PPA 0258

Lake O' the Pines Watershed TMDL Project Documentation Report

FINAL
Deliverable 14B

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1.0 INTRODUCTION

The 303 (d) listing process has identified water quality and aquatic life impairments in the Lake O' the Pines watershed, and various basin stakeholders have identified additional concerns. However, the distribution of the adverse conditions, their severity, possible seasonal components, and their relationships to known or suspected sources of pollutants were initially poorly defined by preexisting data. Sources of impairments in the Lake O' the Pines watershed were not initially identified, but major possible candidates include poultry production and other agricultural operations, industrial and municipal wastewater discharges, lignite mining, and power plant operations. The primary uses of Lake O' Pines are recreation and public water supply, and demand for both uses is expected to continue to grow.

Program Goals and Objectives

This document presents the Total Maximum Daily Load (TMDL) developed for Lake O' the Pines (Segment 0403) with the guidance of the Texas Commission on Environmental Quality (TCEQ) and the U.S. Environmental Protection Agency (EPA). Section 303(d) of the federal Clean Water Act requires that States periodically identify waters that do not or are not expected to meet applicable water quality standards, and to include them on a list of impaired waters, the 303(d) list (40 CFR subsection 130.7). The 303(d) list must be prioritized and waters that qualify for Total Maximum Daily Load (TMDL) project development identified. In general, a TMDL is a plan that specifies the loadings to be allocated to various sources for water quality standards to be met. A separate TMDL should be developed for every parameter preventing the waterbody from meeting water quality standards.

The 303(d) listing process identified water quality and aquatic life impairments in the Lake O' the Pines watershed, and various basin stakeholders have identified additional concerns, including integrity of the public water supply, aesthetic concerns, the warm water fishery, and other water-based recreation. However, the distribution of adverse conditions, their severity, possible seasonal components, and their relationships to known or suspected sources of pollutants were initially poorly defined by preexisting data. Sources of impairments in the Lake O' the Pines watershed were not initially identified, but major possible candidates included poultry production and other agricultural operations, industrial and municipal wastewater discharges, lignite mining, and power plant operations.

The development of a Total Maximum Daily Load allocation for the Lake O' the Pines Watershed has proceeded through a cooperative program directed by Northeast Texas Municipal Water District (NETMWD). Program participants assisting NETMWD in planning, data collection, analysis, and reporting include Paul Price Associates, Inc. (PPA), Texas Commission on Environmental Quality (TCEQ), Dr. George Ward (UT Center for Research and Water Resources), the Caddo Lake Institute (CLI) and its affiliates, Franklin County Water District (FCWD), Titus County Fresh Water District No. 1, and Steering Committee members.

Background Information

The Lake O' the Pines watershed encompasses Segments 0403, 0404, 0405 and 0408 in the Cypress Creek Basin, and includes four major impoundments (Lake Cypress Springs, Segment 0405, Lakes Monticello and Bob Sandlin-Segment 0408, and Lake O' the Pines, Segment 0403), approximately 50 miles of Big Cypress Creek (Segment 0404), and numerous tributary streams (Figure 1-1). Additional maps of the Cypress Creek Basin illustrating significant water bodies, urban areas and highways, tributary streams, permitted dischargers, poultry operations and other points of interest to the project are provided in Figures 1-2 to 1-6. A map of stations all Clean Rivers Program and TMDL stations sampled 1998-2003 within Lake O' the Pines Watershed in Cypress Creek Basin is provided in Figure 1-7. The watershed is part of the 2,812 square mile Cypress Creek Basin, a sub-basin of the Red River drainage located in Northeast Texas between the Sulphur River Basin on the north and the Sabine River Basin to the west and south. The Lake O' the Pines watershed drains much of the western Cypress Creek Basin; an area vegetated primarily by an oak woodland-prairie mosaic. The watershed tends to be the site of the more intense agricultural activity as compared to the eastern basin, and contains the bulk of the Cypress Creek Basin's urban concentrations, industry, and recreational waters. The primary uses of Lake O' the Pines are recreation and public water supply, and demand for both uses is expected to continue to grow.

Annual rainfall ranges from 35 inches per year at the western extreme of the basin to near 50 inches annually at Ferrels Bridge Dam, which was closed to impound Big Cypress Creek, forming Lake O' the Pines in 1958. Temperatures average near 90 degrees Fahrenheit in the summer and winter freezes can be expected each year, but temperatures as low as zero degrees Fahrenheit are rare. The abundant rainfall and low regional slope result in frequent floods that overflow onto floodplains for lengthy periods, leaving water-filled oxbow lakes, sloughs and other water-filled depressions behind when they recede. These floodplain habitats associated with the waterways are used as important dispersal highways by eastern forest dwelling animals to move beyond the forest limits, into areas such as the Blackland prairies, where upland vegetation types present a barrier to them. Regionally, upland soils tend to be acid sandy loams or sands, while bottomland soils are typically brown to dark gray, acid sandy loams to clays. The regional landscape consists of rolling wooded hills with regional elevations of 200 to 800 feet MSL, but with limited local relief, gentle slopes, and broad, frequently flooded, densely vegetated stream bottoms.

The Lake O' the Pines watershed is located within the South and East Central Texas Plains Ecoregions (Ecoregions 33 and 35).[1] The two major vegetational areas corresponding to the South and East Central Texas Plains Ecoregions are, respectively, the post oak savannah and the piney woods. The post oak savannah is a north-south strip in the central part of eastern Texas encompassing most of the subwatersheds draining into Big Cypress Creek. Streams draining directly into Lake O' the Pines are mostly located within the piney woods vegetational region,

[1] Omernik, J.M. 1987 Ecoregions of the conterminous United States. Annals of the Association of American Geographers. 77:118-125.

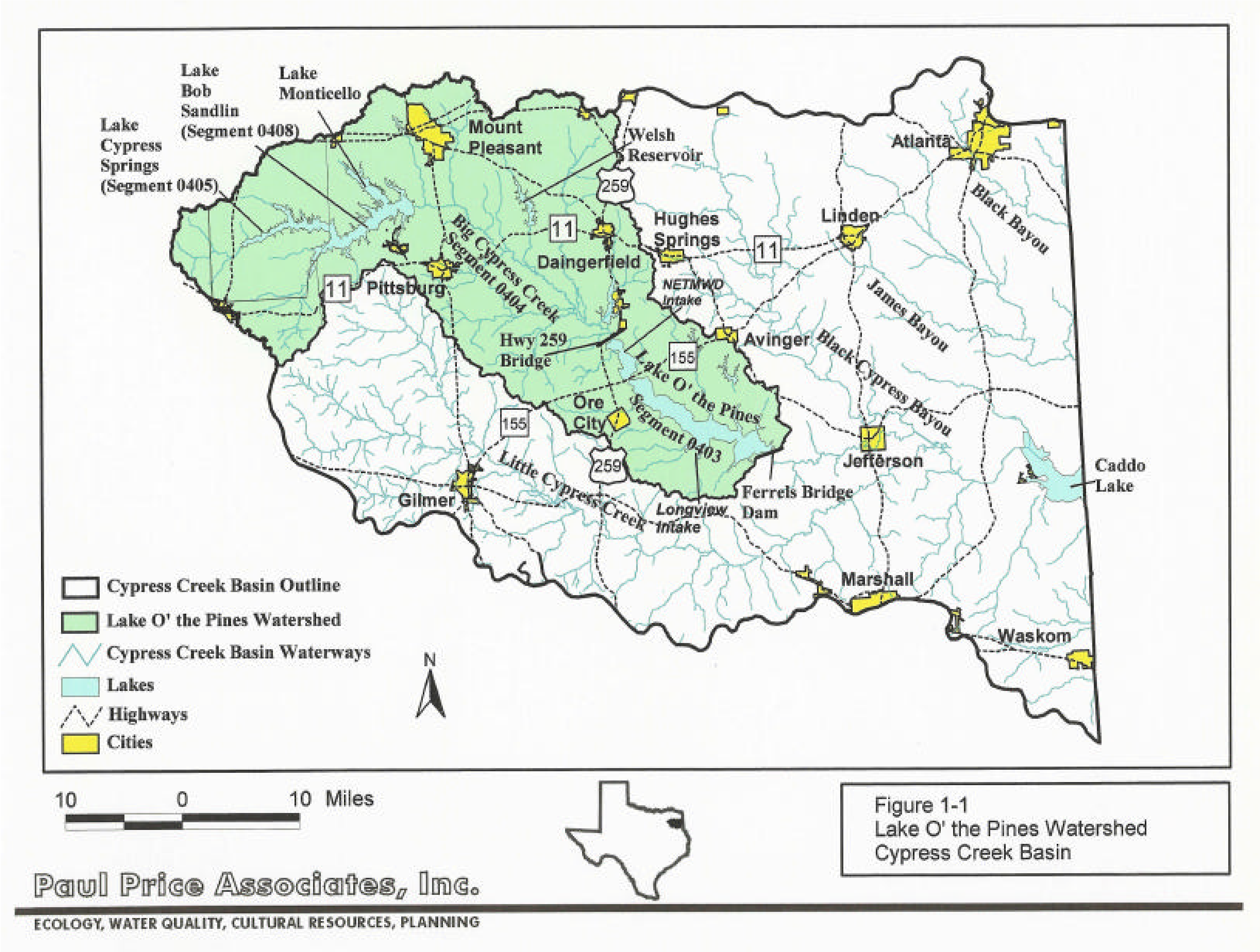

Figure 1-1
Lake O' the Pines Watershed
Cypress Creek Basin

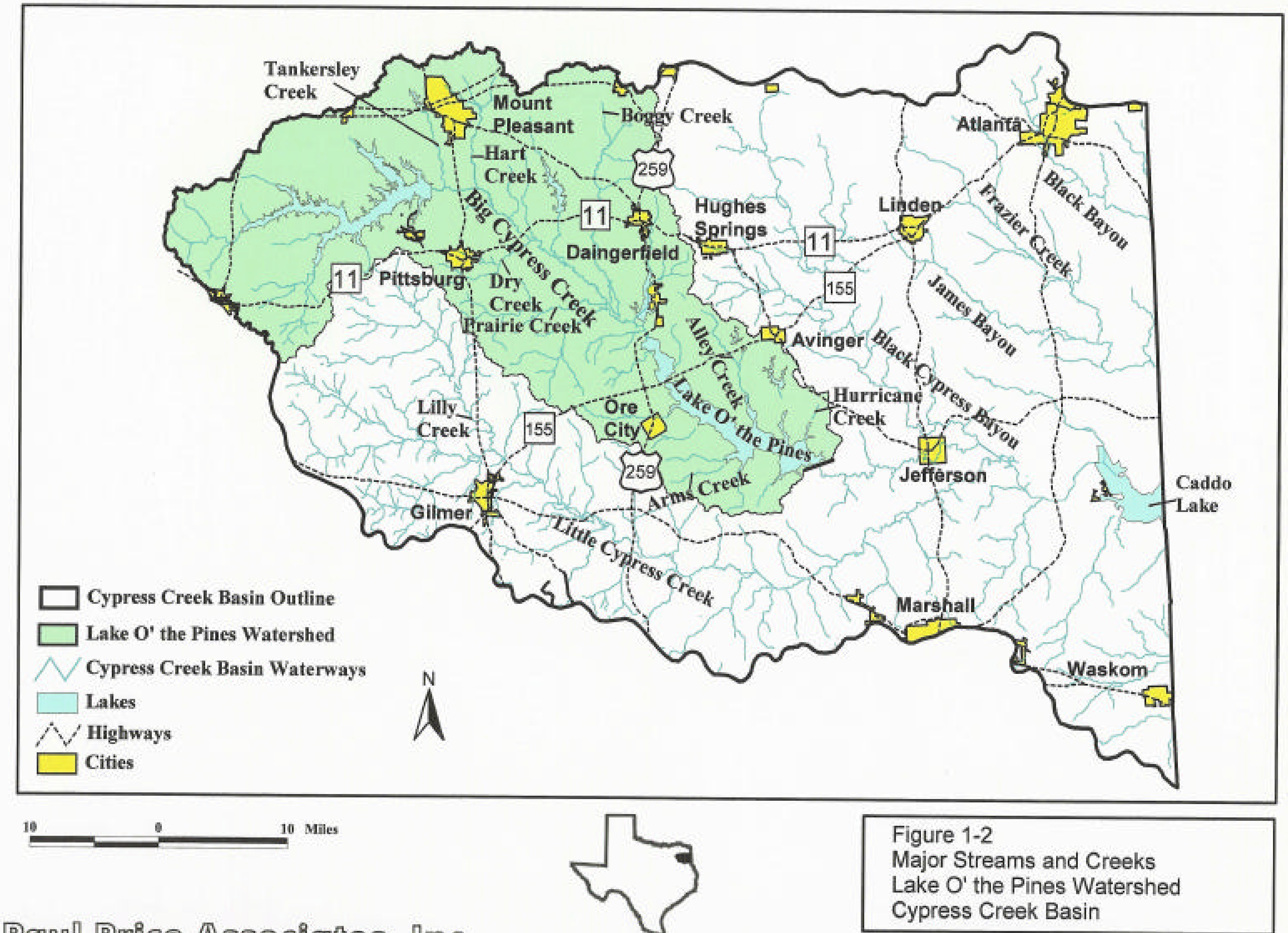

Figure 1-2
Major Streams and Creeks
Lake O' the Pines Watershed
Cypress Creek Basin

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ECOLOGY, WATER QUALITY, CULTURAL RESOURCES, PLANNING

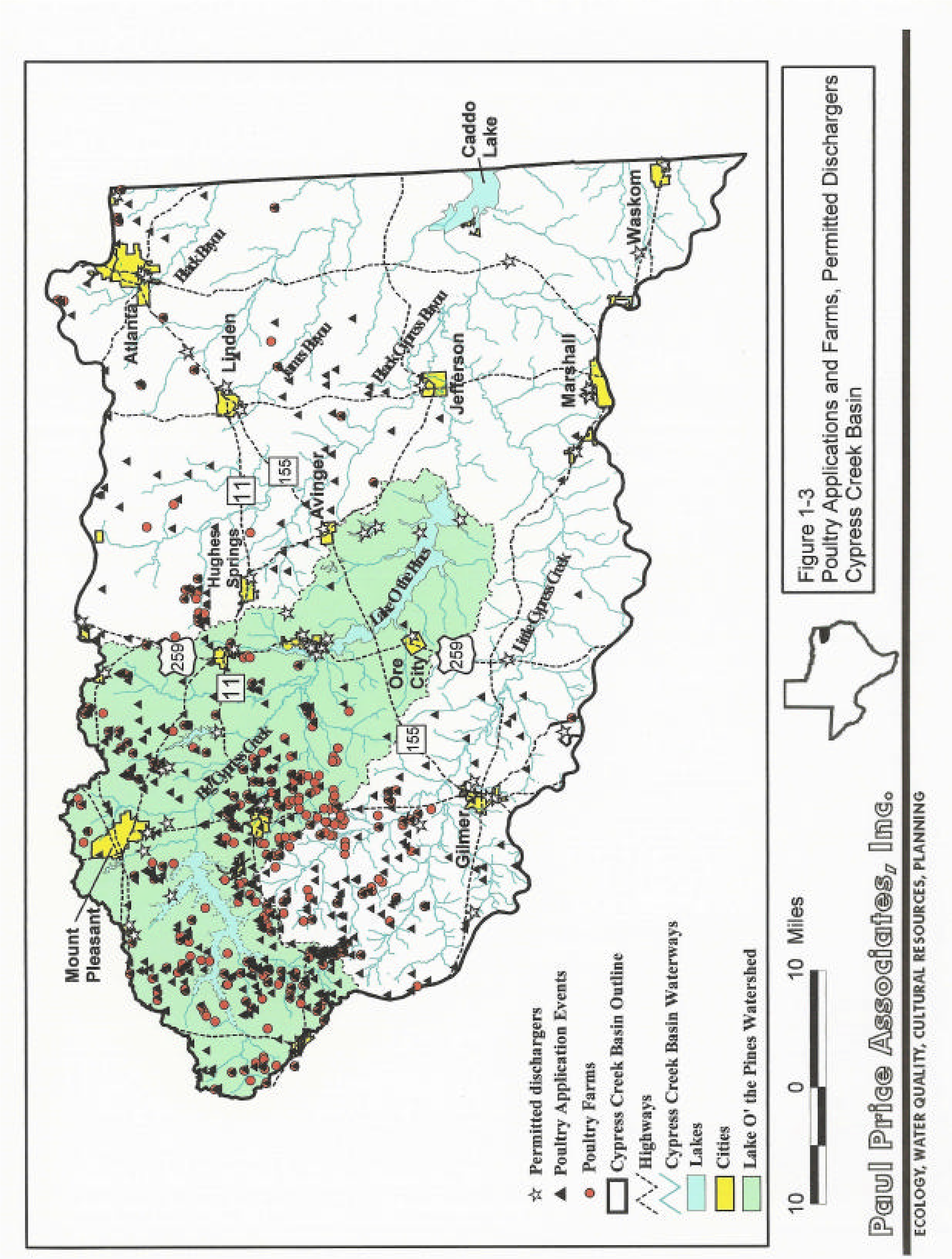

Figure 1-3
Poultry Applications and Farms, Permitted Dischargers
Cypress Creek Basin

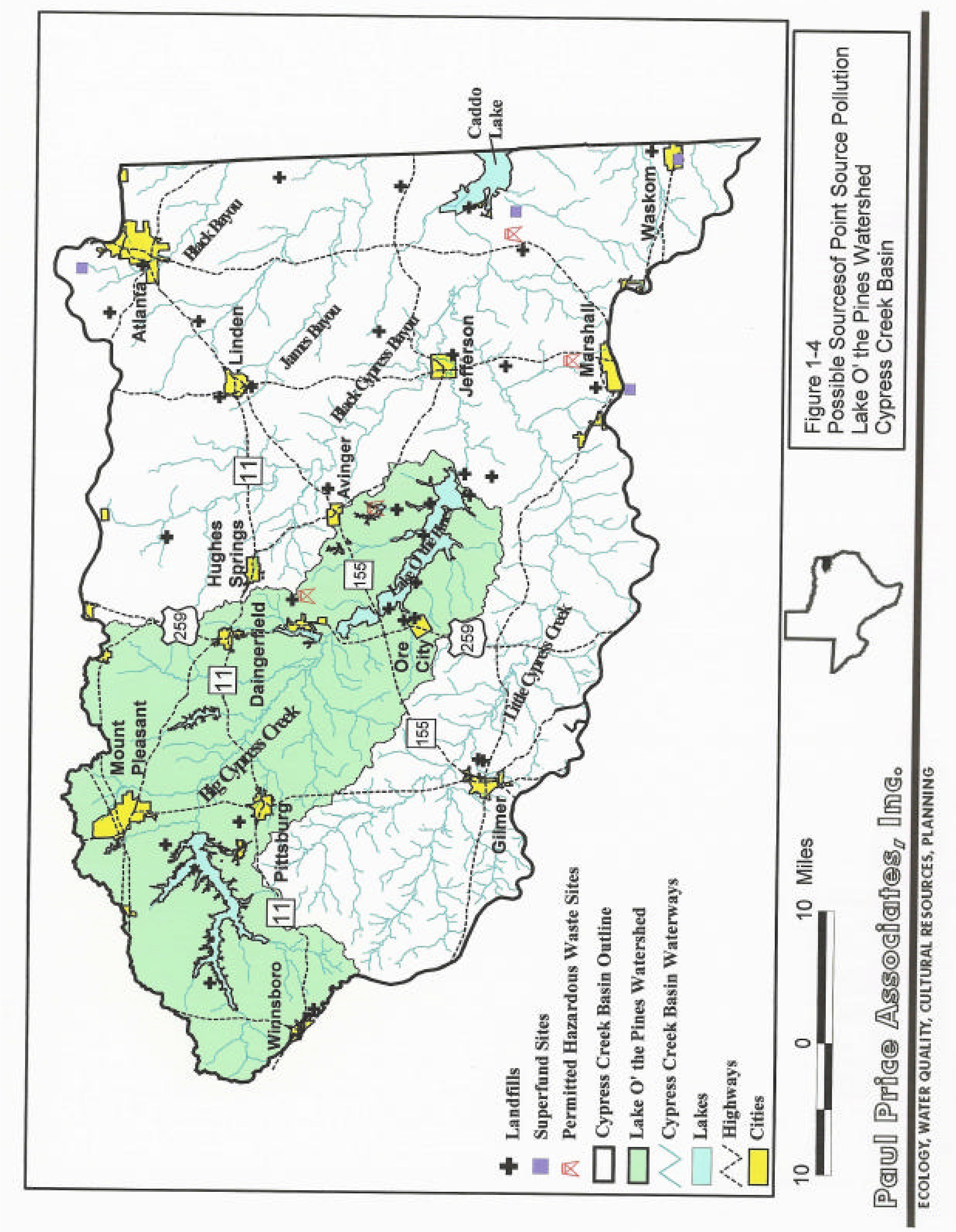

Figure 1-4
Possible Sourcesof Point Source Pollution
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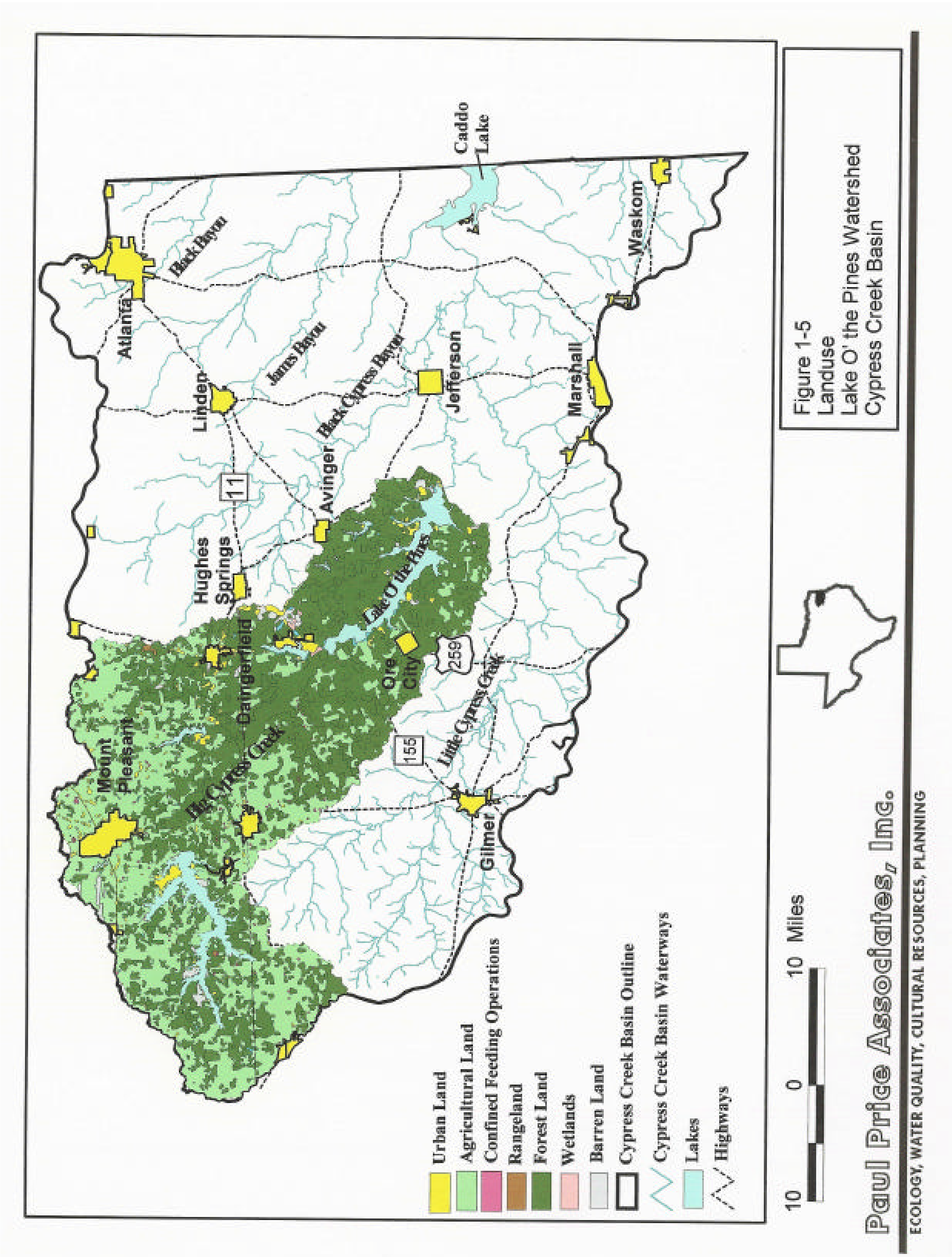

Figure 1-5
Landuse
Lake O' the Pines Watershed
Cypress Creek Basin

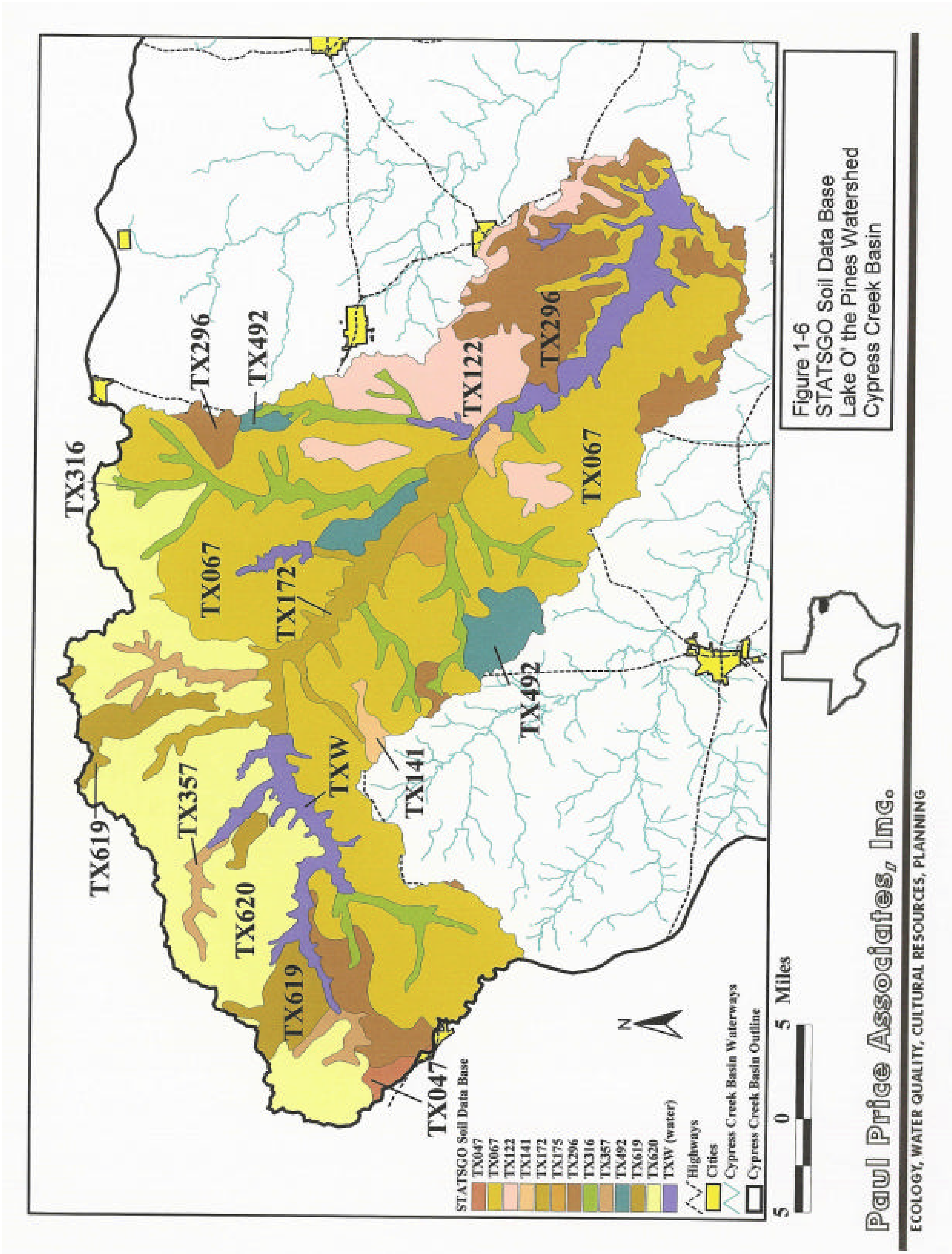

Figure 1-6
STATSGO Soil Data Base
Lake O' the Pines Watershed
Cypress Creek Basin

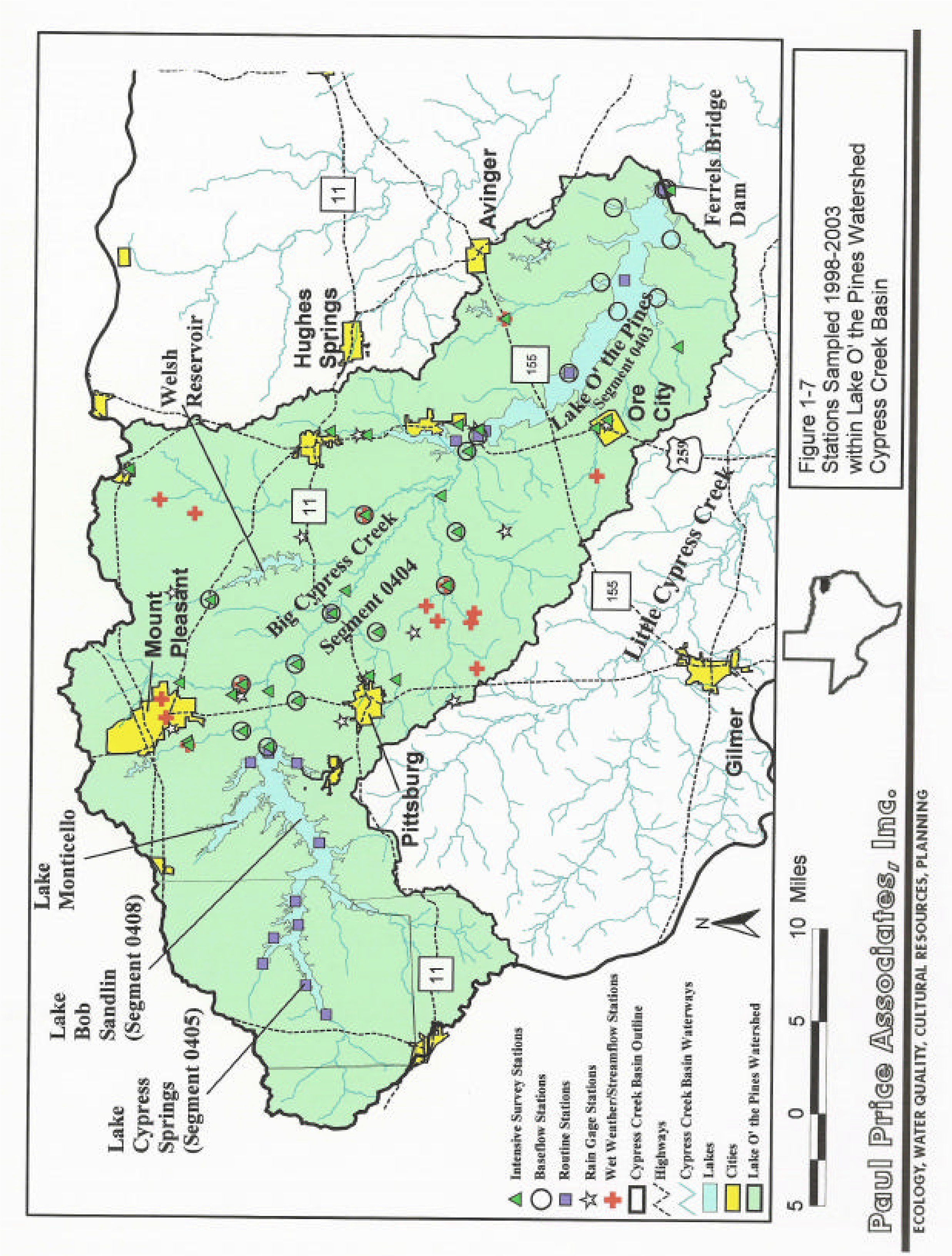

Figure 1-7
Stations Sampled 1998-2003
within Lake O' the Pines Watershed
Cypress Creek Basin

typically a gently rolling to hilly-forested landscape where rainfall tends to be more abundant and uniformly distributed than in the western portion of the basin. The pine-oak forest characteristic of this region of Texas is an ecotone between the eastern pine forests and the oak-hickory forest of the post oak woodlands to the west. Although post oak and blackjack oak constitute the dominant climax overstory vegetation, loblolly and shortleaf pine are generally common.

The Lake O' the Pines watershed includes some of the leading broiler and dairy producing counties in the state. Because most of the latter are located in the Sulphur River drainage basin, or they are in subwatersheds tributary to Lake Cypress Springs and Lake Bob Sandlin, dairies do not have significant direct impacts on Lake O' the Pines. Water quality assessments were prepared for both reservoirs during the fall, 2002 and copies are available from Franklin County Water District and Titus County Fresh Water Supply District No.1. Station 10311, located between Fort Sherman Dam, and the mouth of the first tributary below Lake Bob Sandlin (Tankersley Creek), exhibits the lowest phosphorus and nitrogen levels on Segment 0404. The area around Pittsburg has experienced particularly intense development of poultry production facilities. The Poultry Farm and Litter Application Survey compiled by Pilgrim's Pride Corporation (1998) on behalf of the Cypress Basin Clean Rivers Program indicated that poultry production throughout the Cypress Creek Basin totaled approximately 99,000,000 birds during 1997, nearly 25% of statewide production. This activity generated 132,720 tons of litter, of which 114,511 tons were disposed of on 42,363 acres of disposal sites at application rates that varied from 1 to 5 tons/acre during 1997.

Timber sales factor heavily in the regional economy, particularly in the eastern portion of the basin. Truck crops (vegetables, fruit, melons), hay production and livestock are important throughout the Cypress Creek Basin, but the oak woodland-prairie mosaic characteristic of the western half appears to exhibit the most intense agricultural activity, including confined poultry feeding operations. Lignite and iron ore mining, oil and gas production, and small manufacturing facilities are scattered throughout the basin.

The city of Mount Pleasant, in Titus County, recorded a population of almost 14,000 in the 2000 census, making it the largest urban concentration in the Lake O' the Pines watershed (Table 1-1). The cities of Pittsburg, Daingerfield, Lone Star, and Ore City constitute the other major population centers. The total population projected for the Lake O' the Pines watershed in 2050, including estimates of the rural populations in those portions of eleven counties in the watershed, is 80,808, an increase of about 37%[2]. Manufacturing and electric power generation accounts for the majority of water use within the watershed, with municipal water supply a distant third. Although most rural residents still depend on groundwater from the Carrizo-Wilcox and Queen City aquifers, the demand for treated surface water by rural basin residents and by population centers outside the Lake O' the Pines watershed (e.g., Longview) is increasing.

Historical Water Quality

Intensive surveys were conducted on Big Cypress Creek above Lake O' the Pines (Segment 0404) by the Texas Water Quality Board in 1976, and the Texas Department of Water Resources in 1983. The September, 1976 Survey was conducted during a low flow period during which

[2] Texas Water Development Board, 2002 Board Approved Population Predictions for the 2006 Regional Water Plan.

Table 1-1
Current and Projected Populations of Cities and Portions of Counties within the Lake O' the Pines Watershed

County	% County in Watershed	Urban Areas	2000 Urban Populations	2000 Estimated Rural Population	2000 Total Population	2050 Projected Urban Population	2050 Projected Rural Population	2050 Projected Total Population
Camp	75	Pittsburg	4,347	5424	9771	5327	8257	13584
Cass	1	Hughes Springs*	1856*	356		2117*	407	
		Avinger	464		820	463		870
Franklin	38			3589	3589		6020	6020
Gregg	0			0	0			0
Harrison	3	Marshall*	23935*	1269	1269	25073*	1932	1932
Hopkins	2			750	750		1069	1069
Marion	25			2728	2728		2848	2848
Morris	56	Daingerfield	2,517	4955	9103	2515	5286	8831
		Lone Star	1631			1030		
Titus	45	Mt. Pleasant	13,935	6448	20383	20844	10102	30946
Upshur	15	Ore City	1,106	4540	5646	1645	5733	7378
		Gilmer*	4799*			7248*		
Wood	5	Winnsboro	3,584	1505	5089	5228	2102	7330
Totals					59149			80808

*Not in Lake O' the Pines watershed

Big Cypress Creek was not flowing upstream of Tankersley Creek, and was dominated by wastewater discharges into the streams draining Mount Pleasant, (Hart and Tankersley Creeks) and Pittsburg (Dry Creek).[3] The receiving streams exhibited elevated levels of chloride, sulfate, phosphorus, nitrogen and BOD, reflecting the composition of the wastewater discharges. Discharges of oxygen-demanding material from the city of Mount Pleasant's southwest treatment plant and the American Petrofina refinery were found to result in low dissolved oxygen concentrations (<2 mg/l) in lower Tankersley Creek. Similar low dissolved oxygen levels were observed in Dry Creek, presumably as a result of municipal discharges from Pittsburg. During the intensive survey, dissolved oxygen concentrations in Big Cypress Creek exhibited a diurnal range of 2.5 to 3.1 mg/l at the SH 11 crossing east of Pittsburg. Discharge of total phosphorus (TP) and total nitrogen (TN) from these major point sources were estimated to result in average gross loads of 126.7 and 502.9 lbs/day (57.6 and 228.6 kg/day), respectively. The resulting TP concentration of 1.4 mg/l and TN concentration of 9.09 mg/l at the SH 11 crossing of Big Cypress Creek indicates that low flow loads were about 34 kg/day of TP and 222 kg/day of TN at a discharge of 10 cfs.

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[3] Twidwell, S.R. 1977. Intensive surface water monitoring survey for Segment 0404 Big Cypress Creek – above Lake O' the Pines to Fort Sherman Dam. Texas Water Quality Board Report No. IMS-51, Austin, Texas

Table 1-2 summarizes the results of the intensive survey conducted in August 1983.[4] Source loads were not substantially greater than those observed during 1976, and the Big Cypress Creek station at the SH 11 crossing exhibited substantially lower concentrations and loads of nutrients than did the sources. Lower Tankersley, Hart, and Dry Creeks all exhibited low minimum dissolved oxygen concentrations (<3 mg/l) during the 24-hour period monitored, while Big Cypress Creek at the SH 11 crossing exhibited a narrow diurnal dissolved oxygen range of 3.8 to 4.3 mg/l.

The results of monitoring field and conventional water chemistry parameters in Lake O' the Pines and Big Cypress Creek (Segments 0403 and 0404, respectively) during 1995-1999 are summarized in Tables 1-3 and 1-4.[5] Lake O' the Pines exhibited some of the water quality characteristics of enrichment during this period. For example, average concentrations of chlorophyll-*a*, TDS, ammonia nitrogen, Total Kjeldahl nitrogen (TKN), and total phosphorus, while in the mid-range for Texas reservoirs, were all higher in Lake O' the Pines than in the upstream reservoirs, Lakes Bob Sandlin and Cypress Springs. Conversely, Secchi depth, dissolved oxygen concentration, and pH all exhibited lower average values in Lake O' the Pines than in the other two lakes. Differences among the reservoirs in average values of the biologically active parameters were reflected in the increased range of individual measurements in the Lake O' the Pines data (e.g., dissolved oxygen, pH, Secchi depth).

Big Cypress Creek, Segment 0404, exhibited averages and ranges in water quality parameters that were similar to those observed in Lake O' the Pines (Table 1-4), of which it is the largest tributary. Specific conductance and dissolved constituents in general, including nutrients and inorganic solids, tended to be present at equivalent or higher concentrations in Big Cypress Creek than in Lake O' the Pines. While the average total phosphorus level in Lake O' the Pines was approximately three times the values recorded in the upstream reservoirs, it exhibited only one fifth the average total phosphorus concentration in Big Cypress Creek (0.5 mg/l). The Big Cypress Creek data indicate that most (88%) of the nitrogen present in the water column was present as nitrate plus nitrite, particularly during a series of very high nitrate-nitrogen values observed in samples collected at station 10308 between August, 1997 and September, 1998. This station, Big Cypress Creek at the State Highway (SH) 11 crossing east of Pittsburg, receives wastewater discharges from the treatment facilities in Mount Pleasant, and during baseflow conditions, often reflects the composition of those discharges.

Total phosphorus in Segment 0404 exhibited a behavior similar to that of nitrate nitrogen; extreme values (>2.0 mg/l) were observed only at station 10308, and were confined to the period between August 1997 and September 1998. Lower levels of total phosphorus (but still high in terms of potential aquatic plant productivity, approximately 0.4 mg/l) were observed in late October, 1998 at Big Cypress Creek stations, and at the nearby upstream Lake O' the Pines station (10300). In the main basin of Lake O' the Pines, total phosphorus concentrations were generally at or below 0.1 mg/l, but were often higher than that in the shallow, vegetated upper portion of the lake. The period of highest nutrient concentration in lower Big Cypress Creek and

[4] Petrick, D. 1985. Intensive survey of Big Cypress Creek Segment 0404 August 8-12, 1983. Texas Department of Water Resources, IS-74. Austin, Texas

[5] PPA. 2000. Cypress Creek Basin Summary Report. Prepared by Paul Price Associates, Inc. for submission to TNRCC, Austin, Texas.

Table 1-2
Average Source Discharges for the Period May 1983 – March 1984, Constituent Concentrations Measured 8-12 August 1983, and Calculated Loading Rates

	Discharge (MGD)		TSS	TKN	NH3	NO2+3	TN	OP	TP
	Permit	Actual	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Pittsburg Sparks	0.450	0.397	37	20.8	15.33	3.47	24.27	5.31	6.53
Pittsburg Dry	0.200	0.074	34	5.5	3.93	6.38	11.88	0.36	0.6
Mt Pleasant SE	1.500	0.861	14	9.7	5.29	7.1	16.8	6.45	7.35
Mt Pleasant NE	0.400	0.285	29	14.8	11.3	0.06	14.86	2.42	3.05
Mt Pleasant SW	1.000	1.026	26	20.6	14.49	21.2	41.8	9.66	10.29
Refinery	0.345	0.267	35	22.3	15.86	0.35	22.65	3.11	4.35
Total/Average	3.895	2.910	29	15.6	11.03	6.43	22.04	4.55	5.36
Big Cypress Creek Hwy 11		6.463*	104	1.4	0.61	1.82	3.22	0.35	0.63

Loading Rates kg/day

			TSS	TKN	NH3	NO2+3	TN	OP	TP
			kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d
Pittsburg Sparks			56	31.3	23.04	5.21	36.47	7.98	9.81
Pittsburg Dry			10	1.5	1.10	1.79	3.33	0.10	0.17
Mt Pleasant SE			46	31.6	17.24	23.14	54.76	21.02	23.96
Mt Pleasant NE			31	16.0	12.19	0.06	16.03	2.61	3.29
Mt Pleasant SW			101	80.0	56.28	82.34	162.35	37.52	39.97
Refinery			35	22.5	16.03	0.35	22.89	3.14	4.4
Total			278	182.9	125.88	112.90	295.83	72.37	81.59
Big Cypress Creek Hwy 11		6.463*	2544	34.3	3.67	44.53	78.78	8.56	15.41

* Stream discharge declined from 19 cfs on August 8 to 7 cfs on August 11, 1983. Load calculation reflects 10 cfs discharge recorded August 10, when samples were collected

Table 1-3
Water Quality in Segment 0403 - Lake O' the Pines, 1995-1999

Parameter	Max	Min	Mean	25th Quartile	75th Quartile	n
Temperature (C)	32.3	7.8	**20.9**	11.8	28.3	87
Secchi Depth (m)	1.9	0.33	**1.0**	0.8	1.3	44
Specific Conductance (µhmos)	387	70	**173**	132	214.5	71
Dissolved Oxygen (mg/l)	15.1	2.3	**7.6**	5.7	9.3	48
pH	9.1	5.8	**6.9**	6.7	7.1	48
Total Alkalinity (mg/l)	62	2.5	**23**	14	28.5	16
Chlorophyll-*a* (µg/l)	33	0.5	**7**	1.2	11.2	26
Hardness (mg/l)	85.6	19.1	**42.1**	27.3	59.8	14
Total Dissolved Solids (mg/l)	220	57	**118**	76	160	14
Total Suspended Solids (mg/l)	17	2	**6**	3.75	9.25	16
Ammonia Nitrogen (mg/l)	0.12	0.005	**0.06**	0.025	0.094	26
Total Kjeldahl Nitrogen (mg/l)	1.5	0.14	**0.6**	0.4	0.6	40
Total Phosphorus (mg/l)	0.43	0	**0.10**	0.035	0.11	26
Dissolved ortho-Phosphorus (mg/l)	0.1	0.005	**0.02**	0.005	0.01	12
Total Organic Carbon (mg/l)	11	4.9	**7**	5.75	7.525	40
Fecal Coliform (cfu/100ml)	130	0.5	**25**	0.5	30	18
Sulfate (mg/l)	54	13.2	**31**	21.275	42	14
Chloride (mg/l)	36	3	**17**	11.55	21.75	14
Sediment TOC (mg/kg)	40600	3820	**27540**	21010	39400	3

Table 1-4
Water Quality in Segment 0404 - Big Cypress Creek, 1995-1999

Parameter	Max	Min	Mean	25th Quartile	75th Quartile	n
Temperature (C)	32.3	3.3	**21.8**	14.4	29	53
Secchi Depth (m)	1.1	0.08	**0.6**	0.4	0.76	37
Conductivity (µmhos)	1222	132	**430**	211	539	45
Dissolved Oxygen (mg/l)	11.3	0.8	**6.6**	5.4	8.6	43
pH	8.2	6.3	**7.0**	6.7	7.2	44
Total Alkalinity (mg/l)	100	15	**38**	26	42	29
Chlorophyll-*a* (µg/l)	76.5	0.5	**7.6**	0.5	7.75	30
Pheophytin-*a* (µg/l)	15.2	0	**2.8**	0.5	2.79	30
Hardness (mg/l)	319	41.9	**88**	57.3	88.5	17
Total Dissolved Solids (mg/l)	836	117	**276**	152	348	29
Total Suspended Solids (mg/l)	32	3	**12**	5.5	16	31
Nitrate+Nitrite (mg/l)	48.9	0.05	**7.61**	0.73	5.45	22
Ammonia Nitrogen (mg/l)	0.15	0.005	**0.06**	0.0375	0.07	28
Total Kjeldahl Nitrogen (mg/l)	3.6	0.39	**0.94**	0.72	1.02	30
Total Phosphorus (mg/l)	3.62	0.02	**0.50**	0.13	0.44	29
Ortho-Phosphorus (mg/l)	0.78	0.04	**0.27**	0.10	0.40	8
Total Organic Carbon (mg/l)	12	0.5	**8**	7	9	29
Chloride (mg/l)	103	11	**30**	18	31.4	30
Sulfate (mg/l)	149	16.6	**52**	35	61.25	30
Fecal coliform (cfu/100ml)	2000	0.5	**197**	40	150	40
Sediment Total Organic Carbon (mg/kg)	33000	4930	**17825**	12500	20800	9

upper Lake O' the Pines coincided with a relatively dry year and summer period (July-August, 1998). At this time, Big Cypress Creek was not flowing into Lake O' the Pines, but into Ellison Creek reservoir to make up for evaporative cooling losses. The elevated nutrient episode ends at the same time (September, 1998) that rainfall runoff caused Big Cypress Creek to begin flowing into Lake O' the Pines again.

Nutrient levels in Lake O' the Pines during 1998-1999 were monitored at several stations as part of a Clean Rivers Program Special nutrient study[6]. This study indicated that in Lake O' the Pines, TKN accounted for most of the nitrogen in the water column, and total phosphorus was present in large concentrations (>0.1 mg/l) in the main basin of the lake only during December 1998 and January 1999, in agreement with the routine monitoring data from station 10296 (main

[6] PPA. 1998. Poultry Operations Water Quality Impact Study. Prepared by Paul Price Associates, Inc., Austin, Texas. *In* Poultry Operations Study Report to the 76th Session of the Texas Legislature. (SFR-65). Texas Natural Resource Conservation Commission Water Quality Division, Austin, Texas.

lake basin at Ferrels Bridge dam). The monitoring data summarized in that report (Table 1-5)[7] also reveals very high concentrations of phosphorus, averaging 1.91 mg/l, in the two tributaries to Segment 0404 that drain the Mount Pleasant area, Hart and Tankersley Creeks, both of which receive treated wastewater. Intensive surveys performed on Segment 0404 during August 1998 and 1999 indicated that the wastewater discharge into Tankersley Creek was the largest point source of nitrogen and phosphorus entering Segment 0404 at the time. Other potential sources of nutrients were (and continue to be) present, including other dischargers, urban runoff from Mount Pleasant, Pittsburg and other residential concentrations, leakage from on-site treatment facilities, and intensive agricultural activity, including chicken litter disposal, particularly in the area around Pittsburg.

The results of data screening for the Lake O' the Pines watershed are presented in detail in Tables 1-6 through 1-8. The parameters presented are those in which the data exceeded the state criteria, parameters not listed in the tables were below TCEQ guidance screening levels. Occasional low dissolved oxygen concentrations and elevations of total phosphorus levels resulted in possible concerns for those parameters in Lake O' the Pines. Concern for dissolved cadmium in Lake O' the Pines and in Big Cypress Creek all resulted from single instances of cadmium observed at concentrations just above the quantitation limit (an order of magnitude higher than the criterion concentration). Except for manganese, which exhibited higher sediment concentrations than the criterion in all three samples, the concerns tabulated for sediment metals in Lake O' the Pines all resulted from elevated concentrations in one of three samples.

Depressed dissolved oxygen levels were of potential concern in both the main stem of Big Cypress Creek (Segment 0404) and its tributaries, while fecal coliform concentrations were of concern only in the tributaries. In bottom sediments, copper and lead concentrations were of possible concern or concern only at station 13631, the lowermost station on Big Cypress Creek, just upstream of the US 259 crossing. The opposite was true for manganese, which, with similar concentration ranges at both stations, exceeded the stream sediment screening levels at station 10308, but not at station 13631, which was evaluated using the reservoir criteria. Sediment mercury exhibited a high value (0.88 mg/kg) in one of seven samples from station 13631. Relative to the screening results presented in the 1996 "Regional Assessment of Water Quality" for Segment 0403, Lake O' the Pines, low dissolved oxygen concentrations continued to be a were raised in the more recent data for elevated levels of a more extensive assemblage of metals, but this time in sediments.

Aquatic life uses in Segment 0404 were evaluated directly through a series Rapid Bioassessment Protocols conducted as part of two Clean Rivers Program Special studies.[8] Fish and macroinvertebrate sampling in Big Cypress Creek conducted as part of an intensive survey in August 1998 indicated that three of four locations sampled supported a High aquatic life use based on fish community characteristics, but only Limited or Intermediate aquatic life uses based on the macroinvertebrate assemblages. Additional RBA sampling and habitat assessment was

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[7] Clean Rivers Program data - PPA. 2000. Cypress Creek Basin Summary Report. Prepared by Paul Price Associates, Inc. for submission to TNRCC, Austin, Texas.

[8] Reported to TNRCC TRACS database

Table 1-5
Water Quality in Segment 0404 - Big Cypress Creek Tributaries
(Tankersley Creek, Hart Creek), 1995-1999

Parameter	Max	Min	Mean	25th Quartile	75th Quartile	n
Temperature (C)	29.5	3.9	**19.8**	15.775	25.125	46
Secchi Depth (m)	1	0.2	**0.5**	0.4	0.525	40
Specific conductance (µmhos)	1583	194	**711**	392.75	1149.25	46
Dissolved Oxygen (mg/l)	11.1	1.6	**6.3**	4.625	7.8	46
pH	7.7	6.4	**7.1**	6.925	7.3	46
Total Alkalinity (mg/l)	146	18	**75**	48	97	23
Chlorophyll-*a* (µg/l)	66.4	0.5	**7.6**	0.5	3.61	25
Total Dissolved Solids (mg/l)	1010	142	**465**	277	649	23
Total Suspended Solids (mg/l)	106	5	**26**	11	33	25
Ammonia Nitrogen (mg/l)	7.72	0.01	**0.71**	0.065	0.155	23
Total Kjeldahl Nitrogen (mg/l)	8.72	0.55	**2.02**	0.85	2.07	25
Total Phosphorus (mg/l)	7.12	0.07	**1.91**	0.11	3.12	25
Ortho-Phosphorus (mg/l)	4.8	0.06	**1.92**	0.11175	3.6475	10
Total Organic Carbon (mg/l)	22	0.5	**10**	8	12	25
Fecal Coliform (cfu/100ml)	2800	0.5	**470**	65.75	565	36

Table 1-6
Results of 1995-1999 Data Screening: Lake O' the Pines, Segment 0403

Code	Parameter	n	Mean	Criterion	Exceeds Criterion	% Exceeding
00300	Dissolved Oxygen (mg/l)	48	7.65	5	9	18.75
00400	pH	48	6.88	6.0-8.5	3	6.25
Toxic materials in Water (Chronic)						
					Station	
01025	Cadmium (d) (ug/l)	8	0.78	0.36	10296	---
		6	0.98		10300	---
Nutrients and Chlorophyll-*a*						
00610	Ammonia (mg/l)	26	0.06	0.13	1	3.85
00665	Total Phosphorus (mg/l)	26	0.1	0.2	3	11.54
Sediment Toxicants						
01008	Barium (t) (mg/kg)	3	285.67	287	1	33.33
01029	Chromium (t) (mg/kg)	3	33.97	34	1	33.33
01052	Lead (t) (mg/kg)	3	40	61.5	1	33.33
01053	Manganese (t) (mg/kg)	3	1606.67	1210	3	100.00
01068	Nickel (t) (mg/kg)	3	23.03	25.2	1	33.33
01148	Selenium (t) (mg/kg)	3	1.95	1.73	1	33.33
01093	Zinc (t) (mg/kg)	3	168.57	120	1	33.33

Table 1-7
Results of 1995-1999 Data Screening: Segment 0404 – Big Cypress Creek

Code	Parameter	n	Mean	Criterion	Exceeds	%
Segment and Aquatic Life Standards					**Criterion**	**Exceeding**
00300	Dissolved Oxygen (mg/l)	43	6.64	4.00	5	12
00010	Temperature (C)	53	21.84	32.19	2	4
31616	Fecal Coliform (#/100ml)	30	197.91	400	5	17
Toxic materials in Water (Chronic)						
10253	Cadmium (d) (ug/l)	14	0.52	0.36	13631	---
Ambient Water and Sediment Toxicity						
	Sediment-*C. dubia*				70 %	Affected
Nutrients and Chlorophyll-*a*						
00610	Ammonia Nitrogen (mg/l) 13631	19	0.06	0.13	2	11
00593	Nitrate/Nitrite-Nitrogen (mg/l) 10308 Station	7	20.35	3.10	5	71
	13631	15	1.67	0.41	11	73
00671	Ortho-Phosphorus (mg/l) 10308	4	0.44	1.40	1	25
	13631	5	0.16	0.10	4	80
00665	Total Phosphorus (mg/l) 10308	10	1.09	1.60	3	30
	13631	19	0.18	0.20	5	26
32211	Chlorophyll-*a* (ug/l) 13631	20	10.76	20.00	2	10
Sediment Toxicants						
01043	Copper (mg/kg) 13631	7	17.79	33.00	1	14
01052	Lead (mg/kg) 13631	7	50.76	61.50	2	29
01053	Manganese (mg/kg) 10308	3	455.67	490.00	2	67
71921	Mercury (mg/kg) 13631	7	0.21	0.160	1	14
01093	Zinc (mg/kg) 13631	7	246.91	120.00	6	86

Table 1-8
Results of 1995-1999 Data Screening: Tributaries to Big Cypress Creek, Segment 0404

Code	Parameter	n	Mean	Criterion	Exceeds	%
	Segment and Aquatic Life Standards				**Criterion**	**Exceeding**
00300	Dissolved Oxygen (mg/l)	46	6.27	5.00	10	22
31616	Fecal Coliform (#/100 ml)	36	470.26	400.00	12	33
	Nutrients and Chlorophyll-*a*					
01000	Ammonia Nitrogen (mg/l)	23	0.71	0.30	5	22
00671	Ortho-Phosphorus (mg/l)	10	1.92	1.40	6	60
00665	Total Phosphorus (mg/l)	25	1.91	1.60	11	44
32211	Chlorophyll-*a* (ug/l)	25	7.62	16.50	3	12

conducted at the same stations during August 1999. In contrast to the 1998 observations, macroinvertebrate communities all exhibited High aquatic life use characteristics, while the fish gave mixed results; two stations earned Intermediate/High scores, one scored High, and one scored High/Exceptional. Habitat scores were Intermediate during both years. RBA sampling conducted to support the Poultry Operations Study indicated that Intermediate aquatic life uses (based on fish communities) tended to predominate in watersheds containing the highest densities of poultry production facilities such as Prairie Creek, a tributary of Big Cypress Creek above Lake O' the Pines and Lilly Creek, a tributary of Little Cypress Creek, which is not within the Lake O' the Pines watershed. High aquatic life uses were observed in reference streams such as Boggy Creek, a tributary of Big Cypress Creek above Lake O' the Pines and Frazier Creek, a tributary of James Bayou.[9] Assessments using macroinvertebrate community characteristics indicated that High aquatic life uses were realized in all four streams sampled.

[9] PPA. 1998. Poultry Operations Water Quality Impact Study. Prepared by Paul Price Associates, Inc., Austin, Texas. *In* Poultry Operations Study Report to the 76th Session of the Texas Legislature. (SFR-65). Texas Natural Resource Conservation Commission Water Quality Division, Austin, Texas.

2.0 PROBLEM DEFINITION

Lake O' the Pines (Segment 0403) was placed on the 1996 303(d) list at a medium priority level based on historical data, which indicated that the lake's designated high aquatic life use was only partially supported in approximately one-half of the reservoir. The affected area extended upstream from the dam, and resulted from elevated levels of dissolved zinc in the water. This segment was retained on subsequent 303(d) listings for zinc; with the overall priority level upgraded to "High" on the 1998 303(d) list (Table 2-1).

Although the source of zinc was not identified, the TCEQ began sampling for metals in Lake O' the Pines during Fiscal Years 1998-1999. Results of these initial sampling events were used to assess possible sources, severity, and geographic extent of the impairment. Additional water sampling was done during Fiscal Years 2000-2001 by the TCEQ Region 5 staff, while development of the TMDL for the Lake O' the Pines watershed was initiated by Northeast Texas Municipal Water District. The 2000 Draft 303(d) list (Table 2-2) information for Segment 0403 proposed the delisting of the dissolved zinc impairment, but added as a new concern, low dissolved oxygen concentrations in the upper end of the lake that are occasionally lower than the standard used to assure optimum conditions for aquatic life.

While Big Cypress Creek between Lake Bob Sandlin and Lake O' the Pines (Segment 0404) was not initially listed on the 1996 303(d) list, this segment was placed on the list in 1998 based on three concerns. First, a restricted consumption advisory for the general population, and a no consumption advisory for children younger than seven and women of childbearing age, was issued by the Texas Department of Health in May 1992 for Welsh Reservoir in Titus County, due to elevated levels of selenium in fish tissue. Investigation of selenium loading to Welsh Reservoir and its accumulation in fish tissue was added as a task to the developing TMDL. Second, in July 1996 a Texas Parks and Wildlife Department survey reported a lack of native freshwater mussels in Big Cypress Creek and attributed it to discharges from the Pilgrim's Pride Corporation wastewater treatment plant on Tankersley Creek. This impairment was removed from the 1999, 303(d) list when native mussels were demonstrated to be present in Big Cypress Creek. The third concern focused on intermittent, but chronic, low dissolved oxygen levels that could impair aquatic life use, and impact regional interests. This concern was eliminated through additional analyses of hydrologic, water quality, and biological conditions in Big Cypress Creek by TCEQ (Table 2-3). Hydrologic and habitat conditions in Segment 0404 indicate that the appropriate aquatic life use designation is Intermediate for Segment 0404, with a concomitant dissolved oxygen standard of 4.0 mg/l. In particular, it was found that low dissolved oxygen concentrations occur primarily during summer periods of high temperature, heavy shading, and most importantly, zero, or very low, streamflow.

In the Draft 2000 303(d) list, Segment 404 was subdivided to separate Segments 0404A, Ellison Creek Reservoir, 0404B, Tankersley Creek, 0404C, Hart Creek, and 0404D, Welsh Reservoir (Table2-2). Segments 0404, Big Cypress Creek, 0404B, and 0404C all exhibit bacteria levels that sometimes exceed the criterion established to assure the safety of contact recreation.

Table 2-1
State of Texas 1998 Clean Water Act
Section 303(d) List (06/26/98)
Sections 0403 and 0404 of the Cypress Creek Basin

Segment Number	Segment Name	Overall Priority *	Nonpoint Source	Point Source	Segment Summary **
0403	Lake O' the Pines	U	X	X	Concentrations of dissolved zinc in water occasionally exceed the criterion established to protect aquatic life in approximately ½ of the reservoir extending upstream from the dam (U/PS). A TMDL project is scheduled to begin in FY 1998.
0404	Big Cypress Creek Below Lake Bob Sandlin	H/U	X	X	A restricted consumption advisory for the general population and a no consumption advisory for children younger than seven and women of childbearing age were issued by the Texas Department of Health in May 1992 for Welsh Reservoir in Titus County. The advisory was issued due to elevated levels of selenium in fish tissue. All fish species tested have shown elevated selenium levels (H/NS). A July 1996 Texas Parks and Wildlife Department survey attributed absence of mussels and clams from Big Cypress Creek to effects of discharge associated with the chicken-packing industry. Historical data from the TCEQ's Clean Rivers Program suggests that depressed dissolved oxygen levels are not unusual, although data processed for this listing did not reveal such problems. Low dissolved oxygen levels, possibly related to wastewater discharges, may be an intermittent but chronic problem in local waters and are of concern to regional interests (U/PS). A TMDL project is scheduled to begin in FY 1998.

* *Impaired Waters*: H=high, M=medium, L=low; U= a total maximum daily load (TMDL) analysis is underway or scheduled for development. Where TMDLs underway do not address all listed parameters, the oval priority will show the highest priority single parameter not addressed by the TMDL, but will also show a "U" to indicate that one or more constituents of concern are being addressed through a TMDL.
Threatened waters: T-h=threatened-high, T-m=threatened-medium

** The priority level for each pollutant parameter is shown in parentheses, as in the overall priority column (H=High, M=Medium, etc.). Following the priority level will be the designation "NS" for water bodies that are not supporting their uses as designated in the Texas Surface Water Quality Standards, or the designation "PS" for water bodies that are partially supporting their designated uses. For water bodies listed for non-attainment or partial attainment of numeric or narrative criteria, the designation "CN" or "CP" will follow the priority ranking

Table 2-2.
State of Texas DRAFT 2000 Clean Water Act
Section 303(d) List for the Cypress Creek Basin (09/31/2000)
Sections 0403, 0404 and 0408 of the Cypress Creek Basin

Segment	Waterbody	Cause(s) of Concern/Impairment	TMDL Priority/ Level of Support*	Impairment or Concern	# of Samples Exceeding Criteria versus # of Samples**
0403 Concerns	Lake O' the Pines	Concerns for depressed dissolved oxygen, nitrate + nitrite and total phosphorous	H	(C) DO (C) nitrate+nitrite (C) total P	4 of 27 12 of 43 6 of 18
0404 Impairment and Concerns	Big Cypress Creek Below Lake Bob Sandlin	Impairment for bacteria. Concerns for depressed dissolved oxygen, unknown toxicity, bacteria, nitrate + nitrite, orthophosphorus and total phosphorous	M	(I) Bacteria (C) DO (C) unknown tox. (C) nitrate+nitrite (C) ortho P (C) total P	7 of 20 1 of 8 2 of 6 15 of 22 12 of 20 10 of 15
0404a Concern	Ellison Creek Reservoir	metals in sediment		(C) metals-sed.	6 of 6
0404c Concern	Hart Creek	Use Concern for depressed dissolved oxygen		(C) DO	3 of 10
0404d Impairment	Welsh Reservoir	Levels of Selenium in fish tissue	M	(I) Selenium-fish	advisories and closures
0408 Concern	Lake Bob Sandlin	Cadmium chronic in water		(C) Cadmium	5 samples mean = 0.981

* Overall Priority as listed in the DRAFT Texas 2000 Clean Water Act Section 303(d) List (August 31, 2000)

** Criteria for impairments and concerns can be found in the Guidance for screening and Assessing Texas Surface and Finished Drinking Water Quality Data located on the TNRCC website

Table 2-3
Summary of Rapid Bioassessment Protocol Results
from Big Cypress Creek (Segment 0404)
25 August - 1 September 2000

	Tankersley Creek at FM 3417 10261	**Hart Creek at Titus Co. Rd 10266**	**Big Cypress Below Walkers 16457**	**Big Cypress at Gasline Crossing 16460**	**Big Cypress at Fish Camp 10307**
Habitat					
Total Score	19	18	22	21	17
Aquatic Life Use*	Intermediate	Intermediate	High	High	Intermediate
Nekton					
Total Score	44	46	48	52	47
Aquatic Life Use**	Intermediate	Inter./High	High	High	High/Inter.
Benthic Macroinvertebrate					
Total Score	24	27	34	29	25
Aquatic Life Use***	Intermediate	Intermediate	High	High	Intermediate
	Swauano Creek at SH 49 15738	**Walkers Creek at US 271 16454**	**Greasy Creek at FM 557 16016**	**Dry Creek at Camp Co. Rd. 10274**	**Big Cypress near Greasy 16458**
Habitat					
Total Score	18	21	17	17	18.5
Aquatic Life Use*	Intermediate	High	Intermediate	Intermediate	Intermediate
Nekton					
Total Score	48	44	46	44	49
Aquatic Life Use**	High	Intermediate	Inter./High	Intermediate	High
Benthic Macroinvertebrate					
Total Score	23	28	24	26	30
Aquatic Life Use***	Intermediate	Intermediate	Intermediate	Intermediate	High

Table 2-3 Continued

August 6-8 2001

	Tankersley Creek at FM 3417 10261	**Hart Creek at Titus Co. Rd 10266**	**Big Cypress Below Walkers 16457**	**Big Cypress at GaslineCrossing 16460**	**Big Cypress at Fish Camp 10307**
Habitat					
Total Score	20	20.5	18.5	19.5	17
Aquatic Life Use*	High	High	Intermediate	High / Intermediate	Intermediate
Nekton					
Total Score	54	52	52	50	47
Aquatic Life Use**	High / Exceptional	High	High	High	High/Inter.
Benthic Macroinvertebrate					
Total Score	22	30	31	24	25
Aquatic Life Use***	Intermediate	High	High	Intermediate	Intermediate

	Swauano Creek at SH 49 15738 8 Aug 2001	**Walkers Creek at US 271 16454 6 Aug 2001**	**Greasy Creek at FM 557 16016 7 Aug 2001**	**Dry Creek at Camp Co. Rd. 10274 8 Aug 2001**	**Big Cypress near Greasy 16458 7 Aug 2001**
Habitat					
Total Score	20	21	18	14.5	18.5
Aquatic Life Use*	High	High	Intermediate	Intermediate	Intermediate
Nekton					
Total Score	50	48	52	34	49
Aquatic Life Use**	High	High	High	Limited / Intermediate	High
Benthic Macroinvertebrate					
Total Score	27	24	21	24	30
Aquatic Life Use***	Intermediate	Intermediate	Limited	Intermediate	High

Aquatic Life Use Point Score Ranges

	Limited	Intermediate	High	Exceptional
*Habitat	<13	14-19	20-25	26-31
**Nekton (fish)	<34	40-44	48-52	58-60
***Macroinvertebrates	<22	22-28	29-36	>36

The Cypress Creek Basin Clean Rivers Program presently has studies underway to better define the distribution and severity of this problem. Existing information on the excessive levels of selenium in fish tissues in Welsh Reservoir (Segment 0404D) was reviewed and recommendations for action were made in a report submitted to TNRCC in September, 2000 as part of the Lake O' the Pines TMDL program.[10]

With respect to Lake O' the Pines, the Draft 2000 303(d) list found approximately 2,000 acres in the upper end of the lake exhibited dissolved oxygen (DO) concentrations that are occasionally lower than the 24-hour average criterion (5 mg/l) established to assure optimum conditions for aquatic life. This area, corresponding to the portion of the reservoir above the SH 155 causeway, is a transition zone between the lotic conditions prevailing in Big Cypress Creek and the more typically lentic environment of the lower lake basin (Figure 2-1).[11]

The February 2002 Draft 305(b) assessment of Segment 0403 indicated that excessive nutrient levels were a cause for concern throughout the water body (Table 2-4). While there was also continued concern with depressed dissolved oxygen concentrations in the reservoir above SH 155, that concern was extended to include a new total of 3,700 acres, encompassing the upper part of the main basin in the vicinity of the Northeast Texas Municipal Water District raw water intake, Station 10297 (Figure 2-1). While fisheries appear to be the primary use in the reservoir above SH155, the lower, deeper reach of the reservoir is perhaps of greater concern for water quality and water supply by the Cypress Creek Basin stakeholders, as this typifies the open, well-aerated waters of the lake, and is the location of the major water supply intakes.

Texas Parks and Wildlife Department data on fish kills and other pollution incidents records only a single event in Segment 0403 since 1994. That event was a moderately large (about 9,400 individuals) fish kill that began on July 22, 2002, extending from below SH155 down the reservoir to Ferrels Bridge Dam. Although this kill was attributed to low dissolved oxygen concentrations resulting from "algal respiration", samples collected on July 24, 2002 show that only low to moderate levels of chlorophyll-*a* were present throughout the reservoir (Figure 2-2), and the dissolved oxygen diurnals conducted 23-25 July gave no indications of low concentrations at the stations sampled.

That nutrient and sediment should accumulate in the reach of the lake that receives the bulk of the inflow and that eutrophic conditions should result are not surprising, nor do these conditions necessarily warrant regulatory action. Such eutrophic conditions are a natural and largely unavoidable feature of the aging of a reservoir, and Lake o' the Pines is a relatively old lake,

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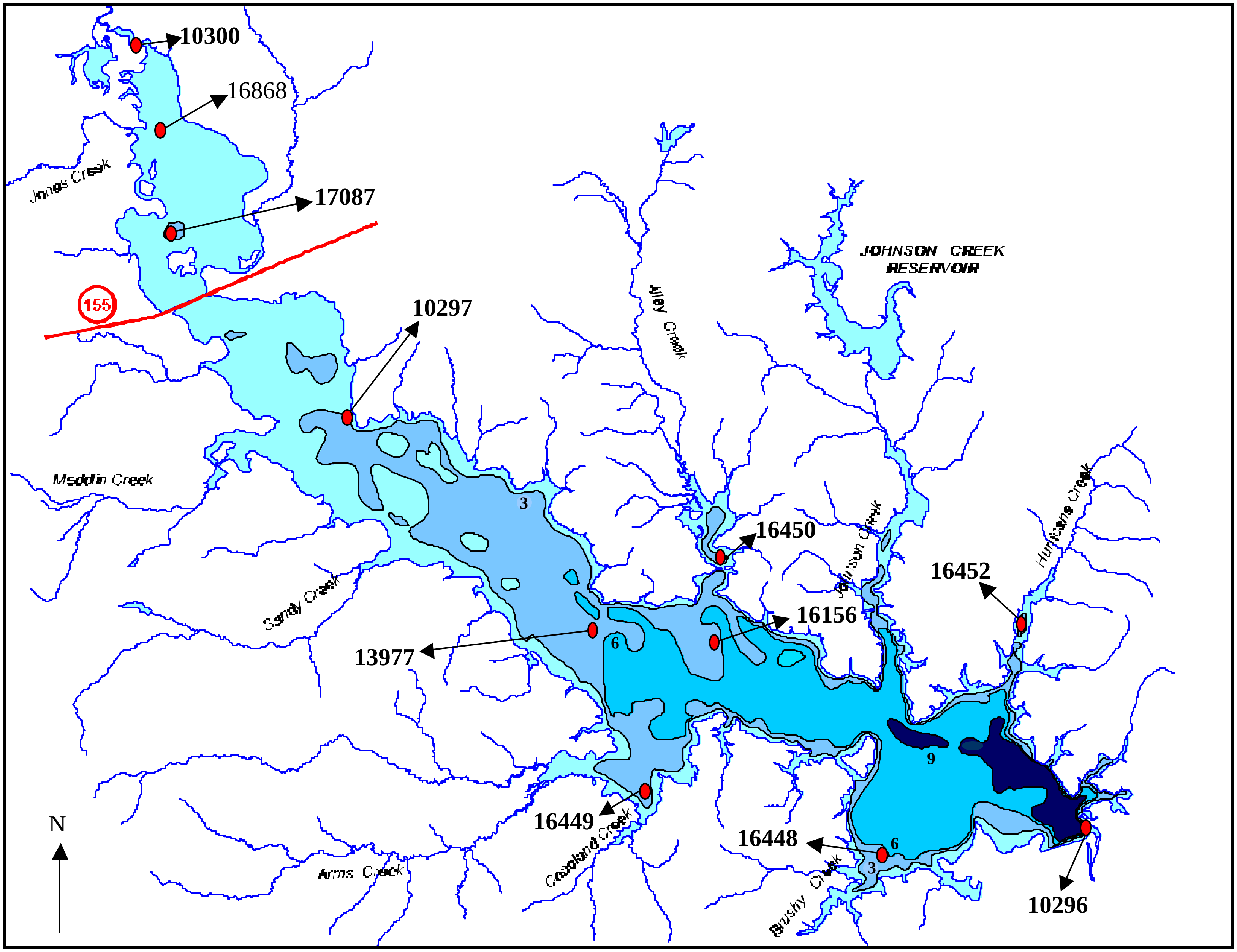
[10] PPA 2000. Summary of Available Information on Selenium Concentrations in Welsh Reservoir with Recommendations for Necessary Corrective Actions. Task 10, Deliverable #35 Lake O' the Pines TMDL. Prepared by Paul Price Associates, Inc., Austin, Texas.

[11] Lind, O.T., 2002. Reservoir zones: Microbial production and trophic state. Lake and Reservoir Management 18(2): 129-137



All Lake Depths Measured in Meters

0 4 km

Figure 2-1
Lake O' the Pines Sample Stations

Table 2-4
Draft FY 2002 305(b) Assessment of Lake O' the Pines, Segment 0403

Stream Information							
Segment	**On Segment?**	**Station(s) / Description**	**Watershed Name**	**Concern / Impairment**			
				Type	**Use or Concern**	**Status**	**Description**
0403	yes	Lower 5000 acres: 10296 Lake O' the Pines near Dam 13977 Lake O' the Pines Site EC 16156 Lake O' the Pines mid lake	Lake O' the Pines	Concern*	Aquatic Life Use	Use Concern	depressed dissolved oxygen: 4 of 27
				Concern	Nutrient Enrichment	Concern	nitrate+nitrite nitrogen: 2 of 25
	yes	Upper 3700 acres: 10297 Lake O' the Pines 30 m from NETMWD intake 10300 Lake O' the Pines Lone Star Landing SE if US 259	Lake O' the Pines	Concern*	Aquatic Life Use	Use Concern	depressed dissolved oxygen: 7 of 25 (grab average) 1 of 4 (24h average) 2 of 4 (24h minimum)
				Concern	Nutrient Enrichment	Concern	nitrate+nitrite nitrogen: 10 of 18
				Concern	Nutrient Enrichment	Concern	total phosphorus: 6 of 18

* Existing concern or impairment identified on the 2000 303(d) list.

Stream Characteristics					
Stream Order	**Slope of land**	**Soil types**	**Stream substrate**	**Eco Region(s)**	**Significant inflows**
5^{th}	Nearly level to gently undulating	Kirvin-Bowie Cuthbert-Teneha Fine sandy loam	Fine silt	35	Big Cypress Creek Jones Creek Alley Creek Johnson Creek Meddlin Creek Sandy Creek Arms Creek
Flow Regime: Lake O' the Pines receives much of its water from Big Cypress Creek (segment 0404). Typical flows from Big Cypress Creek during summer months and early fall are between 10 to 20cfs. Winter and spring flows average 100 to 200cfs with occasional heavy rain events exceeding 10,000cfs. Lake O' the Pines releases a maximum of approximately 3,000cfs during heavy rain events.					

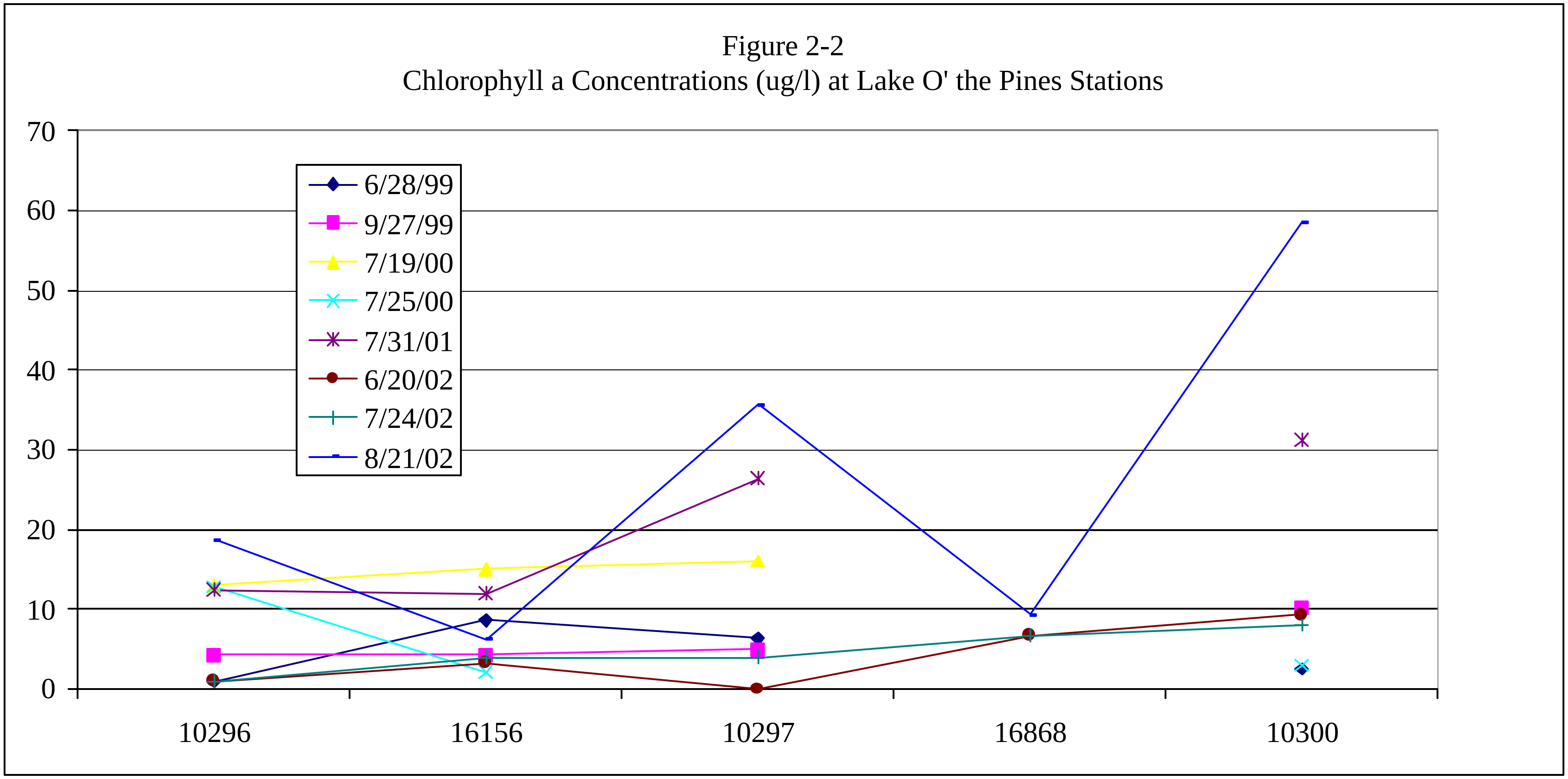


Figure 2-2
Chlorophyll a Concentrations (ug/l) at Lake O' the Pines Stations
70
60
50
40
30
20
10
0
6/28/99
9/27/99
7/19/00
7/25/00
7/31/01
6/20/02
7/24/02
8/21/02
10296
16156
10297
16868
10300

approaching 50 years. The primary site of sediment deposition and delta formation in reservoirs typically occurs at the mouths of the major tributaries where organic and mineral solids, maintained in suspension by the turbulent energy of the streams, enter the lower energy environment of the reservoir.

The reservoir above the SH 155 causeway is predominantly shallow; although depths of 3 m may be found in maintained parts of the inundated Big Cypress Creek channel, most of the area is less than 1.5 m deep and is covered by a large biomass of rooted vegetation, primarily American water lotus, *Nelumbo lutea*, and more variable stands of *Hydrilla verticillata.* The presence of large stands of submerged aquatic vegetation impedes water flow, facilitating sediment deposition, and presumably nutrients associated with soil and organic particles. Perhaps more importantly from the standpoint of the overall lake water quality, the metabolism of the rooted vegetation and its epiphytic community is likely to dominate the dissolved oxygen regime and nutrient budgets of this portion of the reservoir, while the ability of the rooted vegetation to extract nutrients from sediments and return it to the water column in the form of detrital material may be significant in the nutrient dynamics of the entire reservoir. The reservoir reach between SH 155 and Station 13977, while still shallow enough that persistent summer stratification does not occur, is primarily open water, with stands of rooted vegetation confined to marginal areas (Figure 2-1).

Target (Endpoint) Selection

The subject of the appropriate water quality endpoints, or targets, that we should seek to affect through the TMDL program was first raised during the September 22, 1999 Watershed Steering Committee meeting. TMDL Targets are the numerical expressions defining the water quality or biological conditions that a consensus of watershed stakeholders believe will allow achievement of the designated and desired uses of the basin waters. The TMDL Targets serve as the focus of the technical work to be accomplished during TMDL development, the goal that defines success for the process, and a criterion against which to evaluate future conditions.

The Lake O' the Pines watershed steering committee and the Cypress Creek Basin Clean Rivers Program steering committee both expressed the importance of protecting the water supply, recreational and aesthetic uses of Lake O' the Pines. There is a great deal of local concern over preserving those uses, as they are widely perceived to be threatened by activities in the watershed. Although grab sampling has indicated localized violations of the segment standard for dissolved oxygen concentrations, there is presently little direct evidence that those uses are now being impaired.

Several approaches to defining numerical endpoints, technical issues involved in the sampling and analysis of particular parameters, and the problem of linking quantitative measures of water quality impairment (e.g., segment standards) to their immediate biological effectors and the watershed inputs potentially driving them were discussed extensively during subsequent communications with TCEQ staff.

A technical memorandum (with an executive summary) discussing these issues was prepared and provided to the stakeholders to prepare them for additional discussion of TMDL targets (or endpoints) during the July, 2000 steering committee meeting. This memorandum recommended a flexible strategy for developing an appropriate target(s) as we recognized that selection of particular parameters and numerical thresholds will be, to some extent, an ongoing process as our understanding of the system increases during TMDL development. In particular, the relationship between phosphorus loading and the biological response parameters, the possible extent of summer nitrogen limitation episodes, the definition of critical hydrometerological conditions, and the role of the shallow upper portion of Lake O' the Pines in nutrient deposition and regeneration may affect future decisions with respect to Target conditions.

During the August 1, 2000 CRP/TMDL Steering Committee Meeting, Addendum No. 2, *Memorandum on Target Selection* was passed to the group. The steering committee's final comments and consensus was solicited concerning: (1) the major problems in Lake O' the Pines and its watershed; (2) the need to recognize the conditions to be achieved at the end of the TMDL program and how to measure them; and (3) that the research planning is adequate. The technical consultants emphasized the in response to the draft 2000 303d list, low DO conditions in the upper part of Lake O' the Pines must be addressed, in addition to the existing uses of Lake O' the Pines, as previously directed by the steering committee. Roy Darville expressed concerns about air deposition and recent data indicating rapid development in the last two or three years. Arthur Talley (TCEQ Project Manager) stated that Lake O' the Pines is listed on the state's 303d list for low dissolved oxygen concentrations. Therefore, at a minimum, endpoints selected for the TMDL project must result in meeting the dissolved oxygen standard for Lake O' the Pines. At this point, our objective has to be to fix it. Mr. Talley further stated that the minimum objective of the TMDL project is that the dissolved oxygen is too low, and that the problem be better defined and a plan for fixing the problem be developed and implemented.

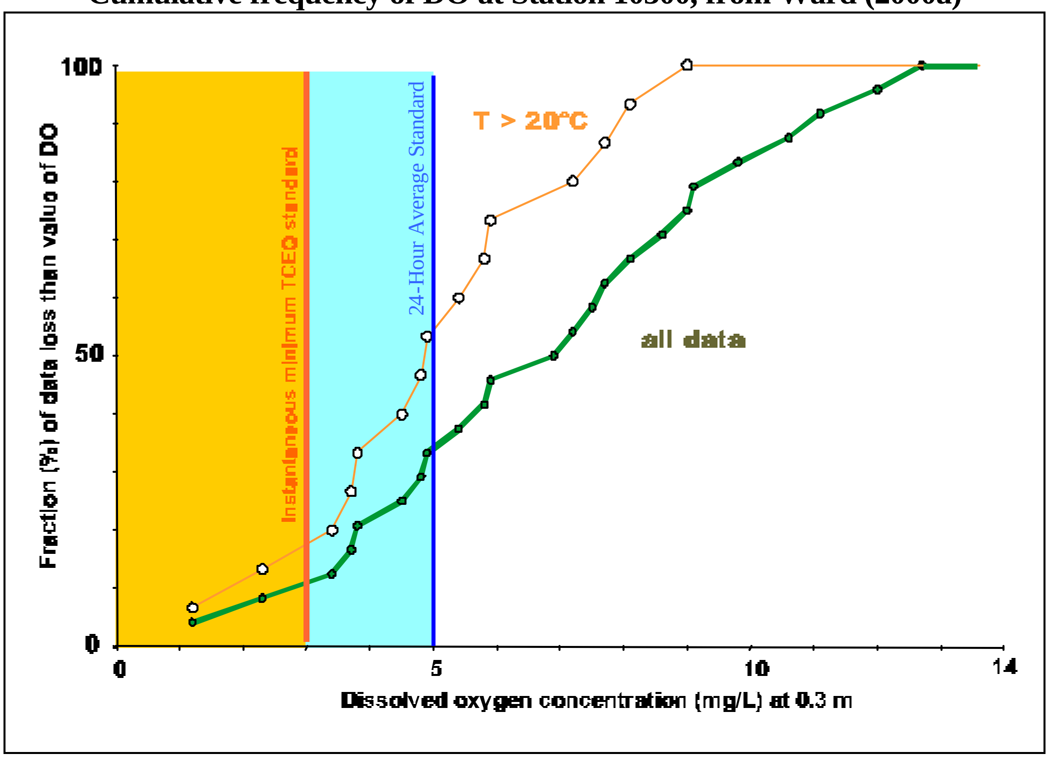
It was noted by project technical consultants that DO problems in the upper portion of Lake O' the Pines will have to be addressed using different analytic and modeling approaches than is typically used to address phytoplankton growth in the main basin of a lake or reservoir. With respect to maintenance of the uses mentioned above, reservoir trophic status would be considered when reductions in nutrient loads needed to achieve Segment Standards are recommended. There was discussion concerning a recommendation to TNRCC to consider sub-dividing the lake into two segments, and what the approach might be.

Critical Conditions

From the outset of this project, consideration of northeast Texas hydroclimatology led to the expectation that nonpoint source loading from storm runoff into the lake would play an important role in lake water quality. Analysis of water quality data from the lake added the expectation that the key parameters would be nutrients, notably compounds of nitrogen and phosphorus, and that kinetic processes usually identified with lake eutrophication would probably be the primary determinants of reservoir quality. These processes include assimilation of N and P, and high rates of photosynthesis and respiration that result in large diurnal excursions in dissolved oxygen. What emerged from the hydrographic studies of the reservoir and the parallel analysis and modeling of Big Cypress Creek was the realization that external nutrient loading of the reservoir does not correspond in time to the occurrence of low-dissolved oxygen episodes.[12]

The analysis of profile and surface grab sample data from the upper reach (Station 10300) confirmed the presence of high dissolved oxygen deficits and large diurnal excursions, and found that the 3 mg/l instantaneous minimum dissolved oxygen concentration established by TCEQ to assure High Aquatic Life use (the present designation for Lake o' the Pines) was violated in 10-15% of measurements, and that the 5 mg/l criterion for grab samples was not achieved in 30-50% of measurements.[13] Figure 2-3 displays the cumulative frequency of dissolved oxygen measured at the 0.3-m ("surface") level, on which are marked the Segment 0403 Surface Water Quality Standard, a 24-hr mean dissolved oxygen of at least 5 mg/L with an instantaneous minimum of 3 mg/L. Dissolved oxygen in Lake o' the Pines is strongly affected by seasonal stratification in the middle and lower reaches of the lake, where depths are sufficient to allow the development of the seasonal thermocline. Although dissolved oxygen data are relatively sparse from the lake, the two best sampled stations being 10296 in the lower reach near the dam and 10300 in the upper reach near the Hwy 259 bridge, they do suggest a systematic increase in dissolved oxygen deficit with position upstream in the system. The uppermost reach, above SH 155, is typically too shallow for thermal stratification and generally exhibits the highest deficits in the lake.

Figure 2-3
Cumulative frequency of DO at Station 10300, from Ward (2000a)



[12] Ward, G. 2001. Seasonal and hydrological controls on dissolved oxygen in Lake o' the Pines. Lake O' the Pines TMDL Project Technical Memorandum. Submitted to TNRCC February, 2001.
[13] Ward, G. 2000. Dissolved oxygen structure and trends in Lake o' the Pines. Lake O' the Pines TMDL Project Memorandum submitted to TNRCC August, 2002.

At Station 10296, since 1973 there has been a declining trend in dissolved oxygen concentration, statistically discernible at a 95% confidence level, with violations of the standard and screening criteria in recent years (Figure 2-4). Moreover, these degraded dissolved oxygen conditions are associated with low-inflow and late summer seasons (Figure 2-5). The data record at 10300 extends back only to 1998, but evidences a similar degradation in oxygen, including a marked increase in dissolved oxygen deficit.[14]

That these are not simply a result of the lower saturation at high temperature was established by a companion analysis of dissolved oxygen deficit. These same conditions apply to the violations of dissolved oxygen standards in the upper reach of the reservoir, for which Lake O' the Pines was placed on the 303(d) list. The low-flow, high-temperature stratified condition, typical of late summer, comprises the set of critical conditions under which violations of water quality standards are occurring, and under which the relationship between pollutants and standards violations are evaluated in the TMDL program.

In addition to the data used for the evaluations discussed in preceding paragraphs, the Lake O' the Pines TMDL program employed a set of deployable probes to obtain additional diurnal (24-hour) data during 2000-2002. Between September 2000 and August 2002, 16 24-hour records of dissolved oxygen concentrations were collected from locations in the reservoir above SH 155, 23 records were collected from the main basin, with data coming from Stations 10297 (NETMWD Intake), 16156 (Longview Intake), and from 16448 and 10296 near Ferrels Bridge Dam, and 15 records were collected from stations located in the Arms Creek, Alley Creek and Hurricane Creek coves (16449, 16450, and 16452, respectively).

In the upper reservoir, average dissolved oxygen concentrations were less than 5.0 mg/l on one occasion (May, 2001), and the minimum dissolved oxygen concentration was less than 3.0 mg/l on another (July, 2001), an exceedance rate of 12.5%. Both exceedences occurred at Station 10300 (Lone Star boat ramp), a narrow, bayou-like channel in the uppermost headwaters of Lake O' the Pines. Half of the measurements in the upper reservoir were made during surveys in June and August 2002 near Stations 16868 and 17087, between Station 10300 and the SH 155 causeway. None of the latter observations revealed dissolved oxygen problems, except in very shallow water (<0.3 m in dense emergent vegetation) or within a few centimeters of the bottom. Diurnal records were also collected in shallow (1-1.5 m), vegetated, areas of the upper reservoir to characterize the dissolved oxygen climate in the midst of extensive stands of *N. lutea*. Of four diurnal records collected during June and August 2002, one exhibited a dissolved oxygen minimum (2.66 mg/l) less than the instantaneous minimum criterion of 3.0 mg/l.

Of the 23 diurnal records collected from the main basin, the three exceedences (13%) all involved Station 10296 (Ferrels Bridge Dam) exhibiting dissolved oxygen concentrations less than the 3.0 mg/l instantaneous criterion, with only one instance of an average concentration below 5.0 mg/l. The records collected in August 2002, were from three consecutive days observations at Station 10296, and contrast strongly with the contemporaneous records from the upper reservoir stations. If only a single record for Station 10296 is admitted to the data set, the exceedance rate would drop to 2/21, 9.5%. The cove station results did not reveal any dissolved oxygen concentration

[14] Ward, G. 2000. Dissolved oxygen structure and trends in Lake o' the Pines. Lake O' the Pines TMDL Project Memorandum submitted to TNRCC August, 2002

Figure 2-4
Epilimnion-mean DO at Station 10296 over time, showing least-squares trend line (solid) and 95% confidence bounds (broken), from Ward (2000a)

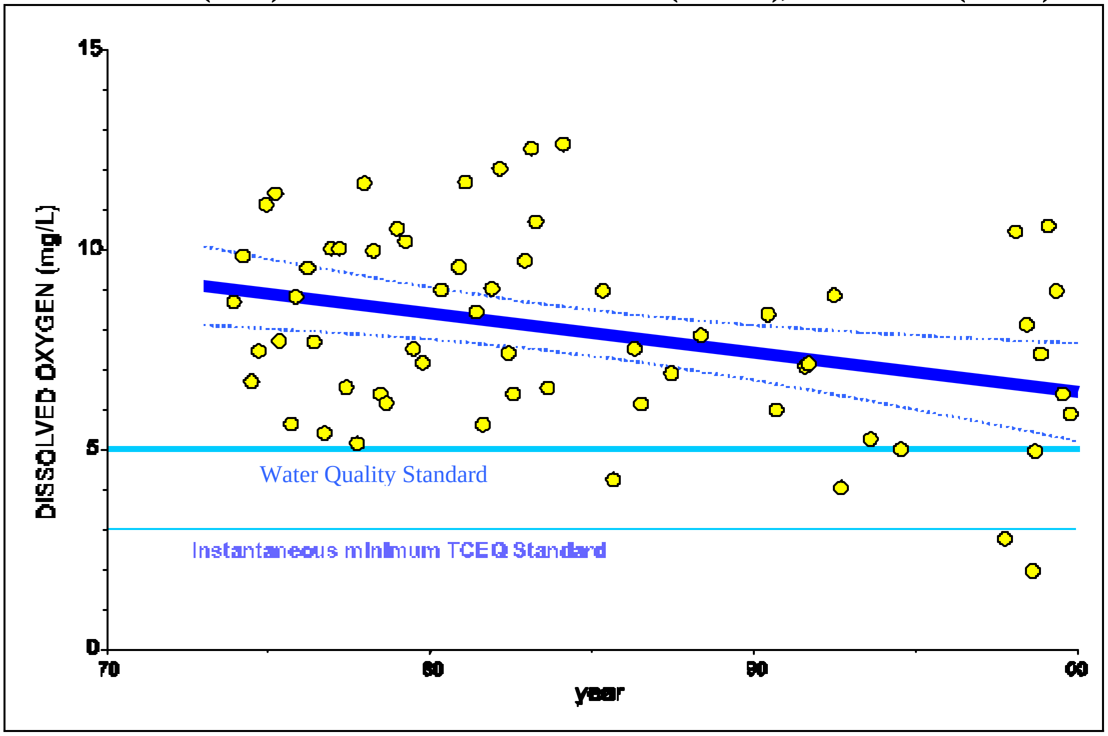
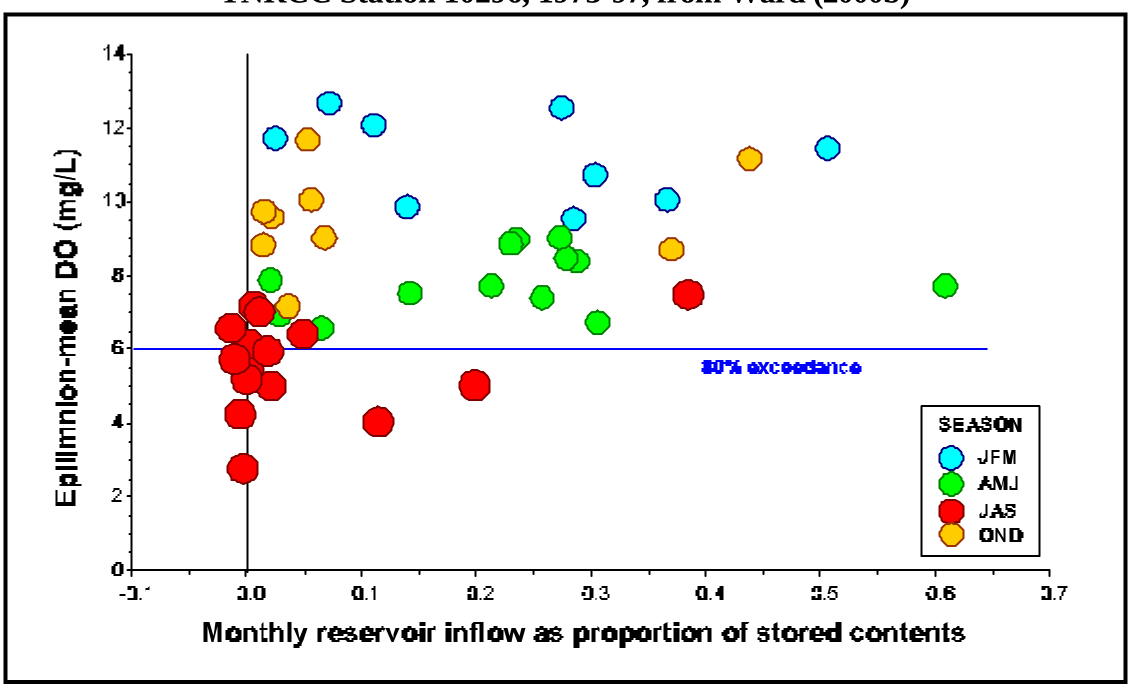


Figure 2-5
Epilimnion-mean DO's versus associated monthly inflows, TNRCC Station 10296, 1973-97, from Ward (2000b)



concerns. If those stations are pooled with the main basin data, the result for the lower reservoir is 2/38, an exceedance rate of 5.8%.

Evidence that low dissolved oxygen concentrations in Lake O' the Pines result from *in situ* photosynthesis and respiration, rather than (for example) consumption of inflowing, oxygen-demanding materials, or ammonia oxidation, includes: (1) relatively low concentrations of total organic carbon (TOC), and ammonia are the typical condition during critical periods, (2) analysis of intensive survey results showed that oxygen demand originating in wastewater discharges was assimilated in the tributary streams,[15] (3) that exceedences tend to correspond with larger 24-hour dissolved oxygen concentration amplitudes, and (4) the high metabolic rates obtained in the analysis of diel oxygen data and observed in respirometer studies.[16] Given that they are occurring in the same water body, the magnitude of dissolved oxygen change over a 24-hour period provides an index of biological activity, of community photosynthesis and respiration. Average 24-hour dissolved oxygen amplitudes tend to vary systematically in Lake O' the Pines, with highest values (averaging about 7 mg/l) in the reach above the SH 155 causeway, intermediate values (about 3 mg/l) in the main basin (Stations 10297, 16156, 16448, and 10296), and lowest values (about 2 mg/l) at the cove stations (Table 2-4). The exceedences observed during three consecutive diurnal cycles (20-23 August, 2002) at Station 10296 were accompanied by dissolved oxygen amplitudes of 7.2, 7.1 and 6.2 mg/l, while the upper reservoir locations, which did not exhibit contemporaneous exceedences, had dissolved oxygen amplitudes ranging from 3.1 to 5.3 mg/l.

The pattern of metabolic activity described above is consistent with a conceptual model of Lake O' the Pines in which photosynthesis and respiration are supported by nutrients that enter the system primarily in Big Cypress Creek inflows, with a decline in community metabolism, and dissolved oxygen criteria violations, at locations successively more isolated from the nutrient supply. Summer chlorophyll-*a* and phosphorus concentrations follow similar patterns; highest values of both parameters tend to be present in the upper reservoir, and lowest in the cove stations. Although there is some indication that dissolved oxygen concentrations may be in long-term decline in the lower reservoir, diurnal dissolved oxygen monitoring does not reveal a concern at this time.

Although phosphorus may appear to be too abundant in Lake O' the Pines to be exerting limits or control on production and coupled respiration, this is not the case as summer total phosphorus concentrations primarily represent phosphorus tied up in living and dead organic material, phosphorus sorbed to mineral particles, or present as polyphosphate, all of which are of only limited availability for new growth. Dissolved phosphorus was rarely, if ever, detected in Lake O' the Pines summer baseflow samples (AWRL = 0.01 mg/l). Summer nitrogen likewise consisted almost entirely of total Kjeldahl nitrogen (TKN) and much smaller concentrations of ammonia, indicating that nitrogen was also present primarily as organic matter (biomass and detritus) and not in an immediately available form. In this condition of general nutrient abundance but limited availability, photosynthesis and respiration rates will tend to depend on

[15] Ward, G.H. 2002. Calibration and Verification of QUALTX Model of Big Cypress and Tributaries. Deliverables 12G and 12I, Lake O' the Pines TMDL Project. Center For Research in Water Resources, University of Texas, Austin, Texas.
[16] Ward, G.H. 2002. Calibration and verification of Lake O' the Pines QUALTX model. Lake O' the Pines TMDL deliverables 12K and 12L, submitted August, 2002.

the rates of regeneration of nitrogen and phosphorus from sediments or from living populations, given appropriate conditions of temperature, light, and other nutrients. Nutrient regeneration rates at any given time and location may depend on both physical factors, such as sediment redox potential, dissolved oxygen concentrations and pH of overlying water, and mixing events (e.g., wind stress, internal waves), and biological factors, including pathogen-induced lysis of algal cells, grazing by fish and macroinvertebrates, or direct excretion from growing algal populations under otherwise favorable environmental conditions.

Violations of DO Standards, based on grab sampling, have been documented at Station 10300 in the Upper Reservoir. Extensive diurnal dissolved oxygen sampling conducted during 2000-2003 as part of the TMDL program, confirm that standards violations are occurring in the upper- and lowermost stations in the reservoir (Table 2-5). In addition, basin stakeholders are concerned that a declining DO trend has been detected at the lowermost station (10296) in the reservoir. Both conditions appear to have resulted from elevated nutrient concentrations throughout the reservoir, which originate in the Big Cypress Creek drainage.

Table 2-5
Diurnal Amplitudes in Dissolved Oxygen Concentration at Lake O' the Pines Stations

Station	Sept 00	May 01	July 01	June 02	July 02	Average
Upper Reservoir						
10300		**4.7***	**17.2**	6.1	7.2	8.8
16868		6.0	6.7	8.1	5.4	6.6
Main Basin						
10297	1.9	2.4	4.9	4.4	4.1	3.5
16156	2.3	2.4	2.0	3.0	1.7	2.3
16448	3.0	4.0	2.8	2.2	3.1	3.0
10296	1.8	1.6	**8.6**	3.6	2.4	3.6
Coves						
16449	1.4	1.7	1.0	3.1	3.6	2.2
16450	1.4	1.2	1.3	1.9	2.2	1.7
16452	1.8	3.4	2.5	1.7	2.1	2.3

* Bold type indicates an occasion when the dissolved oxygen standard was violated

3.0 SOURCE ANALYSIS

Table 3-1 lists permitted discharges in the Lake O' the Pines watershed. While the largest volume discharges are for industrial cooling water, those generally have limited effects on water quality, and little or no effect on Lake O' the Pines as they are discharged into tributary reservoirs specifically constructed for that purpose (i.e., Johnson Creek, Ellison Creek, Welsh, and Monticello Reservoirs). The remaining discharges are primarily effluents from municipal or domestic wastewater treatment plants, and most are small. The dischargers most important to water quality in Lake O' the Pines are the relatively large treatment plants located in Mount Pleasant and Pittsburg. The largest of these, Mount Pleasant southwest (SW) treats waste from the Pilgrims Pride Corporation processing plant, discharging its effluent into Tankersley Creek, a tributary of Big Cypress Creek, Segment 0404. Based on the results of the intensive surveys, the Mount Pleasant southwest plant may account for as much as 97% of the total phosphorus and 89% of the total nitrogen discharged from the four wastewater plants. The remaining Mount Pleasant treatment plants and the Pittsburg plants discharge into Hart and Dry Creeks, respectively, thence to Big Cypress Creek. Constituent concentrations and loads reported from these treatment plants during 1976 and 1983 intensive surveys are reviewed in Section 1.

Table 3-2 presents total phosphorus and nitrogen concentrations and loads measured in samples composited over a diurnal cycle during an intensive survey conducted August 18-20 1998 under baseflow conditions. Also shown are streamflow, nutrient concentrations and loads in Big Cypress Creek at Station 10308, located at the SH 11 crossing east of Pittsburg. This station is located below the tributaries carrying the effluents from Mount Pleasant, which account for 98% of the total phosphorus load, and 130% (sic) of the total nitrogen load measured at that point on Big Cypress Creek. Because of laboratory errors in compositing the samples, we have no meaningful data from the longest sources during the 1999 intensive survey, but Station 10308 exhibited a discharge of 22,018 m^3/day during the intensive survey, and TP and TN concentrations of 6.81 and 39.93 mg/l, respectively, giving estimated nutrient loads of 150 kg TP/day and 879 kg TN/day.

Table 3-3 presents nutrient loads expected from the major point sources (>0.02 MGD) in the Lake O' the Pines watershed when operating at their respective maximum permitted discharge rates. As none of these facilities currently have nutrient limitations, the nutrient concentrations measured during the 1998 Intensive Survey were used with permitted flows to estimate maximum loads. Discharges into tributary impoundments (e.g., Welsh and Ellison Creek Reservoirs) are not included in this tabulation. Annual nutrient loads coming from these facilities (gross loads) would total 29,877 kg/year total phosphorus and 419,964 kg/year nitrogen. Reductions in phosphorus and nitrogen loads relative to the Intensive Survey results (Table 3-2) reflect the approximately 4.6 MGD discharge observed at the Mount Pleasant SW facility in August 1998.

Figure 3-1 shows total phosphorus concentrations in Big Cypress Creek at Station 10308 and at Station 13631, the lowermost station in Segment 0403. The elevated phosphorus concentrations at Station 10308 during 1998-2000, weakly reflected at Station 13631, are likely related to excess discharges from the Mount Pleasant SW facility during that period. The differences in phosphorus concentration between the two stations represent a substantial 78% reduction, with

Table 3-1
Point Source Discharges Potentially Affecting Lake O' the Pines

Outfall Type	Permit #	Facility Name	Name of Permittee	Permitted Effluent Amount (MGD)	Stream Miles to Station (estimated)	
					10296	10300
Segment 0403						
Industrial cooling water, wastewater (2 outfalls)	WQ0001331-000	Southwestern Electric Power	SWEPCO - Wilkes SES	550 MGD and fvd**	8 to 10	19 to 21 downstream
Municipal wastewater	WQ0010241-001	City of Ore City	City of Ore City	0.218 MGD	14	8 downstream
Domestic wastewater	WQ0011260-001	Derdeyn/Ford, Inc.	Derdeyn/Ford, Inc.	0.002 MGD	3	17 downstream
Domestic wastewater	WQ0012563-001	Aquasource Utility	Crestwood Plant	0.02MGD	5	13 downstream
Domestic wastewater	WQ0012411-001	City of Lone Star	Lone Star WWTP	0.44 MGD	19	1
Segment 0404						
Industrial wastewater, cooling water, stormwater (5 outfalls)	WQ0000348-000	Lone Star Steel	Lone Star Steel Company	0.5, 70 MGD and flow variable discharge	19 to 22	1 to 5
Industrial cooling water	WQ0001464-000	Southwestern Electric Power	Lone Star Power Plant	80 MGD	21	3
Industrial wastewater, cooling water (3)	WQ0001811-000	Southwestern Electric Power	Welsh Steam Electric Station	0.006, 20, and 1425 MGD	34	15
Stormwater	WQ0004059-000	T & N Lonestar Warehouse	Star Tubular Services	0.0065 MGD		
Domestic wastewater	WQ0013948-001	Northeast Texas Community College	Northeast Texas Community College	0.01 MGD	39	21
Domestic wastewater	WQ0013821-001	Chapel Hill Independent School District	Chapel Hill ISD	0.032 MGD	40	21
Municipal wastewater	WQ0010575-004	City of Mount Pleasant	Southside Plant	2.91 MGD	42	24
Industrial stormwater	WQ0003877-000	Ergon Asphalt & Elmulsions	Ergon Asphalt and Emulsions, Inc.	flow variable discharge	46	28
Municipal wastewater	WQ0010499-001	City of Daingerfield	City of Dangerfield	0.7 MGD	27	9
Municipal wastewater	WQ0010250-001	City of Pittsburg	City of Pittsburg, Sparks Branch Plant	0.2 MGD	38	19

Table 3-1 (continued)

Outfall Type	Permit #	Facility Name	Name of Permittee	Permitted Effluent Amount (MGD)	Stream Miles to Station (estimated)	
					10296	10300
Municipal wastewater	WQ0010250-002	City of Pittsburg	City of Pittsburg, Dry Creek Plant	0.97 MGD	38	19
Industrial and domestic wastewater	WQ0003017-000	Pilgrim's Pride Corporation	Pilgrims Pride - Southwest Plant	3 MGD	46	28
Municipal wastewater	WQ0010239-001	City of Omaha	City of Omaha	0.02 MGD	42	23
Mine sedimentation ponds (9)	TPDES Permit No. 02697	Texas Utilities Mining Co.	Monticello Mine	flow variable discharge	48 to 51	30 to 33
Segment 408						
Industrial cooling water, stormwater	WQ0001528-000	Texas Utilities Electric Company	Monticello Steam Electric Station	1,785 MGD	49	30
Municipal wastewater	WQ0012146-001	City of Winfield	City of Winfield	0.84 MGD	52	34
Domestic wastewater	WQ0011750-001	Albert M. Miller	Miller's Cove	0.038 MGD	53	35
Mine sedimentation ponds (15)	TPDES Permit No. 02697	Texas Utilities Mining Co.	Monticello Mine	flow variable discharge	47 to 52	29 to 34

****** Flow variable discharge

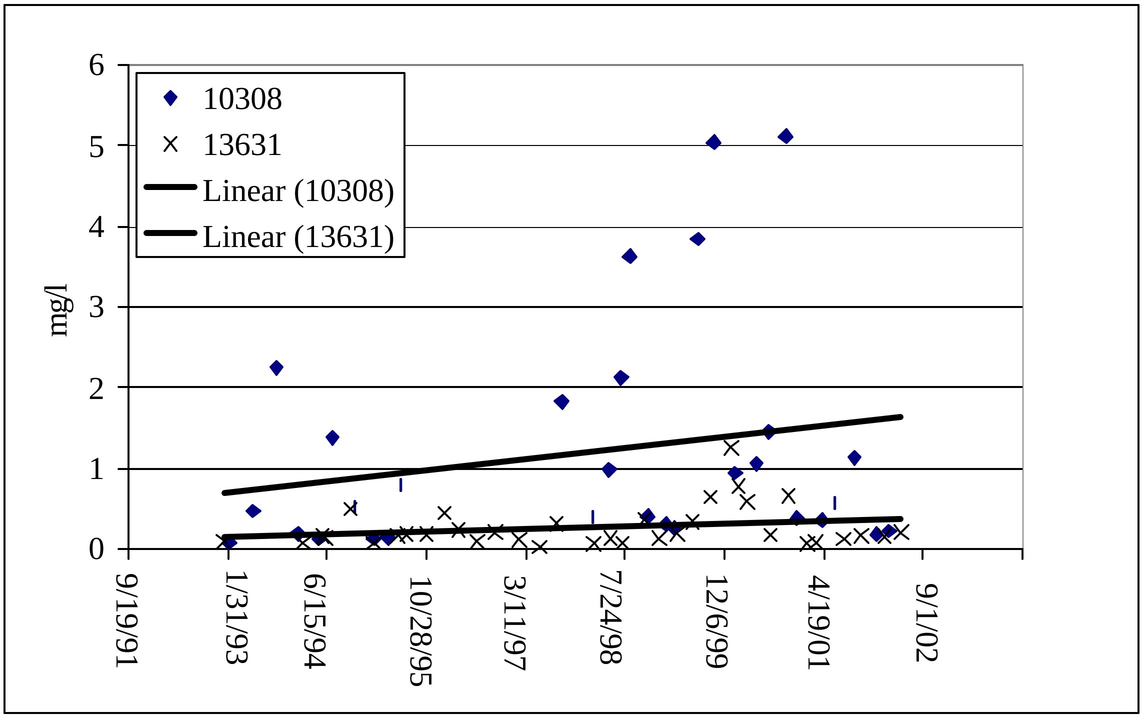
Table 3-2
Major Point Source Nutrient Concentrations and Loads Measured
During 18-20 August, 1998 Intensive Survey

Source	**Permit Number**	**Permitted Flow**	**Flow**	**Total Phosphorus**		**Total Nitrogen**	
		(m^3/day)	(m^3/day)	mg/l	kg/day	mg/l	kg/day
Mount Pleasant WWTP	WQ0010575-004	11,015	5,798	0.241	1.4	23.1	133.9
Pilgrim's Pride Processing Plant WWTP	WQ0003017-000	11,356	17,254	6.44	111.2	73.9	1273.0
Pittsburg – Sparks Branch	WQ0010250-001	3,671	2,837	0.664	1.9	9.03	25.6
Pittsburg – Dry Creek	WA0010250-002	757	122	2.14	0.3	8.54	1.0
Source Total		**26,799**	**26,011**		**114.8**		**1433.5**
Big Cypress Creek 10308			31,804	3.62	115.1	33.9	1078.1

Table 3-3
Major Point Source Nutrient Concentrations and Loads of Major Point Sources
($\geq$ 0.200 MGD) Expected at Maximum Permitted Discharge

Source	**Permit Number**	Max. Permitted flow	**Total Phosphorus**		**Total Nitrogen**	
		(m^3/day)	mg/l	kg/day	mg/l	kg/day
Mount Pleasant WWTP	WQ0010575-004	11,015	0.241	2.6	23.1	254.4
Pilgrim's Pride Processing Plant WWTP	WQ0003017-000	11,356	6.44	73.1	73.9	839.2
Pittsburg – Sparks Branch	WQ0010250-001	3,671	0.664	2.4	9.03	33.2
Pittsburg – Dry Creek	WA0010250-002	757	2.14	1.6	8.54	6.5
Daingerfield	WQ0010499-001	2,649	0.54	1.4	5.72	15.2
Omaha	WQ0010239-001	757	0.98	0.7	1.7	1.3
Source Total		**30,207**		**81.8**		**1149.8**

Figure 3-1
Total Phosphorus Concentrations at Big Cypress Creek Stations 10308 and 13631

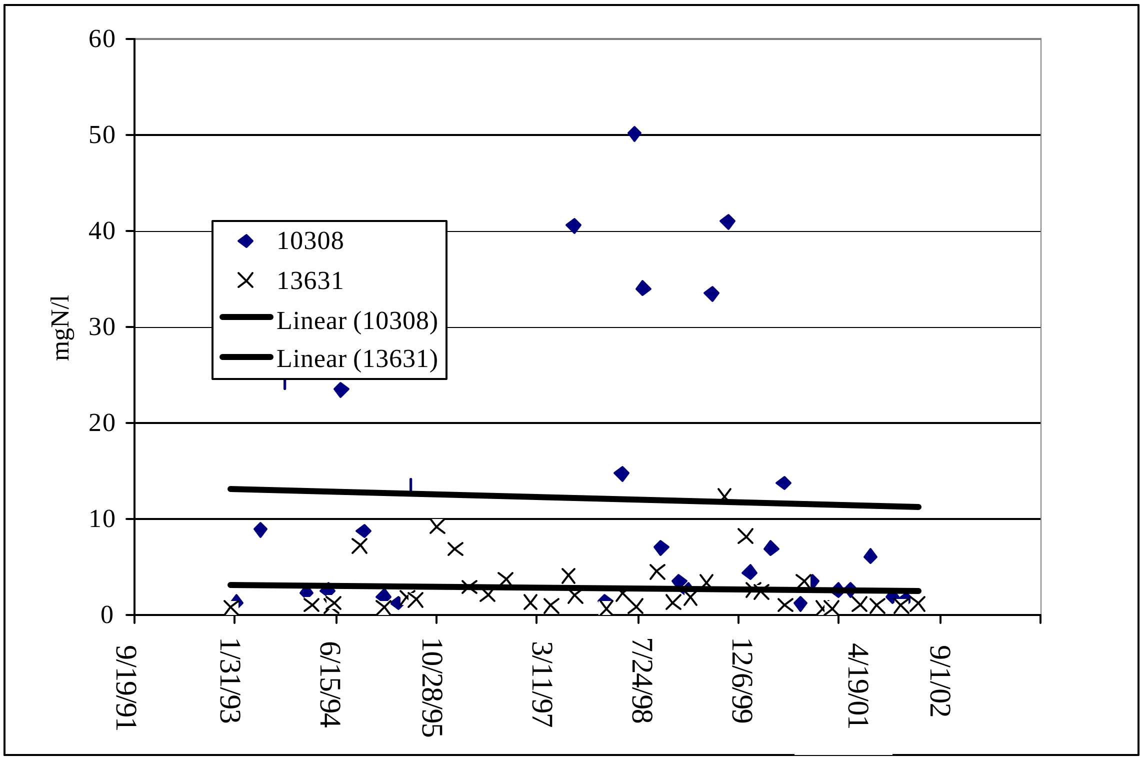


average concentrations of 1.20 mg/l at 10308 and 0.26 mg/l at 13631.

Average annual nutrient loads at stations 10308 and 13631 were calculated by multiplying grab sample results by the monthly average flows for the months in which the sample was collected. Streamflow data was obtained for the USGS gage at Station 10308 and discharge at Station 13631 was calculated from the Station 10308 data by multiplying by the drainage area ratio. Monthly loads were averaged for each year, and then multiplied by 12 to obtain an annual load. For the period 1979-2000, total phosphorus loads at Station 10308 averaged 112,824 kg/year, ranging from 4,370 kg in 1988 to 605,028 kg in 1994. At Station 13631, TP loads averaged 50,855 kg/year, with a low of 1,222 kg in 1979 and a high of 171,374 kg in 1993. The annual average phosphorus load at Station 13631 is 55% less than that at 10308. Although the difference in concentrations noted above might be ascribed to dilution by water of lower phosphorus content, the large reduction in load suggests assimilation or deposition during passage down Big Cypress Creek.

Nitrogen data is much more limited than that for phosphorus, with a particular paucity of measurements that correspond to available streamflow information. Recognizing the higher level of uncertainty, total nitrogen concentrations also vary substantially between these stations, averaging 12.01 mg/l at Station 10308 and 2.76 mg/l at Station 13631, a reduction of 77% (Figure 3-2). Nitrogen loads at the two stations average 2,490,614 kg/year at Station 10308 and 230,322 at Station 13631, a reduction of 91%.

Figure 3-2
Total Nitrogen Concentrations at Big Cypress Creek Stations



The point source loads in Table 3-3 provide annual estimates of 29,877 kg TP/year and 419,964 kg TN/year originating in the larger wastewater treatment plants in the Lake O' the Pines watershed. While the point sources in Mount Pleasant contribute 24% of the average phosphorus load observed at Station 10308, they account for only 16% of the average annual nitrogen load.

The Natural Resource Conservation Service (NRCS) model *SWAT* (Soil and Water Assessment Tool) was adopted for application to the simulation of runoff and associated watershed loads into Lake O' the Pines. Its application in the Lake o' the Pines TMDL project is summarized in the project technical memoranda "*Rationale for selection of watershed model*", "*Validation of watershed loading model*", and *Application of SWAT to Basin Scale Simulation of Lake O' the Pines Watershed*.[17] SWAT is the latest in an evolution of agricultural management models developed by the Agricultural Research Service. Earlier models were intended for application to single small catchments with uniform soils and agriculture practices, the most elementary being

[17] Ward, G. H., 2001: Rationale for selection of watershed model. Tech. Memo., Big Cypress/Lake o' the Pines TMDL Project, Center for Research in Water Resources, University of Texas at Austin.

Ward, G. H., 2002a: Validation of watershed loading model. Tech. Memo., Big Cypress/Lake o' the Pines TMDL Project, Center for Research in Water Resources, University of Texas at Austin

Ward, G.H. 2003. Application of SWAT to Basin Scale Simulation of Lake O' the Pines Watershed. Tech. Memo., Big Cypress/Lake o' the Pines TMDL Project, Center for Research in Water Resources, University of Texas at Austin.

field-scale models. SWAT, however, can simulate multiple subbasins with a variety of vegetation, soils and land-surface characteristics, and still includes most of the sophistication in biomass simulation, nutrient uptake, sediment mobilization and erosion that were features of the earlier agricultural management models. The validation of SWAT for several categories of watersheds from data collected in the Lake O' the Pines watershed was detailed in *"Validation of Watershed Loading Model"*. Data collection did not include "edge of field studies", but focused on monitoring storm runoff in streams of varying classification in multiple subwatersheds. The version of SWAT employed in all of the modeling work for the Lake o' the Pines project is *SWAT2000*.

There are four primary compartments in the SWAT model; hydrology, biology, sediment and chemistry, for which basic input data sets includes physiography, meteorology, soils, vegetation cover, and modifications to the land surface such as tillage, cropping, urbanization, and fertilization. Surface-vegetation biomass is a central variable in the model, and the mathematical expressions for photosynthesis, nutrient and water uptake and storage, growth, senescence and decay are complex. The various coefficients and rate parameters governing these processes are quantified in a "crop" database supplied with the model, with data for 97 vegetation categories. The soil database consists of separate files of soil parameters (horizon depths, grain-size distributions, hydraulic conductivity, etc.) that are derived from soils data maintained by NRCS. Additional data bases supplied with the model include chemical composition of numerous fertilizers, including manure and chicken litter of several types, and parameters related to eight categories of urban development.

The basic element of SWAT is the Hydrological Response Unit (HRU), defined to be a specific area with uniform soil, vegetation, surface slope, and landsurface treatment. A subbasin is a catchment made up of one or more HRU's, a channel reach and a vadose zone compartment. The internal drainage network of a subbasin is parameterized as a single tributary length. For these large-scale simulations of the watershed of Lake o' the Pines, a system of 25 subbasins was employed. Fifteen subbasins were used to depict the complex watershed of the Big Cypress, and ten to depict the other tributaries that flow directly into Lake o' the Pines.

In SWAT the loads are computed as a land-use source, based upon soils, vegetation, season, precipitation, sunlight, air temp, etc., then further altered as a function of movement across the watershed surface, including effects of surface slope, soils, and percolation, then combined with the same load calculation for other landuses to determine the load from a subwatershed. We assumed no further alteration of the load in its traversal down the stream channel to Lake o' the Pines.

Application of SWAT to simulate runoff and nutrient transport from the Lake O' the Pines watershed produced average annual loading estimates of 113,000 kg TP/year and 197,000 kg TN/year, without consideration of point source loads.[18] This work is based on soiled poultry litter application rates provided by Pilgrims Pride Corporation for the years 1998-2000. Because of a lack of information to base extrapolations on, no attempt was made to vary litter application rates through the simulative period, or to account for the application of other (chemical)

[18] Ward, G. 2003. Application of SWAT to Basin-Scale Simulation of the Lake O' the Pines watershed. Technical Memorandum Submitted to TCEQ, Lake O' the Pines TMDL Project, February 2003.

fertilizers. This information, and most of the monitoring data used in developing the TMDL, was compiled prior to the implementation of management practices (BMPs) intended to reduce the runoff of sediments and nutrients from poultry production facilities and litter application sites. Natural, baseline, or landscape loads (e.g., existing land cover categories but without poultry litter or other fertilizer application) were calculated to average 18,200 kg TP/year and 75,400 kg TN/year.

The SWAT non point source estimates, like the point source loads calculated from the Intensive Survey data, or the maximum permitted discharges, are gross loadings deposited from the respective modeled land surfaces into the watercourses draining into Lake O' the Pines. Unlike the other major biologically active elements (carbon, hydrogen, oxygen, nitrogen and sulfur) phosphorus has no phases or compounds that are gases at ordinary temperatures and pressures. As a consequence, phosphorus introduced into an aquatic environment will remain there, and be potentially available for use by macrophytes and microbiota, until it is flushed out or buried in sediments beyond the depth of bioturbation. In the context of the Lake O' the Pines watershed, this implies that any phosphorus reaching the stream network will eventually be transported to the reservoir, assuming Big Cypress Creek is in steady-state equilibrium to the point at which it is affected by Lake O' the Pines backwater.[19] Although the reduction in average phosphorus load between Stations 10308 and 13631 demonstrated in the monitoring data appears to indicate that significant biological assimilation and sorption by fine-grained sediments are taking place in Big Cypress Creek, that data is subject to a low flow sampling bias that does not account for the transport of significant portions of the suspended and bed loads, which will carry the particulate phosphorus fraction. Water samples have generally been collected during periods of low to normal flow, whereas much of the actual transport of water, sediments and dissolved constituents takes place during high flow periods in response to rainfall events.[20] We expect that, during low to normal flow periods in Big Cypress Creek, phosphorus will accumulate in the stream, but will be transported downstream during high flow periods. Although the cycle of sequestration and subsequent scour and transport probably occurs on a longer time scale on the floodplain than in the Big Cypress Creek channel, nutrients in this system can be assumed to eventually reach Lake O' the Pines. Our assumption to assume zero loss of phosphorus in the stream translates to neglecting true sequestration in the bed and floodplain sediments and temporary retention in biomass. The "net" load to the reservoir may therefore overestimated, and this overestimation is part of the implicit margin of safety. These considerations lead us to the conclusion that the gross point and nonpoint source phosphorus loads (29,855 and 113,000 kg/year, respectively) are the appropriate net loads being delivered to Lake O' the Pines.

The nitrogen budget is not such a simple matter due to the variety of biological transformations it is subject to, and the circumstance that nitrogen may be both assimilated (nitrogen fixation) and lost (denitrification) as a result of biological processes in direct exchange with the atmosphere. During low and normal flow periods nitrogen, like phosphorus, will also tend to be assimilated and processed in Big Cypress Creek. The nitrogen, however will tend to be lost from the system through bacterial denitrification, which proceeds most rapidly in environments containing

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[19] Gordon, N.D., et al.. 1992. Stream hydrology. John Wiley & Sons, New York.

[20] Allan, J.D. 1995. Stream Ecology, Structure and Function of Running Waters. Chapman and Hall, London, New York.

abundant organic material and having anaerobic and aerobic zones in close physical proximity, as at a sediment surface.[21] However, even the highest rates of denitrification reported for natural temperate waters couldn't account for the nitrogen losses between stations 10308 and 13631 implied by the differences in monitored average annual loads. Even high reported rates of denitrification would result in only a small (ca. 20%) reduction in the gross non point source load.[22] The difference may lie in the very limited Nitrogen data, and the particular paucity of measurements that correspond to available streamflow information (10 records at 10308, 14 records at 13631 during 1993-2000, only 4 in the same month at both stations).

Allocation of the loads entering Lake O' the Pines is summarized in Table 3-4. Big Cypress Creek was estimated to contribute about 80% of the total annual inflow to Lake O' the Pines, and about 88% of the total phosphorus load. This estimate of the importance of Big Cypress Creek contributions is consistent with the water quality conditions found to prevail in the upper and main reservoir basins, compared with the cove environments into which the minor tributaries flow.

The atmospheric pathway has been found to be an important source of nitrogen compounds to a watershed. For phosphorus, while there is an atmospheric pathway, it is almost always minor, and negligible. For example, in the USGS SPARROW project, which is a thorough, detailed GIS-based evaluation of constituent loads into the nation's watercourses, including atmospheric pathways, Smith et al. (1997) state bluntly, "The atmosphere is assumed to be a negligible source of total phosphorus."[23]

This fact notwithstanding, the runoff from Big Cypress watersheds includes any nutrient deposition on the watershed surface. The atmospheric load is therefore included in the nutrient concentrations in runoff in the automated water samples. The atmospheric load is also included implicitly, but not explicitly, in the model input specification. The SWAT-input parameters characterizing surface landuse (including vegetation) and soils (including surficial soils) are derived from field data and implicitly include all normal sources of nutrients to the landscape, one of which is the atmospheric pathway. Thus validation of the SWAT model implicitly includes validation of the atmospheric loading component. Unless we wished to consider a situation in which the atmospheric load is changed (which is not part of the present TMDL studies), there is no need to separate the atmospheric component and treat it as an independent input.

Atmospheric deposition of phosphorus in inland areas has been reported to commonly fall within the range of 10-100 mg/m^2*year, with the higher values associated with urban-industrial development and dust from aeolian erosion.[24] At the upper limit, a deposition rate of 100 mg/m^2*year would result in a total of 6847 kg/year of phosphorus added directly to Lake O' the Pines by precipitation and dry deposition, about 4.8% of the load from Big Cypress Creek.

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[21] Rheinheimer, G. 1991. Aquatic Microbiology. John Wiley & Sons, New York.
[22] Ford, T.E. (ed). 1993. Aquatic Microbiology; An Ecological Approach. Blackwell Scientific Publications, London, Boston.
[23] Smith, R., G. Schwartz, and R. Alexander, 1997: Regional interpretation of water-quality monitoring data. *Wat. Res. Res. 33* (12), pp. 2781-2798.
[24] Wetzel, R.G. 1983. Linmology. Saunders College Publishing, Philadelphia, Fort Worth.

Table 3-4
Net Nutrient Loads Entering Lake O' the Pines

	Total Phosphorus (kg/year)	Total Nitrogen (kg/year)
SWAT NPS Loads	113,000	197,000
Landscape Loads	18,200	75,400
Non-Point Source loads	94,800	121,600
Point Source Loads	29,877	336,000
Total Anthropogenic Loads	124,677	457,600
Total Loads	142,877	533,000

However, because of the general net transport of water downstream, only that portion of the deposition falling on the upper 3600 acre portion of the reservoir exhibiting low dissolved oxygen concentrations (21% of the surface area – effectively receiving 1% of Big Cypress Creek loading from the atmosphere) would be relevant to the problem addressed by this TMDL.

Nitrogen deposition in precipitation has been reported to average about 100 mg/m^2*year over the continental United States, and to range up to 350 mg/m^2/year in the upper Midwest. Dry deposition of ammonium and nitrate salts in the same region were reported to be even more important, bringing maximum observed atmospheric deposition rates up to 1000 mg/m^2*year.[25] Other authors have indicated even greater atmospheric deposition potentials for nitrogen as nitrate concentrations in rainfall are reported to commonly fall into the range 0.4 – 1.3 mg/l (at an annual precipitation rate of 35 inches, deposition would range from 267 to 1156 mg/m^2*year), but no dry deposition rates were given.[26] Assuming a total atmospheric deposition rate for nitrogen compounds of 1500 mg/m^2*year implies an annual load to Lake O' the Pines of 102,707 kg, or nearly 20% of the Big Cypress Creek loading. Again, only a fraction of this load would seem relevant to excessive nutrient conditions in the upper reservoir, although this magnitude of input is probably significant to the overall mass balance of nitrogen in Lake O' the Pines.

In addition to physical deposition of nitrogen compounds from the atmosphere, biological conversion of molecular nitrogen to ammonium ion (fixation), may be a significant source of nitrogen input to Lake O' the Pines during summer stratification. Nitrogen fixation during the summer may be carried out by blue-green algae (Cyanobacteria) in the aerobic epilimnion, by photosynthetic bacteria concentrated in the metalimnion, by heterotrophic bacteria in the anaerobic hypolimnion, and by benthic algae and bacteria, on shallow sediment surfaces within the euphotic zone. Aggregate rates of nitrogen fixation in lakes and reservoirs are reported to range from <100 to 800 mg/m^2*year, the extreme value corresponding to an annual load of 54,777 kg added to Lake O' the Pines.[27]

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[25] Wetzel, R.G. 1983. Linmology. Saunders College Publishing, Philadelphia, Fort Worth.
[26] Allan, J.D. 1995. Stream Ecology, Structure and Function of Running Waters. Chapman and Hall, London, New York.
[27] Rheinheimer, G. 1991. Aquatic Microbiology. John Wiley & Sons, New York.

Contributions of on site sewage treatment facilities (OSSFs) to the nutrient loads from the Lake O' the Pines watershed are included in the SWAT model as a consequence of subwatershed land uses, and are part of the calculated landscape loads. The Lake O' the Pines cove stations, which monitor runoff from small, generally forested subwatersheds that support low density residential uses near the reservoir exhibit significantly better water quality than the main basin. This indicates that OSSFs do not presently exert a major impact on Lake O' the Pines water quality, at least relative to other non-point and point sources located on tributaries to Big Cypress Creek.

4.0 LINKAGE

The Linkage Section of this report establishes the relationships between constituent loadings and the resultant water quality conditions in Lake O' the Pines. Violations of dissolved oxygen criteria in upper Lake O' the Pines were shown in Section 2 to be the result of high levels of community metabolism, that is, excessive levels of photosynthesis and respiration. In order to further investigate this inference and to better characterize dissolved oxygen conditions in Lake O' the Pines, community primary production and respiration were measured in shallow vegetated and unvegetated habitats above the SH 155 causeway. Large volume Plexiglas respirometers and deployable sondes were employed for this purpose during June and August 2002. Sondes were used to monitor dissolved oxygen concentrations in clear, open-bottomed Plexiglas boxes having volumes of about 250 liters (0.250 m^3) and areas of 0.372 m^2. Actual box dimensions are 24"x24"x30", so total volume is 283 liters, but the boxes are designed to limit sediment penetration to 4", which would result in a volume of 245.4 liters. Gentle circulation within the boxes was provided by battery-powered submersible pumps (1.6 liters/minute). Respirometers were deployed for 24-hour periods to assess night respiration and daylight oxygen production for the entire community, including planktonic and benthic (or attached) biota. Conventional diurnal dissolved oxygen measurements were taken for comparison at nearby representative locations.

The magnitude of the rates of respiration and gross production implied by the respirometer results are quite high, ranging from 5 to 7 gO_2/m^2/day in June, and 4 to 6 gO_2/m^2/day in August 2002 (Table 4-1). The dissolved oxygen amplitudes observed during the summer of 2002 (in both respirometers and in conventional dissolved oxygen diurnals) were only about half of those observed during summer 2001, providing an indication of the interannual range of variation to be expected in this parameter. Diurnal dissolved oxygen data collected during 2001 were used to calculate respiration rates during development of the QUALTX model of Lake O' the Pines.[28] Those calculations gave community respiration rates (i.e., nighttime dissolved oxygen decrease) of 8 – 30g O_2/m^2/d at 20°C, reflecting the more extreme changes occurring on a daily basis during that year.

The levels of production and respiration calculated from the diurnal dissolved oxygen curves in *Calibration and Verification of Lake O' the Pines QUALTX Model*[29] were used as model input to generate satisfactory simulations of the dissolved oxygen distribution in the reservoir. The resultant levels of metabolic activity and biomass necessary to generate the simulated dissolved oxygen distribution was then employed to derive estimates of the quantities of phosphorus and nitrogen needed to support that metabolic activity. On a steady-state, whole lake basis, this amounted to 339,682 kg P/year and 7,305,000 kg N/year, some 2.4 times the annual predicted total phosphorus load, and an 13.7 times the nitrogen load. QUALTX is, however, a steady-state model and, as we know from the 303(d) list itself, and from our subsequent monitoring efforts, reservoir metabolic activity varies in time and space, and adverse dissolved oxygen conditions occur only occasionally, presumably in response to the development of favorable conditions.

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[28] Ward, G.H. 2002. Calibration and verification of Lake O' the Pines QUALTX model. Lake O' the Pines TMDL deliverables 12K and 12L, submitted August, 2002.
[29] Ibid.

Table 4-1
Respiration and Net Production in Lake O' the Pines above the SH 155 Causeway During Summer, 2002

Night Respiration[2] ($mg0_2$/l-h)	MAX Slope Net Production ($mg0_2$/l-h)	Net Production[3] ($mg0_2$/l-h)	Sensor Depth (m)	Comment
27-28 June – Station 16868				
-0.24	0.17	-0.08	1.55	Bottom Set
-0.09	0.83	-0.11	0.08	30cm -Lotus bed
-0.20	0.47	0.37	0.88	Channel
-0.19	**0.22**	**0.05**	**0.74**	Lotus bed
-0.18	**0.10**	**<0.01**	**1.06**	Lotus bed
28-29 June – Above Cason Intake				
-0.28	0.16	0.27	0.48	Channel
-0.25	**0.25**	**0.08**	**0.39**	Lotus bed
-0.28	**0.20**	**-0.10**	**0.42**	Lotus bed
-0.35	0.08	-0.01	0.43	Lotus bed
29-30 June Station 17078				
-0.28	0.19	-0.02	0.70	Open water
-0.20	**0.18**	**0.01**	**0.65**	Open water
-0.15	**0.61**	**0.02**	**0.85**	Open water
-0.04	0.46	0.16	0.68	Open water
20-21 August – Station 16868				
-0.14	**0.0**	**-0.07**	**0.82**	Lotus bed
-0.20	**0.04**	**-0.14**	**0.86**	Lotus bed
-0.29	1.36	0.27	0.45	Lotus bed
-0.22	0.60	0.52	0.65	Channel
21-22 August – Station 16868				
-0.24	0.44	0.30	0.65	Channel
20-21 August – Above Cason Intake				
-0.18	**0.43**	**0.07**	**0.41**	Lotus bed
-0.36	0.94	0.35	0.20	Lotus bed
-0.30	2.02	0.17	0.58	Channel
21-22 August – Above Cason Intake				
-0.33	3.09	0.38	0.58	Channel
22-23 August – Above Cason Intake				
-0.23	0.47	**0.21**	**0.63**	Lotus bed
-0.20	0.10	**-0.09**	**0.93**	Lotus bed

[2]$\Sigma(\delta$DO 15-minute dark intervals 20:01-6:16)/10.25 hours
[3]$\Sigma(\delta$DO 15-minute daylight intervals 7:31-18:31)/11 hours
Bold type indicates respirometer data

The upper reservoir is the direct receiving water for the nutrient loads carried by Big Cypress Creek (Table 3-4). Water quality monitoring data from the TCEQ TRACS database and that collected as part of the TMDL program indicated that phosphorus and nitrogen concentrations at Station 13631 have varied substantially over time (Figures 3-1 and 3-2). While total phosphorus averages 0.173 mg/l over the entire period of record, the 1997-2002 average shown in Table 4-2 reflects the high concentration event centered on January 2000. Total nitrogen concentrations peaked slightly earlier (fall, 1999), but did not exhibit a unique event that substantially altered the long-term average.

In Lake O' the Pines, summer (May-September) phosphorus levels averaged less than 20 µg/l at the cove stations, but were in excess of 40 µg/l at the lower reservoir stations, and were much higher (>100 µg/l) in the upper portion of the reservoir, including the mid-lake (13977) and NETMWD intake (10297) stations (Table 4-2). Using the entire available database (including censored values averaged as their respective quantitation limits), total phosphorus concentration averages about 80 µg/l below SH 155, with few values above 100 µg/l during the period 1993-2002. If censored values (50% of summer total phosphorus results in the lower reservoir) are averaged as zeros, a lower bound of 0.015 – 0.020 mg/l total phosphorus is obtained for the lower reservoir stations, but the averages are based on very few values. Because the total phosphorus data collected at the dam outlet (Station 15135) by USGS during 1983-1992 and by the Lake O' the Pines TMDL program 2000-2002 were analyzed with lower quantitation limits (0.01 mg/l) than most of the reservoir data, the overall average concentration of 0.03 mg/l, and the summer (May-September) average of 0.04 mg/l, are likely the best estimates for the lower reservoir. Censored values accounted for only a small proportion of the data sets at the upper reservoir stations, and introduced little bias into the overall averages. In contrast to the summer results, Station 10300 in the reservoir headwaters exhibited an all season average total phosphorus concentration of 217 µg/l, with peak values exceeding 700 µg/l. While total phosphorus concentrations tended to be substantially higher during the fall-winter spring (October-April) in Lake O' the Pines, the opposite was true for the total nitrogen (TKN) data with higher levels of organic nitrogen present during the summer periods.

Measurements of summer inorganic nitrogen concentrations in Lake O' the Pines are available only for the 2000-2002 period. Excluding values below the quantitation limits (34% of ammonia and 54% of nitrite plus nitrate values), summer ammonia nitrogen concentrations averaged 0.112 mg/l and nitrate plus nitrate nitrogen averaged 0.092 mg/l over all stations (Table 4-2). Setting the censored results to zero gives summer averages of 0.092 mg/l ammonia and 0.030 mg/l nitrite plus nitrate. Results from Station 15135, excluding censored values, show summer outflow concentrations of 0.215 mg/l ammonia and 0.045 mg/l nitrate plus nitrate. Unlike total phosphorus or TKN concentrations, which tend to exhibit a gradient along the reservoir axis, little difference, either among reservoir locations or seasons, is evident in inorganic nitrogen concentrations.

A very rough estimate of the summer standing stock of total phosphorus and TKN (approximating total nitrogen) in Lake O' the Pines is presented in Table 4-3. Summer (May-September) nutrient concentrations in the epilimnion were based on the TCEQ TRACS and TMDL surface sample results for all Lake O' the Pines stations. Constituent concentrations in

Table 4-2
Average Inflow and Summer Epilimnion Concentrations of Chlorophyll-*a* and Major Nutrients, 1997-2002

Station Name	Dam*	Longview Intake	NETMWD Intake	Lone Star Landing	Big Cypress Inflow
Station Number	10296	16156	10297	10300	13631
Chlorophyll-*a* (µg/l)					
Average	8.12	8.00	14.02	14.42	
Standard Deviation	5.64	6.47	12.44	16.60	
n	23	13	13	13	
Total Phosphorus (mg/l)					
Average	0.069	0.042	0.121	0.130	0.289
Standard Deviation	0.101	0.065	0.217	0.061	0.302
n	23	13	13	12	23
Total Kjeldahl Nitrogen (mg/l)					
Average	0.626	0.564	0.819	1.019	2.623
Standard Deviation	0.264	0.162	0.153	0.220	2.750
n	24	13	13	12	23
N:P Ratio (g-atom basis)	20.1	29.7	15.0	17.4	20.1

*Data collected 1993 – 2002

Table 4-3
Lake O' the Pines Nutrient Mass Flux

	TP	TN
Inflows (kg/year)	+142,877	+533,000
Dry/wet deposition and N fixation (up to kg/year)	+6,800	+150,000
Water – Epilimnion (kg)	23,004	182,838
- Hypolimnion (kg)	7,893	32,759
Sediment (kg, 0-20 cm)	289,222	754,826
Lake O' the Pines Total (kg)	320,119	970,423
Denitrification (up to kg/year)		-181,000
Outflows (kg/year)	-17,000	-780,000
Lake O' the Pines Net Annual Gain (Loss) (kg)	132,677	(278,000)

the epilimnion were calculated from surface grab samples from stations 10296, 16156, 10297, 17078, and 10300. Hypolimnion concentrations were based on bottom summer (May-September) samples collected at Stations 10296, 16156, and 13977. The boundary between the epilimnion and hypolimnion was assumed to occur at 5 m, giving an oxic water mass occupying over 80 % of the reservoir volume during summer stratification.[30]

The physical characteristics of sediment cores collected from Lake O' the Pines stations in August, 1999 as part of a Clean Rivers Program special study are summarized in Table 4-3.[31] Sediment data is reported on a dry weight basis and includes a percent solids analysis. To calculate sediment constituents on an areal basis, one must also specify a sediment depth (in this case, 5 cm) and a sediment specific gravity. Two specific gravity numbers are used to span a reasonable range of sediment density. Table 4-4 presents the carbon, nitrogen and phosphorus content of those sediments based on subsamples taken from the surface and at 5, 10 and 20 cm depths. We assume that the phosphorus and nitrogen in the 0-5 cm surface layer in areas not isolated under a persistent hypolimnion is available for exchange with the epilimnion during the summer.

The estimates of atmospheric deposition and nitrogen fixation shown in Table 4-3 are based on the near maximum rates discussed in the preceding section. Denitrification was assumed to occur at a maximal literature rate (64 mg/m^2*day) for 100 days during summer on sediment surfaces under the hypolimnion.[32] These results indicate that phosphorus accumulated in Lake O' the Pines at a rate of 1938 mg/m^2 annually (132,677 kg/68471193 m^2) during the period monitored (1983-2002). The highest surface sediment phosphorus concentrations observed in Lake O' the Pines (ca.37, 500 mg/m^3), would require the annual deposition of 3,538,053 m^3 of sediment, a layer 5 cm deep throughout the reservoir. This is equivalent to a sedimentation rate of 874 acre-feet/year, about three times the sedimentation rate estimated by the Texas Water Development Board, a high rate, but not impossibly so.[33] In spite of the large inputs of nitrogen, accumulation in Lake O' the Pines did not take place during the period monitored, instead the reservoir experienced an average net loss of total nitrogen.

Paired values of total nitrogen and total phosphorus collected during 2000-2002 are used in Table 4-5 to characterize the summer epilimnitic N:P ratios in Lake O' the Pines. Total nitrogen and total phosphorus represent the entire macronutrient pool of the summer reservoir waters, including the inorganic, immediately available nutrients, nitrogen and phosphorus bound to non-living organic and inorganic particulate material which is more slowly available, and that contained in the living tissue of primary producers and microconsumers, which together are performing the bulk of the observed reservoir metabolism. The living tissue fraction, particularly rapidly growing plankton populations, tends to exhibit a N:P ratio of 16:1 on an atom for atom basis, and is expected to take up those nutrients in that ratio for growth. What we find is that it is

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[30] Texas Water Development Board. 1999. Volumetric survey of Lake O' the Pines. Hydrographic Survey Report, Austin, Texas.
[31] CRP. 2000. Targeted Monitoring in the Cypress Basin: Nutrient Study in Lake O' the Pines. Prepared for submission to TNRCC by Paul Price Associates, Inc. and Caddo Lake Institute, Austin, Texas.
[32] Ford, T.E. (ed). 1993. Aquatic Microbiology; An Ecological Approach. Blackwell Scientific Publications, London, Boston.
[33] Texas Water Development Board. 1999. Volumetric survey of Lake O' the Pines. Hydrographic Survey Report, Austin, Texas.

Table 4-4
Carbon, Nitrogen and Phosphorus Content of Lake O' the Pines Sediments

Station	Sample Interval	TOC (mg/m^2)	TKN (mg/m^2)	TP (mg/m^2)	TOC (mg/m^2)	TKN (mg/m^2)	TP (mg/m^2)
Dam (10296)		SpG=2			SpG=2.5		
	0-5 cm	25200	707	376	28127	789	420
	5-10 cm	78467	1119	587	90729	1293	678
	10-20 cm	249684	4074	1400	144729	2362	812
	0-20 cm	**353350**	**5900**	**2363**	**263584**	**4444**	**1910**
Longview Intake (16156)							
	0-5 cm	166296	2556	604	184016	2828	668
	5-10 cm	107784	2433	685	125371	2830	797
	10-20 cm	135997	5972	1713	78113	3430	984
	0-20 cm	**410077**	**10961**	**3002**	**387501**	**9088**	**2449**
NETMWD Intake (10297)							
	0-5 cm	417609	6340	3165	441196	6698	3344
	5-10 cm	79010	2590	814	90538	2968	933
	10-20 cm	147056	4777	3591	84908	2758	2073
	0-20 cm	**643675**	**13706**	**7570**	**616643**	**12424**	**6350**
Lone Star Boat Ramp (10300)							
	0-5 cm	121676	4843	1370	138634	5518	1561
Table 4-4 continued							
	5-10 cm	158153	2656	1430	181146	3043	1638
	10-20 cm	296146	6507	2353	169138	3716	1344
	0-20 cm	**575975**	**14006**	**5153**	**488918**	**12277**	**4543**
Brushy Creek (16448)							
	0-5 cm	152773	5098	1063	163515	5456	1137
	5-10 cm	90299	3329	788	103992	3834	907
	10-20 cm	142567	2124	1182	84149	1253	698
	0-20 cm	**385639**	**10551**	**3033**	**351656**	**10544**	**2742**

Table 4-5
Summer Epilimnion Nitrogen-Phosphorus Ratios
in Lake O' the Pines

Station	Date	TN	TP	mg-atN/l	mg-atP/l	N:P
10300	7/24/02	1.4272	0.098	0.101943	0.003161	32
17087	6/20/02	1.135	0.069	0.081071	0.002226	36
SH 155						
10297	7/19/00	0.928	0.02	0.066286	0.000645	103
10297	8/23/00	0.8666	0.01	0.0619	0.000323	192
Lower Reservoir						
16156	8/23/00	0.7632	0.01	0.054514	0.000323	169
16156	6/20/02	1.057	0.015	0.0755	0.000484	156
10296	8/23/00	0.9184	0.01	0.0656	0.000323	203
10296	7/24/02	0.606	0.01	0.043286	0.000323	134
Cove Stations						
16448	6/20/02	0.847	0.011	0.0605	0.000355	171
16450	6/20/02	0.6978	0.02	0.049843	0.000645	77

phosphorus that is in short supply in this system; the N:P ratios average 127, ranging from 32 to 203, a substantial oversupply of nitrogen relative to the amount of phosphorus present. Considering the values observed at the individual reservoir stations reveals a gradient in the N:P ratio consistent with our hypothesis that phosphorus is being assimilated, driving metabolic activity resulting in violations of the dissolved oxygen criteria, and being deposited through sedimentation during transport through the reservoir.

Considering just inorganic nitrogen, N:P ratios average 31, the same pattern emerges, one that reflects the preferential assimilation of phosphorus as the nutrients move down the reservoir axis from their primary source in Big Cypress Creek.

Examination of the N:P (and carbon) ratios in the sediment samples shows that, in contrast to the water column, sediment phosphorus is abundant relative to nitrogen, the situation seen in the external nutrient sources, and represents the endpoint of phosphorus assimilation and sequestration by burial in deep sediment. It is significant that the phosphorus content of the sediments at the upper stations (10300 and 10297) are two to three times the levels in the lower stations, reflecting the more intense assimilation and sedimentation taking place at those locations. Losses due to denitrification and net export of nitrogen in dam releases reflect the low N:P ratio of the sediments.

The distribution of dissolved oxygen throughout Lake O' the Pines depends on the interplay of lake physical properties and processes, and the biological processes of photosynthesis and respiration. The rate of photosynthesis is usually limited either by light or by the rate at which nutrients can be delivered to metabolizing cells, up to a threshold level beyond which the cellular machinery cannot use more light or nutrient. The highest rates of photosynthesis in algae (and plant cells in general) are achieved in actively growing populations that typically exhibit the highest ratios of chlorophyll-*a* to biomass characteristic of the species. At any point in time, the reservoir will harbor several plant populations with somewhat different distributions, abundances, and physiological states, plus heterotrophic populations, all of which interact with lake physical properties to produce the distribution of dissolved oxygen throughout the lake volume. The magnitude of lake metabolism, and the amount of oxygen produced and respired per unit time (hour, day, year), is generally proportional to its plant biomass; larger standing crops of algae and rooted vegetation usually support greater levels of oxygen production and uptake than do smaller standing crops. The adverse conditions commonly associated with excess nutrient input (turbid water, episodes of low dissolved oxygen concentration, floating algal blooms, taste and odor problems, fish kills) also tend to be associated with large plant standing crops, since it is their metabolism (together with the heterotrophic respiration the plant products support) that causes the problems.

Although the relationship of nutrient input to reservoir metabolism is well known in general, nutrient loads do not precisely predict either nutrient levels within the reservoir, or their effects on photosynthesis and respiration. For example, summer total phosphorus concentrations on the order of 0.04-0.05 mg/l are widely recognized to indicate potentially eutrophic conditions,[34] or to entail a high probability of severe algal blooms,[35] but the physical and biological characteristics of a given water body can greatly influence its response to particular levels of nutrient.[36] A number of empirical models have been developed to relate nutrient loads and levels to phytoplankton biomass, photosynthetic rate, and other phenomena such as composition of the plankton community, and turbidity. These relate directly to daily fluctuations in dissolved oxygen but are critically dependant on a host of physical, chemical and biological factors that are beyond our ability to model in detail, hence the development of steady state models and empirical (e.g., regression) models which ignore much of the detail, but which are sufficiently accurate to be useful as guidelines for analysis.

Given that larger plant biomass in the reservoir will tend to correspond with greater magnitudes of metabolism and, consequently, larger amplitudes of daily dissolved oxygen concentration change during critical conditions, we must inquire as to whether chlorophyll-*a* concentrations will provide an adequate index of that biomass in Lake O' the Pines, and thus of the probability of encountering adverse dissolved oxygen conditions. Chlorophyll-*a* concentrations are illustrated for summer sample dates in Figure 4-1, and station averages are presented in Table 4-2. These results show that chlorophyll-*a* levels in the lower reservoir are moderate, never exceeding the state screening level of 21.4 µg/l. This is confirmed by the outflow data collected at Station 15135 during 2000 – 2002; the six samples collected ranged from the quantitation limit (3.3 µg/l) to a high value of 16 µg/l in August 2000. Two of the highest chlorophyll-*a* measurements (33 and 31.2 µg/l) observed at the upper reservoir stations suggested moderate algal blooms, while the highest value of 58.5 µg/l measurement could be indicative of a severe bloom (Figure 4-1).

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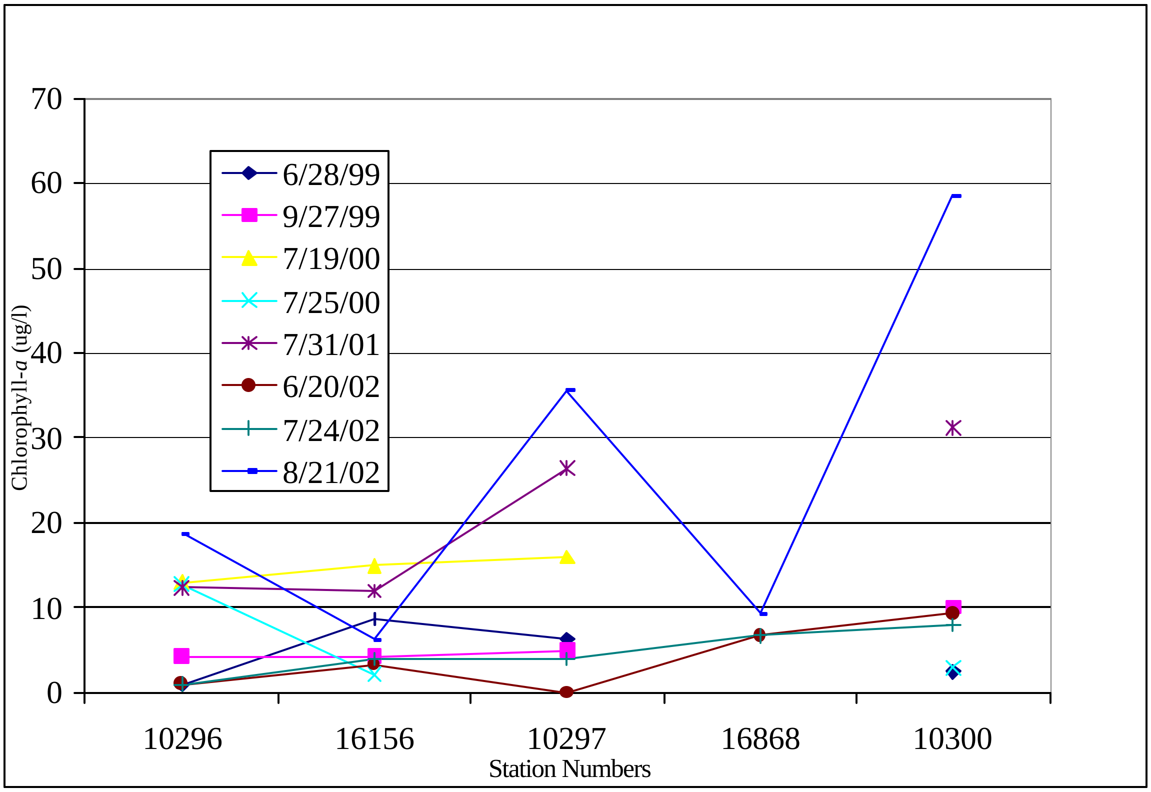
34 Carlson, R.E. 1977. A trophic index for lakes. Limnology and Oceanography 22(2):361-369

35 Havens, K.E. and W.W. Walker. 2002. Development of a total phosphorus concentration goal in the TMDL process for Lake Okeechobee, Florida (USA). Lake and Reservoir Management 18(3): 227-238

36 Stauffer, R.E. 1991. Environmental factors influencing chlorophyll *v.* nutrient relationships in lakes. Freshwater Biology 25: 279-295.

Figure 4-1
Summer Chlorophyll-*a* Concentrations (ug/l) at Lake O' the Pines Stations



In a direct evaluation of this relationship in Lake O' the Pines, dissolved oxygen amplitudes measured during diurnal studies were compared with chlorophyll-*a* and Pheophytin-*a* concentrations measured at the same time. The latter material results when the magnesium atom is lost from the active site of a chlorophyll-*a* molecule, and is an immediate consequence of cell death and lysis, such as occurs during passage through a crustacean gut. Subsequent degradation of the pheophytin proceeds rapidly, so its presence in the water column is a marker of algal population decline from grazing pressure or disease. The analysis was limited by a lack of time correspondence between dissolved oxygen diurnals and plant pigment measurements, but a weak (R^2 = 0.2898) positive relationship between dissolved oxygen amplitudes and Pheophytin-*a* concentration was present (Figure 4-2). Although still positive, the relationship with chlorophyll-*a* was much weaker (R^2 = 0.1097).

Paired values of chlorophyll-*a* and total phosphorus collected at the same stations and dates were employed to directly test the relationship with nutrient levels in Lake O' the Pines. Summer (May-September) data were screened for duplicates, which were averaged, and total phosphorus values below the quantitation limit were eliminated from the data set (Table 4-6). Total phosphorus quantitation limits in much of the original dataset ranged from 0.05 to 0.2 mg/l, much too high to provide meaningful evaluation of the chlorophyll-*a* total phosphorus link. The remaining 46 paired chlorophyll-*a* total phosphorus concentrations were then sorted into 10

Figure 4-2
Dissolved Oxygen Amplitudes Versus Pheophytin-*a* Concentration in Lake O' the Pines

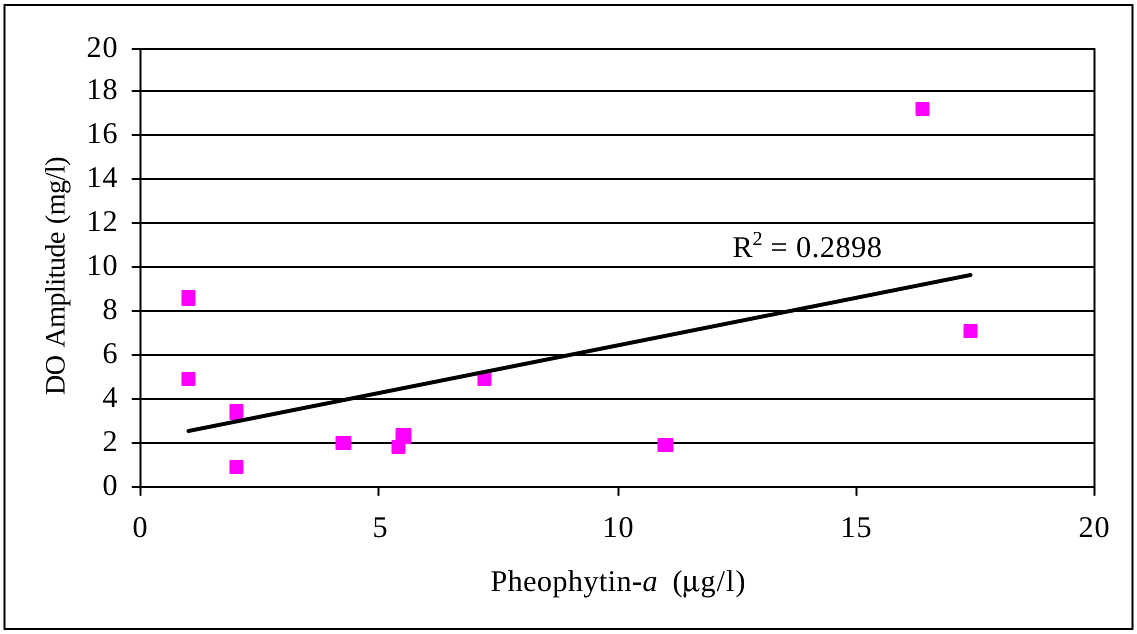


Table 4-6
Paired Summer (May-September) Total Phosphorus (mg/l)
and Chlorophyll a (µg/l) **Measurements From Lake O' the Pines**

Station	Date	TP	Chl a
10296	09/16/97	0.03	12.5
10296	08/24/98	0.03	2.94
10296	09/27/99	0.03	4.27
10296	07/19/00	0.02	13
10296	08/22/02	0.016	7.3
10297	08/12/97	0.11	21.3
10297	06/29/99	0.06	6.34
10297	09/27/99	0.05	4.98
10297	07/19/00	0.02	16
10297	07/13/01	0.5	10.7
10297	07/31/01	0.08	26.4
10297	05/14/02	0.08	18.7
10297	06/20/02	0.063	3.3
10297	07/24/02	0.031	4
10297	08/21/02	0.08	35.6
10297	08/22/02	0.062	5.4
10300	09/16/97	0.1	33

Table 4-6 continued

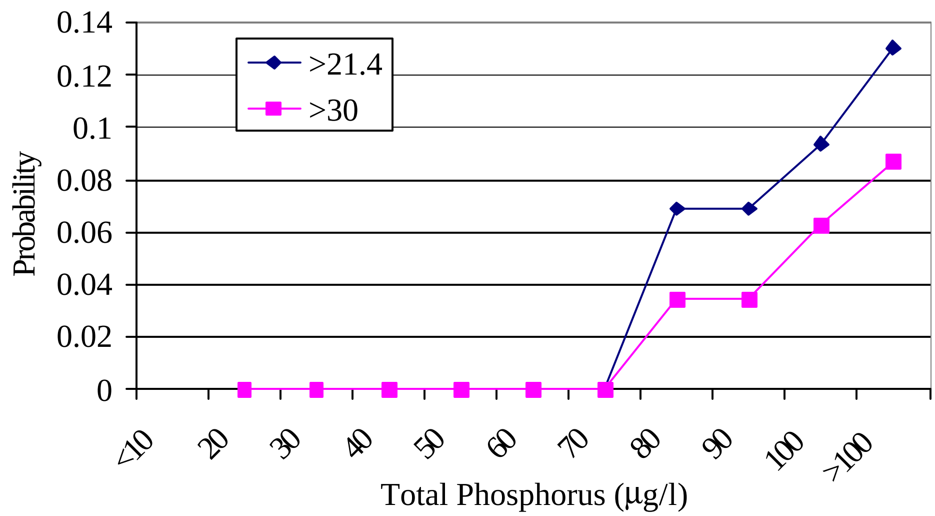
10300	05/11/98	0.07	3.47
10300	07/13/98	0.13	4.2
10300	06/28/99	0.28	2.49
10300	09/09/99	0.18	6.2
10300	09/27/99	0.14	10.1
10300	07/25/00	0.12	2.99
10300	07/31/01	0.15	31.2
10300	05/14/02	0.18	13.4
10300	06/20/02	0.063	9.3
10300	07/24/02	0.098	8
10300	08/21/02	0.16	58.5
13631	07/19/00	0.04	3.3
13631	06/20/02	0.063	17
13631	07/13/01	0.115	18
13631	07/24/02	0.098	9.3
13631	08/22/02	0.078	9.3
13977	05/18/99	0.13	13
16156	06/28/99	0.02	8.65
16156	09/27/99	0.04	4.27
16156	07/19/00	0.25	15
16156	06/20/02	0.015	3.3
16156	08/22/02	0.022	6.7
16448	07/24/02	0.196	2.7
16448	06/20/02	0.011	3.3
16449	07/24/02	0.012	4
16449	06/20/02	0.019	2.7
16868	06/20/02	0.052	6.7
17087	07/24/02	0.068	5.3
17087	06/20/02	0.069	13

equal intervals of total phosphorus concentration, with all total phosphorus values above 0.1 mg/l pooled. Inspection of the data set showed that the State screening criterion for chlorophyll-*a* (21.4 µg/l) was exceeded only when corresponding total phosphorus concentrations equaled or exceeded 0.07 mg/l. Chlorophyll-*a* concentrations averaged 6.8 µg/l when corresponding total phosphorus levels were less than 0.07 mg/l, and 16.7 µg/l when total phosphorus exceeded 0.07 mg/l, a statistically significant difference (t-test, unequal variance, $P<0.002$). Figure 4-3 shows these results as cumulative probabilities for exceeding the two thresholds.

For its observed levels of total phosphorus, Lake O' the Pines exhibits a rather small standing crop of chlorophyll-*a*, and in fact, correspondingly infrequent dissolved oxygen problems. TMDL work on Lake Okeechobee, for example, documented total phosphorus concentrations averaging 0.087 mg/l in open waters and 0.056 mg/l in vegetated near shore areas (comparable to, but opposite from the phosphorus distribution in Lake O' the Pines) that corresponded to chlorophyll-*a* averages of 25 and 26 µg/l, respectively, about twice the levels in Lake O' the Pines.[37]

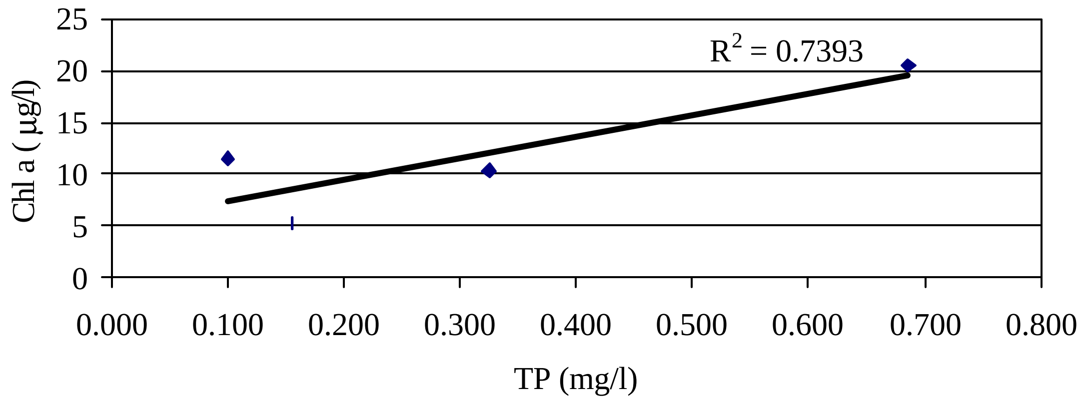
A direct relationship is also implied between average annual total phosphorus concentration in Big Cypress Creek and average summer chlorophyll a concentration in the main basin of Lake O' the Pines, although a lack of chlorophyll a data prior to 1998 severely limits the robustness of this conclusion (Figure 4-4).

Figure 4-3
Threshold Frequencies of Chlorophyll a Versus Total Phosphorus Concentrations



[37] Havens, K.E. and W.W. Walker. 2002. Development of a total phosphorus concentration goal in the TMDL process for Lake Okeechobee, Florida (USA). Lake and Reservoir Management 18(3)

Figure 4-4
Average Annual Total Phosphorus Concentration at Station 13631 Versus Summer Average Chloroplyll a Concentration in Lake O' the Pines the Following Year (1998-2002)



To establish a quantitative relationship between phosphorus loading and concentrations in Lake O’ the Pines, we can employ a simple empirical model developed by Vollenweider to relate landscape loading to lake or reservoir total phosphorus concentration:[38]

$$TP\ (mg/m^3) = \frac{\text{load}\ (mgTP/m^2*year)}{Z\ (\rho + \sigma)}$$

Where load refers to areal loading, or the mass of annual total phosphorus loading (from the SWAT simulation plus the point source load, Table 3-4), divided by reservoir area:

$$= (113{,}000 + 29{,}877\ kgTP/year)*1{,}000{,}000/68{,}471{,}193\ m^2$$
$$= 2087\ mgTP/m^2*year.$$

Z = average depth (reservoir volume/reservoir area, 4.34 m),[39]
ρ = flushing rate (reservoir volume/annual inflow, 1.89), and
σ = sedimentation coefficient (10/Z)

$$TP_{total} = 2087/4.34(1.89 + 10/4.34)$$
$$= 115\ mg/m^3 \ \text{ or } 0.108\ mg/l$$

The estimated load gives excellent agreement with the observed total phosphorus concentrations in the reservoir, recognizing that the model gives an average value over the phosphorus gradient

[38] Cooke, D.G., et al. 1993. Restoration and Management of Lakes and Reservoirs. Lewis Publishers, Boca Raton.
[39] Texas Water Development Board. 1999. Volumetric survey of Lake O’ the Pines. Hydrographic Survey Report, Austin, Texas.

characteristic of Lake O' the Pines. Total phosphorus averaged 0.114 mg/l using all data 1997-2002 and setting censored values to their respective detection limits. When censored values are set to zero, the average falls to 0.096 mg/l. The SWAT landscape load (18,200 kg/year, or 266 mg/m^2*year) can be used to examine the lower limit of average phosphorus concentration potentially achievable in Lake O' the Pines (without human activity in the watershed not an actual, feasible lower limit):

$$TP_{Natural} = 266/4.34(1.89 + 10/4.34)$$
$$= 14.6 \text{ mg/m}^3 \text{ or } 0.015 \text{ mg/l}$$

To minimize the probability of algal blooms (either planktonic or periphytic), it will be desirable to reduce the average total phosphorus concentration in the upper reservoir to below 0.07 mg/l. Given that the current reservoir summer average is about 0.095 mg/l and the upper reservoir stations average about 0.125 mg/l, an approximately 50% reduction in average total phosphorus concentration (to 0.0475 mg/l) would be required. Solving the Vollenwieder model for the appropriate load gives:

$$Load_{desired} = TP^*Z(\rho + \sigma)$$
$$= 47.5 \text{ mg/m}^3 {}^*4.34(1.89+10/4.34)$$
$$= 865 \text{ mgTP/m}^2 {}^*\text{year or } 59{,}200 \text{ kg/year}$$

This equals a reduction in the existing total phosphorus load by 83,677 kg/year, or 58% (142,877 – 59,200 = 83,677 kg/year).

Margin of Safety

The need for a margin of safety in TMDL determination stems from the dilemma of specifying water-quality control strategies on the basis of imperfect science, which is, in turn, driven by the need to implement controls early enough to arrest water-quality degradation and avoid perhaps irreversible impacts of contaminant loads, without affording the time necessary to establish the cause-and-effect linkages to an adequate level of scientific assurance. Quantification of the uncertainty in the science underlying TMDL determination, to the extent possible, is the basis for assigning a margin of safety.

There are two fundamental sources of uncertainty in the various procedures resulting in the TMDL determination for Lake o' the Pines. The first of these are inaccuracies in measurement that arise from limitations of sampling procedures, instrumental imprecision, and inhomogeneities and variabilities in the environment itself, all of which may include both random and systematic (non-random or bias) error. Many of these, especially hydrologic and water-quality data, can be quantified by the exercise of repeated measurements. Some of these, such as land-use designation, crop coverage, soils characteristics, vegetation cover, and diversion and return flow disposition, have acknowledged uncertainties due to information deficiencies and limits of resolution, but there is no acceptable procedure for estimating these uncertainties. Still other factors, such as agricultural cropping strategies, fertilizer applications, wastewater treatment overflows, CAFO animal density, and herding practices on rangelands, must be inferred from sparse anecdotal information, whose uncertainty can only be guessed.

The second fundamental source of uncertainty, and the one which is often of interest to those engaged in predictive modeling of water quality, results from our imperfect understanding of the system under study. This includes approximations of the parameters specified in the model (e.g., rate coefficients, kinetic interactions, etc.), invalid or incorrect premises in the conceptual model on which the system analysis is based (e.g., neglect of benthal fluxes, effects of additional factors such a predation of algae or concentrations of silicates), and the inability to perfectly (or adequately) represent important system features and interactions in the mathematical model chosen to represent it (e.g., approximating horizontal mixing by a dispersion equation). Sometimes these uncertainties may be formally quantified through the use of "sensitivity analyses", in which model input parameters are varied systematically and the corresponding behavior of the model output is determined.[40] A significant, often compromising, problem with such formal sensitivity analysis is that the variation in the input parameter is not tied to its natural range of variation, but is rather assigned an arbitrary value, e.g. ±10%. This leads to erroneous conclusions about the relative importance of the various parameters. In the present project of developing a TMDL for Lake O' the Pines, the approach is taken of quantifying modeling uncertainty as part of the validation procedure, i.e. by examining the variance of field data about the model prediction. This allows us to include a measure of parameter variation that includes at least a portion of the natural range in our assessment of the reliability and accuracy of the simulations. This uncertainty is addressed, for example, in "Calibration and verification of Lake O' the Pines QUALTX water-quality model", August 2002.

In the future-scenario evaluations underlying the TMDL, the specification of conditions for model operation is subject to both types of uncertainty. Errors in measurement may further exacerbate the TMDL projection by forcing the water-quality prediction beyond the range of historical measurement. Future scenarios may include land-use and population forecasts, which are themselves inaccurate (and subject to both types of uncertainty). The conceptual-model uncertainties may become even more problematic because of projected changes to the landscape or to the structure of the receiving water.

Measurement uncertainties

As noted above, the most basic source of uncertainty arises in the measurement itself. Laboratory quality control procedures include the analysis of calibration standards and samples spiked with known amounts of analytes along with each set of field collected samples (Lake O' the Pines TMDL Quality Assurance Project Plan, QAPP, Section A7) to assess the accuracy, or systematic error in lab methods.[41] For parameters requiring calibration standards, percent recoveries of 75-125% of the known concentration must be achieved for the simultaneously analyzed sample set to meet data quality objectives. Laboratory matrix spikes, likewise, must meet recovery rates of 80-120%. Expectations for laboratory analyses are that single

[40] USEPA, 1997. *Technical Guidance Manual for Developing Total Maximum Daily Loads. Book 2: Streams and Rivers, Part 1: Biochemical oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication*. Appendix D Uncertainty Analysis. EPA 823 B-97-002

[41] American Public Health Association, A.W.W.A., Water Environment Federation, *Standard Methods for the Examination of water and Wastewater*. 20th ed, ed. L.S. Clesceri, A.E. Greenberg, and A.D. Eaton. 1998, Washington, DC: American Public Health Association.

measurements will be accurate to within 20-25% of the actual parameter values.

Precision of laboratory methods is assessed through the analysis of laboratory duplicate (split) samples prepared with reagent water and analytes. Precision refers to the repeatability of measurements, without regard to the accuracy or bias inherent in the method, and the analysis of duplicate aliquots of the same sample is an assessment of the random error in lab procedures. For the simultaneously analyzed sample set to meet data quality objectives, differences between laboratory duplicates must not exceed 10 to 30% of the mean value of the two samples (Relative Percent Difference, RPD), depending on the parameter considered (QAPP, Section A7). Criteria for duplicate sample differences approximate 95% confidence intervals based on a long series of measurements of laboratory duplicates for each parameter.

Field duplicates are samples collected from the same location in immediate succession and submitted to the laboratory for separate analysis. Field duplicate results reflect both random error in laboratory methods, and those accruing from environmental inhomogeneities on small time and space scales, sampling error, and sample holding and transport procedures. They are quantitatively evaluated by calculating RPDs, but there are no specific criteria that sample sets must achieve (QAPP Section B5).

Table 4-7 summarizes laboratory duplicate sample criteria for selected parameters and the results of field duplicate sample analysis completed as part of the Clean Rivers Program in the Cypress Creek Basin and for the Lake O' the Pines TMDL Program. Both programs utilized the same laboratory (Ana-Lab Corporation, Kilgore, Texas) and the same sampling, transport and analytical methods (compare Cypress Creek Basin Clean Rivers Program and Lake O' the Pines TMDL QAPPs). Parameters selected for inclusion in this table were those for which duplicate analyses were performed and which were important in development of the TMDL analysis. Censored values were excluded from the calculation only when both measurements of a duplicate set were below the ambient water reporting limit (AWRL, i.e., non-detects, ND in Table 4-7). The presence of censored values is a significant source of uncertainty for several of these parameters. While this is evident in the chlorophyll-*a* and phosphorus results, low concentrations (and non-detects) of nutrients, including both phosphorus and inorganic nitrogen species, tended to occur most often during the critical period (summer stratified conditions) at Lake O' the Pines stations (see "Calibration and verification of Lake O' the Pines QUALTX water-quality model", August 2002).

The variability in field duplicate sample results is much larger than the control criteria based on laboratory duplicate analysis. As noted above, this is because field sampling is subject to a broader source of measurement error, from environmental inhomogeneities on small time and space scales, sampling error, and sample holding and transport procedures. By analogy with the method used to calculate control criteria for duplicate sample sets in the laboratory, 95% confidence intervals were calculated for each parameter in Table 4-7 as two relative standard deviations (RSD) of the of the normalized differences (RDPs) between duplicate samples. The 95%CI can be regarded as an extreme measure of uncertainty to be associated with each parameter as it predicts a difference for single samples, as a percentage of that sample value, within which a duplicate sample result can be expected to fall 95% of the time. Regression

Table 4-7
Precision of Duplicate Sample Sets for Selected Parameters Collected and Analyzed Under the Cypress Creek Basin Clean Rivers Program and Lake O' the Pines TMDL QAPPs

	Lab Precision Criteria (RPD*)	Summary Statistics of Field Duplicate Samples					
		n (%ND)	n(pairs)	Range RPD (%)	Mean RPD (%)	RSD** (%)	95% CI (% sample value)
Total Suspended Solids	20	86 (0)	43	0-149	26.3	32.8	47.6
Total Dissolved Solids	20	78 (0)	39	0-78	22.9	19.1	38.2
Total Organic Carbon	10	82 (0)	41	0-70	8.7	13.0	26.0
Total Kjeldahl Nitrogen	10	86 (4.7)	41	0-115	24.6	24.2	48.4
Nitrite + Nitrate Nitrogen	10	74 (16.2)	32	0-43	9.7	19.0	38.0
Ammonia Nitrogen	10	86 (7)	42	0-176	34.5	40.2	80.4
Total Phosphorus	10	82 (34.1)	36	0-164	36.3	42.7	85.4
Ortho Phosphorus	10	84 (81.0)	9	0-105	29.7	36.9	73.8
Chlorophyll-*a*	30	84 (50.0)	24	0-124	46.1	32.8	65.6

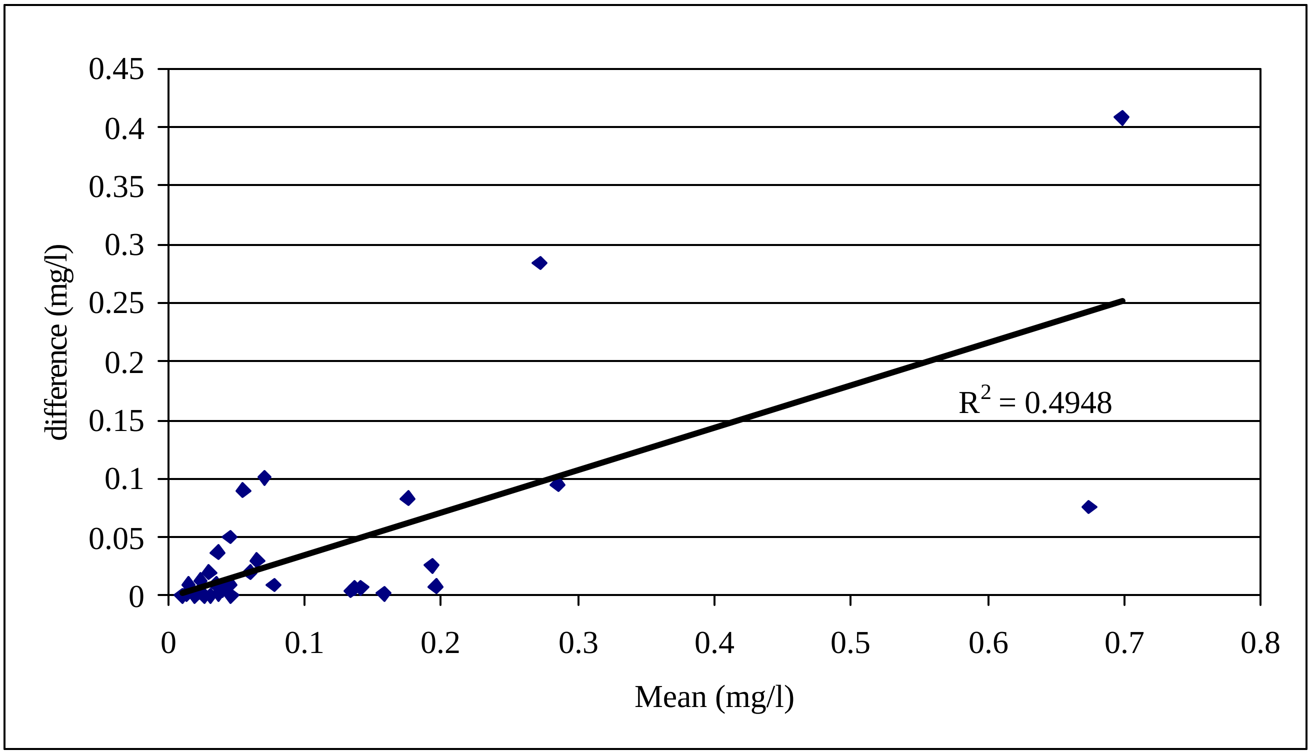
*Relative Percent Difference = $(|X_1-X_2|)/\{(X_1+X_2)/2\}*100$

**Relative Standard Deviation = $\sqrt{\dfrac{n\sum RPD^2 - (\sum RPD)^2}{n(n-1)}}$

analyses of mean and difference values for each parameter set show significant relationships ($P<0.05$) for all except for TOC, TKN and nitrite plus nitrate nitrogen, although R^2 values indicate that most of the variance in duplicate sample differences is unexplained by the magnitude of the means, even for regressions that are highly significant. This is illustrated in Figure 4-5, the regression of total phosphorus duplicate means on differences, which is highly significant ($P<0.001$).

Uncertainty in individual measurements of dissolved oxygen concentration arise through instrument error, which is held to $\pm$ 0.5 mg/l (or $\pm$6 % of saturation) of precalibration readings by appropriate instrument maintenance and pre and post calibration procedures (TCEQ, SWQM YSI Multiprobe Calibration/Maintenance Logbook). However, if a series of dissolved oxygen measurements are carried out at a given location, as in a diel set using a deployable probe

Figure 4-5
Mean of Duplicate Total Phosphorus Concentrations vs Corresponding Difference in Concentrations

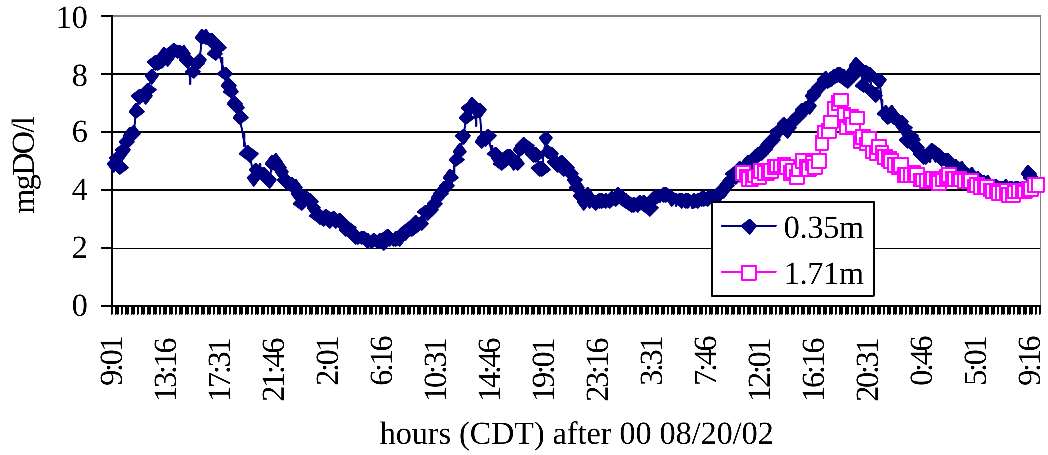


(sonde), the individual oxygen measurements generally show deviations from the expected smooth curve that may be larger than this limit. Additionally, the record may show phenomena, such as nighttime increases in dissolved oxygen concentration, which cannot be explained by primary production and are not likely to result from instrumental error. This is illustrated in Figure 4-6 for Lake O' the Pines near the dam and for a site on Big Cypress Creek.

The largest variability in the dissolved oxygen data from Lake O' the Pines is present in the data from the shallow upper portion of the reservoir. The apparent correlation of dissolved oxygen measurement variability and anomalies with the poorly mixed, diverse habitats represented by the sluggish, vegetated lower reach of Big Cypress Creek and upper Lake O' the Pines indicates that this source of measurement uncertainty is environmental inhomogeneity: *viz*. the spatial variation in dissolved oxygen concentration persisting in an incompletely mixed water column. This actual environmental variability is very likely the source of the uncertainties present in the field duplicate data set that are in addition to the variance arising from laboratory and instrumental errors, and which are reflected in the wide confidence intervals of Table 4-7.

Figures 4-7 and 4-8, respectively, show sonde records made simultaneously in upper Lake O' the Pines in the open water column, and in a Plexiglas enclosure sealed to bottom sediments and stirred with a small submersible pump. These records, typical of those collected during the summer 2002, exhibit the dissolved oxygen variability characteristic of a lake water column (Figure 4-7) versus the much-reduced variability observed in the well-mixed enclosure

Figure 4-6
Epilimnion Dissolved Oxygen concentrations at Lake O' the Pines Station 10296, August 20-23, 2002, and Big Cypress Creek Station 16457, 30 August - 1 September 1999



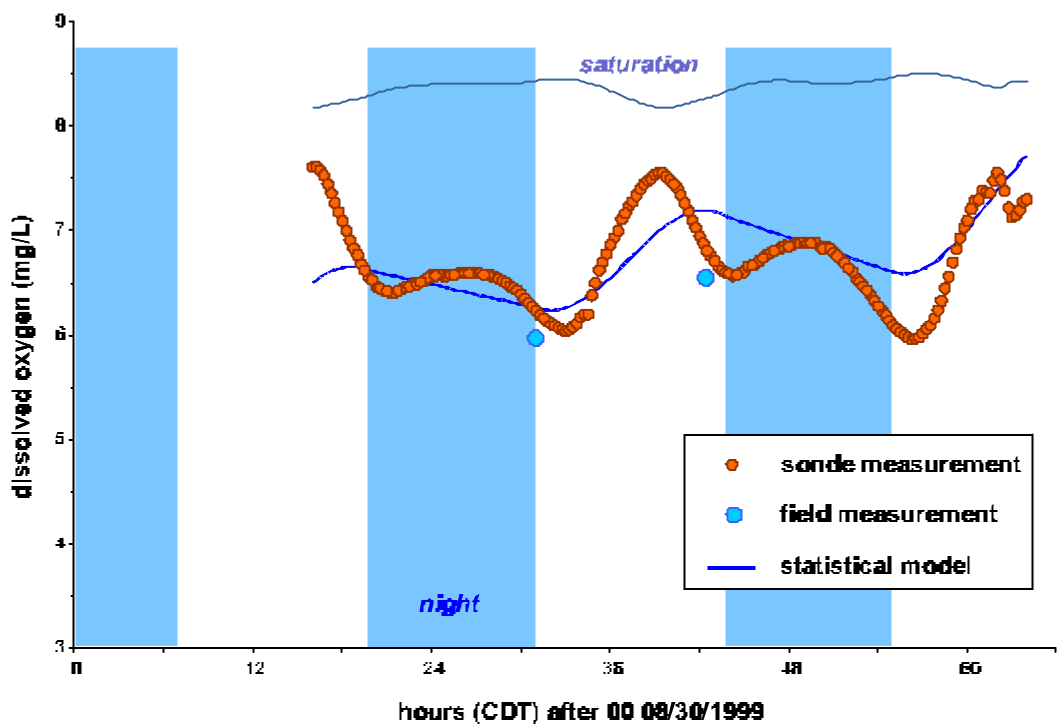
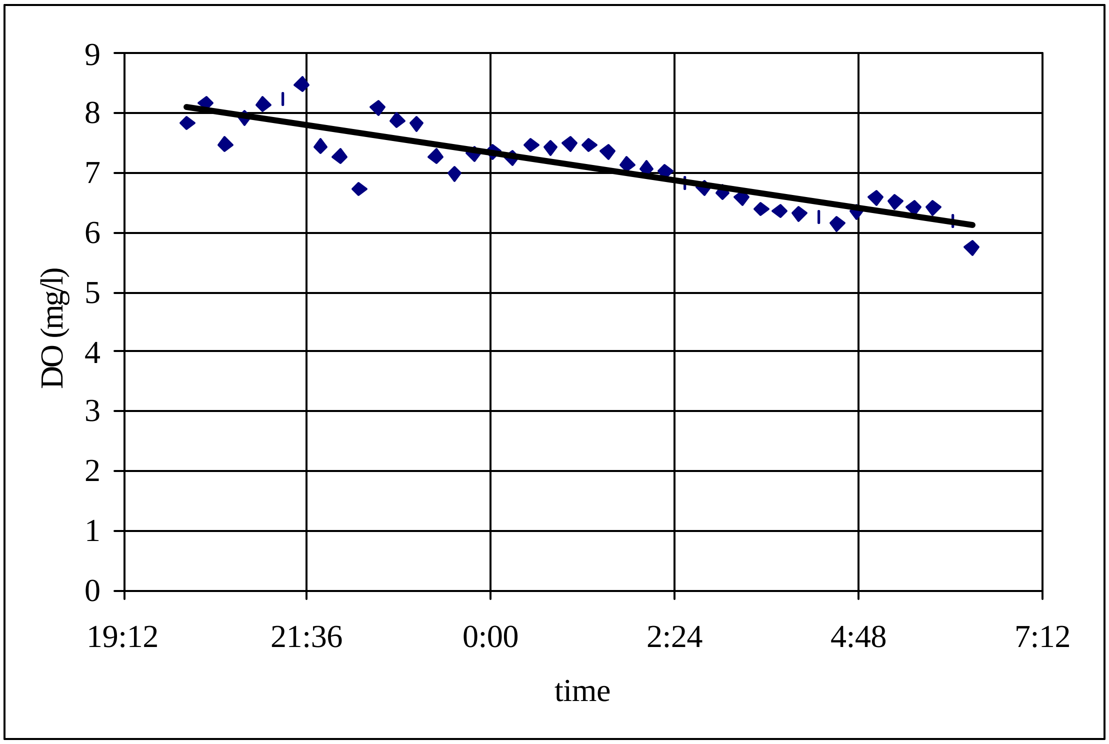


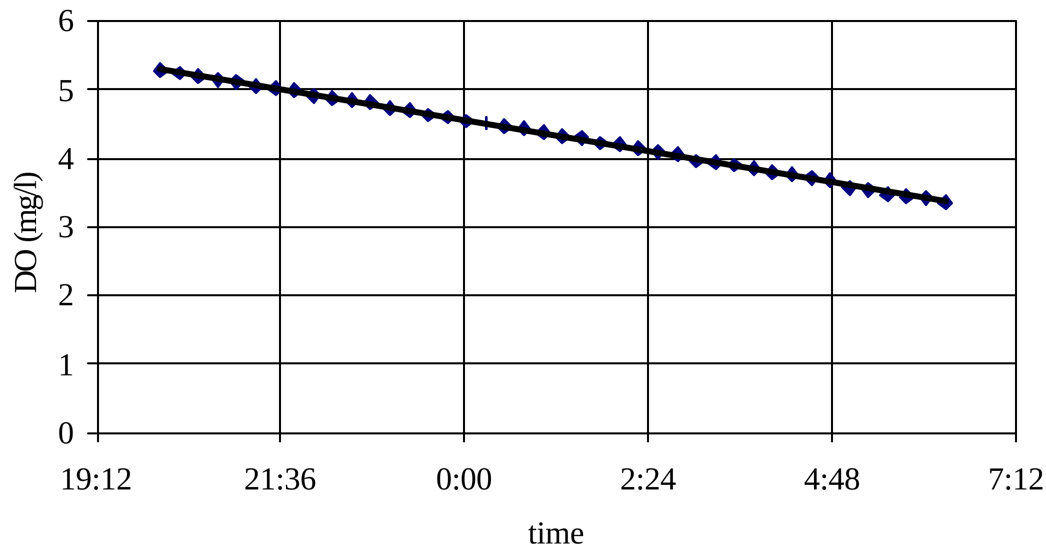
Figure 4-7
27-28 June, 2002 Night Dissolved Oxygen Concentrations at I m Depth in Upper Lake O' the Pines



environment (Figure 4-8). In spite of the differences in concentration ranges and variability of the individual data points, the night respiration rates ($mgO_2/l*h$) estimated from the regression slopes of dissolved oxygen concentrations versus time in three successive series of diel measurements all agreed within 14% of their respective mean values. In the same set of measurements, night respiration rates differed by 45% from one night to the next.

On a larger time and space scale, variability in the environment induces additional variation in water quality measurements whose cause cannot be resolved from the rather coarse information on environmental conditions, such as general streamflow, air temperature and reservoir contents. This larger scale variability is suppressed in data analysis by constructing various average values that are considered to typify the water quality "climate". The water-quality "climate" of Lake o' the Pines and the Big Cypress has been addressed in the analysis of field data from both of these systems. This has included assessment of variability in the measurements. Some of arises from time variation in the system, which is only coarsely sampled by sparse monitoring stations. This includes seasonal variation, some of it is diurnal, and some arises from apparently random fluctuations in the aquatic environment. Certainly, spatial variation (stratification, turbulence, responses to hydrographic "events" etc.) is a major contributor to this variation as well. Annual cycles of change in light penetration, temperature, stratification, and hydrologic inputs to Lake O' the Pines were initially characterized in the technical memorandum "Thermal structure of Lake O' the Pines" (August, 2000). Existing data were reviewed to develop a statistical

Figure 4-8
27-28 June Night Dissolved Oxygen Concentrations in a Metabolism Enclosure in Upper Lake O' the Pines



description of the seasonal changes in water temperature in response to the annual cycle of solar radiation and regional climatic conditions. The annual progression of temperature stratification in Lake O' the Pines was summarized, with statistical delineations of the seasonal development, depth, stability (rate of temperature change with depth) and decay of the thermocline. Data reviewed and employed in this descriptive analysis included water temperature profiles collected from Lake O' the Pines 1973-1999 and meteorology data from the Longview WBAN station 1983-1990.

Existing Data (1973-1999) from Lake O' the Pines was utilized in "Dissolved oxygen structure and trends in Lake O' the Pines" (September, 2000) to characterize the dissolved oxygen budget of the reservoir. This included development of a statistical description of the annual changes in dissolved oxygen concentrations and oxygen solubility in the upper layer (epilimnion) of the reservoir and an evaluation of trends in dissolved oxygen concentrations over time at locations in the upper and lower ends of Lake O' the Pines. These dissolved oxygen trends were evaluated in both a classically defined epilimnion and in a "mixed surface layer" as defined by TCEQ.

The technical memorandum entitled "Volume budget and hydrological variability of Lake O' the Pines" (February, 2001) presented the orderly development of a hydrologic budget for the reservoir. Existing data available from the Texas Water Development Board, U.S. Geological Survey, National Weather Service, and U.S. Army Corps of Engineers were used to develop a preliminary water budget based on statistical descriptions (monthly averages and confidence intervals) of annual rainfall pattern, reservoir area and volume from daily stage data, evaporation from the reservoir surface, and streamflow in Big Cypress Creek, both upstream and downstream of the reservoir.

The hydrologic budget developed in the memorandum discussed in the preceding paragraph was employed in characterizing the dependency of water quality conditions on reservoir throughflow and identifying critical conditions in the technical memorandum entitled “Seasonal and hydrological controls on dissolved oxygen in Lake o' the Pines” (February, 2001). To evaluate the association between reservoir inflows and the development of adverse dissolved oxygen conditions, monthly reservoir inflows were plotted against average epilimnion dissolved oxygen concentrations and deficits (see “Dissolved oxygen structure and trends in Lake O' the Pines”). This analysis showed that the lowest dissolved oxygen concentrations and dissolved oxygen deficits occur during the lowest flow periods during late summer and fall in the lower and middle basins of Lake O’ the Pines. Further analysis indicated that immediate inflow conditions were much better predictors of the tendency toward development of high dissolved oxygen deficits than were cumulative inflows (and hence, loadings) during the 2-6 preceding months.

Modeling and analysis uncertainties

Analytical and modeling work on Lake O’ the Pines (i.e., “Rational for Selection of Lentic Model”, March 2001, and “Calibration and verification of Lake O’ the Pines QUALTX water-quality model”, August 2002) has focused on dissolved oxygen kinetics during the low flow regime of late summer-fall that was identified as the critical period for development of excessive dissolved oxygen deficits. Sonde data taken under these conditions were extensively analyzed to separate respiration and photosynthesis contributions. The uncertainty in the parameterization of these processes is summarized by the standard errors about the statistical model ("standard error of the estimate", SEE) shown in Tables 4-8 and 4-9. (The kinetic coefficients are not the prime concern in this discussion. These are defined and discussed in the cited report.) The SEE is nominally 1 mg/L for nighttime (respiration-dominated conditions), varying primarily with position in the reservoir. The daytime data are noisier, not unexpected given the more complex factors of algal production, varying sunlight, vertical mixing, and patchiness that operate during daylight.

The work on the watershed model drew on baseflow and wet weather data collected throughout the annual cycle to delineate the seasonal progression of nutrient and organic oxygen demand loading of the tributary system and transport to Lake O’ the Pines, summarized in "Validation of watershed loading model", November 2002. The most important output of the watershed modeling is the landscape load of nutrients. This load is comprised of two components: the hydrological component, i.e. the volume of runoff derived from a storm event, and the concentration of constituent in the runoff water. Both are subject to uncertainty. For the runoff volume, the uncertainty in the measured values is exemplified by the data of Table 4-10, in which the estimated error is based upon the quality of the flow measurement, reliability of the rating curve, and "noise" in the precipitation delivery. The uncertainty in flow volume is no better than 15% and can be as high as 40%. (With more data and a longer monitoring history, this would improve over time.) Flow over the course of the runoff event is measured continuously in time. The companion time

Table 4-8
Linear regressions of dissolved oxygen from night periods, diurnal sonde data

Station	*position (km)*	*date*	*N*	K_a	C_r	*r*	*SEE*
a. Main-stem stations							
upper reach							
10300	28.7	24-25 Jul 01	40	0.21	-1.26	0.13	3.87
16868	26.9	24-25 Jul 01	41	0.15	-0.54	0.13	1.70
17087	24.0	24-25 Jul 01	41	0.22	-0.73	0.18	1.23
central reach							
10297	18.5	20-21 Sep 00	49	0.06	-0.17	0.09	0.33
		23-24 Jul 01	41	0.00	-0.32		0.57
lower reach							
16156	8.6	20-21 Sep 00	49	0.00	-0.13		0.24
		23-24 Jul 01	41	0.02	-0.12	0.05	0.20
10296	0.3	23-24 Jul 01	41	0.00	-0.50		2.10
b. Cove stations							
16452	2.0	20-21 Sep 00	49	0.05	-0.12	0.11	0.19
		23-24 Jul 01	41	0.00	-0.13		0.22
16450	2.2	20-21 Sep 00	49	0.00	-0.08		0.31
		23-24 Jul 01	41	0.00	-0.10		0.15
16448	2.5	20-21 Sep 00	49	0.21	-0.65	0.12	0.72
		23-24 Jul 01	41	0.00	-0.13		0.47
16449	2.5	23-24 Jul 01	41	0.00	-0.03		0.11

Table 4-9
Cosine regressions from daylight periods, diurnal sonde data

Station	*position (km)*	*date*	*N*	*S*	*μ*	*SEE*
a. Main-stem stations						
upper reach						
10300	28.7	24-25 Jul 01	55	4.37	-0.04	5.73
16868	26.9	24-25 Jul 01	55	1.20	0.01	1.64
17087	24.0	24-25 Jul 01	55	1.11	0.04	1.57
central reach						
10297	18.5	20-21 Sep 00	46	0.31	-0.01	0.44
		23-24 Jul 01	55	1.04	-0.01	0.95
lower reach						
16156	8.6	20-21 Sep 00	47	0.33	0.00	0.48
		23-24 Jul 01	55	0.41	0.01	0.31
10296	0.3	23-24 Jul 01	55	1.22	0.10	2.49
b. Cove stations						
16452	2.0	20-21 Sep 00	46	0.36	0.01	0.35
		23-24 Jul 01	55	0.33	0.00	0.99
16450	2.2	20-21 Sep 00	47	0.20	0.00	0.34
		23-24 Jul 01	55	0.25	0.00	0.18
16448	2.5	20-21 Sep 00	47	0.56	0.02	0.57
		23-24 Jul 01	55	0.29	0.01	0.66
16449	2.5	23-24 Jul 01	55	0.17	-0.01	0.34

Table 4-10

Storm analyses: hydrograph events

reference	*start*	*duration*	*volume*	*mean*	*est*	*R/R*
	date	*flow*	*error*			
0000 CST	*(days)*	*(hrs)*	*(m3)*	*(m3/s)*	*(%)*	
10263 Tankersley Creek at FM 127						
10-Jan-01	0.81	64.7	2.41×10^5	1.03	20	0.19
11-Oct-01	0.14	44.5	8.02×10^5	5.01	30	0.34
12-Oct-01	0.96	45.0	5.62×10^5	3.47	25	0.21
27-Nov-01	0.96	97.0	4.72×10^5	1.35	40	0.11
10266 Hart Creek at SE 12						
10-Jan-01	0.96	61.2	4.98×10^5	2.26	20	0.25
11-Oct-01	0.52	35.3	5.08×10^5	4.01	30	0.13
12-Oct-01	1.00	52.0	5.91×10^5	3.16	30	0.11
27-Nov-01	1.52	59.5	5.29×10^5	2.47	40	0.07
16455 Alley Creek at SH 155						
10-Jan-01	0.75	40.3	3.29×10^4	0.23	25	0.08
11-Oct-01	0.00	48.0	1.90×10^5	1.10	30	0.10
12-Oct-01	1.00	72.0	3.44×10^5	1.33	30	0.20
27-Nov-01	0.96	97.0	3.27×10^5	0.94	40	0.13
24-Jan-02	0.06	70.5	8.65×10^4	0.34	40	0.12
17030 Prairie Creek Tributary at CR 1264 Crossing						
10-Jan-01	0.57	71.8	4.48×10^3	0.02	20	0.13
10-Oct-01	1.17	20.0	2.26×10^3	0.03	15	0.05
13-Oct-01	0.96	49.0	1.17×10^4	0.07	20	0.12
17031 Prairie Creek Tributary at CR 1140 Crossing						
10-Jan-01	0.71	68.0	1.28×10^4	0.05	20	0.12
10-Oct-01	1.18	43.0	6.73×10^3	0.04	25	0.03
12-Oct-01	0.96	73.0	1.20×10^5	0.46	20	0.38
27-Nov-01	1.39	38.8	8.79×10^4	0.63	40	0.30
17033 Boggy Creek at FM 144 near Omaha-North						
10-Jan-01	0.92	61.3	1.57×10^5	0.71	20	0.18
10-Oct-01	1.19	42.8	1.63×10^5	1.06	20	0.12
12-Oct-01	0.96	73.0	2.73×10^5	1.04	20	0.17
27-Nov-01	1.00	120.0	2.88×10^5	0.67	15	0.14

Table 4-10 continued

17057 Little Boggy Creek at CR 3301						
10-Oct-01	1.22	40.7	1.09×10^5	0.74	15	0.10
12-Oct-01	0.96	86.0	3.15×10^5	1.02	15	0.24
27-Nov-01	1.44	85.5	5.03×10^5	1.63	40	0.31

variation of concentration, the "fluviograph", can only be discretely sampled by a relative handful of data. Even with exact precision of the laboratory analysis, this sparse sampling entails considerable uncertainty in the loading of the event. This is exemplified by Figure 4-9, showing the sampling of one such event in the Cypress watershed.

Phosphorus in runoff, especially, is governed in part by the mobilization of sediment from the watershed, since phosphorus as an affinity for sorption to fine particulates. Therefore the phosphorus load is affected by the accuracy with which suspended sediment loading is modeled, whose uncertainty is limited by the variance in field data. This variance is summarized in Table 4-11. The standard error ranges 20-80%, with a nominal value of 50%. The estimate uncertainty in the phosphorus concentrations are summarized in Table 4-12, and is seen to range 40-100%, with a nominal value of 70%.

Figure 4-9
January 2001 storm event, Station 17033 Boggy Creek, water quality measurements and hydrograph

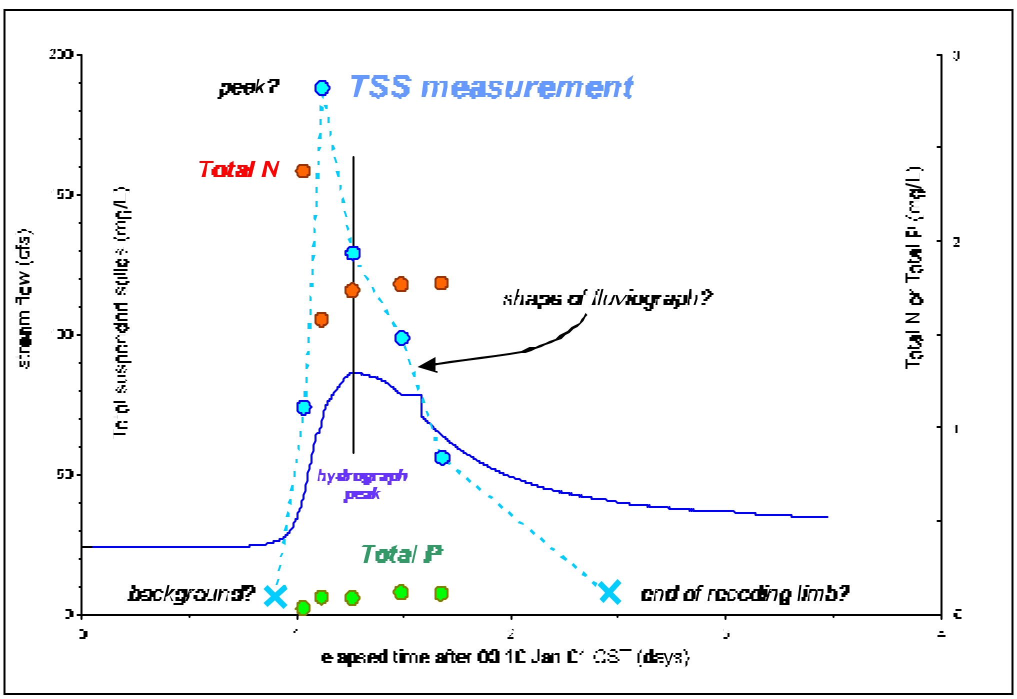


Table 4-11
Total Suspended Solids (TSS) mass loading data for study storms

Station		*mass (g)*	*EMC (g/m^3)*	*EQMC (g/m^3)*	*mean load (g/s)*	*est errort (%)*
10263	***Tankersley Creek at FM 127***					
	10-13 Jan 01	1.00E+07	35.7	41.6	43.0	40
	11-12 Oct 01	4.56E+08	586.1	569.0	2833.4	50
	28 Nov - 1 Dec 01	2.64E+07	43.2	55.9	75.2	50
10266	***Hart Creek at SE 12***					
	10-13 Jan 01	4.46E+07	88.8	89.6	201.6	50
	11-12 Oct 01	7.34E+07	141.6	144.2	574.3	60
	28 Nov - 1 Dec 01	4.64E+07	98.7	87.8	215.0	40
16455	***Alley Creek at SH 155***					
	11-12 Oct 01	1.16E+07	59.3	61.0	66.8	80
	28 Nov - 1 Dec 01	3.37E+07	91.5	102.8	95.9	50
	24-26 Jan 02	1.38E+07	150.2	159.9	54.3	60
17030	***Prairie Creek Tributary at CR 1264 Crossing***					
	10-13 Jan 01	3.03E+05	43.1	63.7	1.1	50
	11-12 Oct 01	4.95E+05	199.2	219.5	6.8	40
17031	***Prairie Creek Tributary at CR 1140 Crossing***					
	10-13 Jan 01	6.16E+05	48.3	57.2	2.5	40
	11-12 Oct 01	4.31E+06	211.9	640.2	27.7	50
	27 - 30 Nov 01	1.29E+07	59.3	146.7	91.8	60
17033	***Boggy Creek at FM 144 near Omaha-North***					
	10-13 Jan 01	1.97E+07	97.5	125.9	89.4	30
	11-12 Oct 01	2.83E+07	103.6	173.4	183.0	30
	28 Nov - 2 Dec 01	3.53E+07	41.2	122.9	81.6	20
17057	***Boggy Creek Tributary at CR 3301***					
	11-12 Oct 01	2.17E+07	103.1	200.1	147.1	40
	28 Nov - 1 Dec 01	4.10E+07	53.5	81.4	132.3	50

Table 4-12
Total phosphorus mass loading data for study storms

Station		*mass (g)*	*EMC (g/m^3)*	*EQMC (g/m^3)*	*mean load (g/s)*	*est errort (%)*
10263	Tankersley Creek at FM 127					
	10-13 Jan 01	2.76E+05	1.01	1.15	1.19	50
	11-12 Oct 01	4.71E+05	0.60	0.59	2.92	60
	28 Nov - 1 Dec 01	7.13E+05	1.44	1.51	2.03	100
10266	Hart Creek at SE 12					
	10-13 Jan 01	5.50E+04	0.13	0.11	0.25	60
	11-12 Oct 01	1.21E+05	0.24	0.24	0.95	70
	28 Nov - 1 Dec 01	1.69E+05	0.40	0.32	0.78	60
16455	Alley Creek at SH 155					
	11-12 Oct 01	8.03E+03	0.04	0.04	0.05	80
	28 Nov - 1 Dec 01	1.45E+04	0.04	0.04	0.04	70
	24-26 Jan 02	7.20E+03	0.09	0.08	0.03	70
17030	Prairie Creek Tributary at CR 1264 Crossing					
	10-13 Jan 01	1.32E+03	0.33	0.30	0.01	50
	11-12 Oct 01	1.46E+03	0.87	0.65	0.02	50
17031	Prairie Creek Tributary at CR 1140 Crossing					
	10-13 Jan 01	2.35E+03	0.21	0.22	0.01	50
	11-12 Oct 01	2.31E+03	0.25	0.34	0.01	50
	27 Nov - 5 Dec 01	3.60E+04	0.31	0.41	0.26	60
17033	Boggy Creek at FM 144 near Omaha-North					
	10-13 Jan 01	2.34E+04	0.13	0.15	0.11	40
	11-12 Oct 01	5.36E+04	0.25	0.33	0.35	40
	28 Nov - 2 Dec 01	9.68E+04	0.15	0.34	0.22	20
17057	Boggy Creek Tributary at CR 3301					
	11-12 Oct 01	3.58E+04	0.22	0.33	0.24	50
	28 Nov - 1 Dec 01	1.91E+05	0.35	0.38	0.62	50

Margin of safety specification

The margin of safety approach being used in the development of the TMDL includes the use of conservative assumptions in 1) establishing numeric targets in Lake O' the Pines, 2) integrating source and transport estimates to derive present and future loadings of nutrients and oxygen demand from the watershed, and 3) delineating the responses of the dissolved oxygen regime in Lake O' the Pines to those loadings.

The uncertainties in the landscape-derived storm runoff data were summarized above. Nominal values for uncertainties are 25% in storm runoff volume, 50% in TSS concentration and 70% in total-P concentration. It is worth emphasizing that these uncertainties derive from the relatively short duration of the wet weather monitoring program, the practical limitations on precise measurement given all of the difficulties of automated sampling, and, most importantly, the natural variability of storm runoff itself. All of these sources of uncertainty would be diminished by continued monitoring in the basin. These uncertainties represent the basic field data, and limit the accuracy with which the SWAT watershed model can be validated, therefore these represent a lower bound on the uncertainty deriving from the model itself. Moreover, in the formulation of a runoff load, the uncertainties are multiplied. In the modeling of phosphorus load, since TSS is an intermediate variable (because of its role as a "carrier" of phosphorus), all three uncertainties are, in effect, multiplied, though to a certain extent this multiplicative phenomenon is reduced by validating the SWAT model separately for flow, TSS and total P. Since the SWAT model was validated for a small number of representative watersheds, but for TMDL determination is applied to the entire Big Cypress basin, and is further operated over a 20-year simulation involving a range of hydroclimatological conditions that exceed the range of validation, additional uncertainty is introduced into this modeling application. Given this, we assume a nominal level of uncertainty in the modeled runoff loads of 100%, i.e. a factor of two about the predicted value.

The numeric target being used in this analysis is the Segment 0403 dissolved oxygen standard. Compliance with that standard (5.0 mg/l) is being evaluated as an average epilimnion dissolved oxygen concentration, in the upper, middle, and lower portions of the lake. Upper Lake O' the Pines consists of shallow water habitat with extensive stands of rooted vegetation and is the direct receptor of the bulk of hydraulic, sediment and nutrient input to the reservoir. That portion of the reservoir above the SH155 appears to be the site of a large proportion of sedimentation and assimilation of nutrients, and is a substantially different environment from the lower portions of Lake O' the Pines. By addressing the nutrient and oxygen demand reductions necessary to meet the Segment 0404 standard (or the degree to which that standard is achievable) in the upper reservoir, achievement of that target in the remainder of the reservoir will be assured by a substantial margin.

In summary, uncertainties in the measurements of dissolved constituents and of stream discharge were considered in our development of loading estimates from point and non point sources in the watershed, and will be employed in assessments of potential future conditions. For example, high and low estimates based on the characteristic uncertainties of hydraulic and water quality measurements can be used as guidance in setting conservative loading levels and corresponding rates of assimilation and nutrient sequestration. It is anticipated that allocations of load to point and non point sources, and any nutrient control strategies that might be employed to reduce loadings, would be intentionally conservative until sufficient additional monitoring data could be developed to allow more refined estimates in later phases of the TMDL implementation.