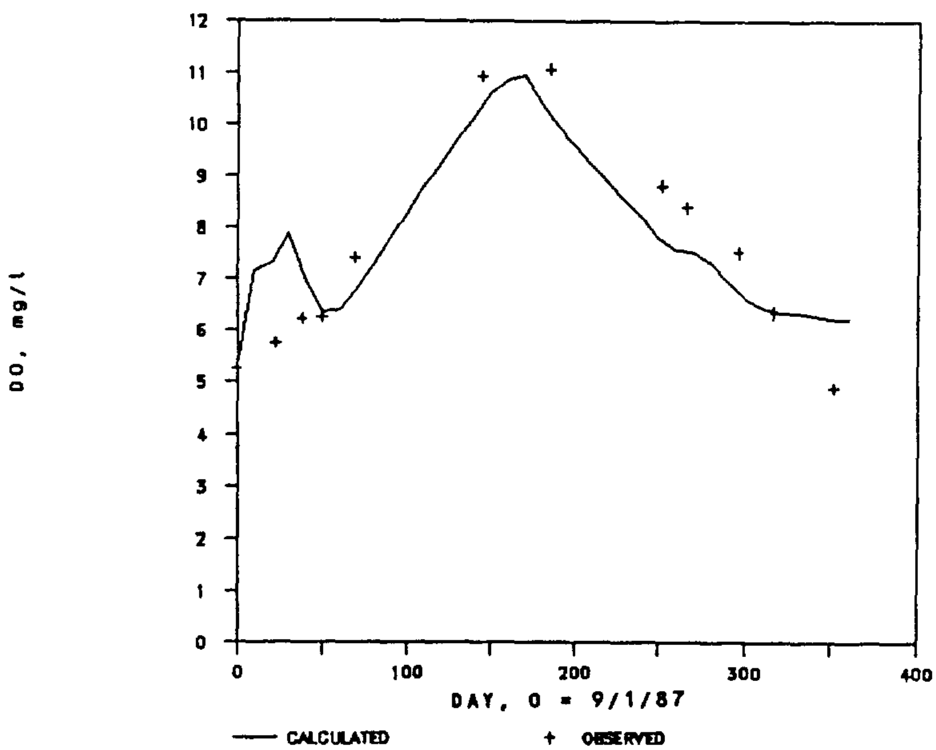


FIGURE IV-14

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FOR DISSOLVED OXYGEN IN LAKE STILLHOUSE HOLLOW

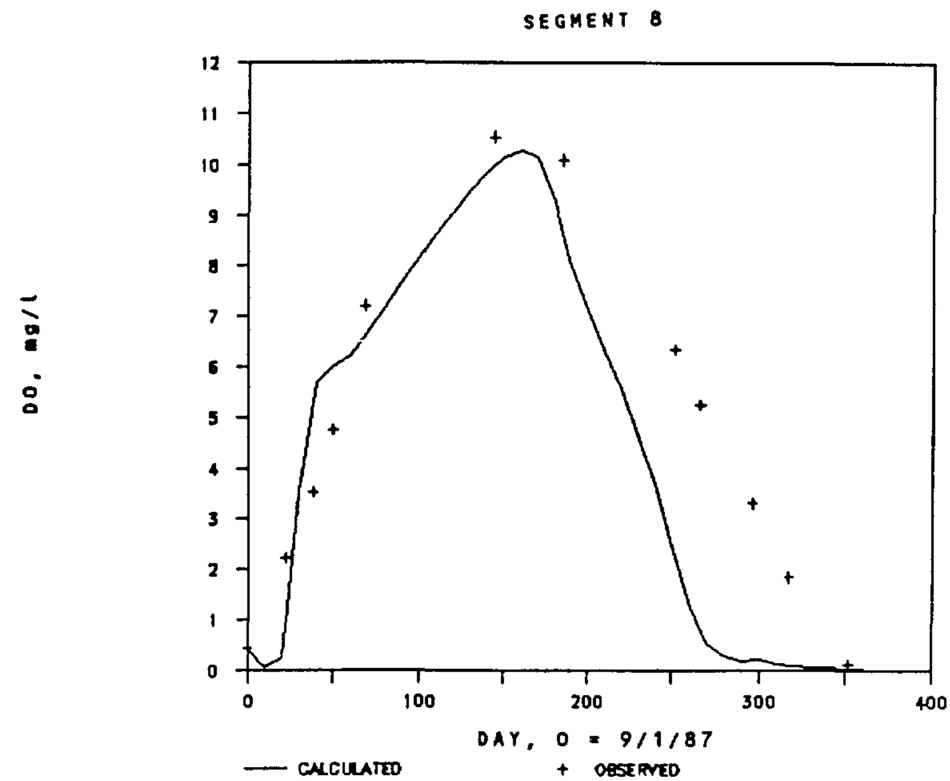


FIGURE IV-14

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FOR DISSOLVED OXYGEN IN LAKE STILLHOUSE HOLLOW
(continued)

by the observed data. This is illustrated in Figure IV-15, which presents comparisons of nutrient limitation factors expressed as the fraction of maximum phytoplankton growth. These factors were calculated as discussed on page II-35. One calculation is based on observed nutrient data and another is based on nutrient profiles generated by the WASP model for inorganic nitrogen and orthophosphorous, respectively.

Lake Belton Model Calibration. Figure IV-16 is a sketch of Lake Belton illustrating the model segmentation and sampling locations. Figures IV-17, IV-18, and IV-19 illustrate the comparison between calculated and measured total nitrogen, chlorophyll a, and dissolved oxygen for the three segments in Lake Belton adjacent to the dam. The comparisons are comparable to those obtained for Lake Stillhouse Hollow and are representative of the order of comparisons between calculated and observed profiles for all of the Lake Belton Segments. The complete set of figures comparing calculated and observed water quality for each individual variable and each model segment in Lake Belton are contained in the Appendix.

Figure IV-20 presents information on growth rate reductions due to nutrient limitations considering both the observed nutrient data and the calculated nutrient profiles. As was the case for Lake Stillhouse Hollow, the model and observations are not in agreement with respect to the factors that are limiting phytoplankton growth. The model contains phytoplankton inorganic nitrogen growth limitations, for some periods of the year, which are larger than those reflected by the observed data.

Use of Lake Models and Water Quality Data to Assess Water Quality Impacts

Projections of the direct water quality effects in Lakes Stillhouse Hollow and Belton were developed for the eight loading scenarios indicated in Table IV-2. These scenarios were selected to determine the sensitivity of

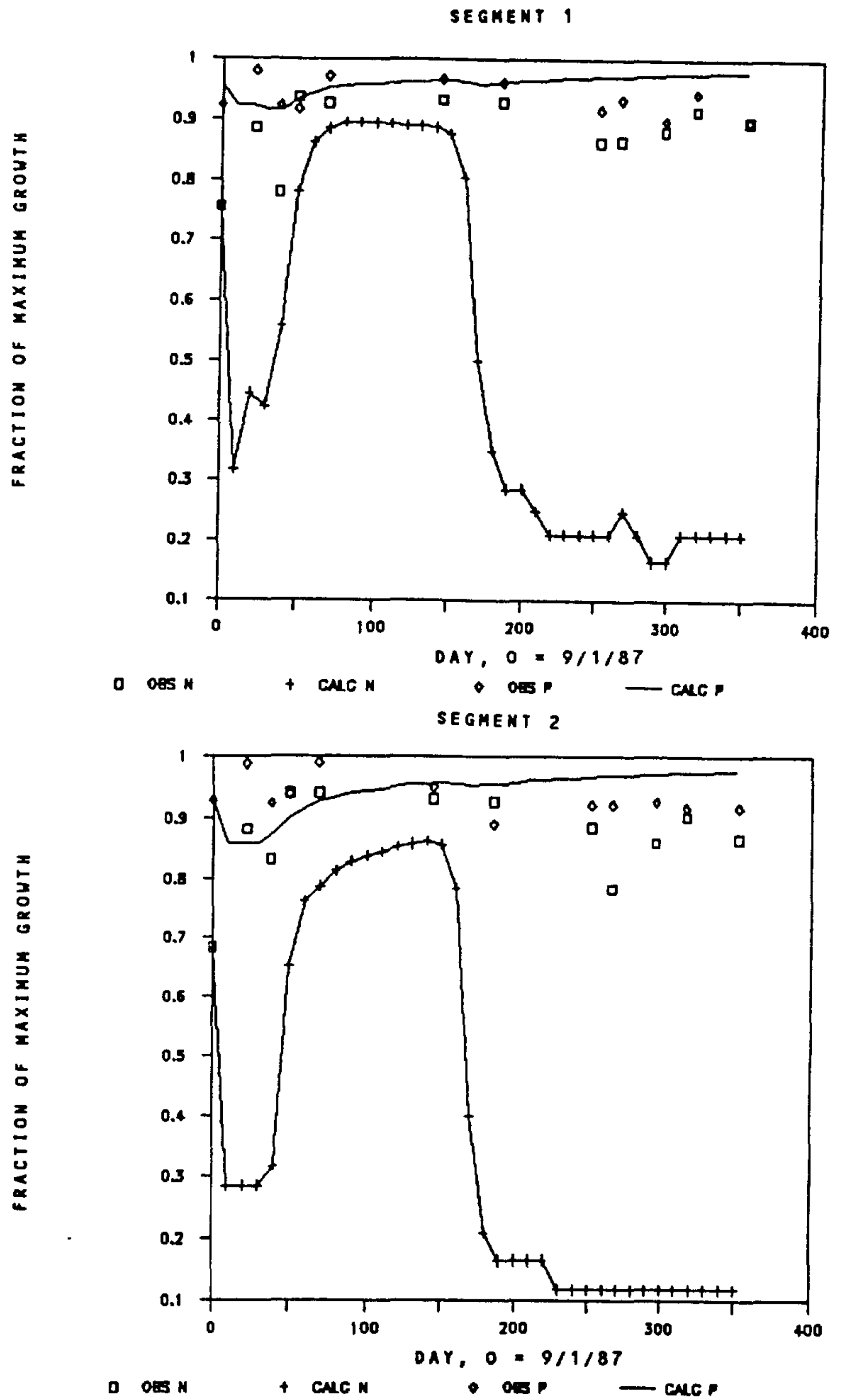


FIGURE IV-15

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FOR NUTRIENT LIMITATIONS IN LAKE STILLHOUSE HOLLOW

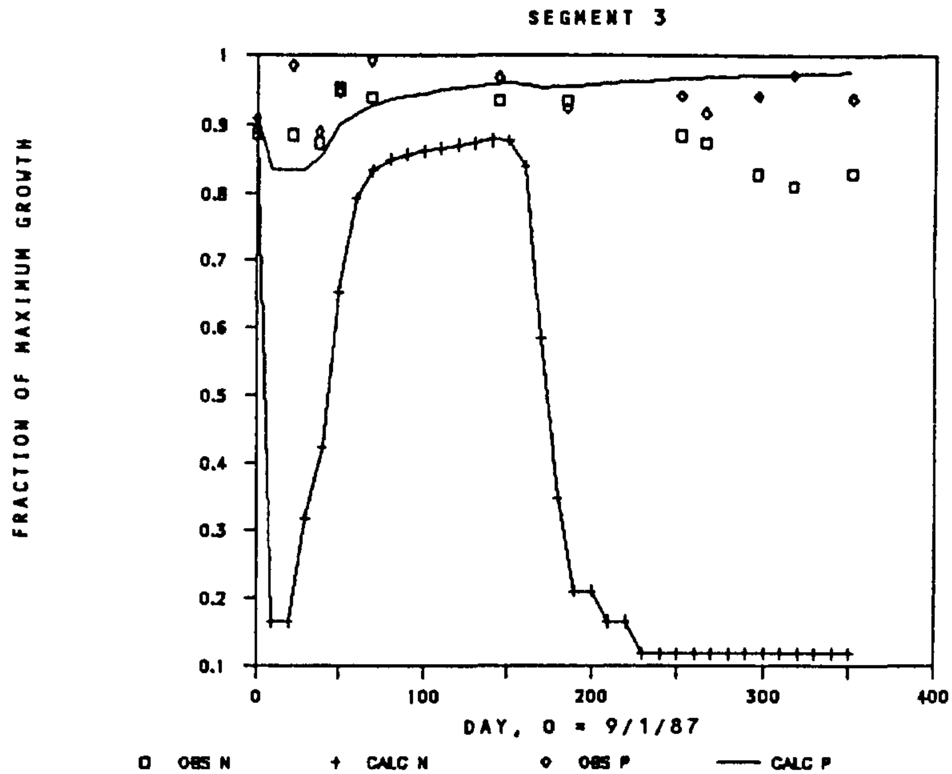


FIGURE IV-15

CALIBRATION MODEL RESULTS AND OBSERVED VALUES
FOR NUTRIENT LIMITATIONS IN LAKE STILLHOUSE HOLLOW
(continued)

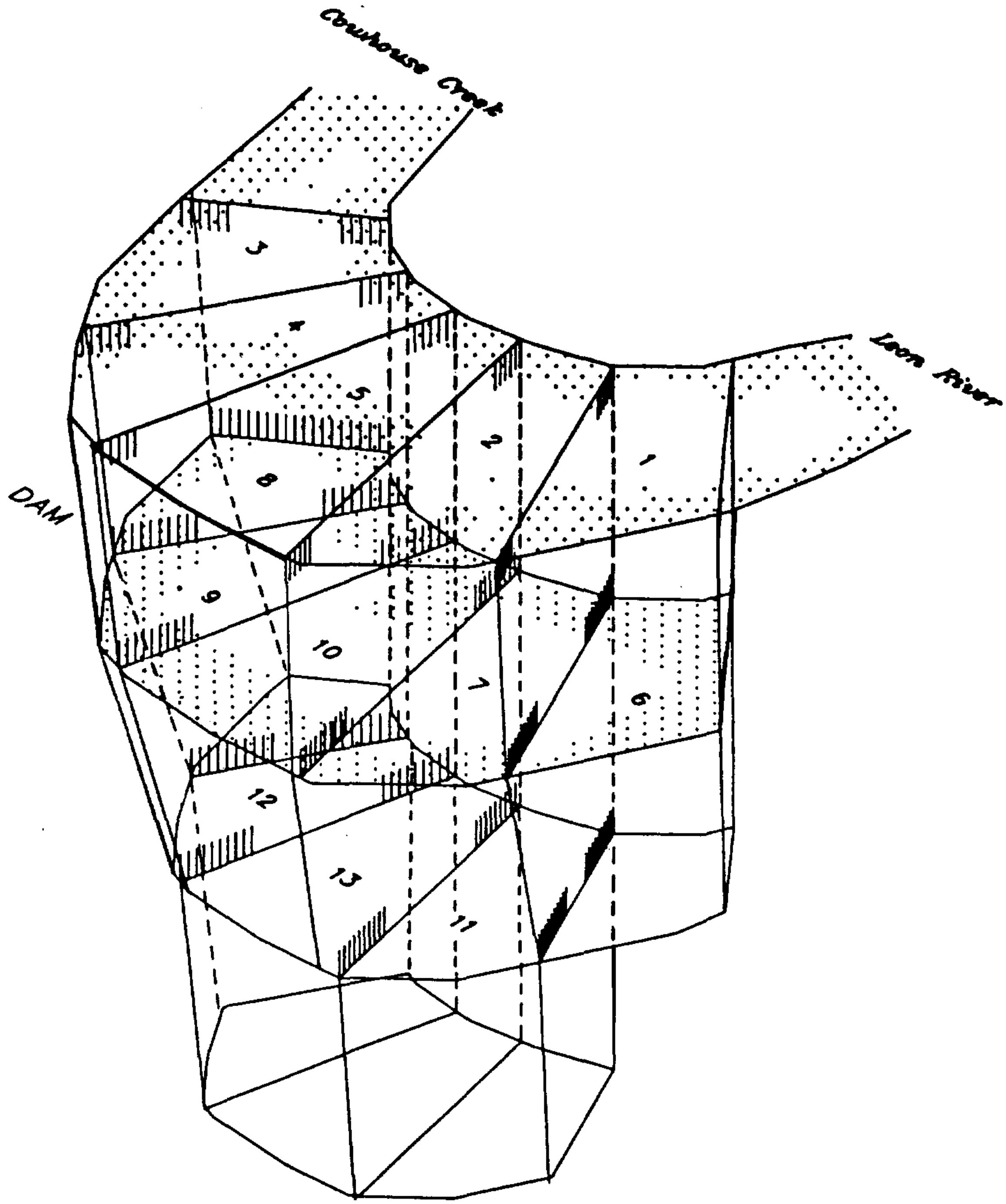


FIGURE IV-16

WATER QUALITY MODEL SEGMENTATION FOR LAKE BELTON

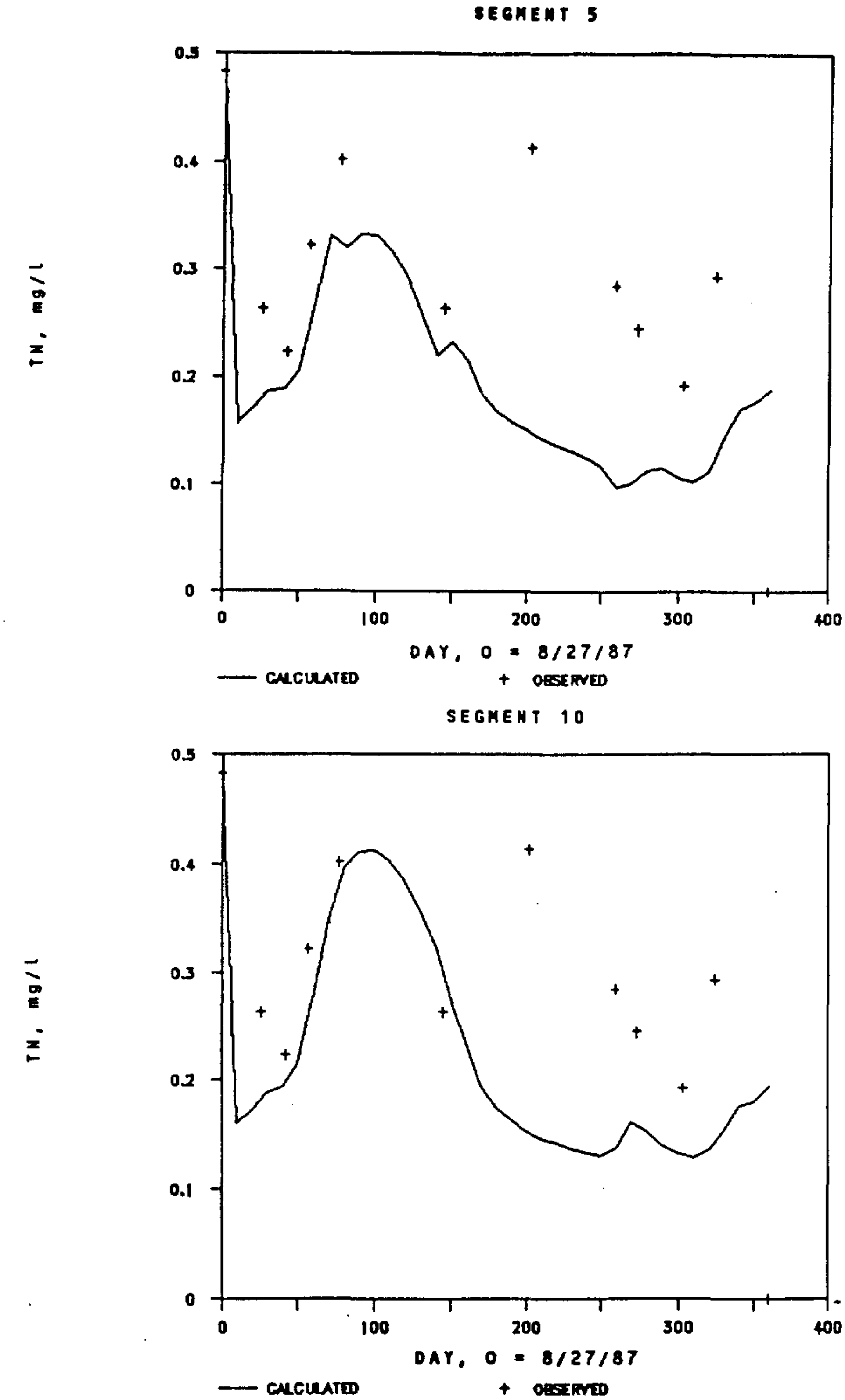


FIGURE IV-17

CALIBRATION RESULTS AND OBSERVED VALUES FOR TOTAL NITROGEN IN LAKE BELTON

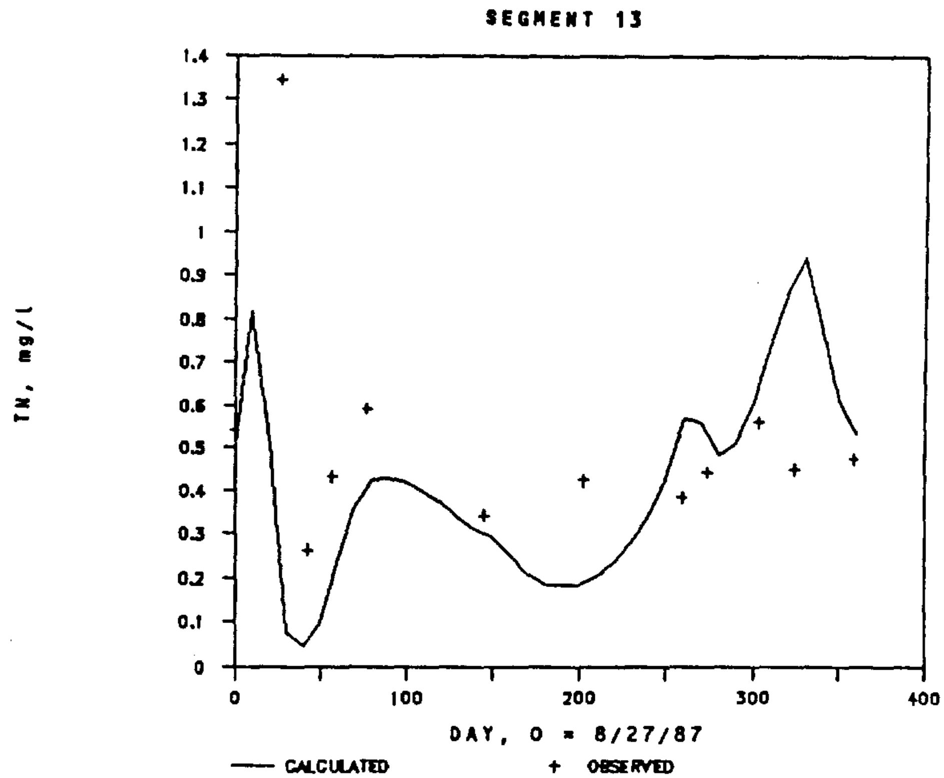
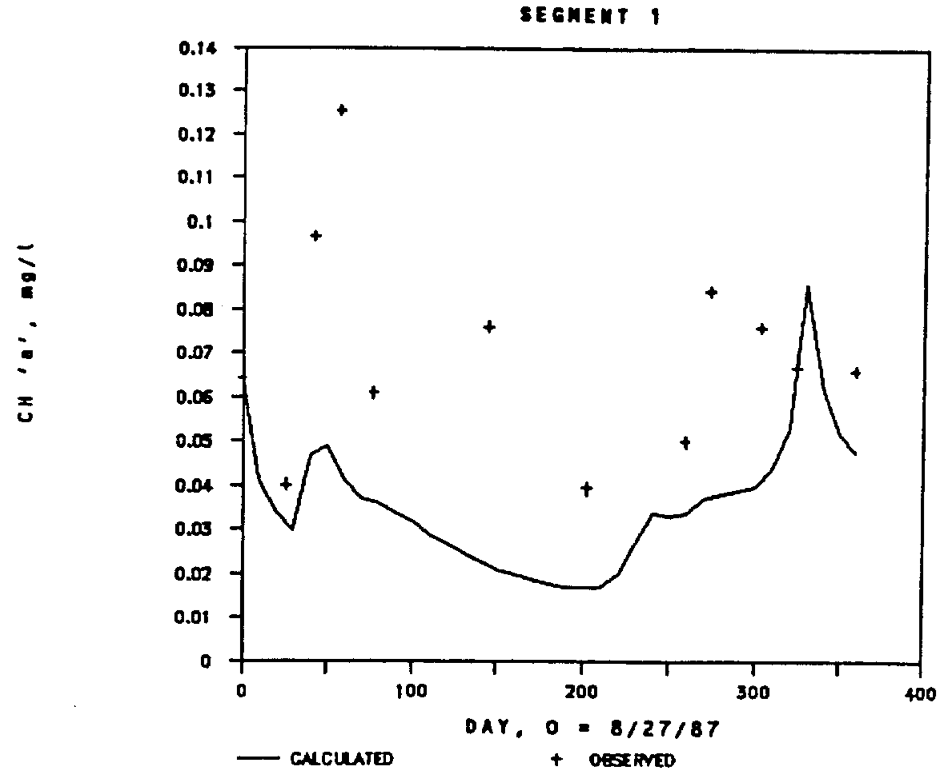


FIGURE IV-17

CALIBRATION RESULTS AND OBSERVED VALUES FOR
TOTAL NITROGEN IN LAKE BELTON
(continued)



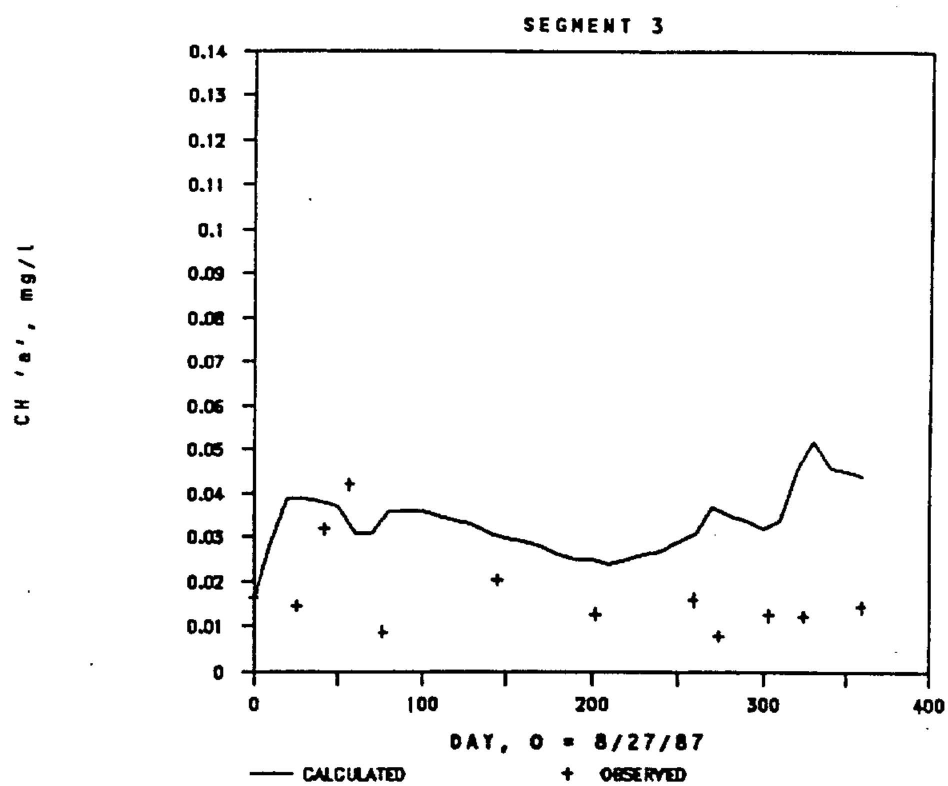
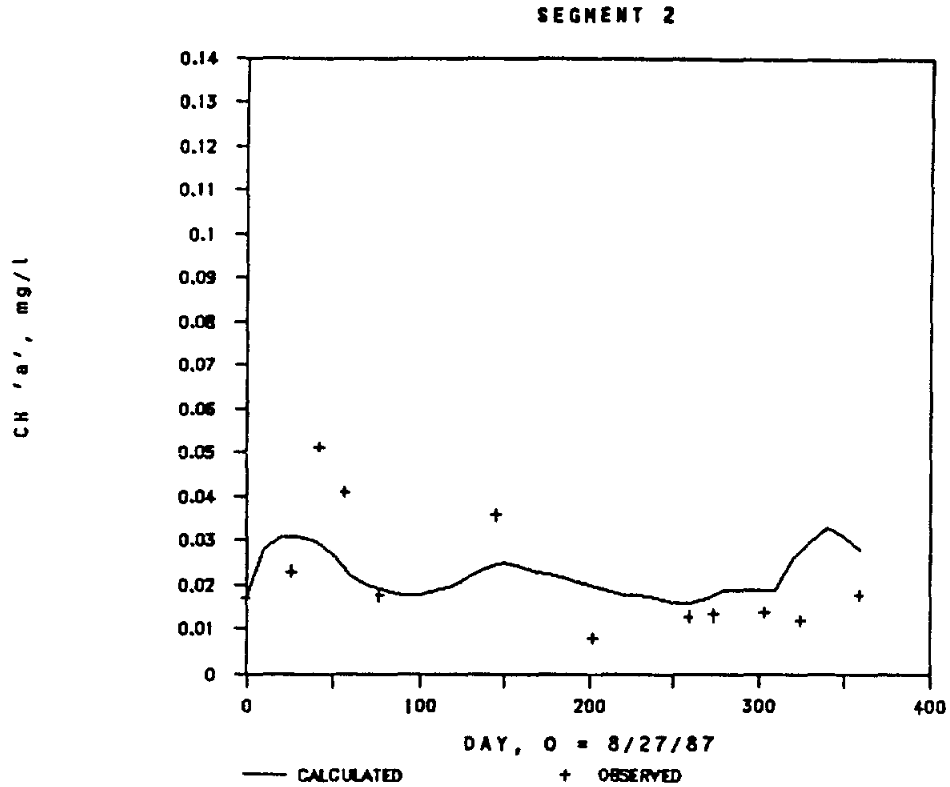


FIGURE IV-18

CALIBRATION RESULTS AND OBSERVED VALUES FOR CHLOROPHYLL 'A' IN LAKE BELTON



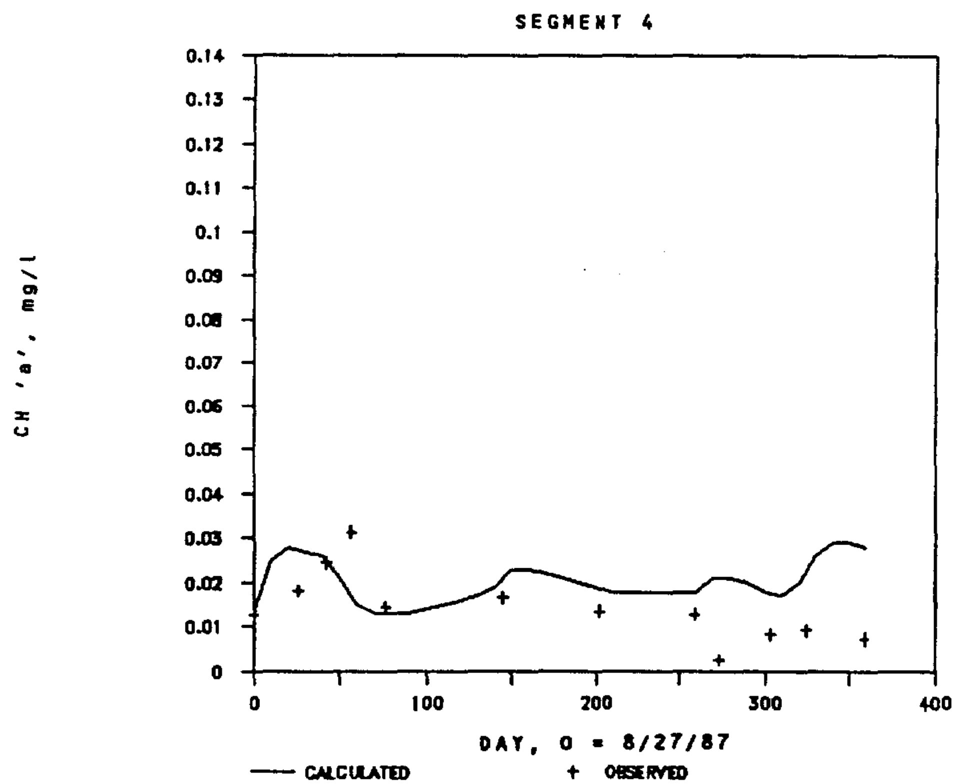


FIGURE IV-18

CALIBRATION RESULTS AND OBSERVED VALUES FOR CHLOROPHYLL 'A' IN LAKE BELTON
(continued)

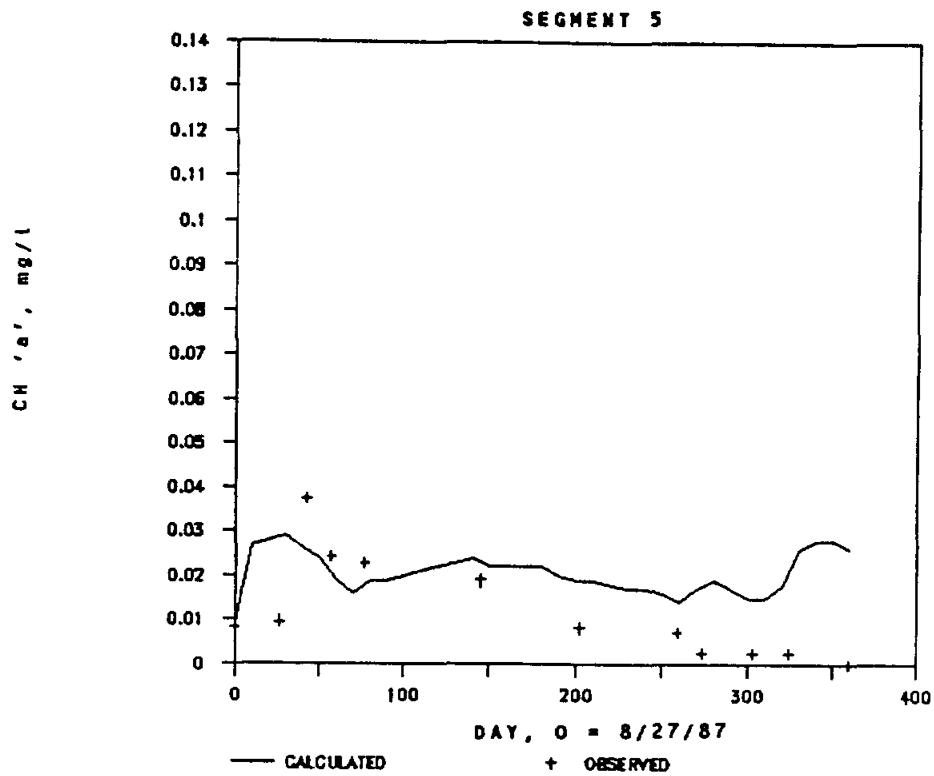
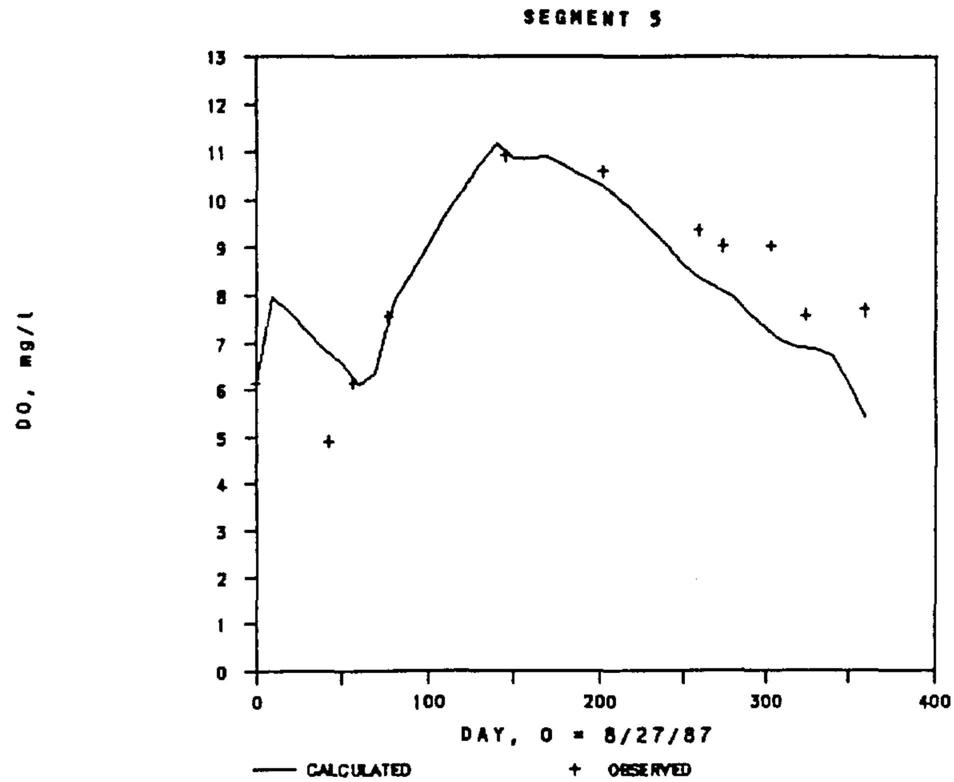


FIGURE IV-18

CALIBRATION RESULTS AND OBSERVED VALUES FOR CHLOROPHYLL 'A' IN LAKE BELTON (continued)



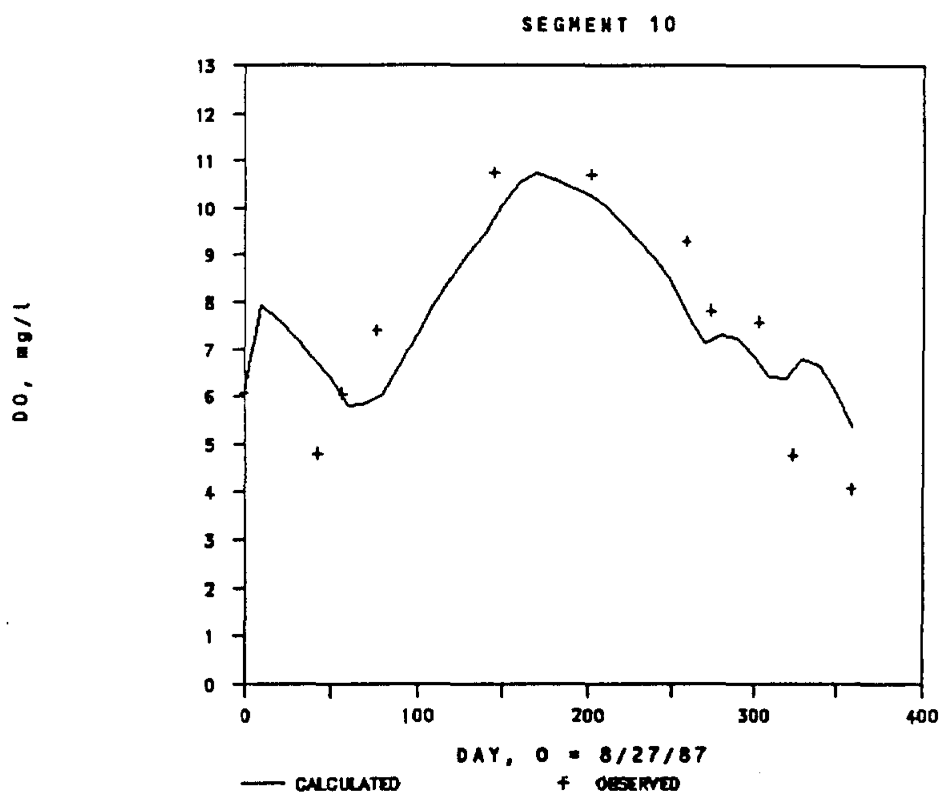


FIGURE IV-19

CALIBRATION RESULTS AND OBSERVED VALUES FOR
DISSOLVED OXYGEN IN LAKE BELTON

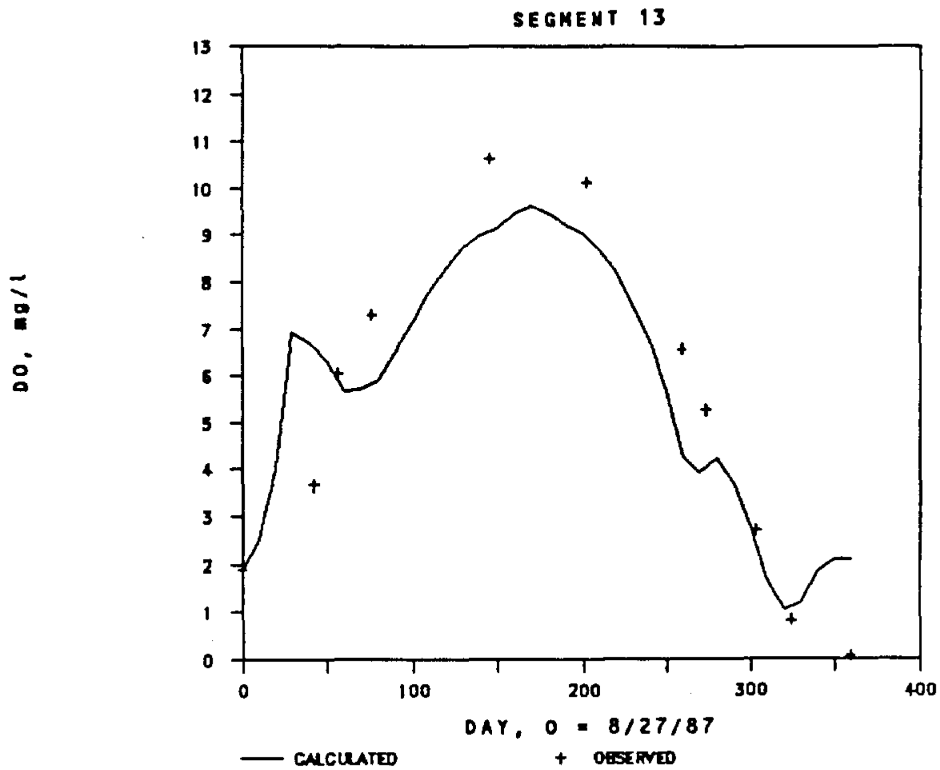


FIGURE IV-19

CALIBRATION RESULTS AND OBSERVED VALUES FOR
DISSOLVED OXYGEN IN LAKE BELTON
(continued)

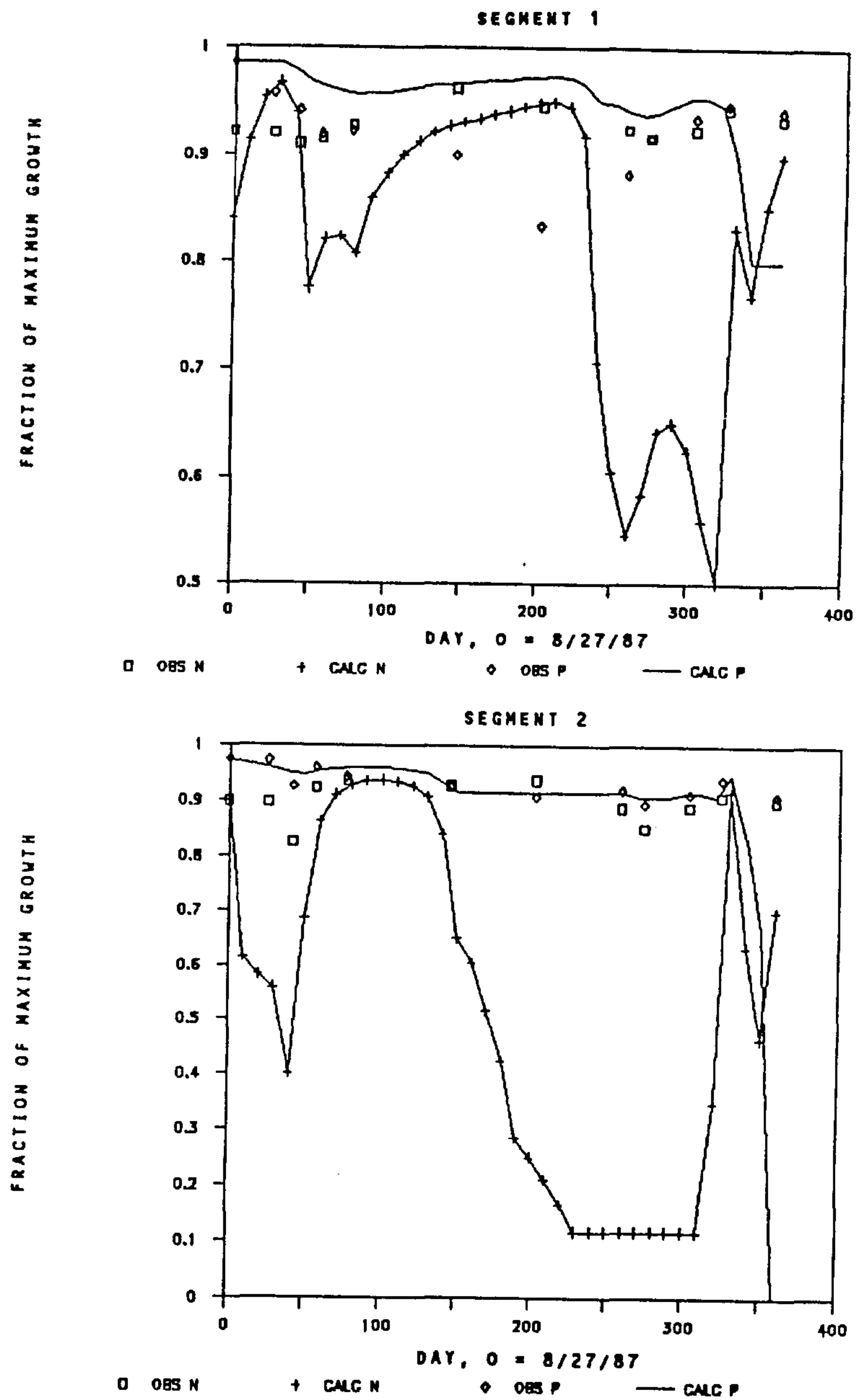
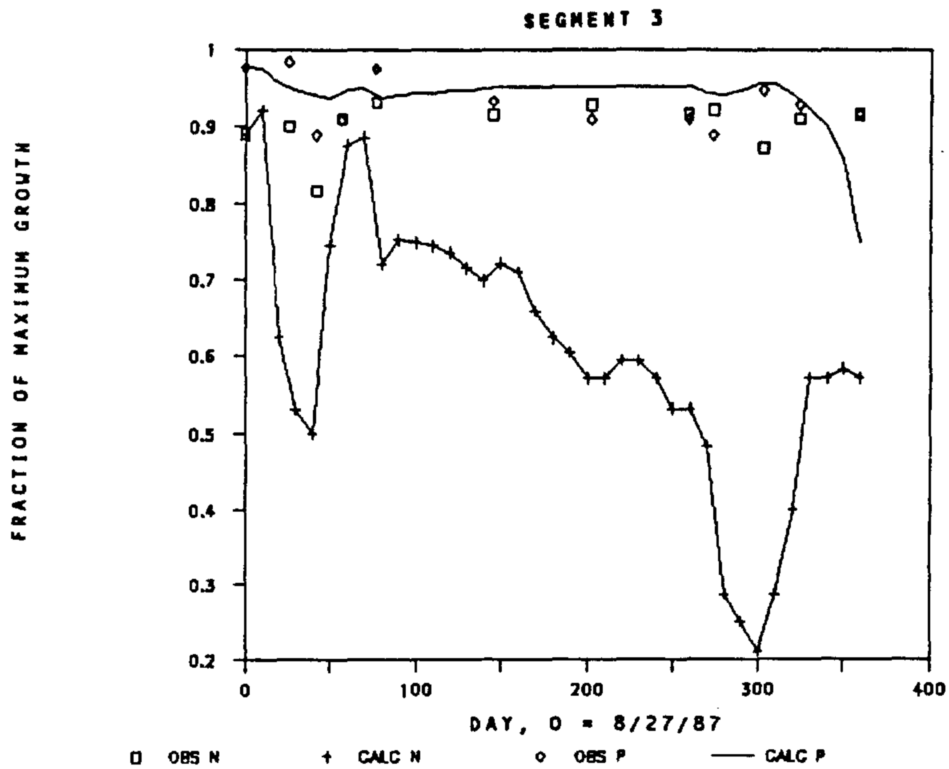


FIGURE IV-20

CALIBRATION RESULTS AND OBSERVED VALUES FOR NUTRIENT LIMITATIONS IN LAKE BELTON



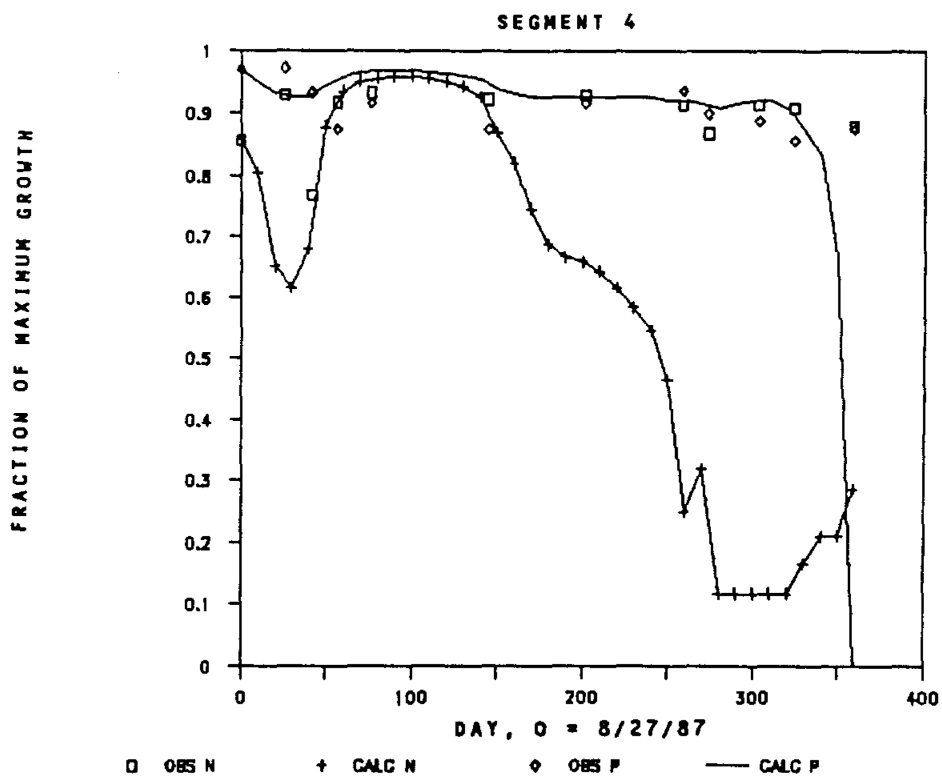


FIGURE IV-20

CALIBRATION RESULTS AND OBSERVED VALUES FOR NUTRIENT LIMITATIONS IN LAKE BELTON (continued)

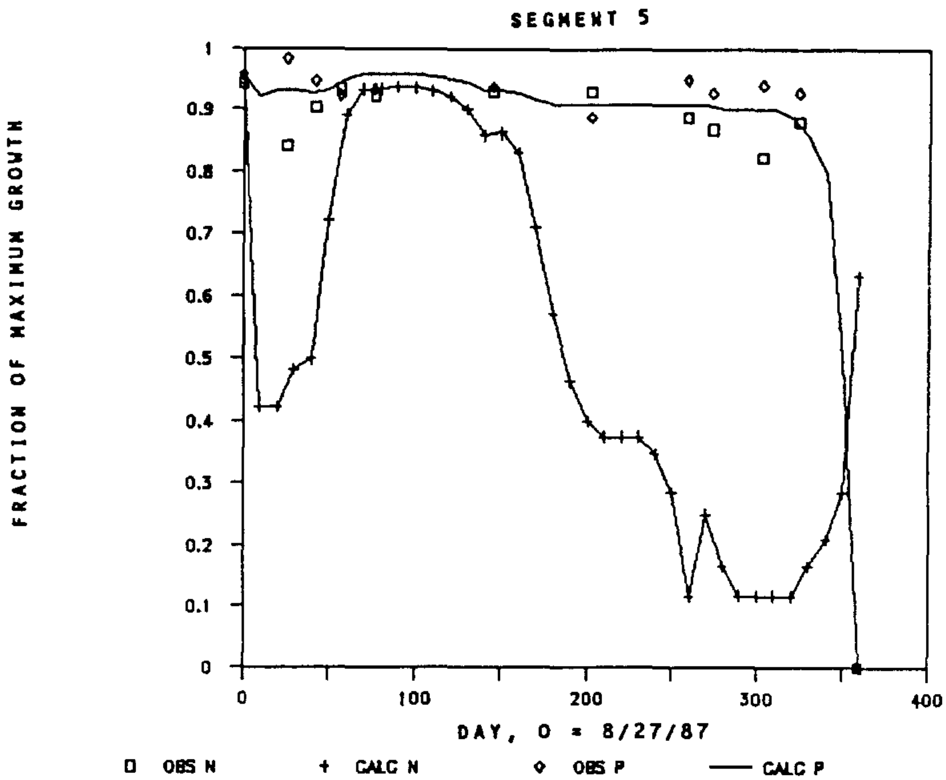


FIGURE IV-20

CALIBRATION RESULTS AND OBSERVED VALUES FOR NUTRIENT LIMITATIONS IN LAKE BELTON (continued)

TABLE IV-2

LOADING SCENARIOS USED IN PROJECTIONS
FOR LAKES BELTON AND STILLHOUSE HOLLOW

	Change in Loading(1)	
Scenario No.	Point Sources	Nonpoint Sources
1	0	-15%
2	0	+15%
3	+50%	0
4	+50%	+15%
5	-25%	0
6	+15%	0
7	-15%	0
8	-25%	-15%

[1]Both nitrogen and phosphorous loads were changed by the amounts shown.

lake water quality to changes in nutrient loading. Both nitrogen and phosphorous input loads were increased in the proportions shown. The changes in calculated chlorophyll 'a' were very small as illustrated in Figures IV-21 and IV-22 where the calculated chlorophyll 'a' profiles are presented for the two most extreme loading scenarios from Table IV-2. As a final check the year 2030 pollution loads shown in Figures III-2 and III-3 were tested. For Lake Stillhouse Hollow, the Killeen/Harker Heights diversion was included without advanced waste treatment. As can be seen in Figures IV-21 and IV-22, projected nutrient loads could have a significant impact on Lake Stillhouse and a lesser impact on Lake Belton.

A series of model runs were obtained which explored the relative roles of point and nonpoint source nutrient inputs and the source of nutrients from the sediment. Based on these calculations, which were sensitivity runs using the calibrated models for each lake, it was concluded that the sediment source of nitrogen was the input controlling nitrogen concentrations. This conclusion was made because a significant input from lake sediments had to be included in the mass balance to obtain the observed nutrient concentration levels. In calculations where this source was eliminated from consideration the chlorophyll 'a' concentrations were reduced by more then 80 percent.

This situation has been observed in a number of other water bodies and is a current area of very intensive research activity. The basic concern with the effects of changes in nutrient inputs (either increases or decreases) shifts from immediate increases in chlorophyll 'a' to long term slow changes in chlorophyll 'a' concentrations. Water quality changes are associated with nutrient accumulations in the sediment and subsequent changes in the rate of release of nutrients from the sediment over time. Therefore, even though the direct effects of changes in nutrient inputs are estimated to be small there are concerns that the long term impacts will be larger. It should be recognized that this is a phenomenon which has only

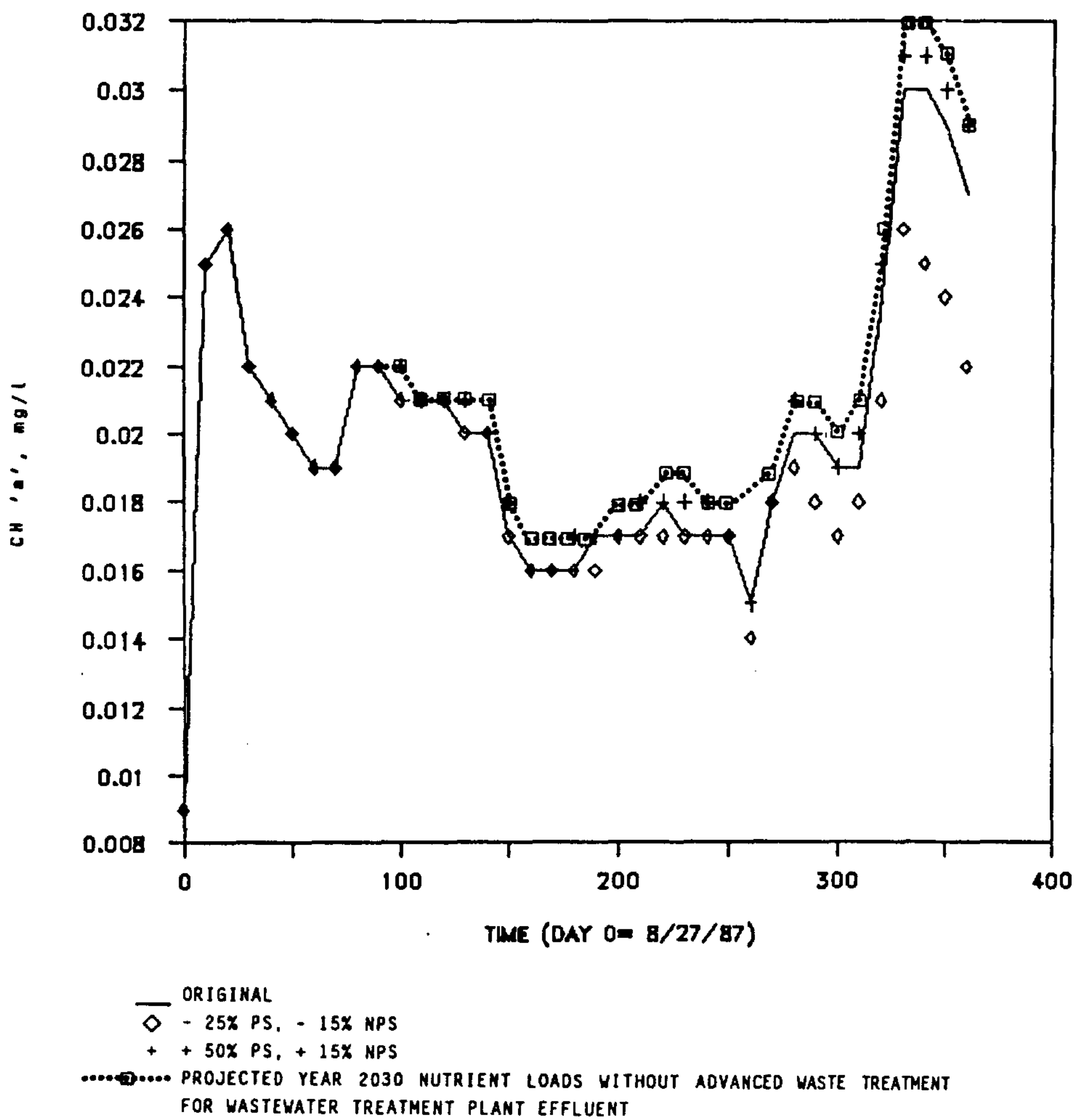


FIGURE IV-21

DIRECT EFFECTS OF WASTE LOADS ON LAKE BELTON
CHLOROPHYLL 'A' PROJECTIONS AT SEGMENT ADJACENT TO DAM

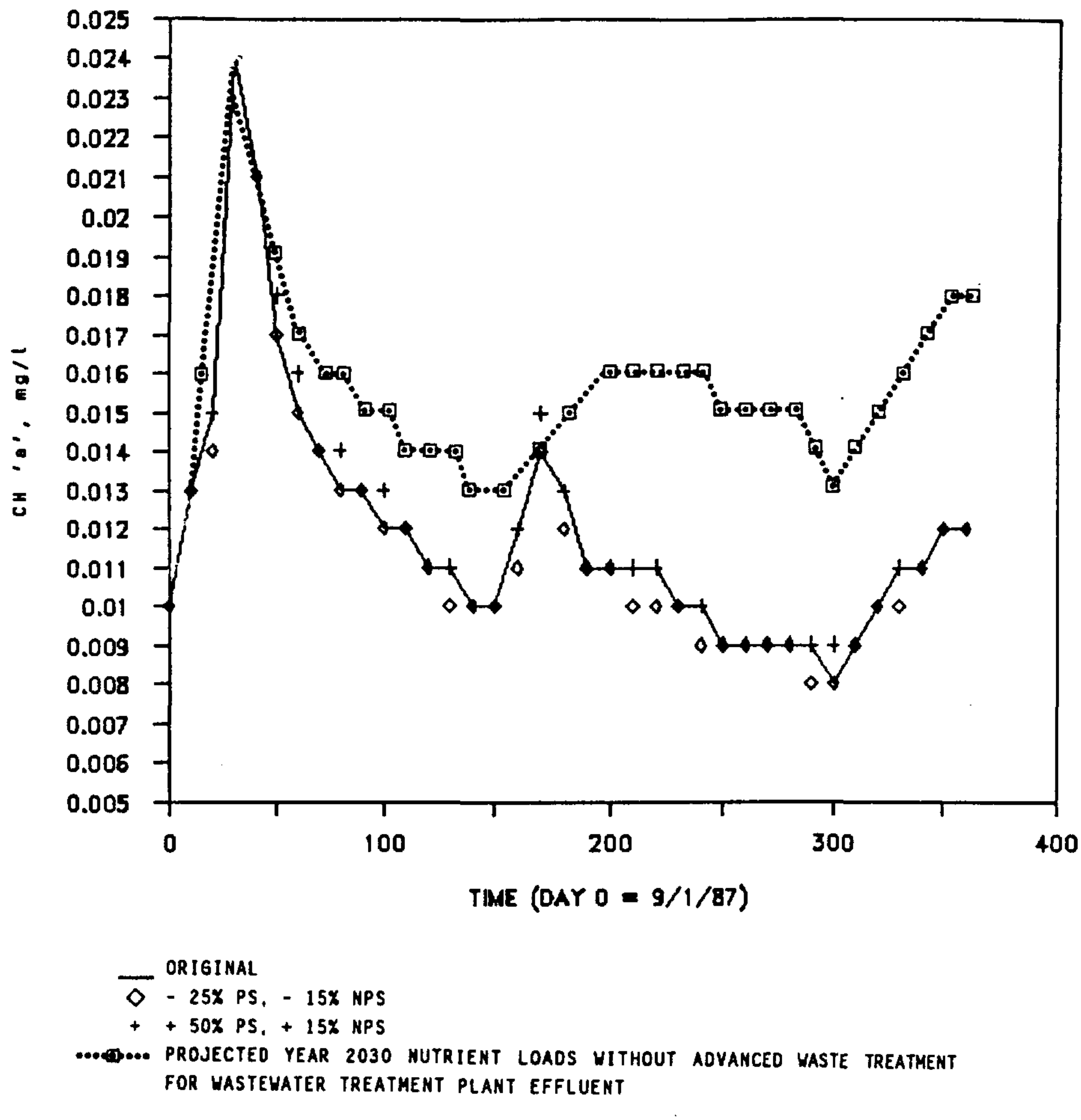


FIGURE IV-22

DIRECT EFFECTS OF WASTE LOADS ON LAKE STILLHOUSE CHLOROPHYLL 'A' PROJECTS AT SEGMENT ADJACENT TO DAM

recently been identified. Unambiguous demonstration that long term water quality impacts from either increases or decreases in nutrient loads which change sediment nutrient accumulations and alter nutrient release rates is not fully documented.

Managers of major water bodies, where this situation has been encountered, have elected to initially assume that the speculated long term relationship between nutrient inputs and water quality changes are real and have introduced programs for managing nutrient inputs to the water bodies.

Examination of both observed data and the model indicates that nitrogen is the limiting nutrient in both lakes during most of the year. Additional sensitivity calculations were developed, for each of the lakes, to examine the possibility that the limiting nutrient could periodically be phosphorous. This was accomplished by computing the in-lake growth rate reduction using values of the Michaelis-Menton half saturation coefficient for phosphorous from the literature. These calculations suggested that, under a series of plausible assumptions, it is possible that phosphorous could become the limiting nutrient for some periods of time. In view of this finding a set of sensitivity calculations were made to estimate the importance of external phosphorous loads from point and nonpoint sources compared to the sediment. For phosphorous, both the sediments and external inputs appear important loading sources in each of the lakes.

The data from the sampling program of this project indicate that chlorophyll 'a' concentrations averaged slightly in excess of 11 ug/l in 1987 through 1988 in contrast to the historical values presented in the State of Texas 1986 Water Quality Inventory which averaged less than 3 ug/l in the main segment of both Lakes Belton and Stillhouse Hollow adjacent to the respective dams. The average chlorophyll 'a' values of 11 ug/l observed in this study represent good water quality. Further, this order of chlorophyll 'a' concentration is usually not in itself associated with water quality problems and water quality objectives from 10 to 25 ug/l chlorophyll 'a' which have been suggested for lakes in other parts of the nation. If, however, the increased concentration of chlorophyll 'a' is part of a trend of rapidly decreasing water quality and increasing chlorophyll 'a' concentrations then there is a water quality concern.

The examination of historical chlorophyll 'a' data for Lake Stillhouse Hollow near the dam presented in Chapter II indicates a possible trend toward increasing algae concentrations at this location. The above observation should alert water resource managers concerning a possible adverse trend and the need to limit nutrient inputs to Lake Stillhouse Hollow pending collection of additional data and the verification of the model used in this study.

An examination of the Lake Belton water quality data in the upstream sampling stations indicate that the chlorophyll 'a' concentrations in the upstream stations on the Cowhouse arm of Lake Belton and on the upstream station of Lake Stillhouse Hollow averaged 2 to 2.5 times the concentration in the main lake stations adjacent to the dam. Criteria for local water quality in upstream ends of lake arms or coves are not available to judge these chlorophyll 'a' values. The Leon River arm of Lake Belton averages over 15 times the concentration in the main segment of the lake near the dam. The chlorophyll 'a' data in the upstream station of the Leon arm were mostly in excess of 100 ug/l. This is a very high concentration value and would inhibit local water use due to appearance and fluctuations in dissolved oxygen concentrations. At these very high concentrations light limitations would be extreme and could indicate that some local upstream source is supplying chlorophyll 'a' while the lake arm is acting as a collecting segment and sink to the sediments. This source could be a combination of wastewater treatment plant effluent and cultivated agriculture which is known to occur in close proximity to the Leon River arm of Lake Belton.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Lakes Belton and Stillhouse Hollow have been classified by the Texas Water Commission as two of the cleanest lakes in the State based on Carlson's Trophic State Index parameters set in The State of Texas Water Quality Inventory, 8th Edition, 1986. Water quality data collected in this study and presented herein in Chapter II show annual average chlorophyll 'a' values of about 11 ug/l at the dam of each lake. Based on this existing water quality and expected year to year variations, which are essentially uncontrollable, an annual average chlorophyll 'a' of between 10 and 15 ug/l at the dam of each lake should be used as an indicator of good water quality. In other words we suggest that existing annual average chlorophyll 'a' values would provide an appropriate target.

Water quality data also indicate that Lake Stillhouse Hollow water quality in terms of algae growth (as measured by chlorophyll 'a') is deteriorating with time. Sampling data collected for this study for both lakes showed higher levels of algae than the historical data. Lake Belton has excessive levels in the Leon River arm of the lake. These increased levels of algae may be due to the continuing point and nonpoint discharges and accumulation of nutrients (i.e., nitrogen and phosphorous) into the lakes. Much of the nutrient load entering the lakes settles to the bottom with soil particles or dead algae and can be recycled back into the water column to contribute to future increases in algae population. Some of the differences in algae population could be attributed to differences in climate conditions.

Results of preliminary water quality modeling performed in this study indicate that Lake Stillhouse Hollow would be adversely impacted by point source nutrient loads unless advanced waste treatment is required to reduce these loads. As shown in Chapter IV, discharges of year 2030 Killeen/Harker

Heights area point sources without advanced waste treatment would increase chlorophyll 'a' values at the dam by 50 percent or more for approximately six months of the year as compared to other scenarios involving up to 50 percent and 15 percent increases in existing point and nonpoint nitrogen and phosphorus loads. The projected values would be above existing chlorophyll 'a' concentrations and the projected values would be above the 10 to 15 ug/l target for Lake Stillhouse Hollow.

As further indicated in Chapter IV, chlorophyll 'a' concentrations at the dam in Lake Belton would not be significantly affected by projected point source discharges. Therefore the existing chlorophyll 'a' concentrations would be essentially unchanged. However, as shown in Figure II-13 for sites 9 and 10, chlorophyll 'a' in the upper arm of Lake Belton is frequently in excess of 100 ug/l. This concentration is above any reasonable criteria.

RECOMMENDATIONS

Based on the above conclusions the following recommendations are made relative to Lakes Belton and Stillhouse Hollow:

1. The discharges into the lakes from point sources should be strongly discouraged in order to reduce nutrient loadings to the lakes.

2. Discharges into the lakes, if allowed, should be subject to the following conditions:

   - Treatment plants should be operated by an operator with at least a Class B certification.
   - Treatment plants should include effluent filters.

- Treatment plants should be monitored in accordance with the requirements of the Texas Water Commission rules and regulations at a minimum frequency of once per week using a 24-hour composite sample.
- Treatment plants should be constructed in a manner which will facilitate future addition of facilities to reduce nitrogen and phosphorus, if necessary.
- Before a permit is granted an analysis should be required to determine the localized water quality impact of the discharge on cove and/or backwater areas.

3. An ongoing water quality monitoring program of each of the lakes should be implemented. Additionally, an annual water quality assessment report should be prepared and the lake water quality models used in this study should be verified.

Based on the stream water quality modeling performed in this study, a number of wastewater treatment plants in the study area may have more stringent permit limits imposed on their effluent discharges in the future. This may be observed in Table V-1, which shows projected effluent limits for wastewater treatment plants discharging into streams modeled in this study. Wastewater treatment plants which may have stricter permit limits imposed in the future include those operated by the City of Gatesville, North Fort Hood, the City of Oglesby, the Temple-Belton Regional Sewerage System, Bell County WCID No. 1, the City of Lampasas (both plants), and the City of Copperas Cove (three plants).

TABLE V-1

PROJECTED FLOWS AND EFFLUENT REQUIREMENTS
FOR LAKE BELTON AND LAKE STILLHOUSE HOLLOW STUDY AREA

Model	Year	Projected Flows			Required Effluent Quality		
		Gatesville (MGD)	North Fort Hood (MGD)	Oglesby (MGD)	Gatesville	North Fort Hood	Oglesby
Leon River above Lake Belton	1990	1.14	0.25	0.05	10/2/6	10/15/2	10/15/2
	2000	1.52	0.33	0.06	10/2/6	10/3/4	10/3/4
	2010	2.02	0.44	0.07	10/2/6	10/3/4	10/3/4
	2020	2.68	0.59	0.07	10/2/6	10/3/4	10/3/4
	2030	3.62	0.79	0.08	10/2/6	10/3/4	10/3/4

Model	Temple-Belton Regional Sewerage System For Permitted Flow of 10 MGD
Leon River Below Lake Belton	10/2/6

Model	Total Flow from Hypothetical WWTP's (MGD)	Required Effluent Quality
Lampasas River Below Lake Stillhouse Hollow	0.65	20/15/2

Note: Effluent Requirements shown in terms of BOD/NH_3-N/DO.

TABLE V-1

PROJECTED FLOWS AND EFFLUENT REQUIREMENTS
FOR LAKE BELTON AND LAKE STILLHOUSE HOLLOW STUDY AREA
(continued)

Model	Year	Projected Flows				Required Effluent Quality			
		WCID #1 (MGD)	WCID #1 STP #2 (MGD)	Harker Heights WCID #4 (MGD)	WCID #3 (MGD)	WCID #1	WCID #1 STP #2	Harker Heights WCID #4	WCID #3
					Alternative #1				
Nolan Creek Model	1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
	2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
	2010	17.04	2.12	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
	2020	19.16	3.64	3.00	0.44	7/2/6	7/2/6	10/3/4	10/15/2
	2030	19.16	7.68	3.72	0.56	7/2/6	7/2/6	10/3/4	10/15/2
					Alternative #2				
	1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
	2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
	2010	17.04	2.12	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
	2020	19.16	3.45	3.00	0.44	7/2/6	7/2/6	10/3/4	10/15/2
	2030	19.16	7.11	3.72	0.56	7/2/6	7/2/6	10/3/4	10/15/2
					Alternative #3				
	1990	14.37	0.00	1.51	0.20	10/2/6	--	10/3/4	10/15/2
	2000	16.53	0.00	1.93	0.26	10/2/6	--	10/3/4	10/15/2
	2010	17.04	1.06	2.36	0.34	10/2/6	10/2/6	10/3/4	10/15/2
	2020	19.16	2.22	2.44	0.44	7/2/6	7/2/6	10/3/4	10/15/2
	2030	19.16	4.16	2.70	0.56	7/2/6	7/2/6	10/3/4	10/15/2

Note: Effluent Requirements shown in terms of BOD/NH^3-N/DO.