TEXAS WATER CONSERVATION ASSOCIATION

DEVELOPMENT OF USE-BASED CHLOROPHYLL CRITERIA FOR RECREATIONAL USES OF RESERVOIRS

FINAL

JUNE 2005

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Support Also Provided By:
Texas Association of Metropolitan Sewerage Agencies
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FINAL REPORT

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LIST OF ABBREVIATIONS

ac	acre
ac-ft	acre-feet
APAI	Alan Plummer Associates, Inc.
avg	average
BRA	Brazos River Authority
CRP	Clean Rivers Program
DO	dissolved oxygen
EPA	U. S. Environmental Protection Agency
ft	feet
GBRA	Guadalupe-Blanco River Authority
H_2SO_4	sulfuric acid
LCRA	Lower Colorado River Authority
ln	log normal
m	meter
mm	millimeters
max	maximum
mg/L	milligrams per liter
min	minimum
ml	milliliters
NO_2	nitrite
NO_3	nitrate
NTU	nephelometric turbidity units
SARA	San Antonio River Authority
SOP	Standard Operating Procedure
SRA	Sabine River Authority
std	standard
SWQM	Surface Water Quality Monitoring
TCEQ	Texas Commission on Environmental Quality
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TP	total phosphorus
TRA	Trinity River Authority
TRWD	Tarrant Regional Water District
TSS	total suspended solids
TWCA	Texas Water Conservation Association
ug/L	micrograms per liter
USGS	U.S. Geological Survey
VSS	volatile suspended solids

FINAL REPORT

DEVELOPMENT OF USE-BASED CHLOROPHYLL CRITERIA FOR RECREATIONAL USES OF RESERVOIRS

CHAPTER I

INTRODUCTION

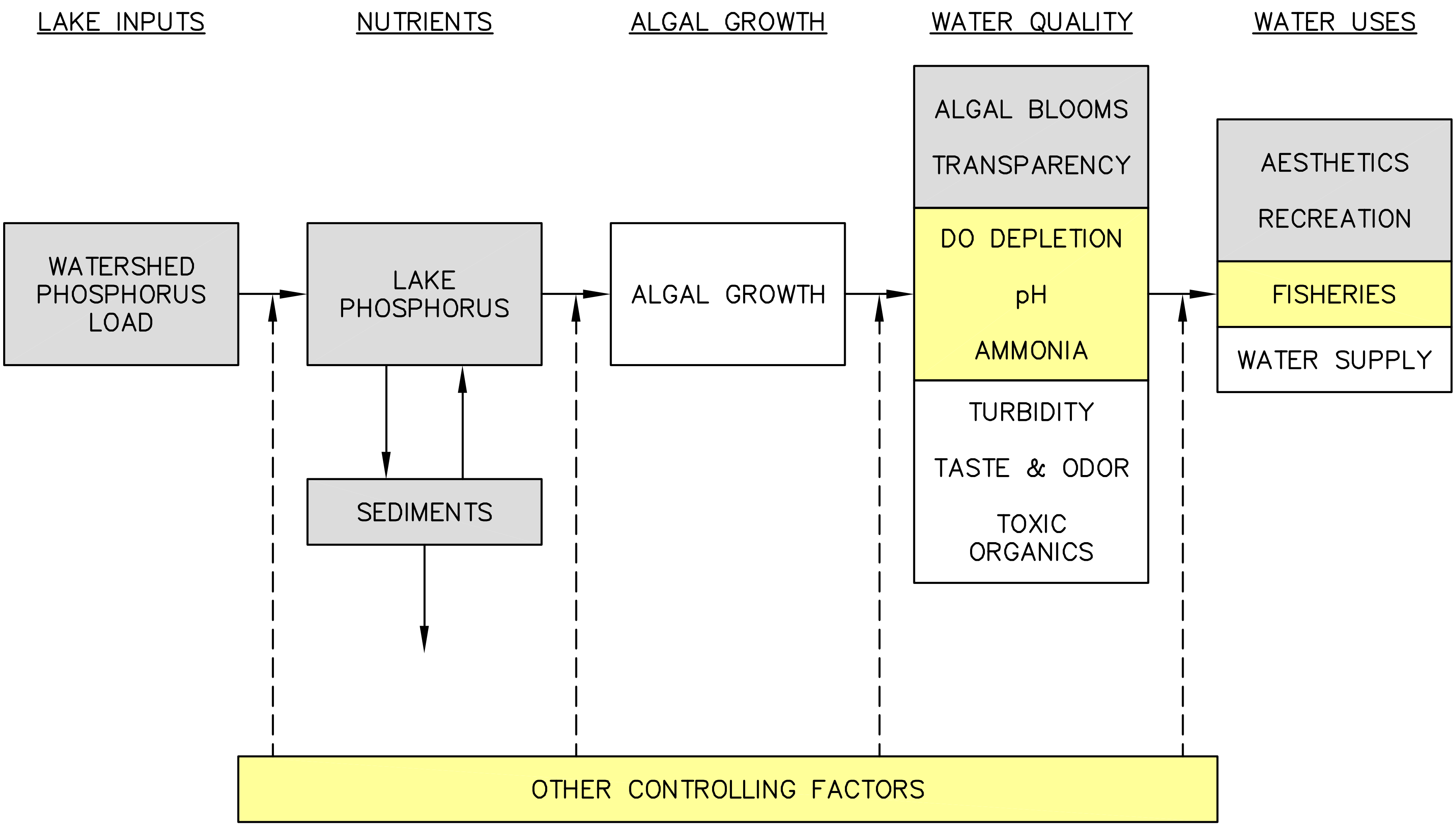
In 2002, the U.S. Environmental Protection Agency (EPA) mandated that states develop numeric nutrient water quality standards for lakes, streams, and estuaries. The Texas Commission on Environmental Quality (TCEQ), the agency responsible for the development of these standards, has established a plan for developing nutrient standards. This plan specifies that major reservoirs will be the first waterbodies for which nutrient standards will be considered.

The Federal Clean Water Act, in Section 303(c)(2)(A), specifies that, whenever a state revises or adopts a new water quality standard, the standard "shall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses." Potential uses of reservoirs include contact recreation, non-contact recreation, fisheries, public water supply, and aquatic life and wildlife support. The purpose of this study is to provide data to the TCEQ that can be used to determine criteria that are supportive of recreational uses. Criteria for recreational uses can then be evaluated in conjunction with criteria supportive of other uses when determining a recommended water quality standard.

The primary manner in which high nutrient concentrations can affect contact and non-contact recreational uses is when the nutrients produce dense growths of algae and/or aquatic vegetation, which are aesthetically undesirable. In some cases, dense growths of vegetation can physically interfere with the use of waters for swimming, skiing, or boating. Use of waters for a public water supply can be adversely impacted if there are algal blooms that result in unpleasant tastes and odors in the treated water. Fisheries, up to a point, are positively affected by increased primary production resulting from increased nutrient loads. In addition, the standing crop of largemouth bass, an ambush predator of high fishery value in Texas, has been shown to be positively correlated with the proportion of reservoir area occupied by rooted aquatic vegetation. However, when eutrophication begins to reduce dissolved oxygen concentrations significantly, fisheries can be adversely affected.

This study recommends that the nutrient water quality standards for reservoirs be based on chlorophyll-*a*, since the density of planktonic algae is most frequently the nutrient-related condition affecting the desirability of reservoirs for recreational uses. Implementing these standards will, ultimately, require an understanding of the relationships between watershed loadings of nitrogen and phosphorus, light attenuation, algal growth, and use impairment due to algal growth. Figure I-1 presents a summary of these relationships, as they relate to phosphorus loads to a reservoir.

This study was a collaborative effort. It was sponsored by the Texas Water Conservation Association, with support from the National Association of Clean Water Agencies and the Texas Association of Metropolitan Sewerage Agencies. Participants in the study were as follows: Brazos River Authority (BRA), Guadalupe-Blanco River Authority (GBRA), Lower Colorado River Authority (LCRA), Sabine River Authority (SRA), San Antonio River Authority (SARA), Tarrant Regional Water District (TRWD), and Trinity River Authority (TRA). Consultants assisting in the effort were William W. Walker, Jr., Ph.D., and Alan Plummer Associates, Inc., (APAI).



From: William W. Walker, Jr., Ph.D.

FIGURE I–1
CAUSAL PATHWAYS LINKING PHOSPHORUS LOADS TO WATER USES

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CHAPTER II

STUDY DESIGN

The basic approach taken in this study was to collect simultaneous data on users' perceptions of whether recreational use was impaired (and, if so, the extent of the impairment) and water quality data. Several other researchers have conducted similar studies to identify the level at which algal growth is objectionable to recreational users of reservoirs (for example, Heiskary & Walker, 1988; Smeltzer & Heiskary, 1990). These researchers concluded that algal bloom frequency is the most significant nutrient-related condition for recreational users. However, they have also found that bloom frequency can be correlated to a growing-season mean chlorophyll-*a* concentration, which is a more practical parameter for a regulatory criterion.

DESCRIPTION OF STUDY RESERVOIRS

Eight reservoirs were selected for the study. The study reservoirs represent a wide range of conditions with respect to size, drainage area, trophic status, primary uses, and ecoregion location. The eight reservoirs are Canyon Lake, Cedar Creek Reservoir, Granger Lake, Lake Bridgeport, Lake Fork Reservoir, Lake Georgetown, Lake Livingston, and Lake Travis. A summary of the size of each reservoir and the ecoregion(s) in which each reservoir is located is presented in Table II-1. Figure II-1 is a map of the geographical locations of the study reservoirs and ecoregion boundaries.

Canyon Lake, located in the Central Texas Hill Country, serves as a water supply reservoir and provides flood control on the Guadalupe River. Water clarity is excellent, and the reservoir is a popular location for boating, fishing, skiing, and scuba diving.

Cedar Creek Reservoir, in northeast Texas, serves as a water supply reservoir and is used for a wide range of recreational activities. This reservoir is one of two reservoirs studied that exhibit high levels of chlorophyll-*a*.

Granger Lake, located in Central Texas, provides public water supply. It is also popular for crappie and white bass fishing. This reservoir maintains a high level of suspended inorganic material that substantially reduces water clarity.

TABLE II-I

DESCRIPTION OF STUDY RESERVOIRS

Reservoir	Level III Ecoregion	Surface Area (acres)	Volume (acre-feet)
Canyon Lake	Edwards Plateau	8,230	378,781
Cedar Creek Reservoir	Texas Blackland Prairies/East Central Texas Plains	32,623	637,180
Granger Lake	Edwards Plateau/Texas Blackland Prairies	4,009	54,280
Lake Bridgeport	Central Oklahoma/Texas Plains	11,649	366,236
Lake Fork Reservoir	Texas Blackland Prairies/South Central Plains	27,690	604,927
Lake Georgetown	Edwards Plateau	1,297	37,010
Lake Livingston	Texas Blackland Prairies/South Central Plains	83,277	1,741,867
Lake Travis	Edwards Plateau	18,622	1,131,650

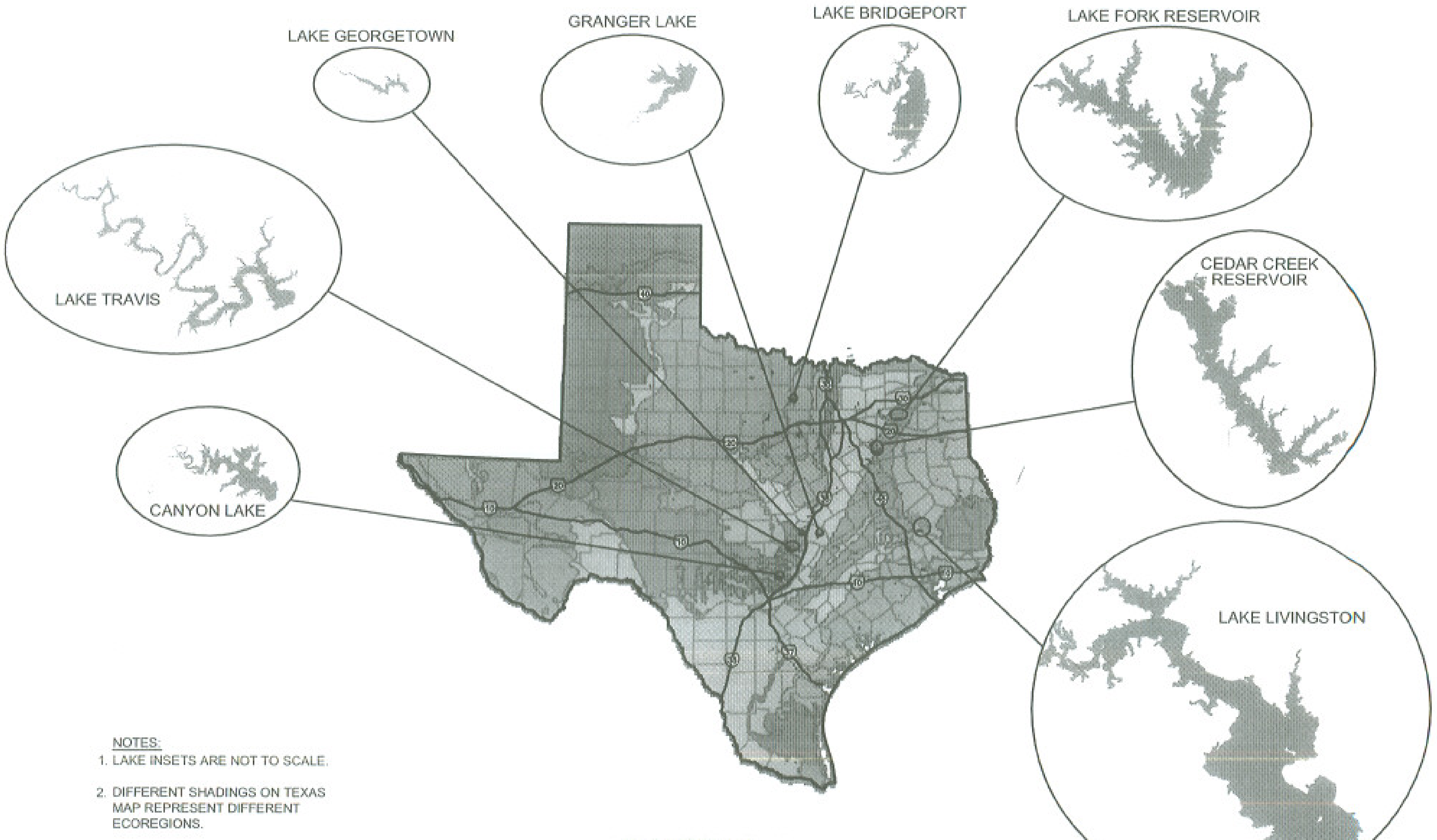


FIGURE II-1
STUDY RESERVOIRS - LOCATIONS

Lake Bridgeport, located northwest of the Dallas/Fort Worth metropolitan area, serves as a source of public water supply, provides water supply for a power plant, is used for fishing and contact recreation, and provides limited flood control. Waters in Lake Bridgeport tend to be of moderately high clarity.

Lake Fork Reservoir, east of the Dallas/Fort Worth metropolitan area, provides public water supply and is known as one of the best largemouth bass fisheries in Texas. The waters in this reservoir are moderately clear.

Lake Georgetown, in Central Texas, provides public water supply and is used for contact recreation, non-contact recreation, and fishing. The waters of Lake Georgetown have high clarity.

Lake Livingston, located in East Texas, is a source of public water supply and is used for contact recreation, non-contact recreation, and fishing. Lake Livingston is the second reservoir studied that exhibits high levels of chlorophyll-*a*.

Lake Travis, located in the Central Texas Hill Country, provides public water supply and agricultural water supply, provides flood control for the Colorado River, and is extensively used for contact and non-contact recreation, as well as fishing. The waters have very high clarity.

STATION LOCATIONS

Each reservoir was sampled at two locations: one site was in the main body, and one site was in a cove or the headwater. A map of each reservoir showing the locations of sampling sites is presented in Appendix A.

The following criteria were used as the basis for selection of the monitoring locations:

- The water depth at the monitoring station should be at least 10 feet.
- The monitoring site is in the proximity of users who can respond to the survey (marina, park, subdivision, etc.).
- The sites selected should not have significant stands of aquatic vegetation.

USER SURVEYS

The user survey is designed to document the user's opinion of the physical condition of the waterbody based on its appearance and to document the user's perception of how suitable the water conditions are for recreational use and/or aesthetic enjoyment. The user survey is conducted at a time and location that generally correspond to the time and location that water quality data are collected.

A copy of the survey form is included in Appendix B. The two main questions presented in the survey are as follows:

1) Please circle the **one** response that best describes the **physical condition** of the lake water **today**:
   a) No algae, or crystal clear water
   b) A little algae visible
   c) Definite algal greenness
   d) Very green; some scum present and/or mild odor apparent
   e) Pea-soup green with one or more of the following: massive floating scums on lake or washed up on shore, strong foul odor, or fish kill

2) Please circle the **one** response that best describes your **perception** of how suitable the lake water is for recreation and aesthetic enjoyment **today**:
   a) Beautiful, could not be any nicer
   b) Very minor aesthetic problems; excellent for swimming, boating enjoyment
   c) Swimming and aesthetic enjoyment slightly impaired
   d) Desire to swim and level of enjoyment of the lake substantially reduced
   e) Swimming and aesthetic enjoyment of the lake nearly impossible

The survey also asks how many times a year the respondent visits the lake and their primary recreational activity for that day.

An attempt was made to collect seven surveys at each monitoring station during each monitoring event. Two of the surveys were to be completed by the staff collecting the water quality samples. The other five surveys were to be completed by members of the general public. The surveys were to be completed on the same day that the water quality samples were collected. No surveys were to be conducted before 10 A.M., and the sampling staff were encouraged to verify that the persons completing the survey had already been on, or near, the area of the lake where the sample was collected.

WATER QUALITY DATA

Following is a summary of the water quality parameters measured for this study, methods used, and preservation techniques. The parameters measured in the laboratory, methods used, and laboratory reporting limits are summarized in Table II-2. The methods and equipment used for field measurements are summarized in Table II-3. Because of the importance to this study of the measurements of chlorophyll-*a* and pheophytin, special procedures were adopted for these analyses. These procedures are described in a separate section below.

General Water Quality Measurements

The laboratories performing the general water quality analyses for each reservoir are identified on Table II-4. All but a few of the samples collected for laboratory analyses were depth-composited grab samples. Equal volumes of sample [500 milliliters (ml) each] were collected at depths of 1 foot (ft), 3 ft and 6 ft and combined into a single sample for analyses. Field measurements of dissolved oxygen (DO), pH, temperature, and specific conductivity also were made at depths of 1 ft, 3 ft, and 6 ft. The only samples that were not depth composites were the samples collected at Canyon Lake in 2003. These samples were surface grab samples and surface field measurements.

Samples collected for nitrogen and phosphorus analyses were preserved with sulfuric acid (H_2SO_4) and analyzed within 28 days. Samples collected for suspended solids analyses were preserved on ice and analyzed within 7 days.

Field duplicate samples were collected periodically for chlorophyll-*a* and pheophytin analyses. The duplicate samples also were analyzed by the LCRA laboratory.

Chlorophyll-*a* and Pheophytin

There were concerns about using chlorophyll as a water quality standard because of uncertainties regarding whether all aspects of the sampling and analytical methods are sufficiently defined to produce consistent results and whether historical data are comparable to recent data. In fact, shortly before the beginning of this study, the Texas Commission on Environmental Quality (TCEQ) contracted with the SRA for a study to determine whether there are steps in the sampling/analysis process that need to be controlled more rigorously and, if so, which steps those are. The results of this study are summarized in Appendix E. Appendix E also

TABLE II-2

LABORATORY WATER QUALITY ANALYSES

Laboratory Analysis	Method	Laboratory Reporting Limit
Nitrogen, Nitrate+Nitrite	EPA 353.2, EPA 353.3, or SM 4500-NO_3 E	0.04 mg/L
Nitrogen, Nitrate	EPA 300.0	0.02 mg/L
Nitrogen, Nitrite	EPA 300.0, in combination with EPA 353.2 or EPA 353.3	0.02 mg/L
Nitrogen, Total Kjeldahl	EPA 351.2 or SM 4500-N_{org} D	0.2 mg/L
Phosphorus, Total	EPA 365.2, EPA 365.4, or SM 4500-P E	0.06 mg/L
Chlorophyll-*a*	EPA 445.0, EPA 446.0, or SM 10200-H	2 µg/L
Pheophytin	EPA 445.0, EPA 446.0, or SM 10200-H	2 µg/L
Suspended Solids, Total	EPA 160.2 or SM 2540 D	1 mg/L
Suspended Solids, Volatile	EPA 160.4 or SM 2540 E	4 mg/L
Turbidity**	EPA 180.1	0.5 NTU

**Samples for Lake Bridgeport and Cedar Creek Reservoir were analyzed using a Hach Field Turbidity Meter.

TABLE II-3

FIELD WATER QUALITY MEASUREMENTS

Field Measurement	Method		Monitoring Equipment					
			BRA	GBRA	LCRA	SRA	TRA	TRWD
Secchi-disc Depth	TCEQ SOP*		200 mm black/white	200 mm black/white	200 mm black/white	200 mm black/white	200 mm black/white	200 mm black/white
Dissolved Oxygen	EPA 360.1 or TCEQ SOP*		Hydrolab	YSI 600 XLM	YSI 600 XLM	Hydrolab	YSI 600 XLM	Hydrolab Surveyor 4
pH	EPA 150.1 or TCEQ SOP*		Hydrolab	YSI 600 XLM	YSI 600 XLM	Hydrolab	YSI 600 XLM	Hydrolab Surveyor 4
Temperature	EPA 170.1 or TCEQ SOP*		Hydrolab	YSI 600 XLM	YSI 600 XLM	Hydrolab	YSI 600 XLM	Hydrolab Surveyor 4
Specific Conductivity	SM 2510 or TCEQ SOP*		Hydrolab	YSI 600 XLM	YSI 600 XLM	Hydrolab	YSI 600 XLM	Hydrolab Surveyor 4

*Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment, and Tissue. Dec. 2003 (RG-415)

TABLE II-4

LABORATORY PERFORMING GENERAL WATER QUALITY ANALYSES

Reservoir	2003 Samples	2004 Samples
Canyon Lake	Guadalupe-Blanco River Authority and Brazos River Authority	Guadalupe-Blanco River Authority and STL*
Cedar Creek Reservoir	TRAC**	TRAC**
Granger Lake	Brazos River Authority	Brazos River Authority
Lake Bridgeport	TRAC**	TRAC**
Lake Fork Reservoir	Sabine River Authority and Brazos River Authority	Sabine River Authority and Analab***
Lake Georgetown	Brazos River Authority	Brazos River Authority
Lake Livingston	Trinity River Authority both Lake Livingston and Central Regional Wastewater System	Trinity River Authority both Lake Livingston and Central Regional Wastewater System
Lake Travis	Lower Colorado River Authority	Lower Colorado River Authority

*STL Laboratories in Austin, Texas
**TRAC Laboratories in Denton, Texas.
***Analab Laboratories in Kilgore, Texas

includes the Standard Operating Procedure for the determination of chlorophyll-*a* that was used by SRA during the study.

In recognition of this, at the outset of the study, all information on sampling and analytical procedures that may need to be rigorously controlled was compiled, and protocols for those procedures were established. Specific aspects of the approved method that were rigorously controlled for this study included the following:

- Samples were field-filtered. The filters containing the collected samples were frozen with dry ice in the field and maintained in a frozen state until analyzed. Samples were analyzed within 14 days.

- The acidification period was maintained as close to 90 seconds as was feasible.

- A micropipette rather than an eyedropper was used to acidify the samples.

For each sampling event, approximately 500 ml of sample were filtered through a glass-fiber filter. The filter was then folded twice, wrapped in aluminum foil, enclosed in a plastic bag, and placed on dry ice for shipment to the LCRA laboratory. All analytical results used in the subsequent data evaluations are the results provided by the LCRA laboratory.

SAMPLING PERIODS AND FREQUENCY

During 2003, samples were collected twice each month during the months of June through September at most sites. In 2004, samples were collected twice each month during the months of April through September. Whenever possible, samples were collected a minimum of two weeks apart. An effort was made not to collect samples that may have been influenced by stormwater runoff.

Periodically, SRA split samples with LCRA, and both SRA and LCRA analyzed the samples for chlorophyll-*a* and pheophytin. The purpose of this was to determine inter-laboratory variability.

CHAPTER III

SUMMARY OF DATA

Data collection began in June 2003 and was completed in September 2004. Sampling events were conducted during June through September in the first year, and April through September in the second year. A total of 1,806 valid recreational user surveys were completed; and over 5,700 water quality measurements were obtained, including 296 measurements of chlorophyll-*a*. The numbers of surveys obtained at each reservoir and each year are shown in Table III-1. Ninety-five percent of the surveys can be correlated with water quality data.

Except for one sampling event at Cedar Creek Reservoir in June 2003, surveys were collected on the same day as water quality samples. In the case of the sampling event on Cedar Creek Reservoir, due to a problem with transporting the samples, water quality samples for laboratory analyses were re-collected on the day following the initial sample collection. (The survey forms were completed on the day that the initial sample was collected).

WATER QUALITY IN RESERVOIRS

Water quality in the various study reservoirs differs significantly in terms of transparency and concentrations of suspended solids, nitrogen, phosphorus, and chlorophyll-*a*. A summary of the water quality data for each reservoir is presented in Appendix C. In this report, unless specified otherwise, analyses reported as being below the detection limit were included in calculations at a value equal to one-half of the detection limit.

General Water Quality

A summary of water quality data for each reservoir is presented in Table III-2. Mean summer values for total nitrogen, total phosphorus, DO, and pH at each reservoir are presented. All DO and pH measurements (1 ft, 3 ft, and 6 ft) were included when computing these averages. The mean values include data from both main body and cove/headwater stations.

The phosphorus concentrations measured in 2003 at Granger Lake, Lake Fork Reservoir and Lake Georgetown were substantially different than the concentrations measured in 2004 at these reservoirs. The 2004 values appear to be more consistent with other characteristics of these reservoirs. Therefore, only 2004 data are included in the averages reported in Table III-2.

TABLE III-1

NUMBER OF USER SURVEYS BY RESERVOIR

Reservoir	2003	2004	Total
Canyon Lake	96	117	213
Cedar Creek Reservoir	129	145	274
Granger Lake	72	70	142
Lake Bridgeport	124	175	299
Lake Fork Reservoir	84	151	235
Lake Georgetown	72	67	139
Lake Livingston	124	190	314
Lake Travis	93	97	190
Total	**794**	**1012**	**1806**

TABLE III-2

RESERVOIR CHARACTERISTICS
NUTRIENTS, DISSOLVED OXYGEN, pH

Reservoir	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	DO (mg/L)	pH
Canyon Lake	0.70	0.05	8.6	8.1
Cedar Creek Reservoir	1.26	0.10	7.8	8.4
Granger Lake	0.62	0.10	7.0	8.1
Lake Bridgeport	0.77	0.06	7.4	8.1
Lake Fork Reservoir	0.95	0.04	7.6	7.7
Lake Georgetown	0.35	0.11	7.4	8.1
Lake Livingston	1.34	0.24	9.3	8.4
Lake Travis	0.36	0.01	8.2	8.4

A comparison of the mean summer transparencies in the main body of each reservoir is presented in Figure III-1. The reservoirs are ordered on Figure III-1 from least transparent on the left to most transparent on the right. In general, study reservoirs located west of Interstate Highway 35 have higher transparencies than reservoirs located in the east and northeast areas of the state. The study reservoirs with the highest transparency are located in the Edwards Plateau ecoregion.

A comparison of the mean summer suspended solids concentrations in the main body of each reservoir is presented on Figure III-2. The relative proportions of inorganic solids and volatile (organic) solids in each reservoir are shown. It can be observed on Figure III-2 that the total concentration and the percentage of inorganic suspended solids in Granger Lake are substantially different than in the other reservoirs. Granger Lake exhibits substantially higher inorganic suspended solids.

Comparisons of mean summer total nitrogen concentrations and total phosphorus concentrations in each reservoir are presented in Figure III-3 and Figure III-4, respectively. Data are presented for both the main body station and the cove or headwater station in each reservoir. The reservoirs exhibit a wide range of nutrient concentrations. As in Table III-2, only 2004 data for phosphorus have been used for Granger Lake, Lake Fork Reservoir, and Lake Georgetown.

<u>Chlorophyll-*a* and Pheophytin</u>

Summaries of the chlorophyll-*a* and pheophytin data obtained by this study are presented in this section. The concentrations of chlorophyll-*a* in each reservoir are presented, as well as a comparison of the data obtained by this study to historical data for chlorophyll-*a* for each of the reservoirs, an evaluation of whether data on pheophytin are needed, and the results of the study of inter-laboratory variability.

Chlorophyll-*a* Concentrations in Reservoirs

A comparison of the mean summer chlorophyll-*a* concentrations in each reservoir is presented on Figure III-5. Values are shown for both the main body station and the cove or headwater station in each reservoir.

The reservoirs are arranged on Figure III-5 in the same order as on Figure III-1, which presents transparency data for each reservoir. As can be observed, the general trend is that, as

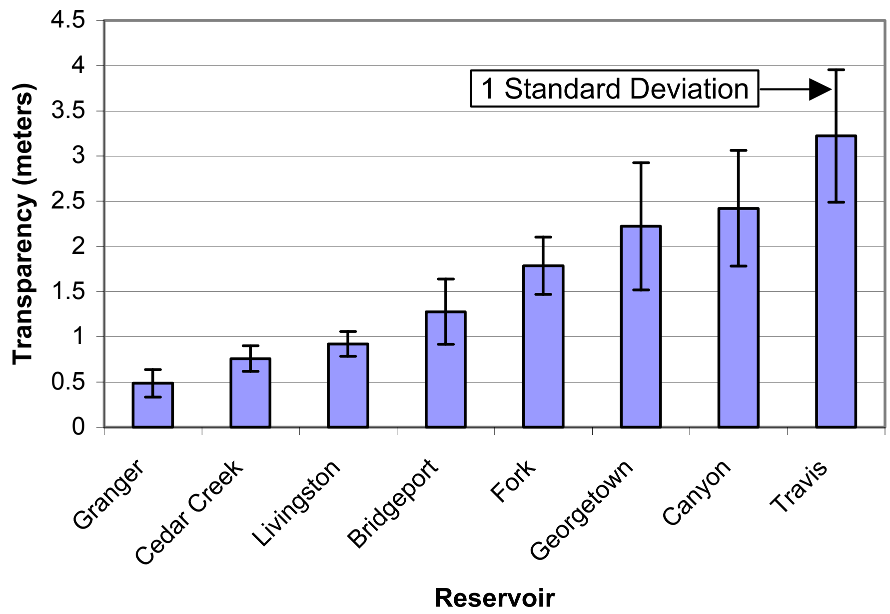


FIGURE III-1
MEAN SUMMER RESERVOIR TRANSPARENCY
MAIN BODY

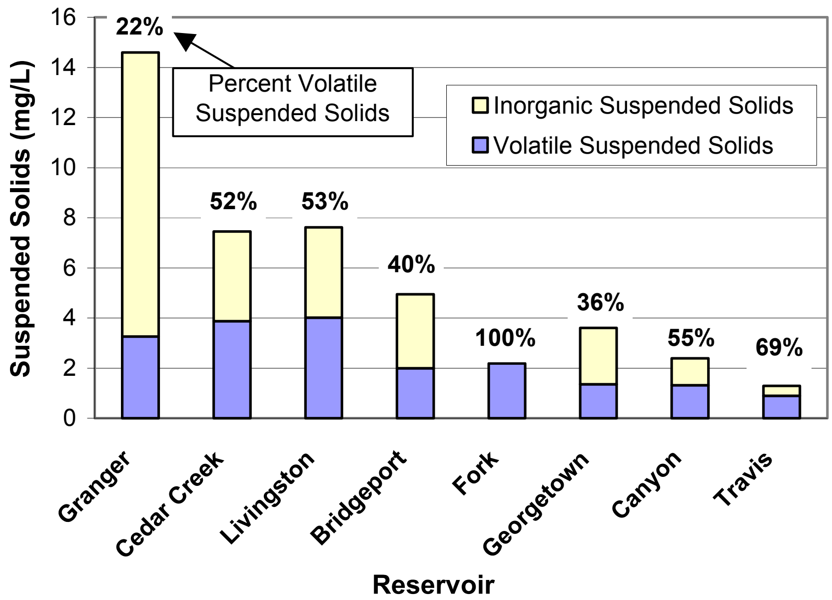


FIGURE III-2

MEAN SUMMER RESERVOIR SUSPENDED SOLIDS CONCENTRATIONS MAIN BODY

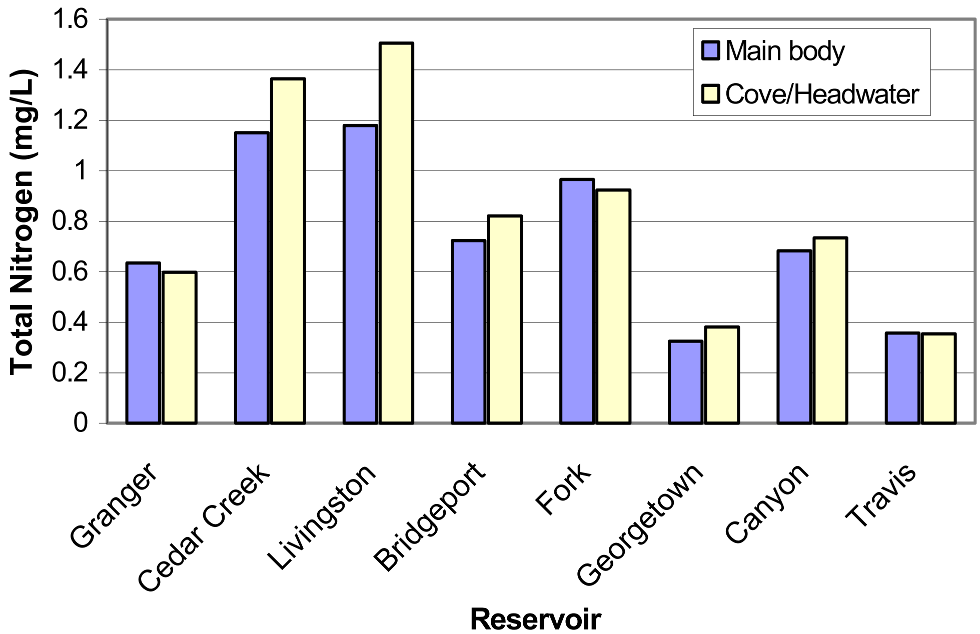


FIGURE III-3

MEAN SUMMER RESERVOIR NITROGEN CONCENTRATIONS MAIN BODY AND COVE/HEADWATER

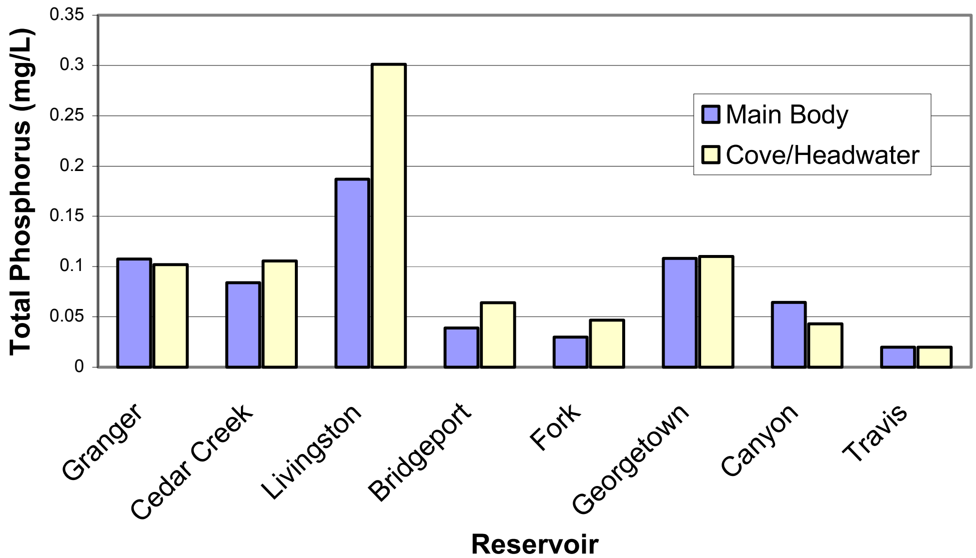


FIGURE III-4

MEAN SUMMER RESERVOIR PHOSPHORUS CONCENTRATIONS MAIN BODY AND COVE/HEADWATER

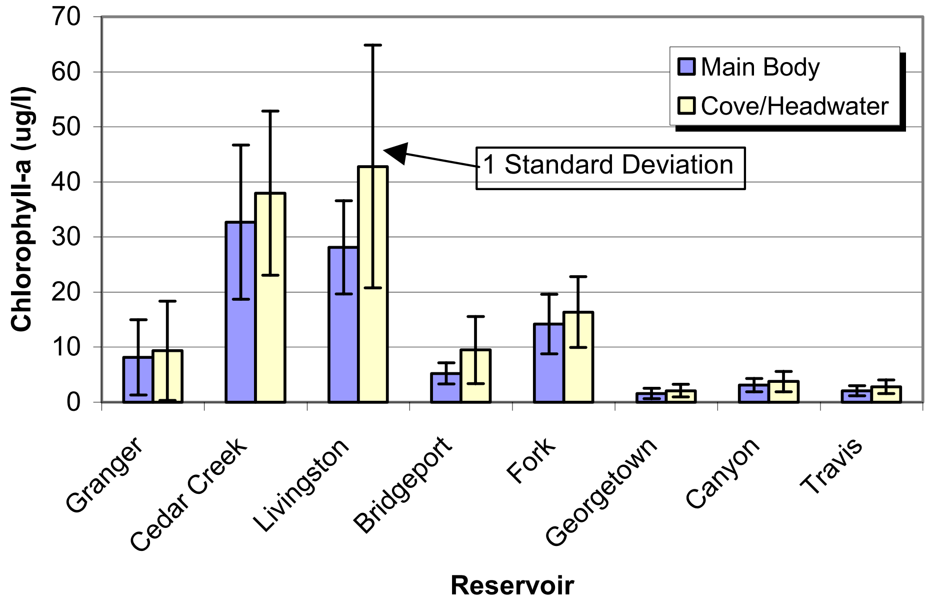


FIGURE III-5

MEAN SUMMER CHLOROPHYLL-*a* CONCENTRATIONS
MAIN BODY AND COVE/HEADWATER

chlorophyll-*a* increases, transparency decreases. The most notable exception to this trend is Granger Lake. As previously noted, the low transparency in Granger Lake is due to inorganic suspended solids rather than algal growth. In fact, the high concentrations of solids probably discourage algal growth by limiting light penetration.

Both algae and suspended solids contribute to reductions in transparency. However, in most of the reservoirs studied, the concentration of suspended solids is low, and algae is the more dominant factor.

Data have also been compiled on the range of chlorophyll-*a* concentrations exhibited at each reservoir. Both main body and cove/headwater stations were included in this summary. The results are presented on Table III-3.

Comparison to Historical Data

When this study was initiated, there was a concern that it might be difficult to use chlorophyll-*a* as the nutrient water quality standard. There was a concern that the analytical method may have changed sufficiently that historical data would not be comparable to recent data. If this were true, there might not be sufficient data available in the TCEQ database to characterize reservoir quality accurately. Therefore, data from this study were compared to historical data in the TCEQ Surface Water Quality Monitoring (SWQM) database. In general, TCEQ data collected between 1993 and 2003 were used. However, the period of record in the TCEQ database varies from reservoir to reservoir. The results of this comparison are presented in Table III-4. As can be observed in Table III-4, the historical data and data from this study are generally comparable. The only reservoirs for which the data are somewhat different are Cedar Creek Reservoir and Lake Livingston. In both cases, the average chlorophyll-*a* concentrations reported by this study are a little higher than the average concentrations based on TCEQ data.

Significance of Pheophytin Measurements

When this study was initiated, it also was not clear whether pheophytin should be included in the evaluation and subsequent water quality standards. Therefore, all samples collected for this study were analyzed for both chlorophyll-*a* and pheophytin. An evaluation was conducted to

TABLE III-3

MAXIMUM AND MINIMUM CHLOROPHYLL-*A* CONCENTRATIONS COMBINED DATA FOR MAIN BODY AND COVE/HEADWATER SITES

Reservoir	Maximum Chlorophyll-*a* (ug/L)	Minimum Chlorophyll-*a* (ug/L)*
Canyon Lake	7	1
Cedar Creek Reservoir	64	10
Granger Lake	36	1
Lake Bridgeport	32	3
Lake Fork Reservoir	27	5
Lake Georgetown	5	1
Lake Livingston	115	8
Lake Travis	5	1

*Values reported as < 2.0 ug/L are included in the summary as 1.0 ug/L

TABLE III-4

COMPARISON OF MEAN SUMMER RESERVOIR CHLOROPHYLL-*a* MAIN BODY THIS STUDY AND TCEQ DATABASE

Reservoir	TCEQ*			This Study		
	Mean** Chlorophyll-*a* (ug/L)	Std. Dev.	N	Mean Chlorophyll-*a* (ug/L))	Std. Dev.	N
Canyon Lake	2	2	17	3	1	15
Cedar Creek Reservoir	24	16	20	33	14	20
Granger Lake	3	2	9	8	7	17
Lake Bridgeport	5	2	25	6	2	17
Lake Fork Reservoir	13	10	25	14	5	19
Lake Georgetown	2	1	9	2	1	16
Lake Livingston	20	12	26	28	8	20
Lake Travis	3	4	22	2	1	19

*Values reported as < 0.5 ug/L or < 0.25 ug/L not included in the analysis
Values reported as < 1.0 ug/L included in analysis as 0.5 ug/L
Values reported as < 2.0 ug/L included in analysis as 1.0 ug/L

**Data averaged for the period 1993–2003 determine the relative significance of the pheophytin data thus compiled. The average pheophytin concentration in each reservoir was determined as well as the percent of the sum of the chlorophyll-*a* and pheophytin concentrations that was represented by pheophytin. Data from main body and cove/headwater stations were combined for this evaluation. The results of the evaluation are presented on Figure III-6. As shown on Figure III-6, the concentrations of pheophytin are either low in terms of absolute magnitude or are a very small percentage of the total chlorophyll/pheophytin pigments that are present. Therefore, neither assessments of reservoir quality nor correlations of user survey results with chlorophyll-*a* concentrations are significantly changed by including the results of pheophytin analyses. It was concluded that assessments of reservoir quality and nutrient water quality standards can be based on chlorophyll-*a* only.

Inter-laboratory Variability

During 2003, as the results of the analyses of chlorophyll-*a* and pheophytin by SRA were compared to the LCRA results, the importance of specific method refinements became clear. Table III-5 presents data that illustrate how the method refinements produced a more reasonable agreement between the results obtained by the two laboratories. For the first three samples analyzed, as shown in Table III-5, LCRA and SRA had significantly different results. These differences were concluded to be due to the fact that LCRA used a micropipette to acidify the samples, and SRA used an eyedropper. The time between acidification and measurement was also found to be important. The results for the subsequent samples were obtained after SRA implemented all of the refined protocols used by LCRA. As shown in Table III-5, substantially better agreement in the analytical results was obtained after those changes were made.

USER SURVEYS

The user surveys received were analyzed to determine the characteristics of the users that filled out the surveys at each reservoir. The characteristics of the users with respect to frequency of visits to the reservoir are summarized in Table III-6. The types of activities in which the survey respondents were participating at each reservoir are summarized in Table III-7.

As shown in Table III-7, the total number of reservoir use activities identified exceeds the total number of surveys completed. This is because, even though the survey form asks respondents to identify their “primary” activity, some respondents identified multiple activities.

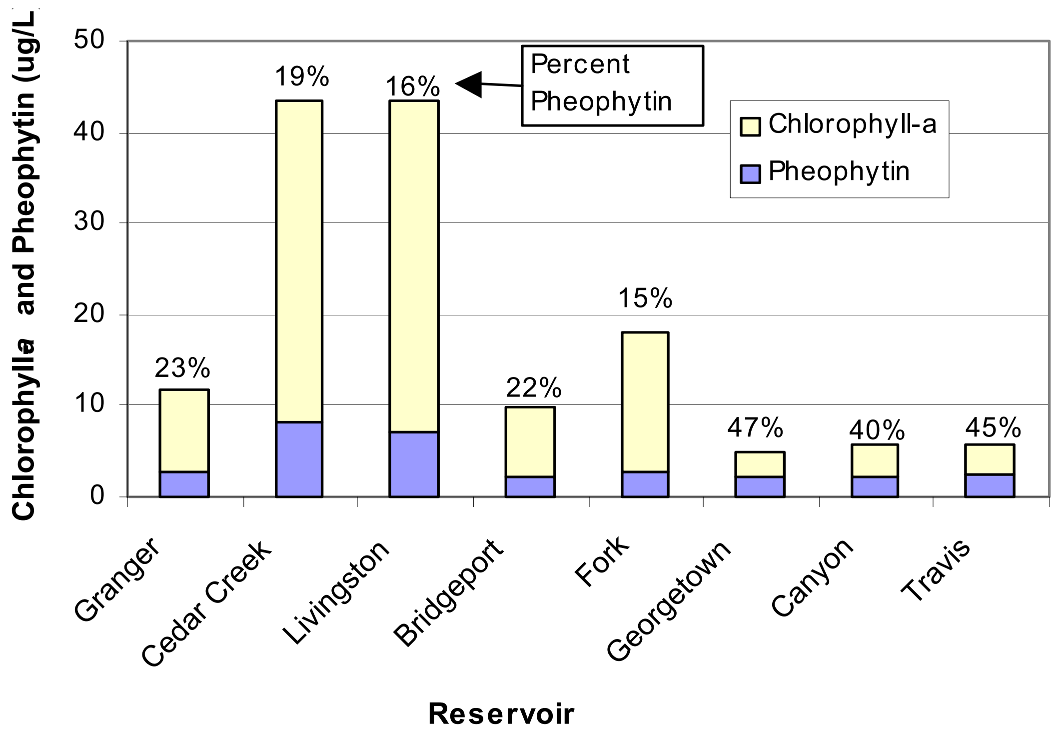


FIGURE III-6

MEAN SUMMER RESERVOIR CHLOROPHYLL-*a* AND PHEOPHYTIN CONCENTRATIONS

MAIN BODY

TABLE III-5

ANALYSES OF SPLIT SAMPLES BY LCRA AND SRA

Year	Sample Number	Chlorophyll-*a* + Pheophytin (ug/L)			
		LCRA Result	SRA Result	|SRA – LCRA|	Relative Percent Difference (RPD)
2003	1*	13.5	19.7	6.2	37.3%
	2*	13.0	24.2	11.2	60.2%
	3*	9.0	48.6	39.6	137.5%
	4	15.6	15.7	0.1	0.6%
	5	12.7	17.3	4.6	30.7%
	6	12.3	16.5	4.2	29.2%
	7	19.0	21.2	2.2	10.9%
	8	18.2	20.3	2.1	10.9%
2004		**Chlorophyll-*a* (ug/L)**			
	1	10.3	6.4	3.9	46.7%
	2	10.6	12.2	1.6	13.1%
	3	7.3	7.9	0.6	7.9%
	4	7.9	7.9	0.0	0.0%
	5	9.4	9.8	0.4	4.2%
	6	9.4	9.6	0.2	2.1%
	7	14.8	14.5	0.3	2.0%
	8	14.8	13.2	1.6	12.1%
	9	22.3	18.6	3.7	19.9%
	10	23.0	20.0	3.0	14.0%
	11	15.8	17.5	1.7	10.2%
	12	15.4	16.7	1.3	8.1%
	13	9.4	11.1	1.7	15.3%
	14	7.4	9.8	2.4	27.9%
	15	5.2	6.0	0.8	14.3%
	16	6.8	8.8	2.0	25.6%
	17	9.5	10.3	0.8	8.1%
	18	13.4	13.5	0.1	0.7%
	19	13.2	13.2	0.0	0.0%
	20	20.8	22.6	1.8	8.3%
	21	14.6	11.7	2.9	22.1%
	22	26.1	24.1	2.0	8.0%
	23	21.9	19.2	2.7	13.1%
	24	21.7	22.9	1.2	5.4%
	25	21.4	22.1	0.7	3.2%
	26	20.4	20.5	0.1	0.5%
	27	16.0	17.7	1.7	10.1%
	28	22.6	27.3	4.7	18.8%
	29	21.6	23.3	1.7	7.6%
	30	15.2	19.4	4.2	24.3%

*Prior to method refinement.

TABLE III-6

USER GROUP CHARACTERISTICS BY FREQUENCY OF VISITS TO RESERVOIR

Reservoir	Permanent Resident	More Than Six Times Per Year	Two to Six Times Per Year	Typically Every Year	First Visit	Total by Reservoir
Canyon Lake	62	64	36	18	29	209
Cedar Creek Reservoir	105	128	21	5	13	272
Granger Lake	8	89	24	10	9	140
Lake Bridgeport	33	156	51	10	49	299
Lake Fork Reservoir	124	36	26	24	25	235
Lake Georgetown	7	88	32	7	5	139
Lake Livingston	164	68	39	17	26	314
Lake Travis	17	122	25	8	15	187
Total	**520**	**751**	**254**	**99**	**171**	**1,795**

TABLE III-7

USER GROUP CHARACTERISTICS BY PRIMARY ACTIVITY

Reservoir	Number of Users							Total Responses by Reservoir
	Swimming	Fishing	Boating	Skiing/ Windsurfing	On-shore Activity	Sampling Crew	Other	
Granger Lake	11	42	17	2	15	56	18	161
Cedar Creek Reservoir	15	82	68	8	22	64	21	280
Lake Livingston	45	113	44	13	60	56	38	369
Lake Bridgeport	17	107	27	27	15	77	31	301
Lake Fork Reservoir	10	139	14	3	4	60	17	247
Lake Georgetown	21	16	14	7	19	56	19	152
Canyon Lake	31	27	67	13	9	46	43	236
Lake Travis	46	14	51	13	12	72	18	226
Total	**196**	**540**	**302**	**86**	**156**	**487**	**205**	**1,972**

It can also be noted from Table III-7 that, if one assumes the surveys for each lake are representative of the general population of users at that lake, the primary type of recreational use varies from reservoir to reservoir. Lake Fork Reservoir is well known for the quality of the fishing, and 56% of the survey respondents engaged in recreation indicated that their primary activity that day was fishing. Only 5% of the survey respondents indicated that their primary activity was contact recreation (swimming, skiing, or windsurfing). In comparison, at Lake Travis, only 6% of the recreational respondents were primarily engaged in fishing, while 26% were engaged in contact recreation.

It is concluded from these data that, in general, reservoir users have different preferences with respect to water clarity/chlorophyll concentration based on the type of recreational use in which they are participating. The reservoirs with high clarity (low chlorophyll concentrations) have more contact recreation users both as a percentage and in terms of absolute numbers.

In addition, it appears that fishermen prefer waters with more chlorophyll. The usage of the lakes with high clarity waters by fishermen is low both as a percentage and in terms of absolute numbers. The reservoirs with moderate levels of chlorophyll appear to be most popular with fishermen.

All the surveys were collected on weekdays (Monday through Friday). It is not known whether this influenced the user population that was surveyed.

CHAPTER IV

RESULTS

The following chapter presents a series of evaluations designed to evaluate relationships between varying concentrations of chlorophyll in waters of reservoirs and users' perceptions of whether recreational uses are impaired. Dr. William W. Walker, Jr., has also performed detailed evaluations of these relationships. His work is presented in Appendix D. Some of Dr. Walker's evaluations are also included in this chapter.

The relationships have been evaluated in several different ways. For example, relationships are examined for the individual reservoirs, for groups of reservoirs with similar transparency characteristics, and for the entire, pooled dataset. In addition, variations in results, based on the type of recreational activity at the reservoir and frequency of visit to the reservoir, are evaluated.

Before conducting the evaluations of relationships, two types of data were eliminated from the database:

- The database was screened to identify surveys that identified a factor other than "algal greenness" as having the most effect on the respondent's assessment of suitability of the reservoir for recreational use. These surveys were not included in subsequent evaluations.

- An attempt was made not to collect samples when water quality was influenced by rainfall runoff. However, visual inspection of the data and reports by the sampling crews of rainfall impacts suggest that a limited number of samples at Canyon Lake, Lake Bridgeport, and Lake Livingston had increased turbidity due to recent rainfall events. These water quality samples and the corresponding survey responses were not included in subsequent evaluations.

RESULTS BY RESERVOIR

Comparisons of the users' responses regarding suitability for use versus chlorophyll-*a* concentrations for each reservoir are presented on Figure IV-1. The potential responses regarding suitability of use were as follows:

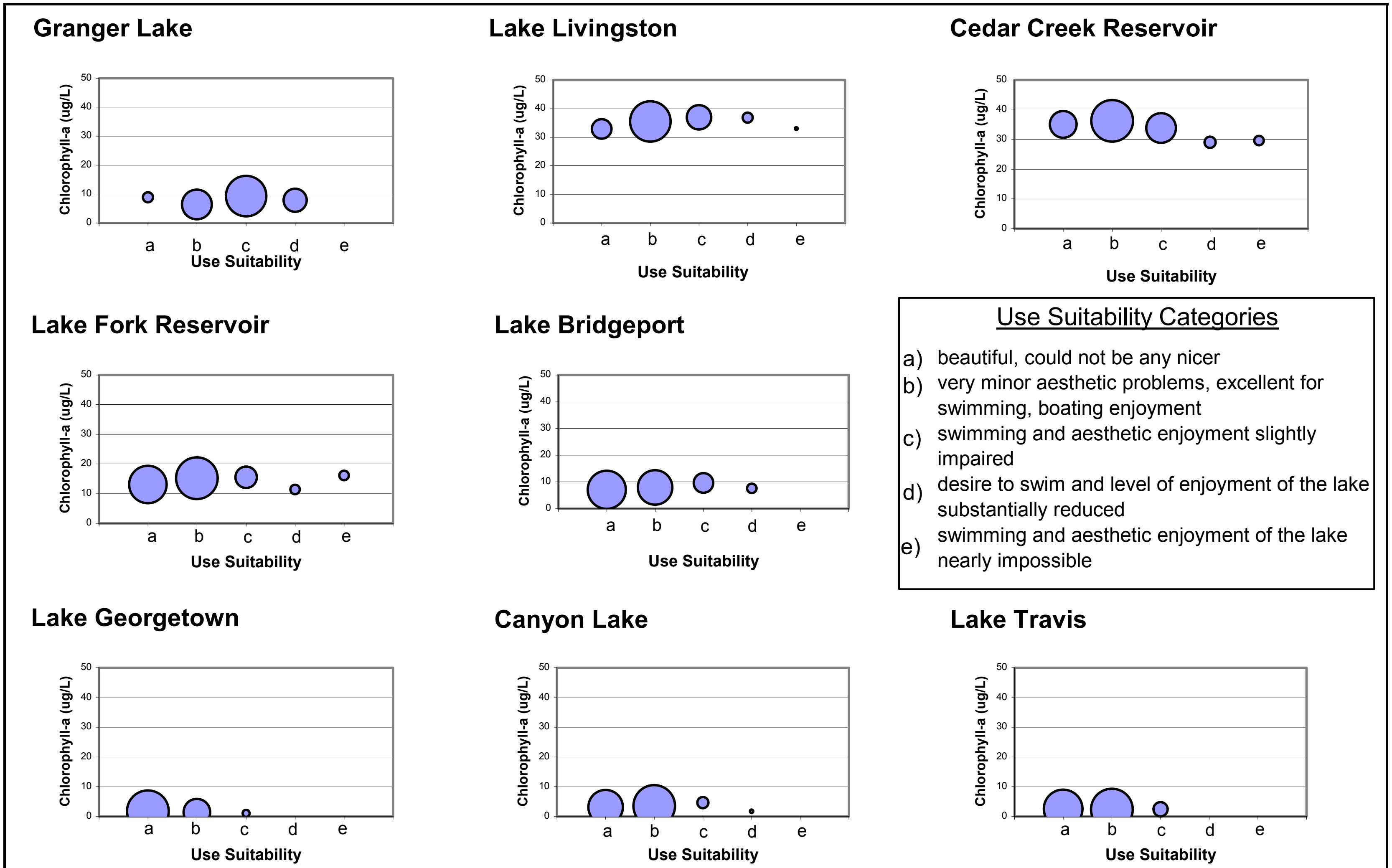


FIGURE IV-1
PERCEIVED IMPACTS ON RECREATIONAL USE VERSUS CHLOROPHYLL-a CONCENTRATIONS FOR EACH RESERVOIR

a) Beautiful, could not be any nicer

b) Very minor aesthetic problems; excellent for swimming, boating enjoyment

c) Swimming and aesthetic enjoyment slightly impaired

d) Desire to swim and level of enjoyment of the lake substantially reduced

e) Swimming and aesthetic enjoyment of the lake nearly impossible

To generate the results presented on Figure IV-1, the following calculations were performed:

- All “a” responses were compiled with their associated measurement of the chlorophyll-*a* concentration, and an average chlorophyll-*a* concentration for that dataset was calculated.

- Similarly, the average chlorophyll-*a* concentrations associated with a response of “b”, a response of “c”, a response of “d”, and a response of “e” were computed.

- The number of responses in each category, “a” through “e”, was also determined.

- The resultant data were plotted such that the horizontal axis identifies the response (“a,” “b,” “c,” “d”, or “e”), and the vertical axis identifies the average chlorophyll-*a* concentration for that response. The result is plotted as a circle. The center of the circle is placed at the average concentration, and the size of each circle is proportional to the number of respondents that classified the waterbody in that respective category (“a,” “b,” “c,” “d,”, or “e”).

A review of these figures suggests that, for a given reservoir, there is a general acceptance of existing water quality. Thus, for Cedar Creek Reservoir and Lake Livingston, a majority of responders categorized the waters as either “a – beautiful, could not be nicer,” or “b – very minor aesthetic problems; excellent for swimming, boating enjoyment,” even though the chlorophyll-*a* concentration averages were between 30 micrograms per liter (ug/L) and 35 ug/L.

Slight trends of increasing perception of use impairment with increasing concentrations of chlorophyll-*a* can be observed in the responses for Lake Bridgeport, Lake Fork Reservoir, and Lake Livingston. In addition, the reservoirs with the higher chlorophyll-*a* concentrations (Cedar Creek Reservoir and Lake Livingston) were classified as “a” less frequently and “c” more frequently than the other reservoirs.

No trends can be discerned in the results for Canyon Lake, Lake Georgetown, and Lake Travis because there was very little variation in chlorophyll-*a* concentrations during the study period. Chlorophyll-*a* concentrations in Lake Georgetown and Lake Travis did not exceed 5 ug/L, and chlorophyll-*a* concentrations in Canyon Lake did not exceed 7 ug/L.

The survey results regarding use suitability for Granger Lake may have been influenced more by the natural turbidity of the reservoir than by chlorophyll-*a* concentrations (even though respondents were specifically asked if “algae/greenness” was the factor on which they based their assessment of use suitability). As can be observed on Figure IV-1, the majority of respondents categorized Granger Lake as “c – swimming and aesthetic enjoyment slightly impaired” or “d – desire to swim and level of enjoyment of the lake substantially reduced.” The average chlorophyll-*a* concentration for these responses was less than 10 ug/L. None of the other reservoirs, even Cedar Creek Reservoir and Lake Livingston, had a majority of the responses in categories “c” and “d”.

RESULTS FOR RESERVOIR GROUPS

As has previously been noted, the reservoirs studied exhibit a wide range of transparencies. The transparency characteristics of the study reservoirs are presented on Figure IV-2. In the following evaluations, the reservoirs have been grouped based on their respective transparencies.

As previously noted, Granger Lake had the lowest transparency. The transparency was always less than 1 meter (m), and the average transparency in the main body of the reservoir was 0.5 m. Also, while in the other reservoirs there is a relationship between decreased transparency and increased algal growth, the decreased transparency in Granger Lake is primarily attributable to inorganic solids. Therefore, because of its unique characteristics, Granger Lake has not been grouped with any other reservoirs.

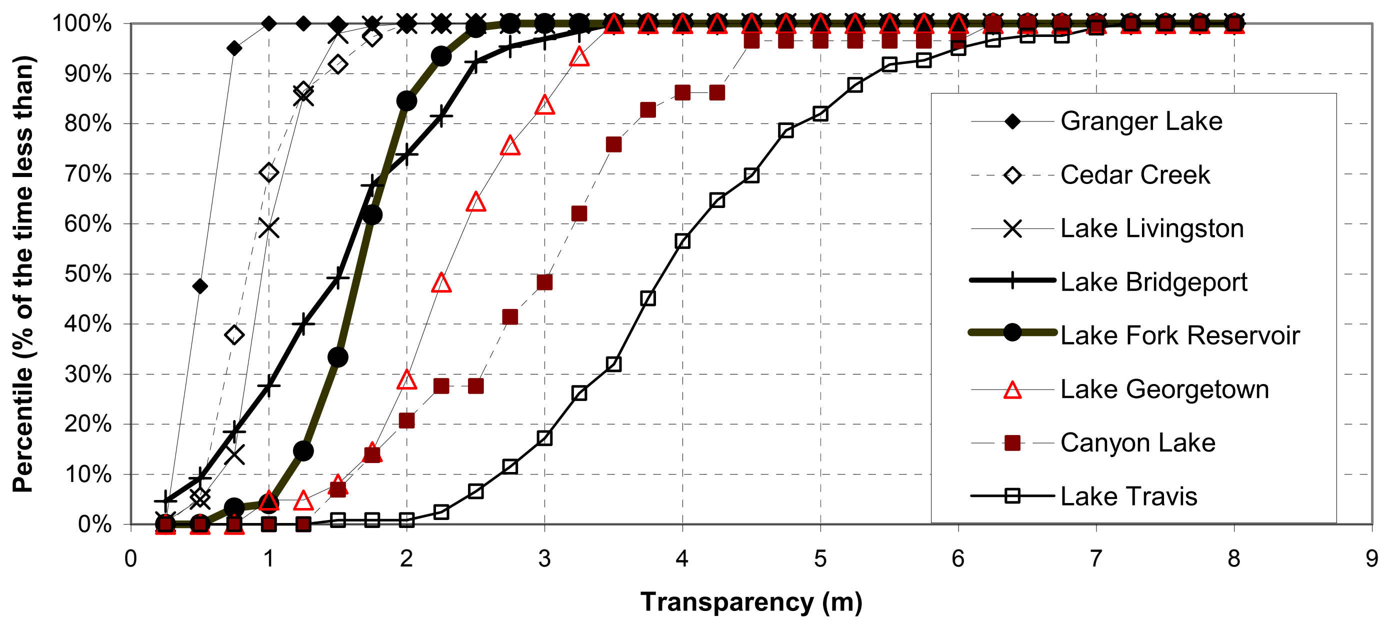


FIGURE IV-2
TRANSPARENCY CHARACTERISTICS OF RESERVOIRS

Transparency levels in Cedar Creek Reservoir and Lake Livingston are very similar. Transparency is always less than 2 m. The average transparencies in the main bodies of Cedar Creek Reservoir and Lake Livingston are 0.8 m and 0.9 m, respectively. Both of these reservoirs have relatively high concentrations of planktonic algae. The average chlorophyll-*a* concentrations in the main body waters of Cedar Creek Reservoir and Lake Livingston are 33 ug/L and 28 ug/L, respectively. Therefore, these two reservoirs have been grouped together.

Lake Bridgeport and Lake Fork Reservoir exhibit moderate levels of transparency and moderate levels of chlorophyll-*a*; so, they have been grouped together. The average transparencies in the main body waters of Lake Bridgeport and Lake Fork Reservoir are 1.3 m and 1.8 m, respectively. The average chlorophyll-*a* concentrations in the main body waters are 5 ug/L and 14 ug/L in Lake Bridgeport and Lake Fork Reservoir, respectively.

The remaining three reservoirs have high clarity and low chlorophyll-*a* concentrations. The average transparencies in the main body waters of Lake Georgetown, Canyon Lake, and Lake Travis are 2.2 m, 2.3 m, and 3.2 m, respectively. The corresponding average chlorophyll-*a* concentrations are 2 ug/L, 3 ug/L, and 2 ug/L.

Evaluations in the remainder of the report do not include data for Granger Lake since the responses for that reservoir are not believed to be related closely to chlorophyll-*a* concentrations. For the remaining three reservoir groups, relationships between chlorophyll-*a* concentrations and the respondents' perceptions of the suitability of the waters for recreational use were evaluated.

When conducting evaluations based on reservoir groups, in addition to analyzing the combined response of all participants in the survey for each reservoir group, evaluations were also conducted in which the data were divided into subsets in order to determine if there were significant differences in the responses of different user groups. For one evaluation, the data were divided into subsets based on the type of activity in which the survey respondent was engaged; and, for the other evaluation, the data were divided into subsets based on the frequency with which the respondents visited the reservoir.

<u>Evaluations of Responses by Reservoir Groups</u>

The datasets that included all users in each reservoir group were evaluated as follows. For each reservoir grouping, chlorophyll-*a* data were compiled into three subsets, and an average concentration was computed for each subset. The first subset was comprised of the chlorophyll-*a* concentrations associated with “a” responses. The second subset was comprised of the chlorophyll-*a* concentrations associated with “b” responses; and the third subset was comprised of the chlorophyll-*a* concentrations associated with “c,” “d,” or “e” responses. The results of this evaluation are presented on Figure IV-3.

Evaluations of Responses Based on Activity at the Reservoir

For the purpose of this evaluation, the respondents were grouped into three categories:

- Sampling crew
- Contact recreation users, which included those who identified their primary activity as swimming, skiing, or windsurfing
- Non-contact recreation users, which included those who identified their primary activity as fishing, boating, on-shore activity, or other

The data were then evaluated to determine whether the professional samplers characterized the waters differently than the public and whether contact recreation users characterized the waters differently than non-contact recreation users.

In some cases, survey respondents identified more than one type of recreational use, even though they were requested to identify their “primary” use. When evaluating responses based on the type of use, if there were multiple responses but contact recreation use was identified as one of the uses, that survey was assigned to the contact recreation use category.

Figure IV-4 presents the results of the evaluation to determine if the sampling crews had a different perception of the level of chlorophyll-*a* that impaired recreational use than the general public. To prepare Figure IV-4, the chlorophyll-*a* data for each reservoir group were aggregated into the following subsets:

- Less than 5 ug/L
- 5 ug/L to <10 ug/L
- 10 ug/L to <20 ug/L
- 20 ug/L to <40 ug/L
- 40 ug/L or greater

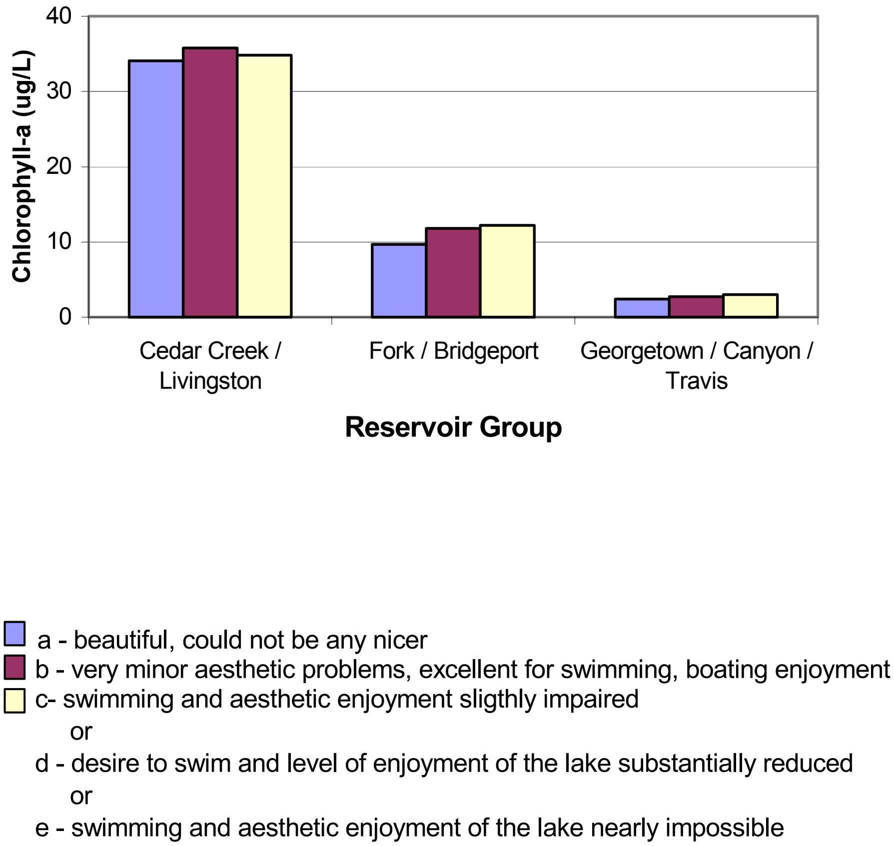
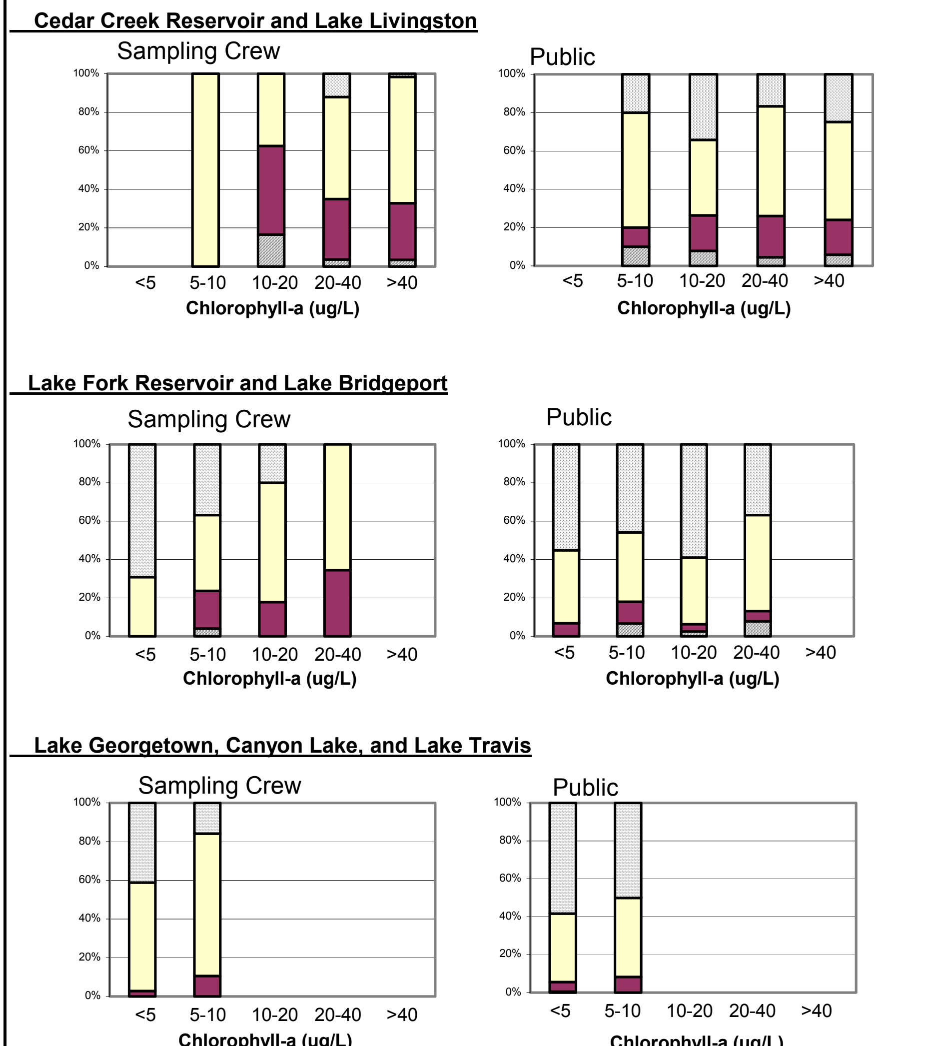


FIGURE IV-3

RECREATIONAL SUITABILITY BASED ON CHLOROPHYLL-*A* CONCENTRATION RESULTS FOR RESERVOIR GROUPS



a - beautiful, could not be any nicer
b - very minor aesthetic problems, excellent for swimming, boating enjoyment
c- swimming and aesthetic enjoyment slightly impaired
d - desire to swim and level of enjoyment of the lake substantially reduced
or
e - swimming and aesthetic enjoyment of the lake nearly impossible

FIGURE IV-4

COMPARISON OF EVALUATION OF RECREATIONAL SUITABILITY BY SAMPLING CREW AND BY PUBLIC BASED ON RESERVOIR GROUPS

Then, each chlorophyll-a subset was evaluated to determine what percent of the samplers categorized the use suitability of the water as “a,” “b,” “c,” “d,” or “e”. The same evaluation was performed for the responses of the public. As indicated on Figure IV-4, the sampling crews were more likely to identify impairment of recreational use than the general public and somewhat more consistent in identifying increased impairment as chlorophyll-a concentrations increased. However, this figure also indicates that, at equivalent concentrations of chlorophyll, the perception of use impact by the samplers varied significantly from one reservoir group to another. Thus, in Cedar Creek Reservoir and Lake Livingston, when chlorophyll-a concentrations were in the 10 ug/L – 20 ug/L range, the sampling crew classified the use suitability of the water as “d” (“enjoyment substantially reduced”) almost 20% of the time. However, when chlorophyll-a concentrations were between 10 ug/L and 20 ug/L in Lake Fork Reservoir and Lake Bridgeport, the sampling crew classified the use suitability as “c” (“slightly impaired”) approximately 20% of the time and did not characterize any of the waters as “d.” The perceptions of the public vary somewhat from one reservoir group to another, also, but not as much as the perceptions of the samplers.

A similar evaluation was performed comparing responses of contact recreation users to responses of non-contact recreation users. The results of this evaluation are presented on Figure IV-5. The conclusions to be drawn from this evaluation are unclear. The contact recreation users exhibited a more consistent tendency to assign fewer “a’s” and more “b’s” as chlorophyll-*a* concentrations increased than did non-contact recreation users. However, non-contact recreation users were more inclined to assign “c,” “d,” or “e” classifications at all chlorophyll-*a* concentrations.

<u>Evaluations of Responses Based on Frequency of Visits</u>

For the purpose of this evaluation, the survey respondents were grouped into two categories:

- Frequent – Visit lake more than six times per year or are a permanent resident
- Infrequent – Visit lake six times per year or less

Responses of the sampling crews were not included in this evaluation

The evaluation was performed in the same manner as the previous comparisons of sampling crew versus the public and contact recreation users versus non-contact recreation users. The results are presented on Figure IV-6. No discernible differences exist between these two groups of users for the reservoir grouping that includes Cedar Creek Reservoir and Lake

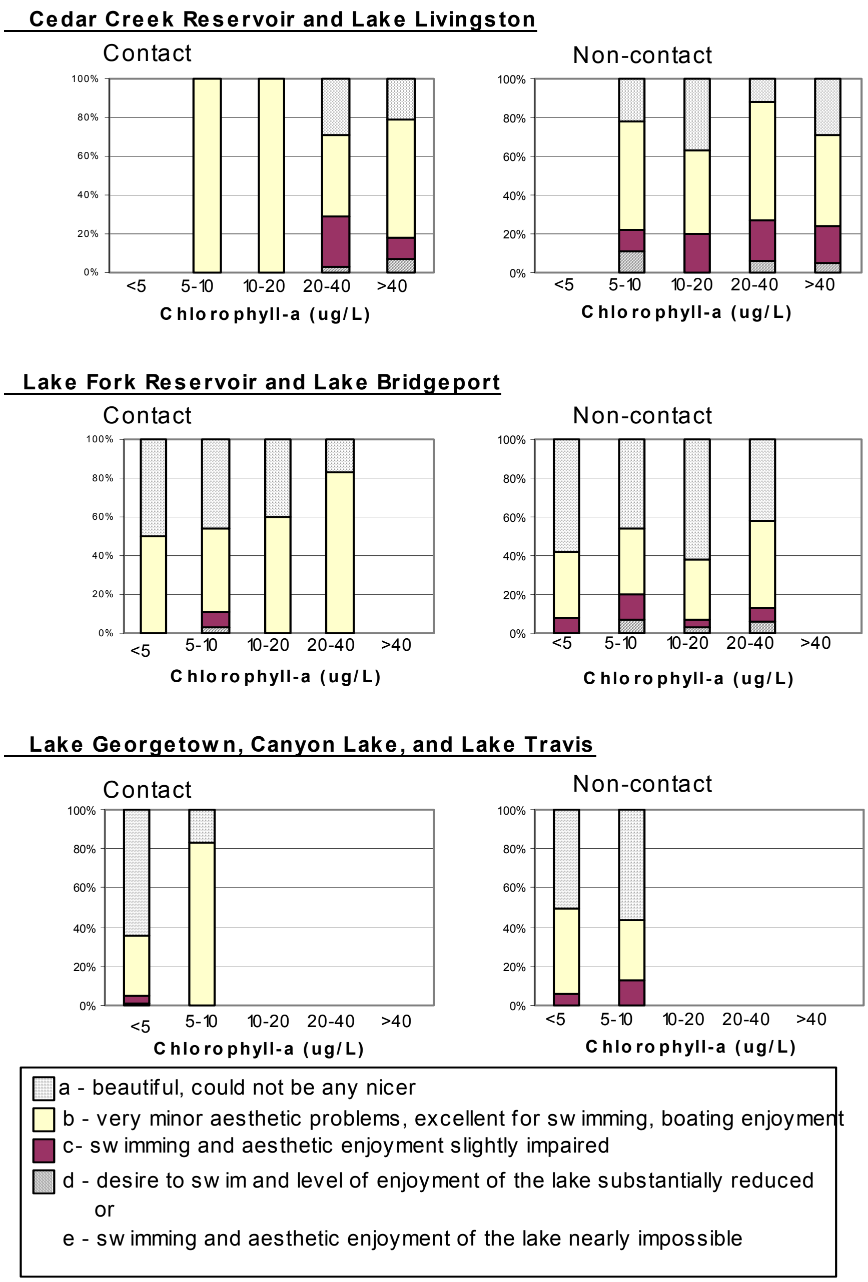


FIGURE IV-5

COMPARISON OF EVALUATION OF RECREATIONAL SUITABILITY BY CONTACT RECREATIONAL USERS VERSUS NON-CONTACT RECREATIONAL USERS BASED ON RESERVOIR GROUPS

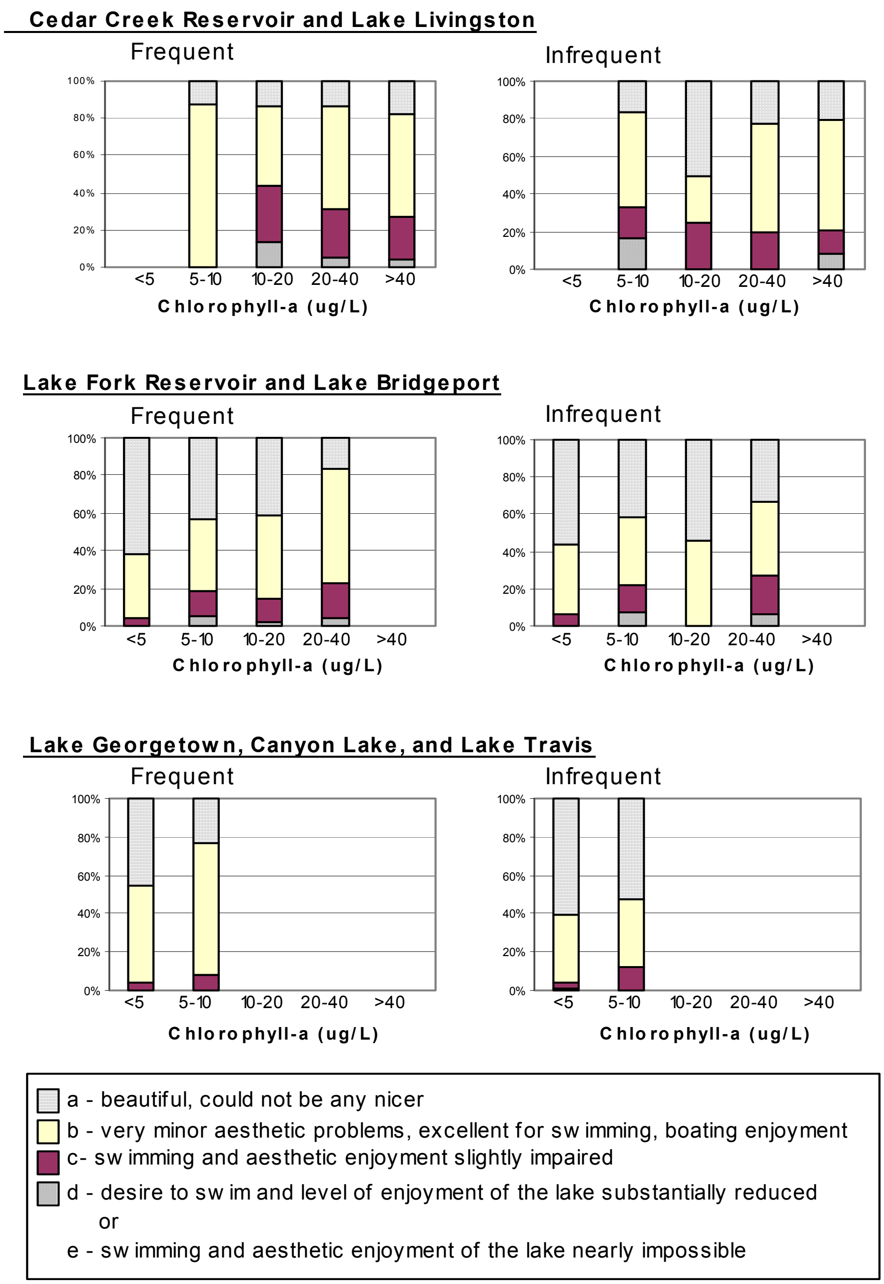


FIGURE IV-6
COMPARISON OF EVALUATION OF RECREATIONAL SUITABILITY BY FREQUENT VISITORS VERSUS INFREQUENT VISITORS BASED ON RESERVOIR GROUPS

Livingston. However, in the other two reservoir groups, the frequent visitors are slightly more likely to perceive use impacts as chlorophyll-*a* concentrations increase than are the infrequent visitors.

RESULTS BASED ON COMPLETE DATASET

Comparisons of perceptions of use suitability and chlorophyll-*a* concentrations were also conducted for a pooled dataset that included the results for all of the reservoirs except Granger Lake. As previously discussed, the responses for Granger Lake regarding suitability for recreational use are believed to have been influenced significantly by factors other than the amount of algae present.

The data were evaluated three different ways. Following are descriptions of the method and the results for each evaluation.

First Evaluation

The first evaluation using the pooled dataset was an investigation of the relationship between the average chlorophyll-*a* concentration in a reservoir (main body and cove/headwater stations) and (1) the combined percentage of the respondents that characterized the recreational use suitability of that reservoir as "c," "d," or "e" and (2) the combined percentage of the respondents that characterized the recreational suitability of that reservoir as "d" or "e." The results of this evaluation are presented on Figure IV-7. There is a strong correlation indicating that, as the chlorophyll concentration of a reservoir increases, more users perceive some degree of use impairment.

Second Evaluation

For the second evaluation, the chlorophyll-*a* concentrations were ordered from lowest to highest. Then, the data originally were aggregated into 10 percentile groups; i.e., the 10% of the data with the lowest concentrations comprised one subset; the next 10% of the data, based on the next lowest concentration group, comprised the second subset; etc. When this was done, because of the number of values below the reliable detection limit in the first subset, the first and second subsets were combined. Therefore, when responses were compared to chlorophyll concentrations, there were nine subsets, which represented the following percentile ranges: 0-19, 20-29 30-39, 40-49, 50-59, 60-69, 70-79, 80-89 and 90-100.

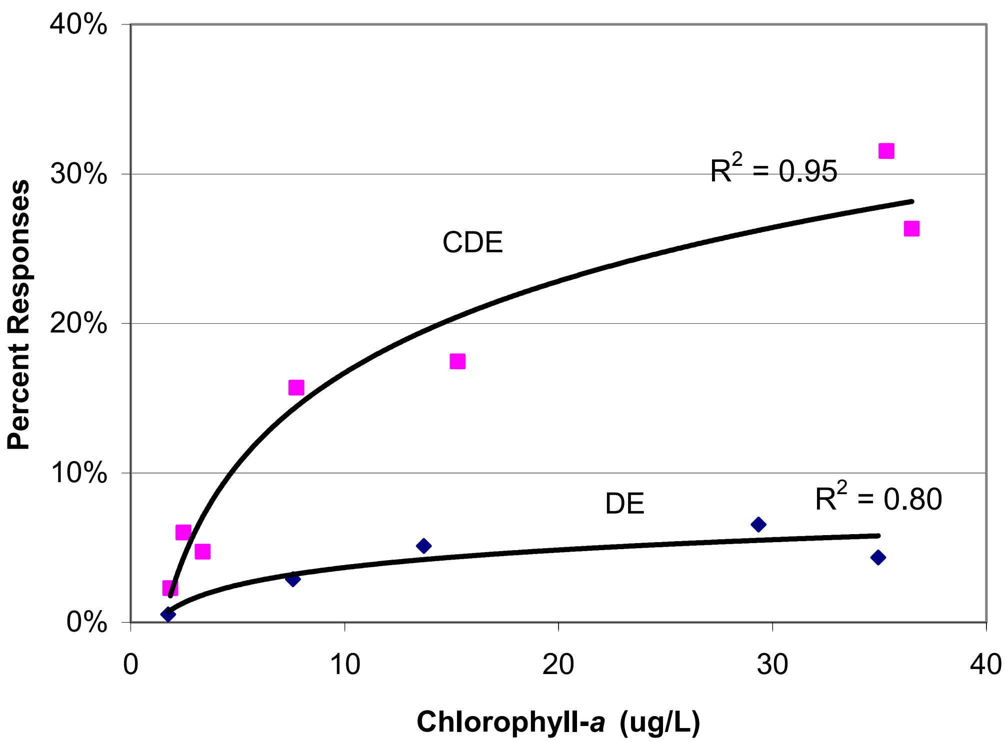


FIGURE IV-7
FREQUENCY OF RESPONSE OF USE IMPAIRMENT
VERSUS CHLOROPHYLL-*A* CONCENTRATION
COMPARISON BETWEEN RESERVOIRS
(Granger Not Included)

Each data point represents a reservoir

For each percentile subset, the following values were computed:

- The average concentration of chlorophyll-*a*
- The percent of the responses that represented the sum of the “c,” “d,” and “e” responses.
- The percent of the responses that represented the sum of the “d” and “e” responses.

The results of this evaluation are presented on Figure IV-8.

The results of this evaluation are very similar to the results of the preceding evaluation. This is not unexpected because the range of chlorophyll concentrations in each reservoir is relatively specific to that reservoir. The cases in which reservoirs exhibit similar concentrations are the three high-clarity reservoirs and the two low-clarity reservoirs. The grouping of data by reservoir and the grouping of data by concentration intervals produce very similar groupings with respect to the results of the user surveys.

Dr. Walker performed this same evaluation for various subsets of the survey respondents. In addition to all observers at all reservoirs (except Granger), he analyzed the responses of the following groups:

- Sampling crews and contact users
- Non-contact users
- Sampling crews and contact users at high and moderate clarity reservoirs

The results of these evaluations are presented in his report (Appendix D) on Figure 14.

<u>Third Evaluation</u>

For the third evaluation, data subsets were prepared wherein all “a” responses for use suitability were placed in a subset: “b” responses were each placed in a subset; and, similarly, “c,” “d,” and “e” responses were placed in a subset. Then, the average chlorophyll-*a* concentration of each subset was computed. The results are presented on Figure IV-9. As shown on this figure, for the larger dataset representing seven reservoirs, there is a relationship between chlorophyll-*a* concentrations and perceived use impairment. A similar evaluation was performed for the survey question that addressed the amount of greenness perceived. The results of that evaluation are also shown on Figure IV-9. Here, too, there is a relationship between the amount of greenness perceived and chlorophyll-*a* concentrations.

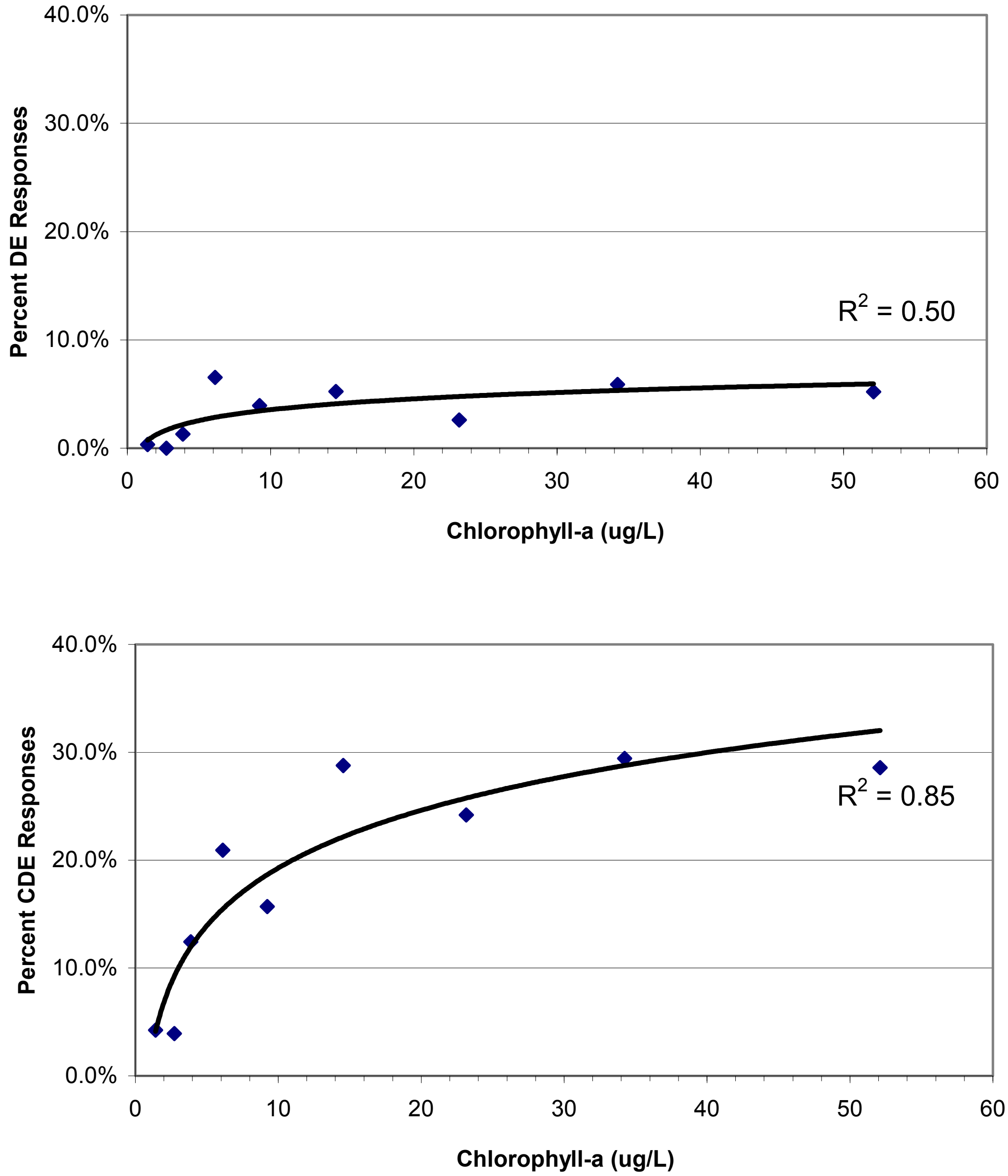
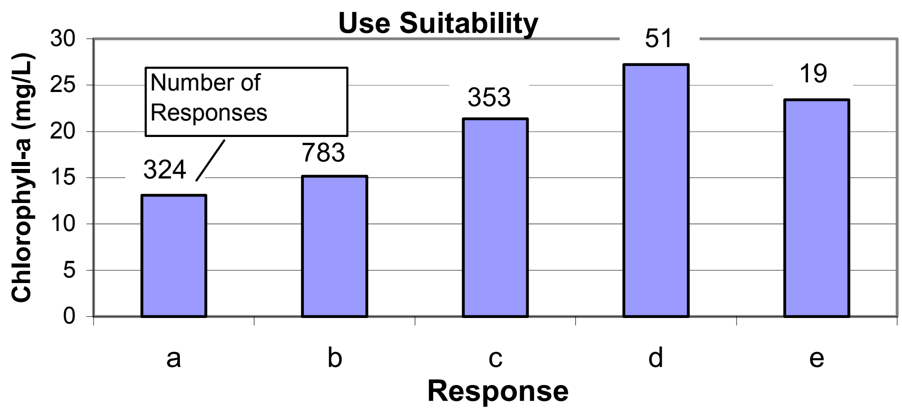


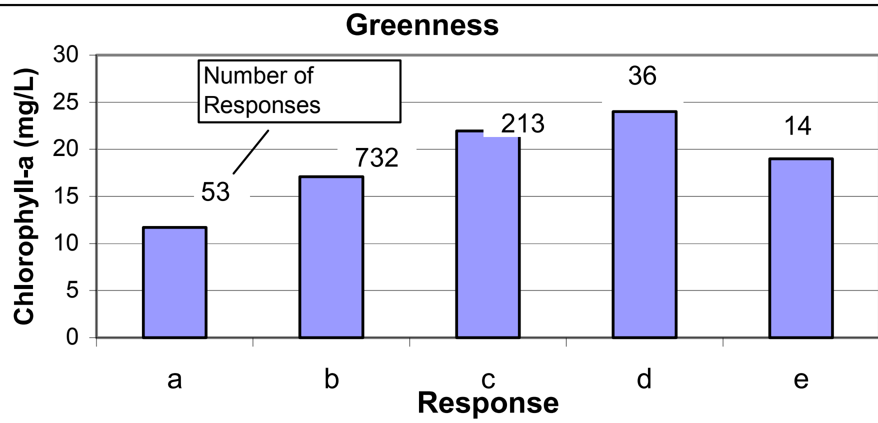
FIGURE IV-8
FREQUENCY OF RESPONSE OF USE IMPAIRMENT VERSUS CHLOROPHYLL-a CONCENTRATION COMPARISON BASED ON CONCENTRATIONS

(Each data point represents a concentration interval)



Use Suitability

a - beautiful, could not be any nicer
b - very minor aesthetic problems
c - swimming and aesthetic enjoyment slightly impaired
d - desire to swim and level of enjoyment of the lake substantially reduced
e - swimming and aesthetic enjoyment of the lake nearly impossible



Greenness

a - no algae, or crystal clear water
b - a little algae visible
c - definite algal visible
d - very green, some scum present and/or mild odor apparent
e - pea-soup green with one or more of the following: massive floating scums on lake or washed up on shore, strong foul oder, or fish kill

FIGURE IV-9

AVERAGE CHLOROPHYLL-*A* CONCENTRATION FOR EACH CATEGORY OF USE SUITABILITY AND GREENNESS ALL DATA POOLED

OTHER FINDINGS

In addition to providing information regarding relationships between users' perceptions of decreased desirability for recreational use and algal density, the study provided information regarding what parameters would be most functional as a water quality standard. The findings of the study in this regard are as follows:

- A standard based on the seasonal mean chlorophyll concentration will also be effective in controlling seasonal maximum chlorophyll concentrations.
- When data for all the reservoirs except Granger Lake are grouped, chlorophyll concentration is a better measure of the potential for recreational use impairment due to nutrients than transparency (measured as Secchi disc depth).

The evaluations on which these findings are based are set forth below:

Relationship Between Chlorophyll Seasonal Maximums and Seasonal Means

In other states where chlorophyll criteria have been established, they are typically expressed as seasonal mean values. Previous research[1,2,3] has shown that a log-normal (ln) distribution model can be used to predict the frequency of algal blooms based on seasonal mean concentrations. In Figure 5 of Appendix D, Dr. Walker presents the relationships for bloom frequency and seasonal mean concentrations for the reservoirs sampled in this study. Figure 5 also includes a plot of the standard deviation versus the seasonal mean chlorophyll concentration. The standard deviation is 0.39 for ln–transformed values, which is in the range found for data for other reservoirs.

Similarly, there is a strong relationship between the seasonal maximum concentration and the seasonal mean concentration of chlorophyll. This relationship for the reservoirs in this study is shown on Figure IV-10. Therefore, although users respond to the frequency of algal blooms rather than an average seasonal concentration, a seasonal mean criterion is a reasonable surrogate for a bloom frequency criterion, and it provides control for extreme conditions. The seasonal mean is a more useful parameter for a standard because the seasonal mean can be measured more precisely than bloom frequencies with a typical monitoring plan.

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[1] Walker, W.W., "Statistical Bases for Mean Chlorophyll-a Criteria," in "Lake and Reservoir Management – Practical Applications," Proc. 4th Annual Conference, North American Lake Management Society, McAfee, New Jersey, pp 57-62, October 1984. http://www.wwwalker.net/pdf/chlacrit85.pdf

[2] Walker,W.W., "Experience in Developing Phosphorus TMDLs for Lakes," presented at "Enhancing States Lake Management Programs," 16th Annual National Conference, North American Lake Management Society, Chicago, April 2003a. http://www.wwwalker.net/pdf/nalms_Chicago_2003.pdf

[3] Walker, W.W., "Consideration of Variability and Uncertainty in Phosphorus TMDLs for Lakes," Journal of Water Resources Planning and Management, American Society of Civil Engineers, Vol. 129, No. 4, July 2003b. http://www.wwwalker.net/index.htm#tmdl_reports

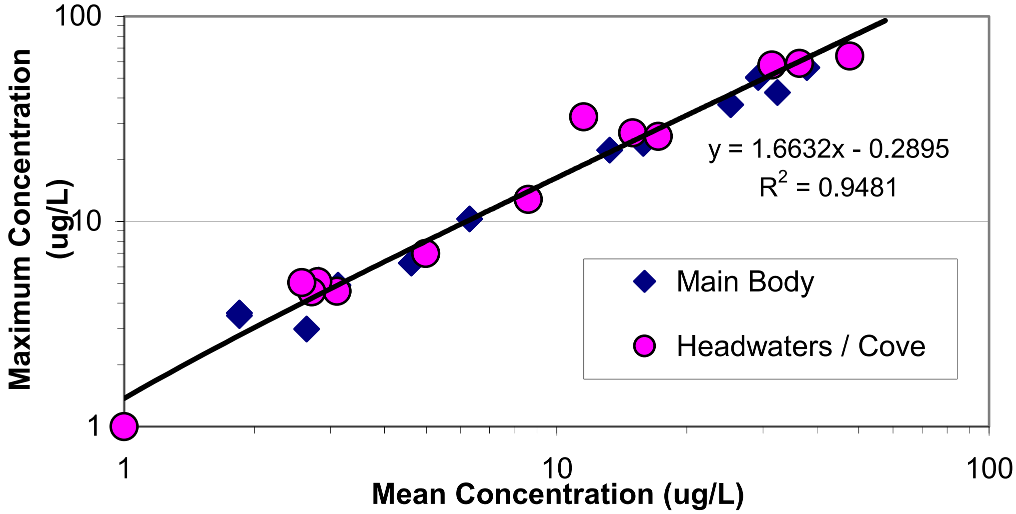

FIGURE IV-10
RELATIONSHIP BETWEEN CHLOROPHYLL-*A* SEASONAL MAXIMUM AND SEASONAL MEAN CONCENTRATIONS

(Each data point represents a reservoir and a specific year)

Selection of Chlorophyll as Parameter for Standard

In EPA guidance documents on developing nutrient criteria, transparency is suggested as a possible water quality standard parameter. The data from this study were evaluated to determine whether Secchi disc depth or chlorophyll would provide the best correlation to impacts on recreational use due to algal growth.

In Figure IV-7, the relationship between the mean chlorophyll-a concentration in each reservoir and the percent of responses represented by the sum of the "c," "d," and "e" responses for that reservoir is presented. A similar analysis was conducted, which compared the average Secchi disc depth for each reservoir to the percent of "c," and "d," and "e" responses for that reservoir. The results of that evaluation are presented on Figure IV-11. The coefficient of determination (R^2) for the relationship with chlorophyll-*a* is 0.90, and the coefficient of determination for the relationship with Secchi disc depth is 0.66. There is a stronger correlation with chlorophyll than with transparency; so, chlorophyll is a better choice for a standard.

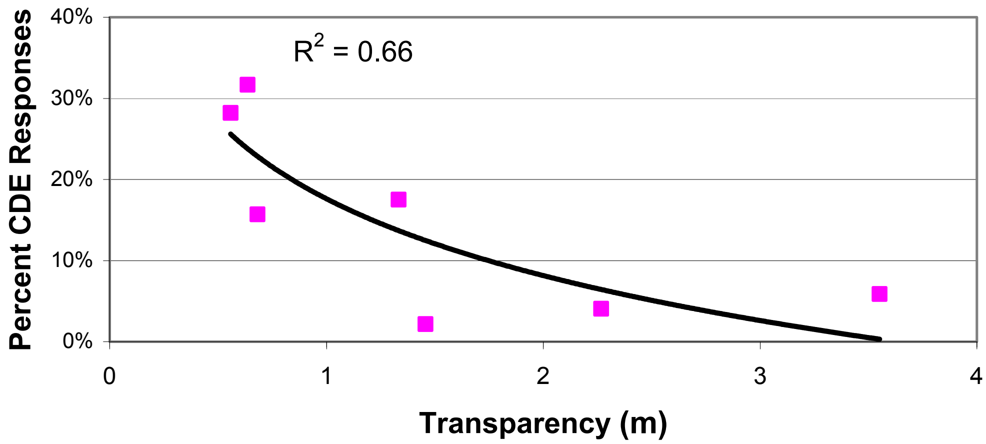

FIGURE IV-11

**FREQUENCY OF RESPONSE OF USE IMPAIRMENT
VERSUS TRANSPARENCY
COMPARISON BETWEEN RESERVOIRS**

(Each data point represents a reservoir)

CHAPTER V

STUDY CONCLUSIONS

In association with water quality monitoring, a total of 794 user surveys were conducted in 2003 and 1,010, in 2004 on eight reservoirs across the state. Evaluations of water quality data and user surveys resulted in the following conclusions:

- Lake Granger had high inorganic suspended solids (>10 mg/L), and algal growth was inhibited. Therefore, it was deleted from most data evaluations.

- When all reservoirs but Lake Granger were grouped, a significant relationship ($P<0.05$) was found between Secchi depth and degree of user satisfaction (Figure IV-11) while a significant negative relationship ($P<0.001$) was found between chlorophyll-*a* concentration and degree of user satisfaction (Figure IV-7).

- At all reservoirs the cove sites had higher mean chlorophyll-*a* concentrations than the main body (Figure II-5).

- This study found good agreement with historical chlorophyll-*a* data from the TCEQ database for most of the study reservoirs.

- Pheophytin concentrations were found to be small in relation to chlorophyll-*a* and not necessary for inclusion when doing data analysis.

- Field filtration, freezing and one-day shipping of chlorophyll-*a* samples to a common laboratory produced a dataset with a coefficient of variation of 0.41, which is lower than most other datasets of this nature.

- Reservoir users appear “acclimated” to the conditions of each reservoir, such that use suitability is related to the typical chlorophyll-*a* concentration for that reservoir. This may explain why there is a not a larger disparity in users’ opinions between Lake Travis at 4 μg /L and Cedar Creek at 35 μg/L.

- The mean chlorophyll-a concentration for users selecting “d” (desire to swim and level of enjoyment of the lake is substantially reduced) is 27.2 μg/L (Fig IV-9).

- Seasonal maximum chlorophyll-*a* averages 1.66 times seasonal mean chlorophyll-*a* ($R^2=0.95$, Fig IV-10).

- The data from the seven reservoirs evaluated (Canyon Lake, Cedar Creek Reservoir, Lake Bridgeport, Lake Fork, Lake Georgetown, Lake Livingston, and Lake Travis) fit the log normal distribution models used elsewhere in the country for relating the summer mean concentration of chlorophyll-*a* to the frequency of a bloom concentration.

- Based upon the bloom-frequency models, a bloom of 30 μg/L is expected more than 25% of the time with a mean growing season concentration of 24 μg/L or greater. If a bloom is defined as 40 μg/L, then the mean reservoir concentration increases to 31 μg/L. (means visually identified on Walker’s Figure 5 in Appendix D).

- Samplers (trained scientists) were more likely to identify use impairment than the public, but the level of chlorophyll-a that defined this impairment differs from reservoir to reservoir.

- Contact users and non-contact users did not show a great difference in opinions on use impairment.

- Little difference was apparent between frequent and infrequent visitors of the reservoir.