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ANALYSIS OF USE AND NUTRIENT DATA ON SELECTED RESERVOIRS OF THE TRINITY RIVER BASIN

Prepared for:

Trinity River Authority of Texas
Clean Rivers Program of the Texas
Commission on Environmental Quality

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) launched a National Nutrient Strategy initiative in 1998. The main goal is to have states and tribes adopt numerical criteria for either nutrients or response variables such as chlorophyll *a*. Texas, like most states, currently only has narrative nutrient criteria, mainly because the effect of nutrients is very hard to quantify. While other constituents might cause responses such as toxicity or low dissolved oxygen levels, the main concern for nutrients under normal conditions is their effect on aquatic plant growth. Since absolute levels are hard to define and many other factors affect aquatic plant growth, setting nutrient criteria becomes difficult.

To act as an incentive to states and tribes, the EPA developed a method for selecting numerical nutrient criteria and applied the method on a national basis. The EPA methodology is empirical in that it recommends establishing criteria based on a percentile of existing data for systems (lakes & reservoirs, and rivers and streams) that share some type of geographic similarity. The common factor in their method is being one of 14 Ecoregions defined for the continental U.S. They suggest two methods. One is to select the relatively pristine water bodies in the ecoregion and set the criteria at the 75th percentile of the data. If sufficient pristine waters are not available, the EPA recommends the criteria be set at the 25th percentile (i.e. towards the low concentration end) of the data. With that approach one would expect a high proportion of waters to exceed the criteria. The results of that application were nutrient (total nitrogen and total phosphorus) and response variable (chlorophyll *a* and Secchi depth) values that might be suitable for lakes in the Rocky Mountains or northern New York, but are well below those that exist in even the most pristine Texas reservoirs. For example, Medina Lake west of San Antonio, known for its exceptional water clarity and low nutrients, would exceed the EPA values substantially. EPA has indicated that if states and tribes do not come up with satisfactory numerical criteria, they would impose their values. If such levels were imposed, and serious efforts made to achieve the criteria, massive expenditures would likely be required. Texas has taken the situation seriously and has agreed to develop numerical criteria for some reservoirs by the end of 2004.

A major concern that is a basis for this study is the role of designated uses. The 1972 federal Clean Water Act specified that states and tribes adopt, with EPA approval, water quality standards. These standards are to include:

- Designated water uses such as swimming, drinking water supply, etc.,
- Criteria to determine whether the uses are being achieved, and
- An anti-degradation policy.

Texas has water quality standards with the criteria for nutrients being narrative rather than numerical. The EPA method for picking numerical criteria does not consider uses and the relationship between uses and criteria. To be consistent with the Clean Water Act and ensure that numerical criteria have a strong technical basis, it is desirable to have criteria that protect the intended or designated uses, but are not so draconian that they produce undesirable and unintended costs and consequences. This study was conceived and designed to explore and develop the relations between the uses, both existing designated and actual, and the concentrations of key nutrient parameters.

Study Objectives

- Explore the available data on the uses for selected reservoirs in the Trinity River Basin, ,
- Identify possible mechanisms to relate criteria to actual uses, and
- Develop a general approach to the establishment of numerical nutrient criteria.

Study Approach

Nine reservoirs in the Trinity River Basin were selected for detailed study based on geographic, land use and size diversity, and data availability factors. Data were retrieved from a range of sources including the Clean River Program, Texas Parks and Wildlife Department (TPWD) that manages the fisheries in each reservoir, approximately 40 organizations that supply water to the public from these reservoirs, and a number of agencies that own and manage the reservoirs. These include Dallas Water Utilities, North Texas Municipal Water District, Tarrant Regional Water District, and Trinity River Authority of Texas (TRA), and the U.S. Army Corps of Engineers. A Technical Steering Committee was established by the TRA to guide the study. Analyses were organized around three major uses that are now specified in the standards:

- Recreation,
- Aquatic life propagation, and
- Water supply.

Significant Findings

The major findings of the study were:

Use Support — All of the study reservoirs are heavily used for recreation, water supply, and support healthy aquatic life communities. <u>By that measure, all the reservoirs supported their designated uses.</u> However, in dealing with the nutrient issue, the Texas Commission on Environmental Quality (TCEQ) has developed screening criteria that are the 85th percentile of data from Texas reservoirs. Using those screening criteria values, some of the reservoirs have some stations that have some data above the screening levels. <u>By that measure, 7 of the 9 study reservoirs are listed as having a concern with nutrients.</u> As a practical matter and by definition, 15% of data would be above such screening levels. In most cases, the stations with data higher than the screening levels were in coves or arms of the reservoirs. In some cases these cove or arm stations are different from the main body stations.

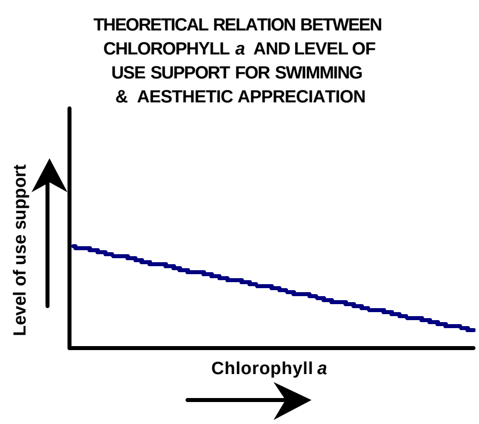
Chlorophyll a — Each nutrient parameter, total nitrogen (TN) and total phosphorus (TP), were evaluated along with the main response variables, chlorophyll *a* and Secchi depth. It was determined that chlorophyll *a* was the parameter most directly related to uses, and that it should be the parameter selected for numerical criteria development.

Anti-Degradation — Whatever method is employed to determine numerical criteria, it is unlikely that major increases in chlorophyll *a* will be allowed for any large public multi-use reservoir, simply because of the anti-degradation policy. The main activity in determining numerical chlorophyll *a* criteria will thus be in identifying where reductions are needed and how much these reductions need to be to support the expected uses.

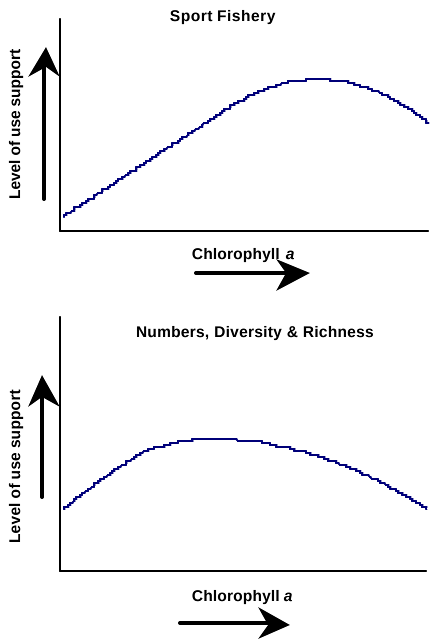
Anti-Degradation Approach for Less-Impacted Reservoirs — The TCEQ is proposing to use an anti-degradation approach to set numerical criteria for less impacted reservoirs. To date, less impacted reservoirs are defined as those that have <10% of their watersheds involved in urban or agricultural use and have no major wastewater discharges. In general terms, it would appear to make sense to set numerical criteria at levels representative of existing conditions for such reservoirs, because there would be little practical opportunity for changing conditions.

Relations Between Chlorophyll a and Use Support — Each major use was evaluated in relation to the overall level of nutrient enrichment, as represented by average chlorophyll *a* concentration. In no case were precise quantitative relationships available, but the general patterns and directions were clearly established.

With recreation, including swimming, boating, skiing and aesthetic appreciation, it is well understood that better water clarity, as represented by lower chlorophyll *a* levels, should have a higher level of use support. This is illustrated graphically as a decline in the level of use support with higher chlorophyll *a* levels.



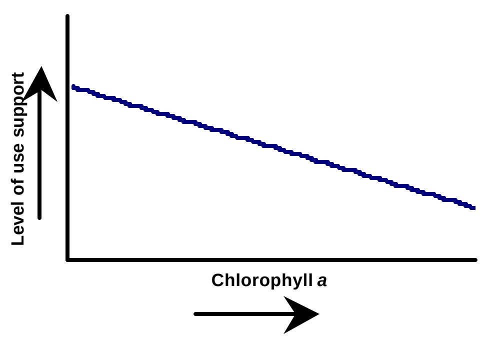
THEORETICAL RELATION BETWEEN CHLOROPHYLL *a* AND LEVEL OF AQUATIC LIFE USE SUPPORT



In the case of the aquatic life support use, the literature and fundamental principles strongly support the idea that, up to a point, more chlorophyll *a* and primary production (food) will support a larger, healthier, and more productive fishery. The optimal level of chlorophyll *a* to support a healthy recreational fishery in small lakes and reservoirs is well understood but less is known about what that optimal level might be for larger reservoirs. With that said, the levels that would maximize fishery uses are likely much higher than that of any of the study reservoirs.

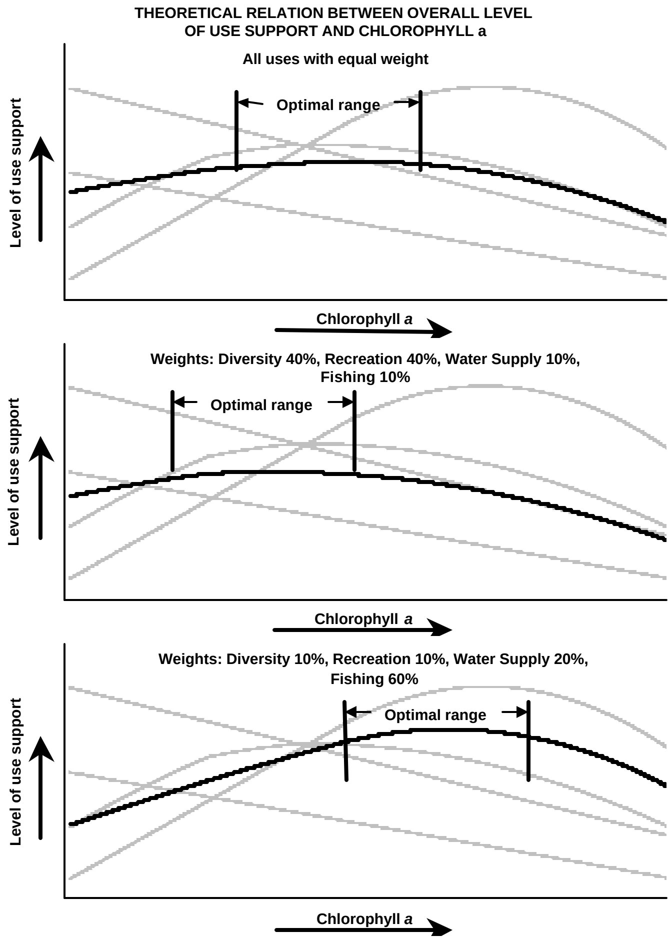
Another dimension of aquatic life use support is species diversity and richness. While we could locate no studies of reservoirs specific to this topic, biological experience suggests that species diversity or richness would probably peak at an average chlorophyll *a* level less than what would be expected for maximum recreational fishery production. Species that have sensitive life stages or narrow habitat requirements might disappear with higher chlorophyll *a* levels. Very low chlorophyll *a* levels can have negative effects on recreationally important species, and also impact species diversity and richness. The lower chlorophyll *a* level that might be optimal for diversity and richness is also illustrated.

THEORETICAL RELATION BETWEEN CHLOROPHYLL *a* AND LEVEL OF WATER SUPPLY USE SUPPORT



All of the reservoirs were built for water supply and all successfully serve that use. While the data are very scattered, it appears that higher chlorophyll *a* increases the cost of water treatment to some degree. No water supplier indicated their water was not suitable as a public supply or that they had any real problem in treating the water to a satisfactory level. Nevertheless, a higher cost is a measure of use support, leading to the theoretical relation illustrated.

Optimizing Use Support — From the above there is no clear limiting or threshold value for chlorophyll *a* levels to support uses and there is a difference in direction of effects of chlorophyll *a* with the uses considered. Furthermore, the mix or level of activity for the various uses can be expected to be different with each reservoir. The study data suggests that the existing levels of chlorophyll *a* are “acceptable” but not necessarily optimal to best satisfy the mix of competing uses of the public. For each reservoir it is the level to which the existing uses have adapted, rather than the best level to support the uses. To achieve what might be viewed as optimal for existing and reasonable potential uses will require some mechanism for the public’s competing uses to be represented and balanced in a rational and structured fashion.



There are mathematical means to determine the optimal average concentration of chlorophyll *a*, provided the relations between use support and average chlorophyll *a* are known, and the relative weight to assign to each use is accepted. If these weights were known for a given reservoir, an optimal level could be computed using standard linear optimization techniques. An example is shown for different mixes of uses, using the theoretical use-support and chlorophyll *a* relations described.

Selecting Numerical Criteria for Impacted Reservoirs — For reservoirs that now have higher levels of chlorophyll *a* some mechanism is needed to balance the conflicting needs and develop an optimal level of use support. There are many ways this can be done. One that has worked well in a similar situation is the model offered by the Regional Water Planning Groups, established by the Texas Water Development Board, to deal with the complex and often competing water supply needs of various interests in different regions of Texas. In a similar manner, the TCEQ could appoint representatives of each major use (e.g., swimming, fishing, water supply) as well as the overall health of the system, and charge them to jointly determine a target chlorophyll *a* level or range that would be near optimal to maximize the overall level of use support for one or more reservoirs in a region.

Criteria and Attainment — Whatever method of selecting numerical criteria for impacted reservoirs is employed, it is essential that it be developed in concert with the method for determining attainment. The high degree of natural variability in chlorophyll *a* levels from month to month, year to year, and in different parts of the same reservoir on the same day need to be considered and reflected in any criteria that are ultimately selected.

Better Definition of Uses — The foregoing discussion is in terms of three broad uses (Recreation, Aquatic Life and Water Supply) that are currently in the Texas Surface Water Quality Standards. In reality the uses are much more complex, involving many dimensions and differences between reservoirs. As part of a larger effort to develop use-based criteria, there is a need to develop more detailed and specific uses and the water quality requirements to support these uses.

Separate Criteria for Coves and Arms of Reservoirs – This study focused on data from the main body or pool of reservoirs, but it was noted that where problems were identified, they were frequently at stations in coves or arms where conditions are often different. Serious consideration should be given to establishing criteria and/or screening levels for coves and arms to more accurately reflect their specific conditions.

Contents

Appendices

Figures

Page

Tables

Page

1.0 INTRODUCTION

Nutrients, primarily nitrogen and phosphorus, are a water quality concern because in excess supply they can stimulate high concentrations of aquatic plants and degrade the quality of a water body. At the same time, a certain amount of nutrients are necessary to support the base of the aquatic life food web. Finding the right balance is an important water quality management function. The U.S. Environmental Protection Agency (EPA) has set a goal of establishing quantitative nutrient criteria, and an important consideration is the role of water uses. This study, supported by the Texas Clean Rivers Program (CRP) administered by the Trinity River Authority of Texas (TRA), describes a process of investigation of the relationship between a range of water uses supported by reservoirs in the Trinity River basin and possible criteria for nutrients.

1.1 BACKGROUND

The 1972 Federal Clean Water Act specified that states and tribes adopt, with EPA approval, water quality standards. These standards are to include:

- Designated water uses,
- Criteria to determine if the uses are being achieved, and
- An anti-degradation policy.

Because the effect of nutrients is often very hard to quantify, most states adopted narrative nutrient criteria. The language in the Texas Standards §307.4 (e) reads:

> Nutrients from permitted dischargers or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use. Site-specific nutrient criteria, nutrient permit limitations, and/or separate rules to control nutrients in individual watersheds will be established where appropriate after notice and opportunity for public participation and proper hearing.

This language works fine to support a response to an existing problem, but because it provides no quantitative levels, it is not very useful for anticipating and avoiding a problem. To address that, EPA set out a National Nutrient Strategy in 1998. The main goal of the nutrient strategy is to encourage states and tribes to establish and adopt NUMERICAL criteria for nutrients or response parameters such as chlorophyll *a* and water clarity in all waters of the nation.

1.1.1 Key Elements of EPA's National Nutrient Strategy

The EPA recognized that nutrient levels and nutrient-related problems vary widely across the country for any given type of waterbody. To accommodate differences in waterbodies, separate efforts for streams and rivers; lakes and reservoirs; estuaries and coastal waters; and wetlands were mounted. For each type of waterbody, an eco-regional approach was employed for the development of nutrient water quality criteria.

A key part of their program was development of waterbody-type technical guidance documents intended to serve as "user manuals" for assessing trophic state and developing region-specific nutrient criteria. Another part was establishment of an EPA National Nutrient Team with Regional Nutrient Coordinators to develop regional databases and to promote State and Tribal involvement. Finally, EPA's program calls for monitoring and evaluation of the effectiveness of nutrient management programs as they are implemented. Table 1-1 lists guidance documents published by the EPA.

Table 1-1
Guidance Published by EPA

Guidance	Published date
Lakes and Reservoirs	April 2000
Rivers and Streams	July 2000
Estuarine and Coastal Marine Waters	October 2001
Wetlands	Anticipated in 2003
Series of Wetland Modules to help states and tribes establish biological and nutrient assessment and monitoring programs for wetlands.	Ongoing

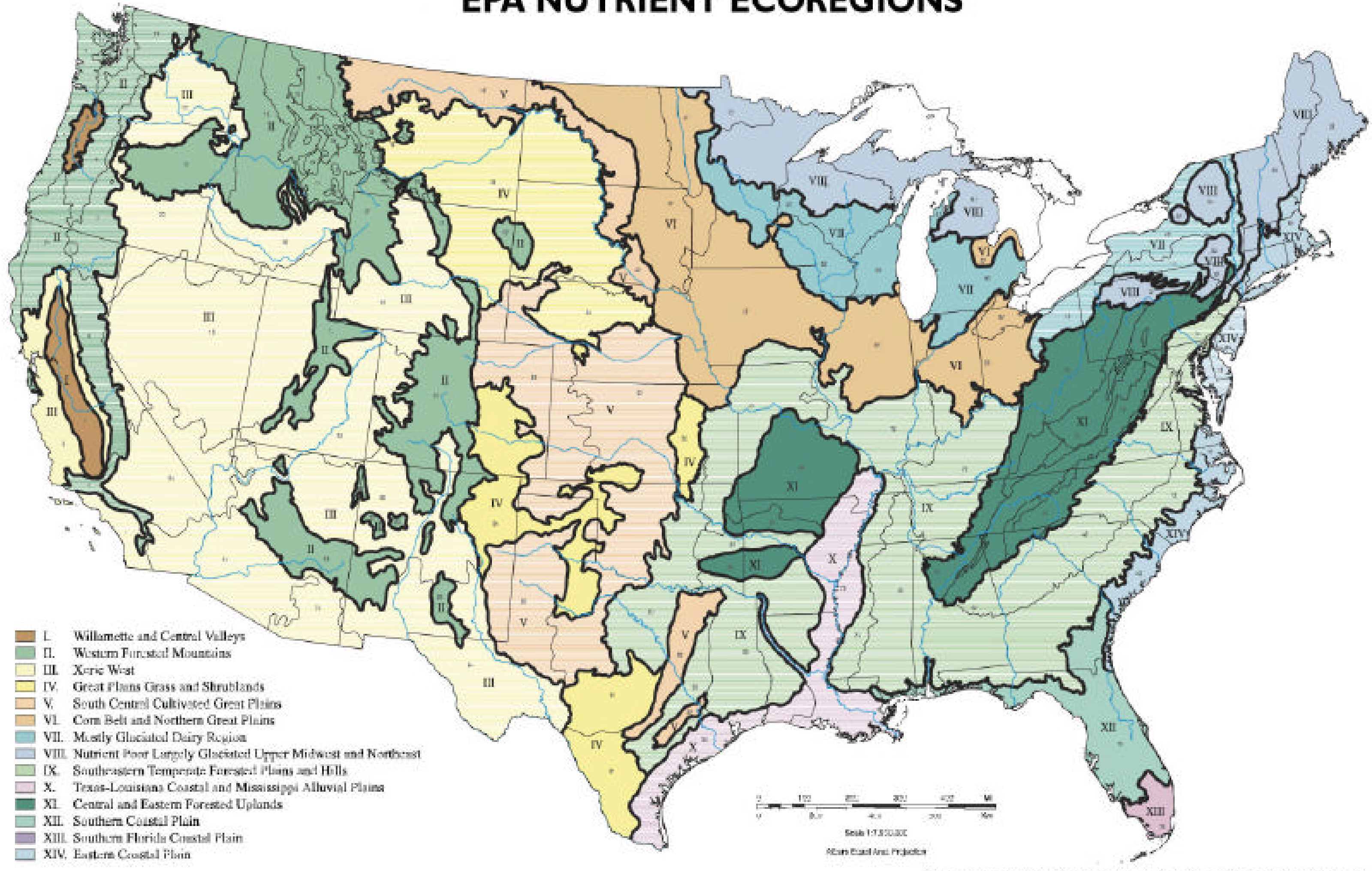
1.1.2 Summary of EPA's Approach for Lakes and Reservoirs

EPA set out to make their default approach very conservative. The basic element of the approach is to identify for each ecoregion shown in Figure 1-1, a group of pristine waters (those that had little anthropogenic influences) that could serve as the reference group. The 75th percentile of the Total N, Total P and chlorophyll *a* data from this reference group is to be the criteria for that ecoregion. A major limitation is that the ecoregions depicted cover very large portions of the country, with major differences in climate and geography. An answer obtained for such a broad area may not be relevant to a specific locale.

If no pristine water bodies exist in the ecoregion, the 25th percentile of all waters in an ecoregion is specified by EPA as the value to select for the criteria. This approach to setting a numerical criterion essentially assures that three fourths of the water bodies have higher values than the criterion and would thus be listed as not meeting water quality criteria. Table 1-2 provides a summary of EPA's recommended criteria levels for lakes and reservoirs and streams and rivers for each of the 14 ecoregions. Needless to say, these levels are much lower than typically found in the Trinity River Basin.

This situation is viewed as generally undesirable, and Texas along with many states are working hard to find better procedures. EPA is encouraging states develop procedures more appropriate to their specific situation. If they don't develop an acceptable methodology, the EPA has indicated its intention to impose

FIGURE 2-1
EPA NUTRIENT ECOREGIONS



Adapted from Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Nutrient Ecoregion IV.
EPA 822-B-01-013

TABLE 1-2
SUMMARY OF EPA'S RECOMMENDED CRITERIA LEVELS
FOR LAKES, RESERVOIRS, STREAMS AND RIVERS

Aggregate Ecoregions Lakes and Reservoirs

Parameter	Agg Ecor II	Agg Ecor III	Agg Ecor IV	Agg Ecor V	Agg Ecor VI	Agg Ecor VII	Agg Ecor VIII	Agg Ecor IX	Agg Ecor XI	Agg Ecor XII	Agg Ecor XIII	Agg Ecor XIV
TP µg/L	8.75	17.00	20.00	33.00	37.5	14.75	8.00	20.00	8.00	10.00	17.50	8.00
TN mg/L	0.10	0.40	0.44	0.56	0.78	0.66	0.24	0.36	0.46	0.52	1.27	0.32
Chl *a* µg/L	1.90	3.40	2.00 S	2.30 S	8.59 S	2.63	2.43	4.93	2.79 S	2.60	12.35 T	2.90
Secchi (m)	4.50	2.70	2.00	1.30	1.36	3.33	4.93	1.53	2.86	2.10	0.79	4.50

Aggregate Ecoregions for Rivers and Streams

Parameter	Agg Ecor I	Agg Ecor II	Agg Ecor III	Agg Ecor IV	Agg Ecor V	Agg Ecor VI	Agg Ecor VII	Agg Ecor VIII	Agg Ecor IX	Agg Ecor X	Agg Ecor XI	Agg Ecor XII	Agg Ecor XIV
TP µg/L	47.00	10.00	21.88	23.00	67.00	76.25	33.00	10.00	36.56	128 *	10.00	40.00	31.25
TN mg/L	0.31	0.12	0.38	0.56	0.88	2.18	0.54	0.38	0.69	0.76	0.31	0.90	0.71
Chl *a* µg/L	1.80	1.08	1.78	2.40	3.00	2.70	1.50	0.63	0.93 S	2.10 S	1.61 S	0.40 S	3.75 S
Turb FTU/ NTU	4.25	1.30 N	2.34	4.21	7.83	6.36	1.70 N	1.30	5.70	17.50	2.30 N	1.90 N	3.04

*This value appears inordinately high and may either be a statistical anomaly or reflects a unique condition. In any case, further regional investigation is indicated to determine the sources, i.e., measurement error, notational error, statistical anomaly, natural enriched conditions, or cultural impacts.

Turb - Turbidity

Chl *a* - Chlorophyll *a* measured by Fluorometric method, unless specified. S is for Spectrophotometric and T is for Trichromatic method.

N for NTU. Unit of measurement for Turbidity.

the percentile values listed in Table 1-2, effectively listing all the waters of the Trinity River Basin. The Texas Commission on Environmental Quality (TCEQ) has agreed with EPA to have numerical criteria for some reservoirs by the end of calendar 2004. It has formed a Work Group to coordinate the process and is making progress towards having values for at least some reservoirs.

While progress is being made at TCEQ, it is not clear at this time whether the uses of the reservoirs will be considered in the course of this process. At a meeting in February, 2003, the presentations made by the TCEQ were directed towards the identification of reference or relatively pristine or "less-impacted" reservoirs and methods for selecting criteria from the pool of available data. There was no governmental presentation made that addressed the tie between uses ("existing, attainable or designated" from the Texas Standards) and criteria, as described in the Clean Water Act. This is worrisome because in law, the criteria are designed to be measures that quantify the degree to which uses are attained. If criteria were developed without consideration of uses, there is a potential issue of legitimacy. From a more practical perspective, it is questionable if arbitrary percentile-based criteria would be useful or in the pubic interest.

1.2 STUDY OBJECTIVES

The objectives of the study are to explore the available data on the uses for selected reservoirs in the Trinity River Basin and with that exploration, identify possible mechanisms to relate criteria to actual uses. With that identification of mechanisms, a more general approach to the establishment of numerical nutrient criteria will be discussed.

1.3 PROJECT STEERING COMMITTEE

The project was supported by the CRP, administered in the Trinity River Basin by the TRA. In the Trinity River Basin, the CRP is a cooperative effort with partners representing various entities active in water quality issues. To aid in the management and coordination of the study, a technical Project Steering Committee was established. Table 1-3 lists the members and their affiliations. This Steering Committee was instrumental at several stages in the project development.

Table 1-3
Technical Steering Committee-
Trinity River Basin Nutrient and Use Support Study

Member	Organization
Jim Scanlon	City of Fort Worth
Keith Kennedy	North Texas Council of Governments
David Brown	USGS
Shah Khan	U.S. Army Corps of Engineers
Dolan McKnight	North Texas Municipal Water District
Robert McCarthy	Dallas Water Utilities
Woody Frossard	Tarrant Regional Water District

Member	Organization
Melissa Mullins	Texas Parks and Wildlife Department
Richard Browning	TRA
Glenn Clingenpeel	TRA
Mike Knight	TRA-Lake Livingston

1.4 DOCUMENT ORGANIZATION

As noted above, this study documents an investigation into the relationships between the levels of nutrients and the uses that selected reservoirs in the Trinity River Basin can support. The first step in the investigation is the selection of reservoirs to study. This is described in Section 2.0. Section 3.0 addresses what is currently known about uses and criteria in the basin. It also addresses the judgments made as to the actual uses that are supported and the uses that will be considered in the evaluation of the relations between nutrient levels and uses.

The next three sections, 4, 5, and 6, address the detailed data available in three broad areas, recreation, aquatic life and public water supply. Each of these sections contains an overview of the use and some of the major literature describing the use. They also contain a summary of the available data for the selected study reservoirs, and an analysis of the data and how it relates to nutrient levels.

The next major section, 7.0, integrates the results of the previous three sections into how the data might be used to support development of use-based numerical nutrient criteria. It also discusses the approaches that are being considered during the development process.

2.0 RESERVOIR AND PARAMETER SELECTION

There are a total of 21 reservoirs in the Trinity River Basin that are designated water quality segments. These are distributed over the entire basin but differ substantially in their design, age, uses and the level of data availability. The immediate requirement for this study was to select from that large number of reservoirs a manageable list to be the focus of the project. These will be referred to as the study reservoirs.

Five main criteria were established for the selection of the study reservoirs:

1) Overall geographic distribution throughout the basin,
2) Coverage of all the major ecoregions,
3) Including reservoirs with a range of nutrient inputs levels and physical size,
4) Availability of water quality and fishery information, and
5) Endorsement by the Project Steering Committee.

Based on these criteria nine reservoirs were selected for more detailed analysis. This report section describes the process of selection of reservoirs and also parameters for analysis. It also includes a summary of available data for the selected study reservoirs.

2.1 CANDIDATE RESERVOIR DATA

Figure 2-1 shows the 21 segment reservoirs, along with the four major ecoregions represented in the basin. From this the density of coverage in some ecoregions is higher than in others.

The next main selection criterion was the availability of data. Table 2-1 lists the number of observations available for candidate reservoirs in the coordinated monitoring database maintained by the TRA and the TCEQ. As can be seen in the table, there are very large differences in the amount of data available, reflecting different mandates and responsibilities of the agencies responsible for managing the reservoirs.

Another consideration was that the selected reservoirs include those with a wide range of nutrients and chlorophyll *a* as well as physical size. There were a number of choices with average chlorophyll *a* levels greater than 20 ug/L, but fewer at the lower end of the range. Houston County Lake was selected as one of the lower nutrient and smaller reservoirs. Lake Bridgeport was selected as another low nutrient lake in a different part of the basin.

In addition to the water quality observations, fisheries data were available to varying degrees for all of the reservoirs. However, differences in the fisheries data were not used in the selection process.

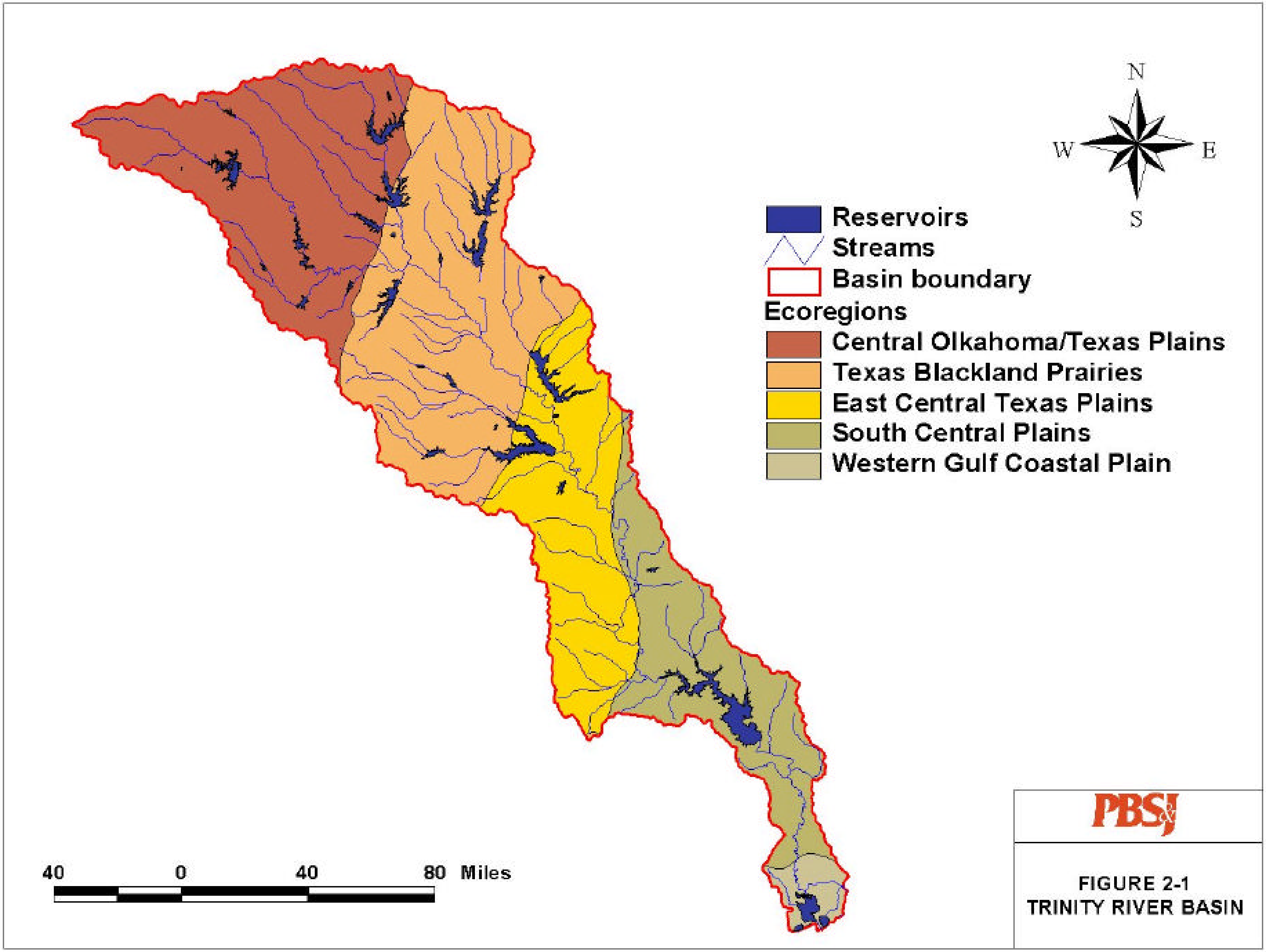


FIGURE 2-1
TRINITY RIVER BASIN

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TABLE 2-1
DATA AVAILABILITY OF CANDIDATE RESERVOIRS (1997 TO 2002 DATA)

Reservoir	Operator	Ecoregion	TP (mg/L)		Chl *a* (mg/L)		Secchi depth (m)		TSS (mg/L)		VSS (mg/L)	
			Num of data	Avg	Num of data	Avg	Num of data	Avg	Num of data	Avg	Num of data	Avg
Eagle Mountain Lake	TRWD	COTP	142	0.084	141	21.3	291	0.7	142	18.2	43	3.8
Grapevine Lake	CORPS	COTP	58	0.041	54	14.4	58	0.8	59	9.5		
Lake Amon G. Carter	City of Bowie	COTP	1	0.100	1	0.5			1	22.0	1	3.0
Lake Arlington	City of Arlington	COTP	6	0.033	6	22.0	34	0.8	6	12.4		
Lake Benbrook	CORPS	COTP	54	0.062	54	18.0	52	0.9	54	11.8		
Lake Bridgeport	TRWD	COTP	60	0.041	60	4.5	57	1.2	60	7.4		
Lake Weatherford	City of Weatherford	COTP	6	0.043	6	8.6	6	0.7	6	10.3	6	4.8
Lake Worth	City of Fort Worth	COTP	12	0.053	12	14.2	12	0.5	12	16.3	12	5.3
Ray Roberts Lake	CORPS	COTP	70	0.130	12	14.9	18	1.1	69	26.4		
Lake Lewisville	CORPS	COTP/TBP	25	0.084	12	13.5	9	0.6	24	12.3		
Joe Pool Lake	CORPS	TBP	11	0.051					3	9.0		
Lake Bardwell	CORPS	TBP	8	0.046	8	11.0	12	0.4	8	14.5	8	3.8
Lake Lavon	CORPS	TBP					27	0.6				
Lake Ray Hubbard	City of Dallas	TBP	49	0.112	22	25.8			50	15.6		
Mountain Creek Lake	Exelon	TBP										
Navarro Mills Lake	CORPS	TBP	7	0.062	7	8.0	5	0.4	7	24.9	7	6.7
White Rock Lake	City of Dallas	TBP										
Richland Chambers Reservoir	TCWC	TBP/ECTP	87	0.049	87	13.4	133	0.8	87	7.8		
Cedar Creek Reservoir	TCWC	ECTP	170	0.106	170	24.3	284	0.7	170	15.2	44	4.3
Houston County Lake	Hou. Co. WC&ID No. 1	SCP	11	0.028	11	5.7	11	1.5	11	3.0	11	2.3
Lake Livingston	TRA	SCP	63	0.358	119	19.0	219	0.6	216	75.0	213	10.7

Notes:
1. Data collected at depths <= 0.5 m.
2. Storetcode: TP (00665), Chl *a* (32211), Secchi depth (00078), TSS (00530), VSS (00535).
3. Ecoregions:
   - COTP - Central Olkahoma/Texas Plains
   - TBP - Texas Blackland Prairies
   - ECTP - East Central Texas Plains
   - SCP - South Central Plains

2.2 SELECTION PROCESS

Combining the geographic distribution information with the list of available data, an initial selection was made by the study team. This selection is shown on Figure 2-2, along with ecoregion information.

A meeting was held with the project Steering Committee on December 13, 2002, where the above information was presented. After discussion of the various aspects of the situation, the Steering Committee endorsed the tentative selection of the nine reservoirs.

As the study progressed, it became apparent that one of the reservoirs, Lake Livingston, was sufficiently large that it would be useful to divide it for analytical purposes into an upper and lower reservoir, using the U.S. Highway 190 causeway as the dividing line. Upper Lake Livingston had more of the characteristics of a river while lower Lake Livingston was more "reservoir-like."

2.3 DETAILED DESCRIPTION OF STUDY RESERVOIRS

Table 2-2 provides a more in-depth description of the selected study reservoirs. The reservoirs in the upper part of the basin were all constructed with flood control as a major objective. Lower down in the basin most of the reservoirs were constructed as constant level structures with water supply as the primary purpose. However, even these constant level structures provide a measure of flood control benefit. All of the reservoirs are a water supply source, although with some the yield is passed through to the next reservoir downstream before the water is diverted (e.g., Bridgeport yield is included with Eagle Mountain). Some of the reservoirs, particularly those developed by the U.S. Army Corps of Engineers (USACE), included public recreation benefits in the determination of whether the project was a suitable public works investment. All are used for public recreation to some degree. The table includes subjective high, medium or low assessment of the degree of recreational use. A final use included in the study reservoir group is hydroelectric generation. Lake Ray Roberts has hydroelectric generator that produces some electricity from reservoir releases.

The reservoirs cover a broad range in size from about 1,500 acres to over 80,000 acres and have a similar broad variety of watershed characteristics. Some of the reservoirs have upstream wastewater discharges as a significant portion of their water supply yield, while others do not receive much of their inflow in this fashion. Comparing the percent yield from point source column with the measures of enrichment in the right portion of the table, it can be seen that there is some relation. For example, Bridgeport has limited point source inputs and low enrichment measures. On the other hand, Cedar Creek has a small point source input and the highest Trophic State Index (TSI) value while Lake Livingston has a high point source input and lower TSI value. Many factors including watershed characteristics and proximity play a role in determining relative nutrient levels

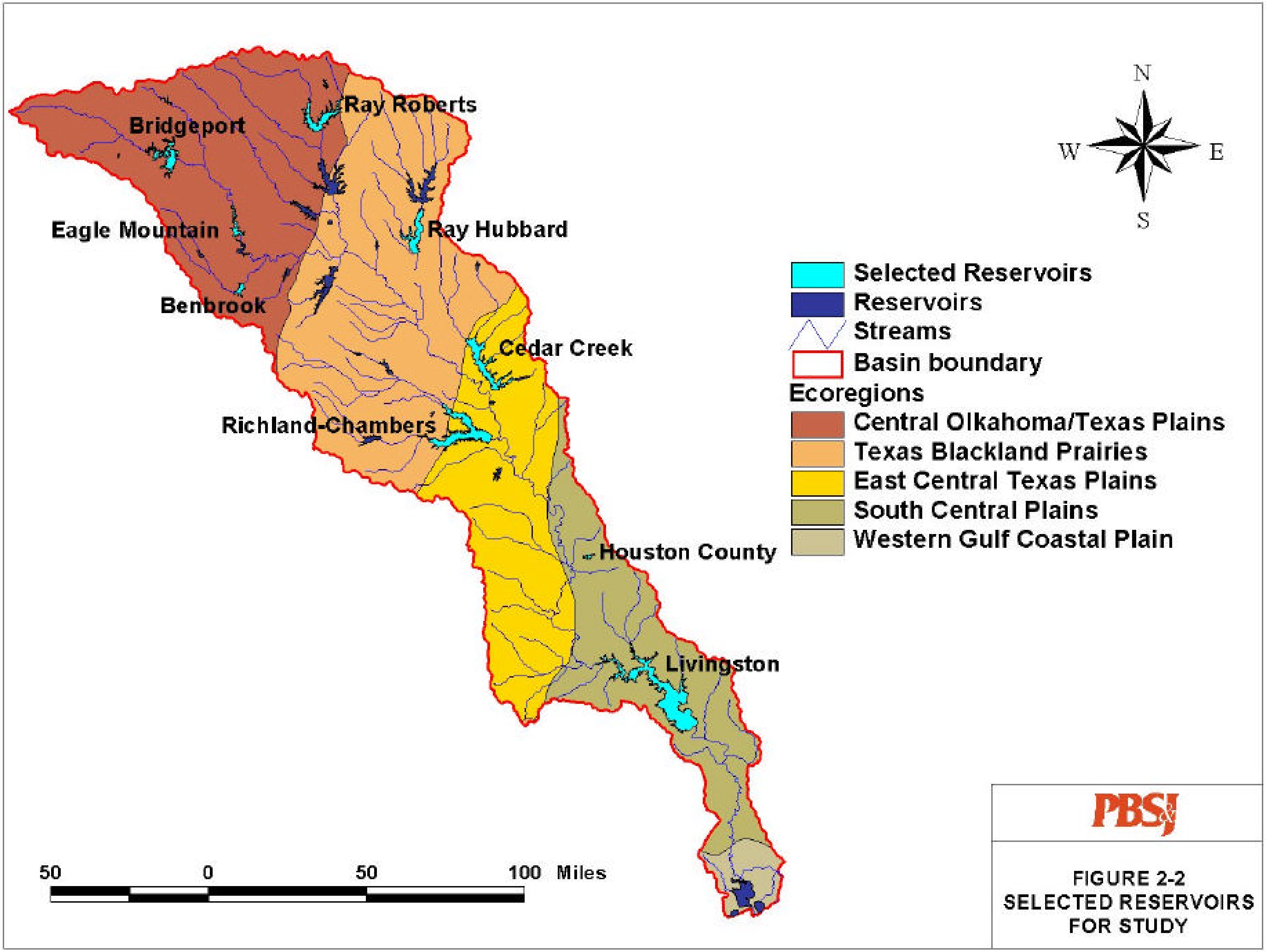


FIGURE 2-2
SELECTED RESERVOIRS
FOR STUDY

TABLE 2-2
STUDY RESERVOIR DETAILS

	INTENDED USES										% YIELD	EST		Chlorophyll *a*		TP		
RESERVOIR	WATER SUPPLY	FLOOD CNTRL	RECRE-ATION	LAKE SIZE (ac) [1]	WTRSHD SIZE (mi^2) [2]	WTRSHD LANDUSE	AGE (yrs)	FEDERAL AGENCY	LOCAL CONTACT	YIELD (mgd) [3]	FROM POINT SOURCE	POINT SOURCE (mgd)	WQ DATA AVLBLTY [4]	Ave (mg/L)	Num of data	Ave (mg/L)	Num of data	TCEQ TSI RANK ADJ [5]
Ray Roberts	X indrect	X	M/L	29,350	676	Ag	16	USACE	Dallas - Robert McCarthy	See Note 7	NA	3.5	Moderate	14.9	12	0.091	24	Not Available
Bridgeport		X	L	12,900	1,082	Ag(non-crop)	70		TRWD - Woody Frossard	See Note 8	insignficant	<1	Good	4.46	148	0.041	153	42
Eagle Mountain	X	X	M	6,480	753	Ag	68		TRWD - Woody Frossard	69.5	3% [8]	2	Excellent	18.98	189	0.079	193	97
Benbrook [6]	X	X	M	3,635	320	Ag	50	USACE	TRWD - Woody Frossard	6.07	41% [6]	2.5	Excellent	18.38	221	0.065	223	88
Ray Hubbard	X		H	21,683	304	Urban	34		Dallas - Robert McCarthy	50.4	56%	28	Moderate	25.82	22	0.112	49	Not Available
Cedar Creek	X		M	32,623	940	Ag	38		TRWD - Woody Frossard	156	3%	5	Excellent	23.01	143	0.087	143	98
Richland Chambers	X		M	41,356	1,432	Ag	15		TRWD - Woody Frossard	187	3%	5	Excellent	13.59	261	0.049	261	77
Houston County	X		L	1,523	44	Forest	36		Hou. Co. WCID No. 1				Moderate	5.22	13	0.028	13	Not Available
Livingston	X		M	83,277	6,764	Urban/Ag/Natural	33		TRA	1120	46%	520	Good	20.34	131	0.313	154	92

[1] surface acres at normal pool elevation.
[2] uncontrolled watershed
[3] based on drought of record. Does not reflect normal flow conditions
[4] data from TRACS database supplemented with TRA database, 1989 to 2002.
TRWD TP consistently lower than others and chlorophyll *a* known to have high variability from their lab (TRAC Laboratories).
[5] State-wide ranking - adjusted index based on scale of 1-100. Higher ranking indicates more eutrophic conditions.
[6] receives imports from Cedar Creek/Richland Chambers not included in yield estimates; % PT over estimated.
[7] included in yield for Lewisville.
[8] included in yield for Eagle Mountain, % PS yield for latter thus under estimated.

2.4 PARAMETER SELECTION

The selection of water-quality parameters not only focused on nutrients, but also on those constituents that may be manifested through eutrophication. In the case of large reservoirs, the main concern is generally excess planktonic algae, single-celled aquatic organisms that become more populous with increased nutrient concentrations. Filamentous algae can also increase with increasing nutrient concentrations. Filamentous algae typically grow from the bottom and float to the surface or accumulate in mats on the surface and can be persistent in small reservoirs or in coves in large reservoirs. However, wave energy along shorelines often prevents any substantial growth or accumulations in larger reservoirs. High levels of phytoplankton (hereafter referred to as algae) can degrade water quality and limit its ability to support aquatic life. Dense concentrations of algae can deplete dissolved oxygen in the water through respiration. This problem can be exacerbated through the decomposition (and subsequent microbial respiration) of dead algal cells, especially in the event of a sudden die-off. Dense algal concentrations can also reduce the depth of the photic zone, resulting in shallow, hypoxic hypolimnions, which ultimately reduces available aquatic habitat.

A typical measure of algal concentration is one based on the amount of plant pigment, chlorophyll *a*, found in a water sample. While there are limitations on the accuracy and reliability of this measure, it is employed far more widely than collecting and identifying algal cells. Another measure of algal density is water clarity, frequently measured with a simple device called a Secchi disk. The deeper the disk can be observed the clearer the water. If the primary cause of decreased water clarity is algae, and not runoff or wind wave induced turbidity, the Secchi disk depth is a good measure of algae levels. The EPA employed both chlorophyll *a* and Secchi disk depth as direct measures of excess algal concentrations in lakes and reservoirs.

If temperature, light, and nutrient supplies are sufficient, algae are capable of rapid growth rates, potentially doubling in density in a day. Factors that can limit the growth of algae include colder temperature, lack of light (from self-shading if algae are in high concentrations), lack of one or more key nutrients, or predation. In most cases, the only parameter over which man has some control in dealing with excess algae is nutrient levels. Many measures of nutrient concentrations could be employed. The form of nutrients that are actually available for use by algae is the dissolved inorganic state. For example, algae can use dissolved ortho-phosphate (PO_4^--P), ammonium nitrogen (NH_4^+-N) and nitrate-N (NO_3^--N). Primarily because there are very little data of this type collected at meaningful analytical reporting levels, the EPA Guidance Manual for Lakes and Reservoirs (EPA, 2000) requires that numeric criteria be developed for only total nitrogen (TN) and total phosphorus (TP). By definition, TN and TP include the algae itself as well as the nutrients in the water that might be available for algal use, but are generally correlated with levels of algae. More importantly, there are much larger data sets of TN and TP available for statistical analysis.

2.5 SELECTED PARAMETERS AND STUDY RESERVOIRS

Figure 2-3 illustrates a relationship between Secchi depth and chlorophyll *a* developed by Carlson (1977). In the preliminary screening of potential study reservoirs, the team plotted a number of the Trinity River Basin reservoirs in relation to Secchi depth and chlorophyll *a*. Also included on the figure are Lakes Amistad and Braunig as an example of trophic extremes found in Texas. Lake Amistad (lacustrine zone) is typically very clear with light extinction owed primarily to sparse algal concentrations and dissolved calcium carbonate, whereas Braunig Lake is nutrient rich with light extinction primarily resulting from algal turbidity. All the Trinity River Basin reservoirs are below Carlson's curve, indicating a lower Secchi depth from non-algal turbidity, such as suspended sediments and tannic staining, characteristic of streams and reservoirs in this region. While the Trinity Basin reservoirs are all below the curve, they nevertheless exhibit some relation between average Secchi depth and average chlorophyll *a*. Houston County and Bridgeport have chlorophyll *a* and high Secchi depth while Cedar Creek, Eagle Mountain and Livingston are at the other end.

Figure 2-4 illustrates relationships between various water quality parameters for each of the study reservoirs. With the exception of upper Lake Livingston, there is good agreement between average nutrient concentrations and average chlorophyll *a*. As expected, when nutrient concentrations increase, so do chlorophyll *a* concentrations. Upper Lake Livingston is characteristically turbid with suspended sediments, which leads us to believe that even though nutrients are high, sediments in the water column prevent algal growth through shading. As discussed in later sections, the relationship between non-algal turbidity and nutrients will be an important consideration in evaluating the fate and relevance of nutrients in the study reservoirs.

FIGURE 2-3
RELATIONSHIP BETWEEN SECCHI DEPTH AND CHLOROPHYLL *a*

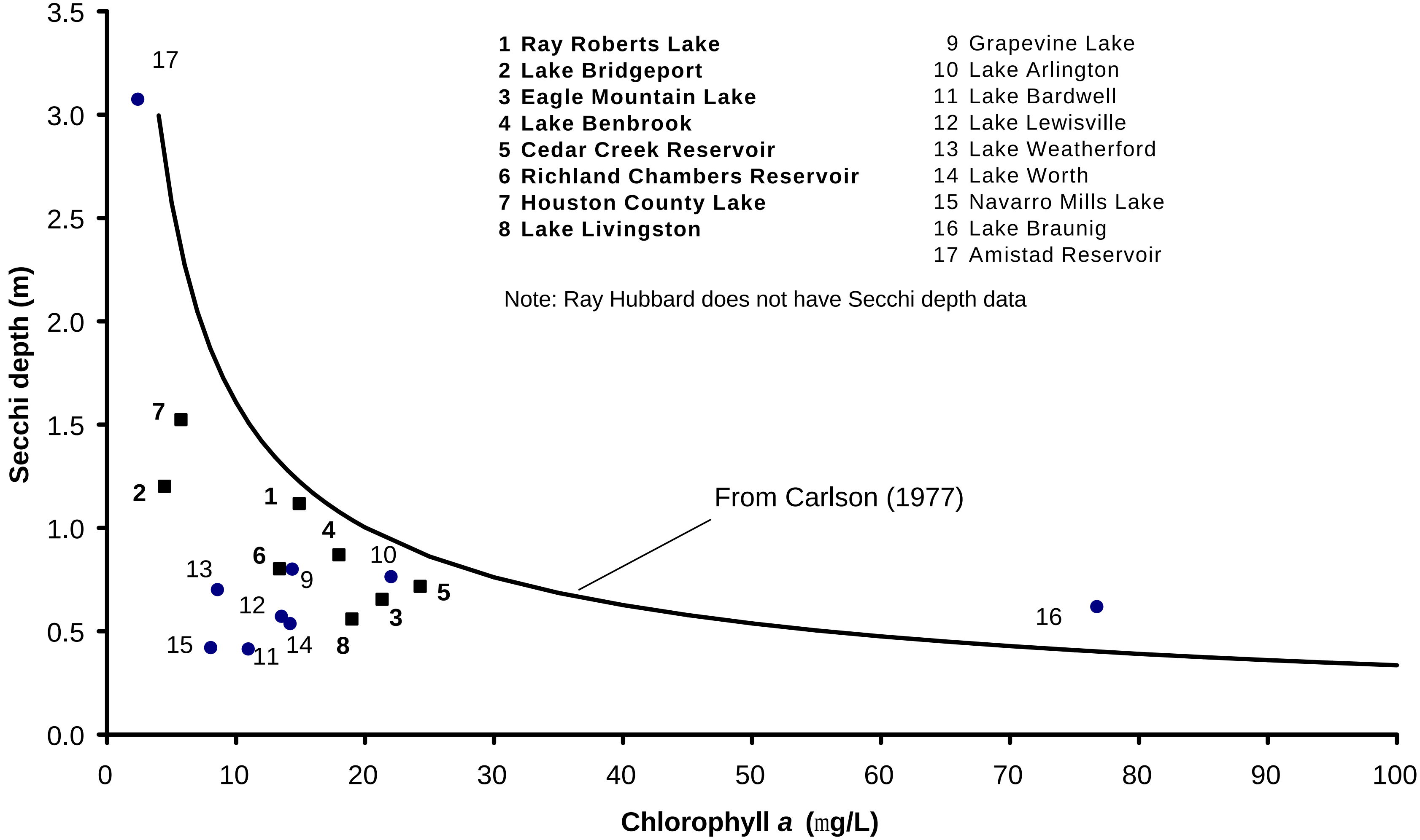
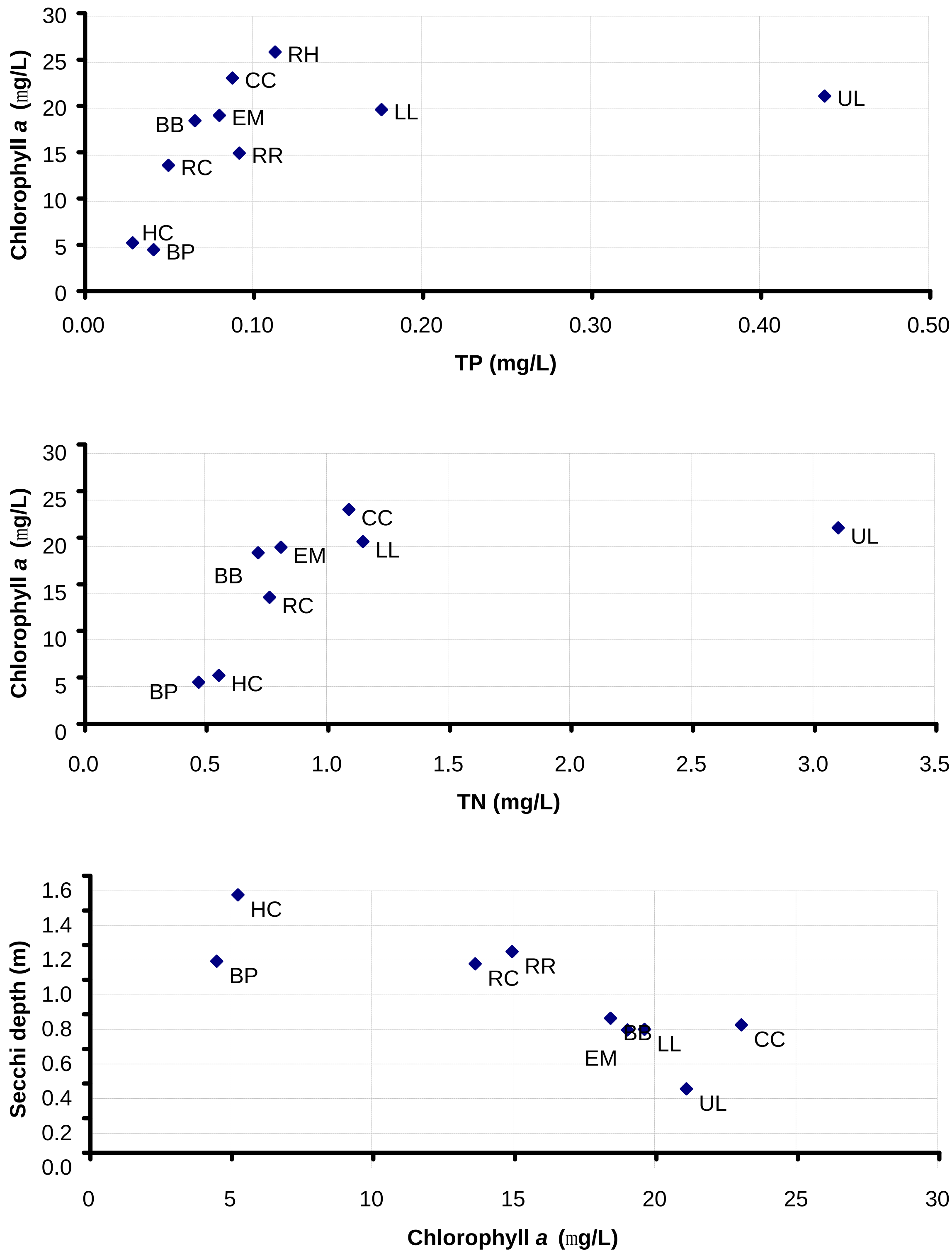


FIGURE 2-4
RELATIONSHIP BEWTEEN WATER QUALITY PARAMETERS



CC, Cedar Creek; EM, Eagle Mountain; HC, Houston County; BB, Benbrook; BP, Bridgeport;
LL, Lower Livingston; RH, Ray Hubbard; RR, Ray Roberts; RC, Richland-Chambers; UL, Upper Livingston.

3.0 USES AND CRITERIA

The nine study reservoirs all have three designated uses in the Texas Surface Water Quality Standards — Contact Recreation, Aquatic Life and Domestic Water Supply. Table 3-1 shows the uses and the numerical criteria that are now in the standards. It can be seen that all reservoirs have identical designated uses and there are small differences in some of the numerical criteria.

This section describes these existing uses, along with the criteria and the attainment status for the study reservoirs. In the discussions of each of the uses, the modifications and more complete list of uses considered as part of the study are described.

3.1 RECREATIONAL USES

The only recreation use now designated is contact recreation. The specific criteria associated with that use are for indicator bacteria. The criteria (there are two for the moment as the state is in the process of changing from the older Fecal Coliform (FC) criterion to one based on *E. coli*) were developed from epidemiological studies of people at public beach swimming areas and are designed specifically to address gastroenteritis and ear/eye infections associated with full-body contact swimming activities (EPA, 1986). These bacteria criteria have little relation to nutrient levels.

Table 3-2 presents a summary of the geometric means of available indicator bacteria monitoring data for the study reservoirs. The main bodies of all of the study reservoirs meet the water quality criteria for contact recreation by a comfortable margin. The upper portion of Livingston is more riverine, and has markedly higher bacteria levels than the lower portion. However, even it has geometric mean concentrations that are well below the criterion. Figure 3-1 presents plots of the average FC bacteria concentration versus the average TP concentration and Secchi depth. The upper Livingston data also have higher TP and lower water clarity, suggesting there may be some limited relationship between nutrients and bacteria. However, this is not suggested to be a casual relationship (i.e., nutrients cause bacteria) but rather a reflection of more riverine character of upper Livingston.

All of the nine study reservoirs are used for recreation, but the swimming or contact component of this recreation is probably not the dominant use. A more complete listing of recreational activities supported would include to varying degrees:

- sport fishing from boat and bank,
- pleasure boating with no significant water contact,
- boating activities involving water contact such as skiing,
- shoreline swimming and diving, and
- park activities such as camping and hiking that are enhanced by a view of water.

TABLE 3-1
DESIGNATED USES AND CRITERIA FOR STUDY RESERVOIRS IN STANDARDS

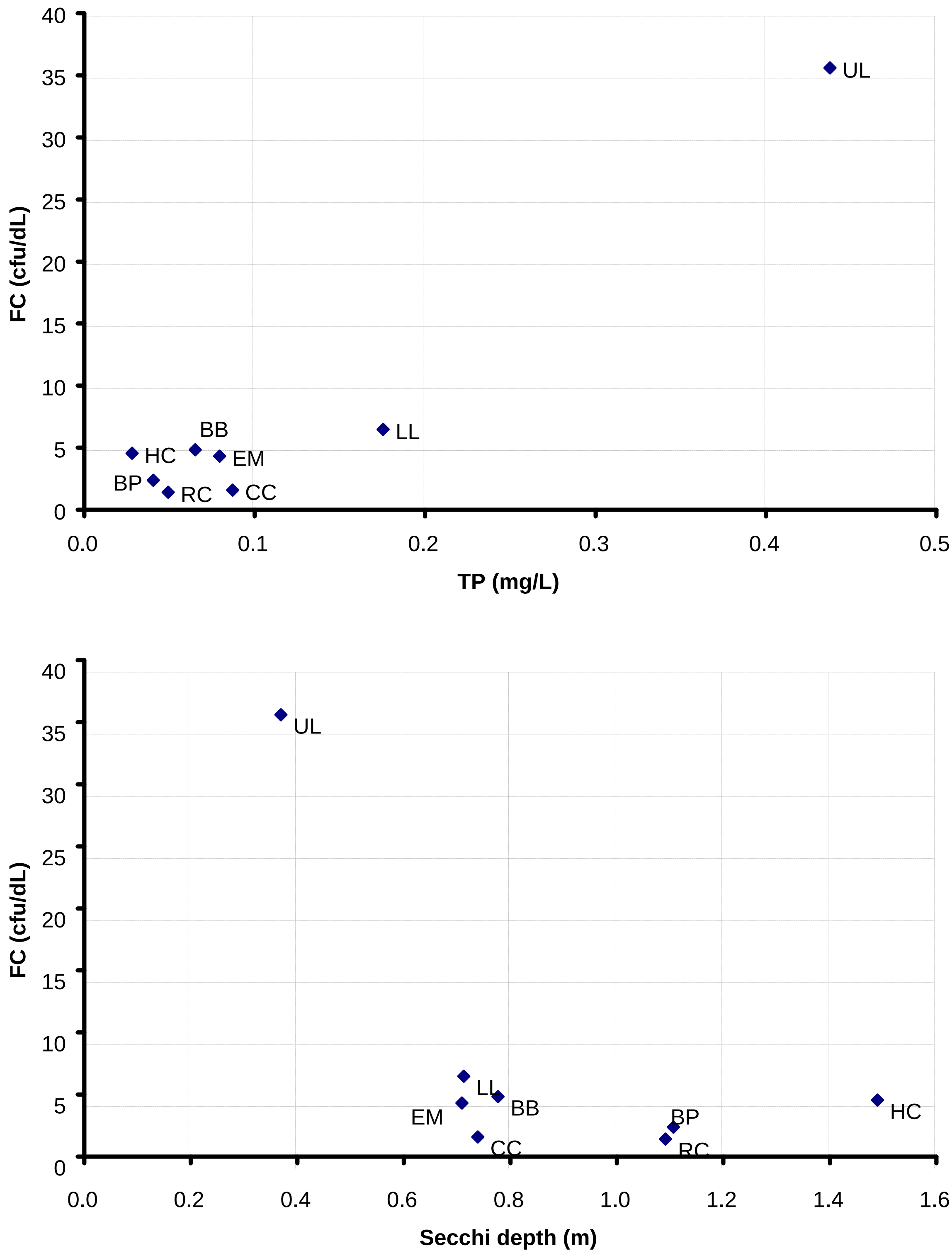
Segment No.	Segment Name	Uses			Criteria						
		Recreation	Aquatic Life	Domestic Water Supply	Cl (mg/L)	SO_4 (mg/L)	TDS (mg/L)	Dissolved Oxygent (mg/L)	pH Range (SU)	Indicator Bacteria (cfu/dL)	Temperature (deg F)
0840	Ray Roberts Lake	CR	High	PS	80	60	500	5	6.5-9.0	126/200	90
0811	Bridgeport Reservoir	CR	High	PS	75	75	300	5	6.5-9.0	126/200	90
0809	Eagle Mountain Reservoir	CR	High	PS	75	75	300	5	6.5-9.0	126/200	94
0830	Benbrook Lake	CR	High	PS	75	75	300	5	6.5-9.0	126/200	93
0820	Lake Ray Hubbard	CR	High	PS	100	100	500	5	6.5-9.0	126/200	93
0818	Cedar Creek Reservoir	CR	High	PS	50	100	200	5	6.0-8.5	126/200	93
0836	Richard-Chambers Reservoir	CR	High	PS	75	110	400	5	6.5-9.0	126/200	91
0813	Houston County Lake	CR	High	PS	75	75	300	5	6.5-9.0	126/200	93
0803	Lake Livingston	CR	High	PS	150	50	500	5	6.5-9.0	126/200	93

Notes:
1. The indicator bacteria is E. coli (criterion 126 cfu/dL). Fecal Coliform is an alternative indicator (criterion 200 cfu/dL).
2. CR: Contact Recreation; PS: Public Supply.

TABLE 3-2
SUMMARY OF INDICATOR BACTERIA MONITORING DATA

Reservoir	FC (Storet code 31616)				EC (Storet code 31699)			
	Start Date	End Date	Number of data	Geometric Mean (cfu/dL)	Start Date	End Date	Number of data	Geometric Mean (cfu/dL)
Ray Roberts	*No data*							
Bridgeport	03/21/90	05/15/02	125	2	02/07/02	05/15/02	6	1
Eagle Mountain	04/27/89	04/24/02	166	4	01/29/02	04/24/02	8	3
Benbrook	03/23/89	06/12/02	166	5	03/13/02	06/12/02	6	2
Ray Hubbard	*No data*							
Cedar Creek	07/14/93	04/10/02	134	2	01/16/02	04/10/02	10	2
Richland Chambers	02/22/89	06/05/02	233	1	03/05/02	06/05/02	8	2
Houston County	07/13/93	10/29/01	11	5	02/06/02	02/06/02	1	4
Livingston (Upper)	02/23/93	04/23/02	113	36	01/29/02	04/23/02	6	49
Livingston (Lower)	01/27/93	04/23/02	119	6	01/30/02	04/23/02	4	2

FIGURE 3-1
RELATIONSHIP BEWTEEN TP, SECCHI DEPTH AND BACTERIA



CC, Cedar Creek; EM, Eagle Mountain; HC, Houston County; BB, Benbrook; BP, Bridgeport;
LL, Lower Livingston; RH, Ray Hubbard; RR, Ray Roberts; RC, Richland-Chambers; UL, Upper Livingston.

Some of this more complete list of recreational activity may be related to nutrient levels, at least to some degree.

Sport fishing activities are a major component of recreational use in Texas reservoirs. For this study we will assess this use under the aquatic life category (Section 5.0 of this report) in terms of the quality of the fishery. The reason for addressing recreational fishing under aquatic life is the belief that fish are the reason that brings participants to the lake, and the fishing quality is the primary factor in determining the degree to which the recreational fishing use is supported. However, it is recognized that fishing and fish abundance is only a part of a total recreational experience that also involves things such as aesthetic appreciation, exercise, companionship, and adventure.

Section 4.0 of this report addresses the other recreational activities noted above. It relates the available data and literature to the degree to which boating, water sports, swimming and aesthetic appreciation can be related to nutrients and response parameters. This section explores the possibility for such relations and the degree to which available data might support a relationship.

3.2 AQUATIC LIFE USE

As noted in the introduction, all study reservoirs are assigned a HIGH aquatic life use designation. The criteria associated with this use are dissolved oxygen (DO), pH, and temperature. These criteria apply to the surface mixed layer when stratified or the entire water column if not stratified.

Section 303(d) of the Clean Water Act has been interpreted to require that if criteria are not attained, the water should be listed and a Total Maximum Daily Load (TMDL) study performed to determine requirements to achieve attainment. A detailed procedure for determining attainment has been developed by the TCEQ and the EPA (TCEQ, 2001). Table 3-3 summarizes the criteria for the study reservoirs along with the year 2002 draft 303(d) listings. Lake Livingston has a number of stations listed for DO and one for pH. Cedar Creek has a number of stations listed for pH, and Richland-Chambers has one station listed for pH. All of these draft listings are given a "D" rank indicating that additional data collection is needed before making a determination regarding a TMDL analysis.

There are no numerical nutrient criteria at this time but there are screening levels established by the TCEQ. These screening levels are based on the 85th percentile of available data. The nutrient-related screening levels for lakes and reservoirs are:

NH_3-N	0.11 mg/L
NO_2+NO_3-N	0.43 mg/L
Total P	0.18 mg/L
PO_4-P	0.09 mg/L
Chlorophyll *a*	22.7 ug/L

TABLE 3-3
DRAFT 2002 303(d) LISTINGS FOR STUDY RESERVOIRS

Area	Parameter	Category	Rank
Segment 0818, Cedar Creek Reservoir			
Caney Creek cove	high pH	5c	D
Clear Creek cove	high pH	5c	D
Cove off lower portion of reservoir adjacent to Clearview Estates	high pH	5c	D
Lower portion of reservoir east of Key Ranch Estates	high pH	5c	D
Lowermost portion of reservoir adjacent to dam	high pH	5c	D
Middle portion of reservoir downstream of Twin Creeks cove	high pH	5c	D
Twin Creeks cove	high pH	5c	D
Upper portion of reservoir adjacent to Lacy Fork cove	high pH	5c	D
Upper portion of reservoir east of Tolosa	high pH	5c	D
Uppermost portion of reservoir downstream of Kings Creek	high pH	5c	D
Segment 0836, Richland-Chambers Reservoir			
Lower portion of Chambers Creek arm	high pH	5c	D
Segment 0803, Lake Livingston			
Cove off upper portion of reservoir, East Trinity	depressed dissolved oxygen	5c	D
Lower portion of reservoir, East Willow Springs	depressed dissolved oxygen	5c	D
Lower portion of reservoir, East Wolf Creek	depressed dissolved oxygen	5c	D
Lowermost portion of reservoir, adjacent to dam	depressed dissolved oxygen	5c	D
Middle portion of reservoir, East Pointbank	depressed dissolved oxygen	5c	D
Middle portion of reservoir, downstream of Kickapoo Creek	depressed dissolved oxygen	5c	D
Upper portion of reservoir, centering on SH 19	depressed dissolved oxygen	5c	D
Upper portion of reservoir, west of Carlisle	depressed dissolved oxygen	5c	D
Upper portion of reservoir, west of Carlisle	high pH	5c	D

Notes:
1. Both Category 5c and Rank D mean additional data and information will be collected before a TMDL is scheduled.
2. DO criteria for all three reservoirs are 5 mg/L.
3. pH criteria are: Livingston 6.5-9.0, Cedar Creek 6.0-8.5, Richland-Chambers 6.5-9.0.

If these screening levels were exceeded at one or more stations, a "concern" is noted. Table 3-4 lists those study reservoirs that currently have concerns, and the parameter that triggered the concern. Seven of the nine study reservoirs have concerns listed. However, most of the concerns identified are in arms or coves that tend to have higher a higher ratio of inflows to unit volume than the main body of the reservoirs.

Table 3-5 lists a further category of concerns identified for the study reservoirs. These deal with special situations where there are not sufficient data for formal listing, but still an indication that a problem might exist.

A limitation of the present standards is that with the aquatic life use so loosely defined (high) it is very difficult to associate specific criteria. A major challenge is that these reservoirs are not natural aquatic ecosystems but rather man-made waters that are each managed for their highest and best recreational fishery uses. Because they are artificial systems there is no body of data and research that can be used to define a natural state. Management activities include stocking, harvest limitations, and in some places efforts to improve habitat. Because the study reservoirs differ substantially in physical characteristics, age, water level variations, habitat, and nutrient levels, there are substantial differences in the fisheries and management measures employed.

Section 5.0 describes efforts to determine what appropriate uses may be, approaches to measure these uses, and their relationships to nutrients and chlorophyll *a*.

3.3 WATER SUPPLY

All of the study reservoirs are designated in the standards for the Public Water Supply use and all except Bridgeport were constructed with that as one of the intended purposes. All of the reservoirs are used to some extent as a water supply source, although diversion points are not always directly from each reservoir.

The existing criteria (Table 3-1) that relate to the water supply use for each reservoir (water quality segment) appear to be limited to the chloride, sulfate, and total dissolved solids (TDS) parameters. These parameters are important for water supply and the criteria were some of the first adopted in Texas. They were based an assessment of ambient data available at the time, and not values needed to support a particular use. In abbreviated terms, the criteria were set using a procedure that approximates the 95th percentile of the data (Beyer, personal communication, 2002). In effect they function as anti-degradation measures, providing a means to stop activities that might increase the salt content of the water.

In addition to the segment-specific values, criteria common to all waters relate to the public water supply use. The Maximum Contaminant Levels (MCLs) for drinking water supplies (30 TAC 290) are included where appropriate in the Table 3, Human Health Protection portion of the Standards (TCEQ, 2000). However, none of these criteria values appears to have a relation to nutrient levels.

TABLE 3-4
WATER QUALITY CONCERNS IN DRAFT 2002 WATER QUALITY INVENTORY

Location	Water Quality Concern	Parameter of Concern
Segment 0840, Ray Roberts Lake		
Buck Creek cove	Nutrient Enrichment Concern	ammonia
Buck Creek cove	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Upper portion of Elm Fork arm	Nutrient Enrichment Concern	ammonia
Upper portion of Jordan Creek arm	Nutrient Enrichment Concern	ammonia
Upper portion of Jordan Creek arm	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Upper portion of Jordan Creek arm	Nutrient Enrichment Concern	orthophosphorus
Upper portion of Jordan Creek arm	Nutrient Enrichment Concern	total phosphorus
Segment 0809, Eagle Mountain Reservoir		
Ash Creek cove	Algal Growth Concern	chlorophyll *a*
Indian Creek cove	Algal Growth Concern	chlorophyll *a*
Lower portion of reservoir east of Walnut Creek cove	Algal Growth Concern	chlorophyll *a*
Lowermost portion of reservoir near east end of dam	Algal Growth Concern	chlorophyll *a*
Middle portion of reservoir near Cole subdivision	Algal Growth Concern	chlorophyll *a*
Upper portion of reservoir near Newark Beach	Algal Growth Concern	chlorophyll *a*
Upper portion of reservoir near Newark Beach	Nutrient Enrichment Concern	total phosphorus
Walnut Creek cove	Algal Growth Concern	chlorophyll *a*
Segment 0830, Benbrook Lake		
Lower portion of reservoir	Algal Growth Concern	chlorophyll *a*
Lower portion of reservoir	Nutrient Enrichment Concern	ammonia
Middle portion of reservoir	Algal Growth Concern	chlorophyll *a*
Upper portion of reservoir	Algal Growth Concern	chlorophyll *a*
Segment 0820, Lake Ray Hubbard		
Lower portion of East Fork arm, centering on IH 30	Algal Growth Concern	chlorophyll *a*
Lower portion of East Fork arm, centering on IH 30	Nutrient Enrichment Concern	ammonia
Lower portion of East Fork arm, centering on IH 30	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Middle portion of East Fork arm, centering on SH 66	Algal Growth Concern	chlorophyll *a*
Middle portion of East Fork arm, centering on SH 66	Nutrient Enrichment Concern	ammonia
Segment 0818, Cedar Creek Reservoir		
Cedar Creek cove	Algal Growth Concern	chlorophyll *a*
Cedar Creek cove	Nutrient Enrichment Concern	ammonia
Cedar Creek cove	Nutrient Enrichment Concern	orthophosphorus
Cedar Creek cove	Nutrient Enrichment Concern	total phosphorus
Lower portion of reservoir east of Key Ranch Estates	Algal Growth Concern	chlorophyll *a*
Lowermost portion of reservoir adjacent to dam	Algal Growth Concern	chlorophyll *a*
Middle portion of reservoir downstream of Twin Creeks cove	Algal Growth Concern	chlorophyll *a*
Middle portion of reservoir downstream of Twin Creeks cove	Nutrient Enrichment Concern	ammonia
Upper portion of reservoir adjacent to Lacy Fork cove	Algal Growth Concern	chlorophyll *a*
Segment 0836, Richland-Chambers Reservoir		
Confluence of Richland and Chambers Creek arms	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Lower portion of Richland Creek arm	Algal Growth Concern	chlorophyll *a*
Lowermost portion of reservoir, adjacent to dam	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Segment 0803, Lake Livingston		
Lowermost portion of reservoir, adjacent to dam	Algal Growth Concern	chlorophyll *a*
Lowermost portion of reservoir, adjacent to dam	Nutrient Enrichment Concern	orthophosphorus
Middle portion of reservoir, centering on US 190	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Middle portion of reservoir, centering on US 190	Nutrient Enrichment Concern	orthophosphorus
Middle portion of reservoir, centering on US 190	Nutrient Enrichment Concern	total phosphorus
Middle portion of reservoir, downstream of Kickapoo Creek	Nutrient Enrichment Concern	orthophosphorus
Riverine portion of reservoir, centering on SH 21	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Riverine portion of reservoir, centering on SH 21	Nutrient Enrichment Concern	orthophosphorus
Riverine portion of reservoir, centering on SH 21	Nutrient Enrichment Concern	total phosphorus
Upper portion of reservoir, centering on SH 19	Algal Growth Concern	chlorophyll *a*
Upper portion of reservoir, centering on SH 19	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Upper portion of reservoir, centering on SH 19	Nutrient Enrichment Concern	orthophosphorus
Upper portion of reservoir, centering on SH 19	Nutrient Enrichment Concern	total phosphorus
Upper portion of reservoir, west of Carlisle	Nutrient Enrichment Concern	nitrate+nitrite nitrogen
Upper portion of reservoir, west of Carlisle	Nutrient Enrichment Concern	orthophosphorus
Upper portion of reservoir, west of Carlisle	Nutrient Enrichment Concern	total phosphorus

Note:
The parameter for algal growth concern is "excessive algal growth" in the Water Quality Inventory.

TABLE 3-5
USE ATTAINMENT CONCERNS IN DRAFT 2002 WATER QUALITY INVENTORY

Location	Use	Level of Concern	Parameter of Concern
Segment 0840, Ray Roberts Lake			
Upper portion of Jordan Creek arm	Contact Recreation Use	Use Concern	bacteria
Segment 0809, Eagle Mountain Reservoir			
Old Ranch cove	Aquatic Life Use	Use Concern	depressed dissolved oxygen
Segment 0818, Cedar Creek Reservoir			
Cedar Creek cove	Aquatic Life Use	Use Concern	depressed dissolved oxygen
Uppermost portion of reservoir downstream of Kings Creek	Aquatic Life Use	Use Concern	depressed dissolved oxygen
Prairie Creek cove	General Use	Use Concern-Limited Data	high pH
Segment 0836, Richland-Chambers Reservoir			
Confluence of Richland and Chambers Creek arms	Public Water Supply Use	Threatened	atrazine in finished drinking water
Lower portion of Chambers Creek arm	Public Water Supply Use	Threatened	atrazine in finished drinking water
Lower portion of Richland Creek arm	Public Water Supply Use	Threatened	atrazine in finished drinking water
Lowermost portion of reservoir, adjacent to dam	Public Water Supply Use	Threatened	atrazine in finished drinking water
Remainder of reservoir	Public Water Supply Use	Threatened	atrazine in finished drinking water
Upper portion of Chambers Creek arm	Public Water Supply Use	Threatened	atrazine in finished drinking water
Upper portion of Richland Creek arm	Public Water Supply Use	Threatened	atrazine in finished drinking water
Segment 0803, Lake Livingston			
Cove off upper portion of reservoir, East Trinity	General Use	Use Concern-Limited Data	high pH
Middle portion of reservoir, centering on US 190	General Use	Use Concern	high pH
West Carolina Creek cove, off upper portion of reservoir	General Use	Use Concern-Limited Data	high pH

Notes:
1. Use Concerns-Limited Data are identified for indicators where less than 10 samples were available for assessment and some exceedances were identified.
2. Use Concerns are identified for indicators that support the designated use as determined by an adequate number of samples (10-sample minimum), but a few reported exceedances (for example, 3 of 20 samples) indicated a potential water quality problem.
3. Threatened water bodies either show a significant decline in water quality or have recently shown toxic contaminates at levels of some concern for drinking water use.

Section 6.0 of the report addresses the information available on the water supply use and how it can be affected by nutrients. One of the aspects explored is differences in taste and odor problems and treatment cost at different levels of nutrients and chlorophyll *a*.

4.0 RECREATION

This section addresses the various forms of recreation provided by the study reservoirs and investigates and discusses how these might be related to the level of nutrients and the primary response parameters, chlorophyll *a* and water clarity. With the exception of limited fisheries implications, no studies were located that related nutrients or nutrient-response parameters to recreational-use impairment for the study reservoirs.

As noted in Section 3.0, all of the study reservoirs currently have only one form of recreational use designated in the Water Quality Standards. This is the contact use, whose indicator bacteria criteria are based on an acceptable increase in illness rates from swimming. All of the study reservoirs have indicator bacteria levels much lower (cleaner) than required by the present criteria. Recreational fishing is addressed under Aquatic Life Use in Section 5.0 in order to provide a comparative discussion regarding a means of measuring aquatic life attainment goals.

In addition to contact recreation (includes swimming and sports such as water skiing and wind surfing) and fishing, the study reservoirs support a number of recreational uses that were considered for this study. They include:

- pleasure boating with no significant water contact
- aesthetic appreciation
- other (e.g., waterfowl management)

The emphasis is on the relationship of these uses to the levels nutrients and response parameters. The section begins with a discussion of available participation data, discusses the uses drawing from related studies, and concludes with a discussion of applied research techniques that might be applied to contribute to improved understanding of relationships.

4.1 PARTICIPATION DATA ON STUDY RESERVOIRS

In the early stages of the project an effort was made to identify and document available recreational participation data. A telephone survey of potential data sources was conducted.

It was found that the only reservoirs that maintained data on recreation visits and participation were those operated by the USACE. A possible reason is that recreation is considered a public economic benefit under the rules employed by the USACE in determining if a project is worthy of federal funding. Of the nine study reservoirs, only Benbrook and Ray Roberts are USACE projects, where recreational benefits are considered explicitly. Because recreation was considered in decision making on these projects, there may be a need to maintain records for evaluating the extent to which recreational use follows that considered in project planning.

Table 4-1 presents visitation data for both lakes Benbrook and Ray Roberts for fiscal years 1995 through 2002. The visitation data also include a distribution of activities into boating, fishing, skiing, and swimming. These breakouts are noted to be based on activity surveys that are over 20 years old, but they appear to be the best information available. From these breakouts there appears to be a substantial difference between the two reservoirs. While the overall number of visits for the two reservoirs are not that different (1.1 versus 1.7 million per year), the participation rates at Benbrook for boating, fishing and skiing are much smaller than at Ray Roberts. Part of the explanation may be the larger size of Ray Roberts and its popularity as a fishing reservoir. Conversely, the swimming rates at Benbrook are higher than at Ray Roberts, even with lower total visits. The reason for the higher swimming rate at Benbrook is not known. It would not appear to be water clarity, as the chlorophyll *a* levels on Benbrook are higher than on Ray Roberts.

Visitation data at Texas Park and Wildlife Department (TPWD) park facilities surrounding Ray Roberts were supplied for FY 99 to 02 and are summarized in Table 4-2. Recognizing that the monthly reporting periods are slightly different, the data appear to track with the USACE reports for Lake Ray Roberts in Table 4-1.

The data include monthly visitation totals for each of the facilities. The average of the four years of monthly values for each TPWD facility are plotted in Figure 4-1. The usual seasonal variation is exhibited for all facilities, but there are substantial differences between facilities in the difference between summer and winter participation.

While there is some information available on recreational participation, it does not appear to cover enough of the study reservoirs to make meaningful analysis possible. However, the availability of data on USACE reservoir projects statewide could be a valuable resource for additional studies of the recreation use in relation to nutrient and response parameter levels.

4.2 PLEASURE BOATING AND WATER SPORTS

The color and clarity of water, as well as any odors associated with algae blooms or decomposition gasses, could play a role in user perception and development of criteria associated with those uses. The degree to which pleasure boating and water sports can be tied to nutrient concentrations remains to be determined. Even without supporting data, some generalizations can be made, of which, user perception for pleasure boating and water sports may be closely related to those for swimming and aesthetic appreciation.

Pleasure boating ranges from simply riding around to more competitive activities, such as sailboat racing. Water sports include activities such as skiing, wakeboarding, wind surfing and jet-skiing. It is reasonable to expect that proximity to metropolitan areas, access, and the physical nature of the study reservoirs may influence these activities more so than symptoms of eutophication, but quantitative data on this point are

TABLE 4-1
VISITATION DATA FOR LAKE BENBROOK AND LAKE RAY ROBERTS

Period	Total Visits	Boating	Fishing	Skiing	Swimming
Lake Benbrook					
Oct 1995 to Sept 1996	904,800	90,480	117,624	18,096	90,480
Oct 1996 to Sept 1997	1,312,600	131,260	183,764	26,252	131,260
Oct 1997 to Sept 1998	1,535,800	138,222	199,654	15,358	138,222
Oct 1998 to Sept 1999	1,216,100	121,610	182,415	12,161	121,610
Oct 1999 to Sept 2000	1,100,774	99,816	156,661	14,763	106,248
Oct 2000 to Sept 2001	1,208,163	106,328	192,791	16,498	95,913
Oct 2001 to Sept 2002	1,099,991	91,926	158,311	14,473	93,358
Average	**1,196,890**	**111,377**	**170,174**	**16,800**	**111,013**
Lake Ray Roberts					
Oct 1995 to Sept 1996	591,500	189,280	242,515	5,915	29,575
Oct 1996 to Sept 1997	1,704,100	647,558	886,132	187,451	85,205
Oct 1997 to Sept 1998	1,602,100	608,798	833,092	176,231	80,105
Oct 1998 to Sept 1999	2,233,300	826,321	1,161,316	223,330	89,332
Oct 1999 to Sept 2000	1,953,374	700,915	1,003,581	205,123	88,268
Oct 2000 to Sept 2001	2,280,441	548,102	1,032,027	170,746	130,694
Oct 2001 to Sept 2002	1,565,997	322,369	638,155	113,161	105,029
Average	**1,704,402**	**549,049**	**828,117**	**154,565**	**86,887**

Data Sources: USACE - Benbrook Lake Office (received 8 January 2003)
- Grapevine, Lewisville, and Ray Roberts Lakes Office (received 7 January 2003)

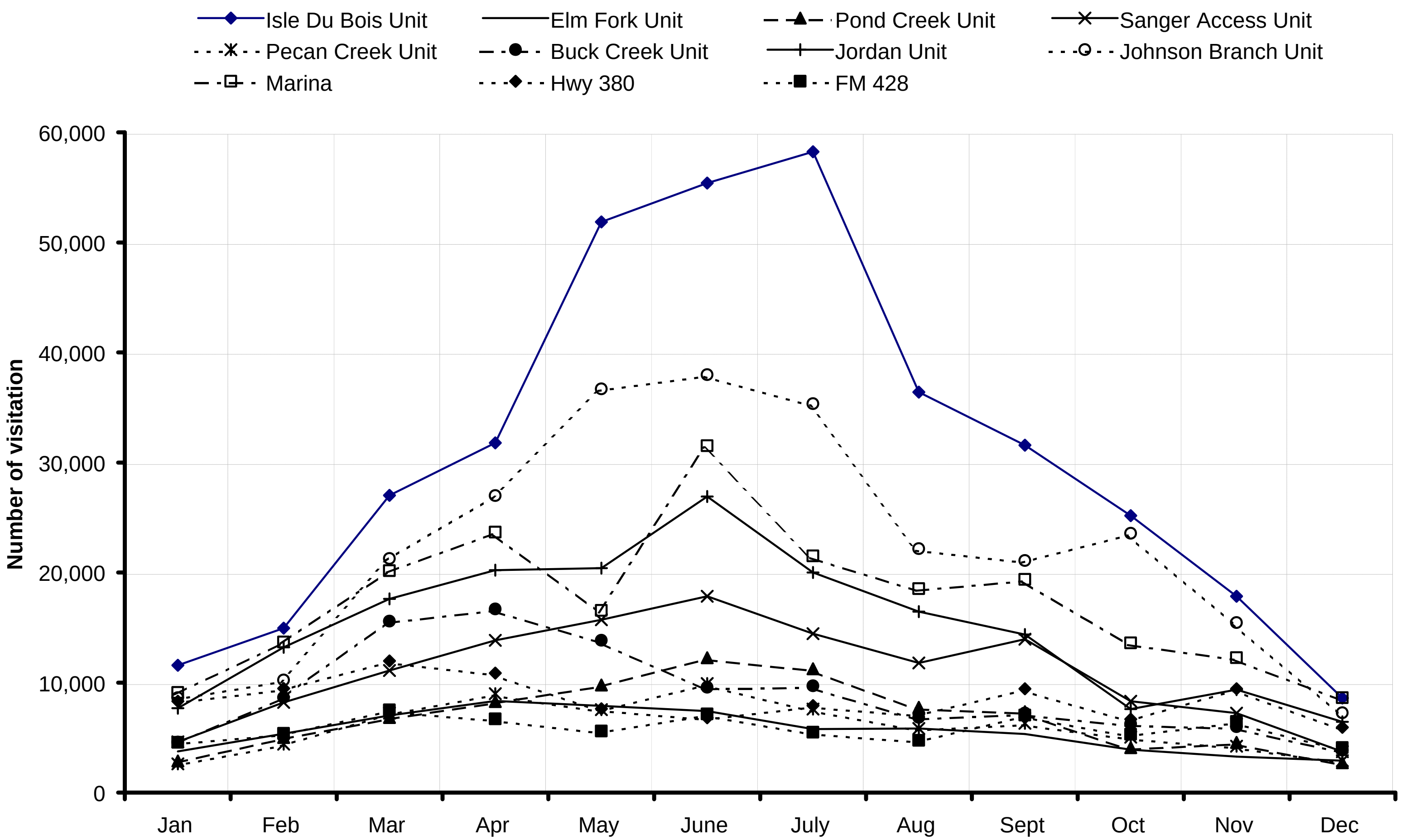
Notes:

1. These numbers are a "best guess" and are based on surveys completed over 20 years ago.
2. The numbers do not add up because one person is typically involved in more than one activity (Example: all skiers are also boaters).

TABLE 4-2
RAY ROBERTS LAKE STATE PARK VISITATION DATA

	FY 99	FY 00	FY 01	FY 02
Isle Du Bois Unit	381,478	374,270	352,406	373,051
Elm Fork Unit	64,210	85,661	74,620	42,008
Pond Creek Unit	109,563	101,345	72,765	47,108
Sanger Access Unit	158,473	159,932	131,913	72,321
Pecan Creek Unit	94,733	86,307	63,873	45,001
Buck Creek Unit	220,308	116,393	57,402	40,657
Jordan Unit	216,748	245,735	160,367	97,804
Johnson Branch Unit	279,837	261,557	244,229	280,564
Marina	296,428	280,753	188,578	68,270
Hwy 380	21,785	118,188	124,860	61,494
FM 428	29,358	85,768	66,723	45,477
TOTAL	1,872,921	1,915,909	1,537,736	1,173,756

FIGURE 4-1
AVERAGE MONTHLY VISITATION OF TPWD FACILITIES ON LAKE RAY ROBERTS



lacking. Reservoirs close to the Dallas-Fort Worth metropolitan area receive a higher degree of use than reservoirs in rural areas simply because of location.

While not a study reservoir, one example of degree of use versus water quality may be Lake Lewisville, a large USACE reservoir just north of Dallas. A Water-Related Recreation Use Study for Lewisville Lake indicated that part of the reservoir was at capacity for summertime boating (USACE, 1999). The study was conducted to address the need for additional marinas, since many marinas were near capacity. They found that most (66.5%) of the vessels were contributed from the reservoir's 29 boat ramps while the remainder (33.5%) of the vessels were contributed from marinas. An increase in wet storage would mean an increase in boat traffic. It is apparent that the reservoir's high degree of use is a result of abundant access, but that improving access would also increase boating. This reservoir's high degree of use comes in spite of marginal water quality. A cursory review of available data indicate that mean Secchi transparency is about 0.6 meters making it one of the more turbid reservoirs in the Dallas-Fort Worth area. This information suggests that access facilities and location are important for boating use and that boaters may sacrifice perception of water quality for convenience. With the available data, it was not possible to distinguish between the types of boating, such as fishing, pleasure boating, or water sports. However, since peak usage occurs during the summer, it can be assumed that pleasure boating and water sports make up a majority of the use.

In-reservoir physical properties also influence the type and degree of pleasure boating and water sports. Reservoirs that are large, deep, and free of hazards, such as inundated timber and stumps, are more likely to be used for recreational boating (particularly sailing), and water sports. Lake Ray Hubbard and Cedar Creek Reservoir maintain the highest mean chlorophyll *a* concentrations at 25.9 and 24.3 ug/L, respectively, but support a high recreational-boating and water-sport use. On the other hand, Houston County Lake is one of the clearest study reservoirs, with a mean Secchi depth of about 1.5 meters. Even though it has very low mean TP (0.003 mg/L) and mean chlorophyll *a* (5.7 ug/L), it receives relatively little recreational-boating or water-sport use. This is because it has a number of features that are not conducive to these activities, including its relatively small size, substantial distance from metropolitan areas, poor access, and a large number of boating hazards. This contrasts to the high degree of use that the metropolitan-area reservoirs receive despite clear differences in trophic state.

While none of the study reservoirs have an overabundance of submerged aquatic vegetation (SAV), the problems that SAV can pose to pleasure boating and water sports are worth mentioning. SAV can clog motor cooling-water intakes and wrap around propellers. Those involved in water sports may come in contact with SAV, potentially reducing the quality of their recreational experience. In particular, *Hydrilla*, an introduced species, has impaired recreational use in a number of reservoirs across the State. The relationship between dense SAV coverage and nutrients has been somewhat misunderstood by the public. While abundant nutrients can promote SAV growth, it is often light penetration that determines the degree of SAV coverage. Reservoirs that maintain a high degree of TSS, such as algal turbidity, are not conducive to excessive SAV growth. Reservoirs that are eutrophic may support SAV in shallow littoral zones or mats of filamentous algae, resulting in a visible perception of nuisance vegetation, but they rarely support problematic SAV outside of shallow areas.

4.3 SWIMMING AND AESTHETIC APPRECIATION

Similar to other uses, swimming and aesthetic appreciation are significantly influenced by proximity to metropolitan areas and access. Swimming would have the same considerations as boating and water sports, but would likely be more adversely impacted by poor water clarity and presence of aquatic plants. Appearance of the water is only one portion of the experience associated with pleasure boating or water sports. Much of the attention is often focused on the participants, equipment, or vessels. On the other hand, water contact is a major part of the experience for most swimmers. Most would agree that clear water is more desirable for swimming than turbid or stained water. Those who swim from the shore would likely be the first to observe the symptoms of eutrophication. Aquatic plants and in particular, filamentous algae, tend to grow along shallow littoral zones. Contact with mats of algae or other aquatic plants can impart a poor swimming experience. To compound the problem of eutrophication, the littoral zone is often the first area to become turbid from suspended sediments through wave action or swimming. While turbidity from sediments is not necessarily the result of eutrophication, it does tend to have an additive affect with algal turbidity. Quite often, boaters will move to areas of perceivably good water quality, such as open-water areas, to recreate, while those who use the shoreline may not have that opportunity. As such, shoreline swimming may be the most sensitive of the recreational uses. Nutrient or nutrient-response parameter criteria established for shoreline swimming would probably be protective of recreational boating and water-sport uses.

Aesthetic appreciation is inherent to most reservoir uses and includes appreciation by those who may not be involved in direct water use. Examples of this may include those who picnic, camp, or live near the water. Reservoirs that are clear and free of excessive plant growth are typically valued more so than those which manifest symptoms of eutrophication.

Translations of nutrient and nutrient-response parameters into reservoir-user impairment are scarce to non-existent for Texas. Smeltzer and Heiskary (1990) linked nutrients and nutrient-response parameters to user responses in Vermont and Minnesota. They found that user sensitivities to eutrophic conditions differed greatly between ecoregions, in that users had different expectations depending upon the quality of the water in which they were accustomed. They also found that Minnesota lakes with a TSI (Carlson, 1977) < 50 were classified as fully supporting swimming and aesthetic use. Lakes with an average TSI of 51–59 were supporting, but threatened and those with an average TSI from 60–65 were classified as partially supporting. Lakes with a, average TSI >65 were classified as non-supporting. If we compare mean chlorphyll *a* concentrations to the TSI in terms of Smeltzer and Heiskary's (1990) findings, Lakes Bridgeport and Houston County would be fully supportive of swimming and aesthetic uses according to Minnesota standards. The remainder of the study reservoirs would be considered as either supporting, but threatened or partially supporting. However, this comparison is drawn from annual means and it is possible that summer chlorophyll *a* values would be higher, resulting in possible exceedances of those criteria during periods of high public use. It is possible that in the absence of non-algal turbidity characteristic of the reservoirs in this study, that chlorophyll *a* might be higher, resulting in an increase in TSI values and commensurate reduction in use support.

A study of user perception for Lake Champlain, Vermont indicated that chlorophyll *a* concentrations above 6 ug/L frequently produce perceptions of use impairment (Smeltzer and Heiskary, 1990). Considering the high correlation between chlorophyll *a* and TP found in their study, they suggested that a TP concentration of 25 ug/L might be an appropriate nuisance criterion for Lake Champlain. User surveys for Lake Pepin, a run-of-the-river reservoir between Wisconsin and Minnesota, Heiskary and Walker (1995) found that chlorophyll *a* concentrations exceeding 40 ug/L and 60 ug/L were associated with "nuisance" and "severe-nuisance" perceptions of water quality. They recommended a summer-mean chlorophyll *a* concentration of 30 ug/L as a water quality goal for Lake Pepin. Since Lake Pepin is a run-of-the-river reservoir, hydraulic residence time was an important consideration for full algal response to phosphorus. Under high flows, ambient phosphorus concentrations could be considerably higher than during periods of low flow without manifesting the effects of eutrophication.

In summary, chlorophyll *a* appears to be the parameter that most closely represents user perception of water quality. Although chlorophyll *a* can be highly correlated with phosphorus, algal response to phosphorus can be variable between reservoirs. User perception of eutrophication may also be somewhat variable from region to region or reservoir to reservoir. The reservoirs in this study pose another dimension to user perception due to high, non-algal suspended solids and tannins associated with east Texas systems. Due to high turbidity, not necessarily associated with eutrophication, sensitivity of users to chlorophyll *a* may be less than that observed in other studies. This leads us to believe that site-specific criteria may be important for capturing reservoir variability and inherent differences in user perceptions.

It is important to note that these inferences pertain to non-angling recreation. As discussed in Section 5.5, differences may exist between angler and non-angler goals in relation to trophic state. It is difficult to draw conclusions regarding potential recreational-use attainment for the study reservoirs based on available data.

4.4 SUMMARY AND DISCUSSION

As noted above, there have been a number of studies addressing recreational values and the importance placed on various measures of water quality. Much of the work involves some form of survey research where potential recreation participants are asked questions dealing with their perception of a particular waterbody and values that they would place on varying levels of quality. The term typically applied to this type of survey research is Contingent Valuation Studies. User perception and contingent valuation studies based on swimming and aesthetic appreciation in specific reservoirs may be an appropriate means for gathering additional data to aid in setting recreation-use criteria.

Until such specific studies are carried out, there is a lack of data on the relation between recreation and nutrients in the study area waters. The study now being conducted by the Texas Water Conservation Association (TWCA, 2003) promises to go a long way to fill this gap. The two reservoirs where we have significant recreation participation data, Benbrook and Ray Roberts, do not provide much illumination. They have very different recreational participation rates for all activities, but fairly similar nutrient and chlorophyll *a* conditions. From the data and literature available, all that can be said is that it is expected that clearer water will be more desired for recreation than less clear water, but the strength of this desire is unknown. There does not appear to be a willingness on the part of a major portion of the public to drive a substantial distance to use a clearer reservoir such as Houston County, when less clear waters are available nearby.

5.0 AQUATIC LIFE USE

This section of the report is an investigation into the aquatic life use (ALU) and how it might be related to the level of nutrients and response parameters, chlorophyll *a* and water clarity. It includes the fishing use that is a popular form of recreation that the reservoirs support.

As discussed in Section 3.0 of this report, all of the study reservoirs are currently designated to support a "high" ALU (Texas Surface Water Quality Standards, TCEQ, 2000). The criteria associated with this use are DO, pH, and temperature. These criteria apply to the mixed surface layer when stratified or the entire water column if not stratified. The TCEQ defines the mixed surface layer as the portion of the water column from the surface to the depth at which the temperature decreases by greater than 0.5 °C (TCEQ, 2003). For the most part, these criteria are attained in the study reservoirs. As noted in Section 3.2, there are some cases where further work is being performed to determine if the present criteria are being attained.

There are no numerical nutrient criteria at this time but there are screening levels for nutrients established by the TCEQ. These screening levels are based on the 85th percentile of available data. The status of the study reservoirs relative to these screening criteria is summarized in Section 3.0.

5.1 BIOLOGICAL CRITERIA

Biological criteria for streams, as a measure of ALU attainment, are well developed. For example, the TCEQ has published metrics that can be used to characterize the fish and benthic communities, and allow a direct determination of the degree of biological use support.

The situation is fundamentally different for reservoirs, and that constitutes a limitation for this analysis. The primary reason for the lack of established biological metrics is that these reservoirs are artificial systems. They do not have a history of research and data that can be used to define what a natural and pristine environment and habitat would be like. Instead, data are only abundant for species that are managed for recreational fishing. This led the study to using a different approach for evaluating reservoir fish communities. Before results are discussed, it is important to provide a background and discussion on the relevance of using existing ALU criteria for assessing fish community health.

An overwhelming majority of lentic (standing water) waters in Texas currently exist in numerous reservoirs that were constructed on rivers and streams. These man-made systems are relatively new, most of which were constructed during the later half of the 1900s. Prior to the construction of reservoirs, the preponderance of aquatic habitats in Texas were free-flowing streams and rivers. These systems ranged from sluggish and stained bayous of east Texas to swift, clear and rocky rivers and streams of central and west Texas. As such, approximately 200 species of fish have adapted to these environments across the state, many of which only reside in specific regions, watersheds, or streams (Hubbs, 1991).

Bioassessments are generally accepted as a means for assessing the health of biological communities and can be a direct measure of goals relative to the Clean Water Act (EPA, 1986). Current evaluations of fish communities are often based on the Index of Biotic Integrity (IBI) established by Karr et al. (1986). This methodology was further developed by Linam et al. (2002) to provide a better representation of the fish assemblages in the various aquatic ecoregions across the Texas. These procedures were developed specifically for streams and rely heavily on species richness, diversity, and indicator species inherent to those systems. Results are typically expressed as ALU (TNRCC, 1999). However, the methodology was not intended for the evaluation of lentic systems (Karr et al., 1986).

Limited work has been performed in investigating approaches for evaluating reservoir community health. Hickman and McDonough (1996) evaluated the use of a "relative fish assemblage index" in relation to the metrics derived by Karr et al. (1986). Their goal was to test quantitative sampling methodology and the precision of established metrics for reservoirs, but they did not make any suggestion as to the applicability or the quality of the metrics for evaluating reservoir communities.

It has been well documented that dams and reservoirs alter natural stream communities and function (Yeager, 1993). Hydrology, shoreline development ratio, physical habitat, and fisheries management actions are all examples of factors that may shape reservoir fish communities. However, not all reservoirs impart the same degree of change to fish communities. For instance, run-of-the-river reservoirs may support fish assemblages reflective of natural waters if at least some of the lotic habitats are present and fish from upstream can migrate into the impoundment. On the other hand, habitat features of off-channel reservoirs are typically very dissimilar to natural streams and fish migration is much more impaired, resulting in differences in fish community structure and function. Jennings et al. (1995) concluded that the term "biotic integrity" (a rating system based on species richness, diversity, and indicator species for streams) is inappropriate for reservoir applications.

5.2 AVAILABLE AQUATIC LIFE DATA

While methods may exist for evaluating natural lake communities in other parts of the country where such systems exist, they would hardly be applicable to Texas reservoirs because of variations in adaptations to those environments and significant differences in physical properties between different parts of the country. Adjusting existing stream metrics to reservoirs might be possible, but various species, integral to existing IBIs, simply do not occur in the study reservoirs. The approach of using some measure of community "integrity" based on species richness and diversity was considered, but the available data did not support this approach. The data obtained for this study were from routine population monitoring by the TPWD and were collected in the context of recreational-fish management. Their emphasis was on monitoring "target" species that included recreational species such as the black basses (*Micropterus* spp.), catfishes (*Ictalurus* spp.), crappies (*Pomoxis* spp.), and temperate basses (*Morone* spp.) as well as various forage species such as the sunfishes (*Lepomis* spp.) and shads (*Dorosoma* spp.). The TPWD uses standardized boat electrofishing, gill netting, and frame netting to collect samples for population monitoring. These techniques are somewhat biased toward sampling of larger fish (Nielson and Johnson, 1985), which ultimately skew results towards larger fish or species that attain larger sizes. Data from techniques that collect smaller individuals, such as seining or dip netting, were not part of the TPWD's routine monitoring and, thus, were not available.

Fisheries data were presented in TPWD's Performance Reports required under the Federal Aid in Fisheries Restoration Act and the Statewide Freshwater Fisheries and Monitoring Program. Four district offices provided the reports for the study reservoirs and these were:

TPWD Office	Study Reservoirs
Denison (2-A)	Bridgeport, Ray Roberts
Fort Worth (2-D)	Ray Hubbard, Eagle Mountain, Benbrook
Tyler (3-C)	Cedar Creek, Richland-Chambers
Bryan (3-E)	Lake Houston County, Livingston

The emphasis for collecting target species is not without purpose. An important use of these reservoirs, as well as most reservoirs in Texas, is recreational fishing. Funding for monitoring programs comes almost exclusively from anglers and, therefore, monitoring of fish populations is typically in line with angler prerogatives. This method of managing reservoirs is generally accepted by the angling and non-angling public. Since reservoir fish communities and existing data preclude assessments of "integrity," classifying reservoir fish populations by angler use may be a practical approach. However, this use would need to be further defined beyond just recreational fishing. The TPWD does not have a fishery designation for the study reservoirs. However, the TPWD recognizes that certain sport fish do better in certain reservoirs as a result of varying chemical and physical characteristics. Since the structure and function of fish populations are generally a result of existing reservoir conditions, management strategies are based upon the response of fish communities to existing reservoir conditions.

5.3 NUTRIENTS AND FISHERIES RESOURCES

It is well known that basic fertility is necessary for promoting productive warm-water recreational fisheries in lentic environments (Boyd, 1988; Bennet, 1970; McComas 2003). Lake managers typically regard phosphorus as the constituent that most often limits fish production (Boyd, 1988). Fertilization with nitrogen and phosphorus-based compounds is commonly employed to increase forage biomass via algal production. It has been suggested that fish biomass does not peak at TP levels less than 100 ug/L (Ney, 1996). However, measurements of nutrient or algal content are often not feasible or practical in recreational-fish management. Instead, the relationship between nutrients, chlorophyll *a*, and water clarity has been somewhat simplified to aid in applied fisheries management. In systems where light extinction is driven by algal biomass, water clarity is used as a measure of fertility. Given that increased algal production equates to increased fish biomass, target Secchi transparency is usually around 0.5 meters (18 inches) for managed ponds (Masser, 1992). This translates to chlorophyll *a* concentrations ranging from about 60 to 70 ug/L (Almazan and Boyd, 1978; Boyd 1988). The reverse of this situation is also true. Lower nutrient and chlorophyll *a* concentrations with increasingly clear water decreases fish production, which is important to note for lentic systems managed for recreational fishing.

High algal densities for large lakes or reservoirs may not necessarily be desirable, even when recreational fishing is an important use. Increasing algal production increases the rate of respiration that results in wide diel fluctuations in dissolved oxygen in the littoral zone and hypoxia in the hypolimnion. In addition, increased algal turbidity reduces the depth of the photic zone, which, in turn, increases the volume of hypoxic water. This may limit fish movement and habitat utilization and, after sudden destratification (turnover), may result in fish kills. This is common at Braunig Lake, a eutrophic cooling reservoir used for electric generation near San Antonio. Mean chlorophyll *a* and TP concentrations are typically around 75 ug/L and 0.5 mg/L, respectively. Under stratified conditions, the volume of hypoxic water is often near or exceeds the littoral volume. After a rapid mixing in the fall, DO concentrations commonly fall below 1 mg/L, resulting in fish kills (TPWD, 2003).

5.3.1 Study Reservoir Nutrients, Chlorophyll *a*, TSS, and Fish Communities

Fish kills due to chronic low DO concentrations may be regarded an ultimate symptom of eutrophication. TPWD maintains a database of fish kills and pollution complaints known as Pollution Response Incident and Species Mortality (PRISM). While TCEQ also investigates similar incidents, they do not maintain a database. Instead, the two agencies collaborate on data input into PRISM. A review of these data for the study reservoirs provided only one reported fish kill that may have had some relationship to nutrients. This incident took place in September 1996 on Richland-Chambers Reservoir and involved predominantly pelagic species near the dam. Low DO was the cause, but there was no evidence of a dense algal bloom. An unexplained sudden destratification was the apparent cause of the low-oxygen conditions. It is, however, possible that excessive hypoxic conditions in the hypolimnion may be partially the result of oxygen consumption associated with respiring or decomposing algal cells. As for the remainder of the reservoirs, the database provided no other documented fish kills or complaints related to eutrophication. This information suggests that these reservoirs have not demonstrated visible symptoms of problematic nutrient enrichment.

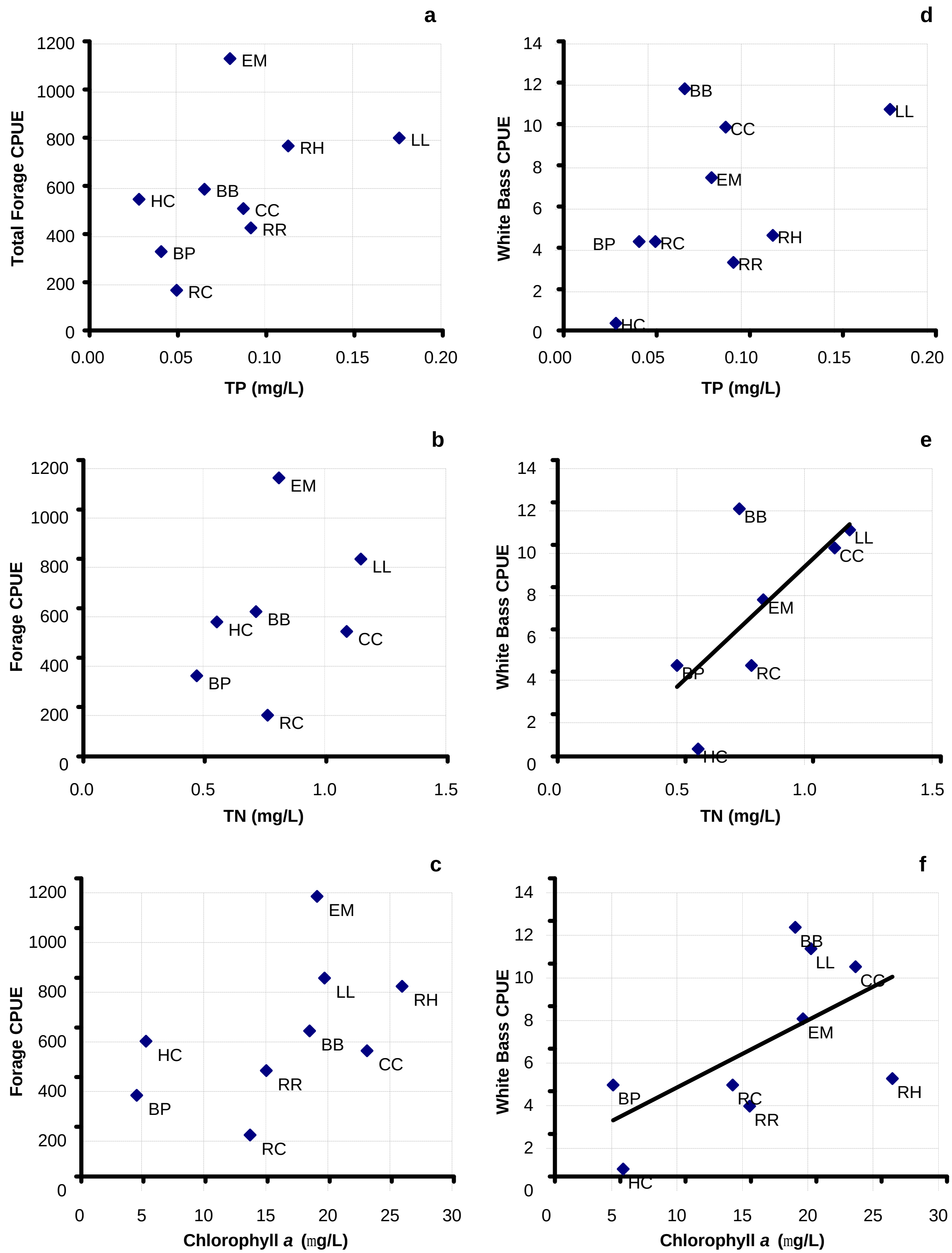
As previously discussed, fish biomass or standing crop typically increases with increasing nutrient enrichment. Standing crop is usually estimated using rotenone, a fish toxicant, in surveys of known area (Nielsen and Johnson, 1985). In reservoirs, this technique is done in coves and is known as cove-rotenone surveys. Recent cove rotenone data were not available for the study reservoirs. TPWD ceased using cove rotenone as a sampling tool in the late 1980s and early 1990s. As a consequence, no direct measures of standing crop were available. However, current sampling techniques (electrofishing, gill netting and frame netting) are useful for estimating abundance of target species and sampling of individual fish for estimates of growth, condition, age and various other population indices. Data obtained form the TPWD's routine monitoring were used to characterize target-species populations. It is important to note that TPWD changed from fixed-station sampling to randomized sampling around 1996. While this change may not have substantially changed gill net and frame net catch-per-unit-effort (CPUE) in some instances, changes in electrofishing CPUEs complicated comparisons between the two data collection techniques (Richard Ott, personal communication). As a result, only data from randomized sampling were used for this study.

To identify relationships between target species and various measures of fertility and water clarity, the following fish data and indices were used. Black bass, shad and sunfish data were collected by electofishing. Channel catfish (*I. punctatus*), blue catfish (*I. furcatus*), and white bass (*M. chrysops*) were collected with gill nets. Crappie were collected with frame nets. Sunfish and shad were grouped together to represent forage. Largemouth and spotted (*M. punctulatus*) bass were grouped together to represent black bass. Blue and channel catfish were grouped together to represent catfish. White and black crappie were grouped together to represent crappie. CPUE was used as a measure of relative abundance. Weight-length ratios (Wr) were used to estimate the body condition of largemouth bass (*M. salmoides*). Wr was calculated from the ratio of weight of sampled fish to an expected or standard weight based on length. Wr values between 95 and 105 are considered normal. Individuals less than 95 are considered lean where those over 105 may be considered obese. To determine possible differences associated with feeding habits, condition was evaluated for adults (>12 inches) sub-adults (<12 inches) and the entire population of largemouth bass. Proportional Stock Density (PSD) was used to describe the population size-structure. PSD is the ratio of fish of stock size (typically sub-adults) to fish larger than stock size (adults).

Based on fundamental relationships that suggest various aspects of fish populations are positively correlated with reservoir fertility, we hypothesized that these relationships would also apply to the study reservoirs. To test this, the above reservoir population indices means were plotted against mean Secchi depth, chlorophyll *a*, TSS, TP, and TN. A sampling of results is shown in Figure 5-1a-r. A complete tabulation of the relationships investigated and the variance explained (r^2 values) are listed in Table 5-1.

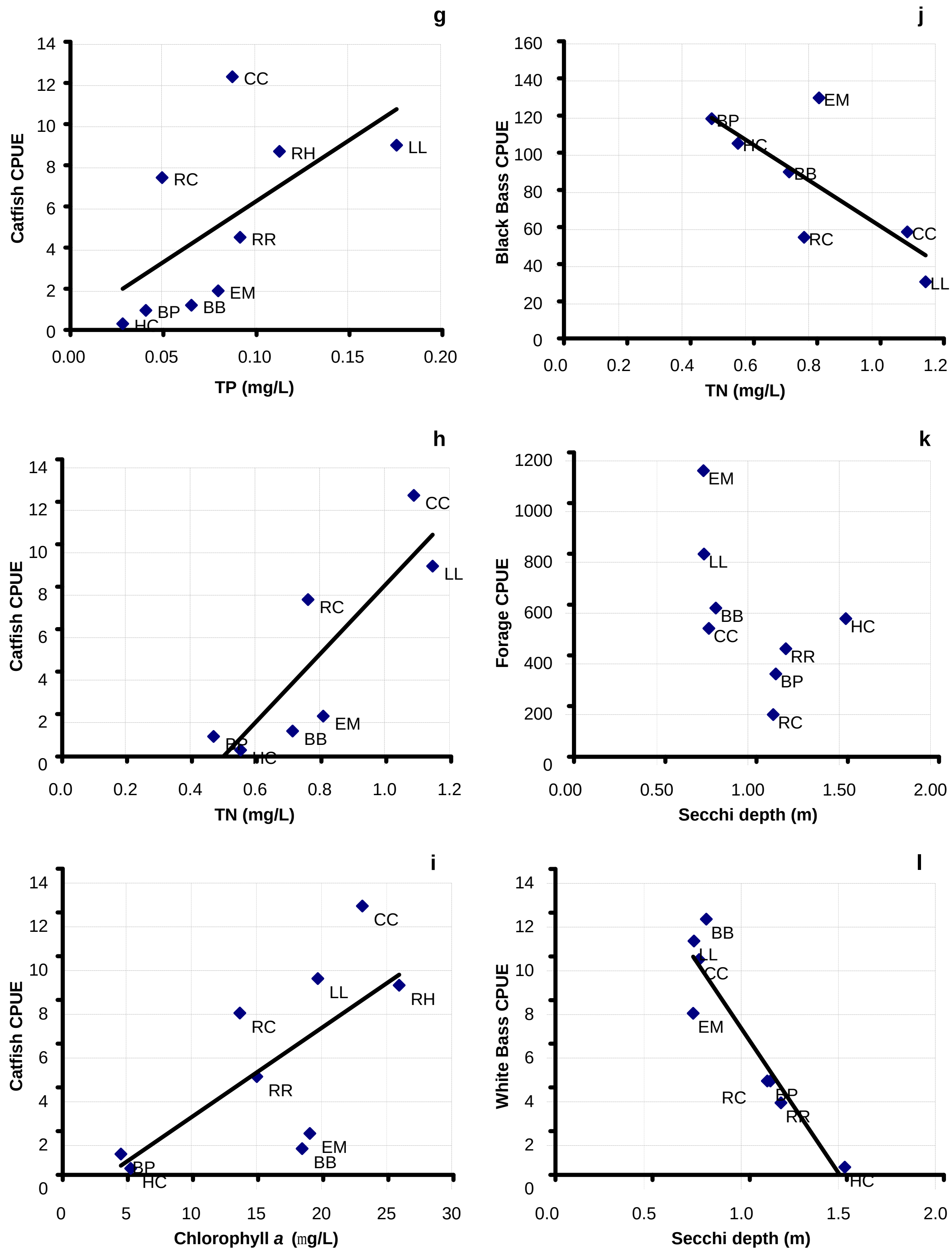
The assessment of the data for study reservoirs indicates, forage, white bass, and catfish abundance increased with increasing nutrient and chlorophyll *a* concentrations (Figure 5-1a-I). Correlations of these relationships were moderate to weak with r^2s ranging from 0.12 to 0.73. Crappie and black bass demonstrated little relationship between abundance and fertility with r^2s ranging from 0.12 to 0.00 (Figure 5-1). The only exception to this appeared to be black bass, where abundance decreased with increasing TN ($r^2 = 0.55$) (Figure 5-1j). Increases in forage abundance with increasing nutrients and chlorophyll *a* were probably the result of increased algal and invertebrate (primarily zooplankton) abundance that respond favorably to increased nutrient enrichment. As expected, the data suggested an increase in catfish and white bass abundance that was probably the result of improved reproductive and recruitment success associated with the increase in invertebrate and forage-fish abundance. However, crappie and black bass abundance were not in line with this expectation. While black bass and crappie

FIGURE 5-1
RELATIONSHIP BETWEEN FISHERIES INDICES AND WATER QUALITY VARIABLES
(Regression lines are shown when significant at 90% confidence level)



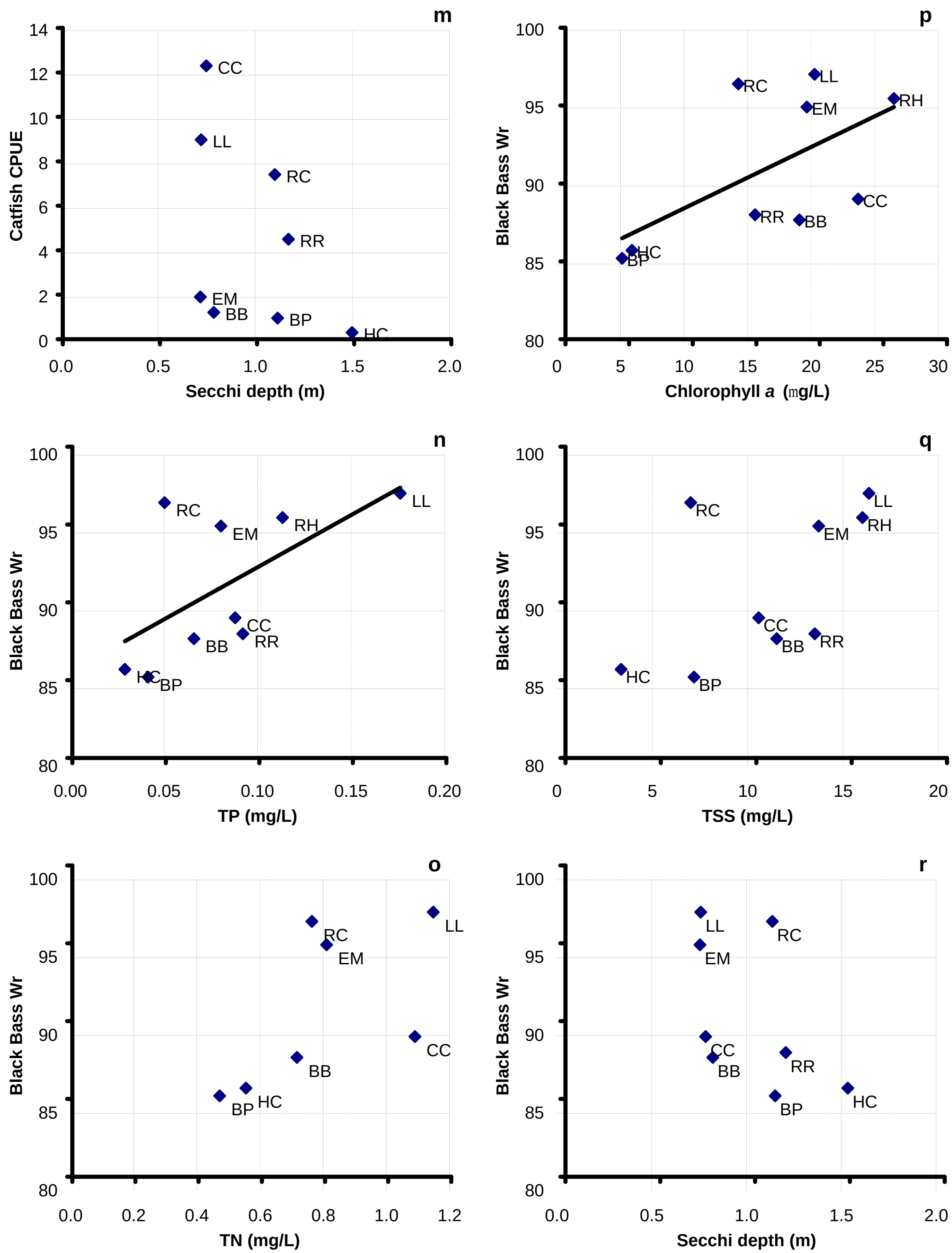
CC, Cedar Creek; EM, Eagle Mountain; HC, Houston County; BB, Benbrook; BP, Bridgeport; LL, Lower Livingston; RH, Ray Hubbard; RR, Ray Roberts; RC, Richland-Chambers.

FIGURE 5-1 (CONTINUED)
RELATIONSHIP BETWEEN FISHERIES INDICES AND WATER QUALITY VARIABLES
(Regression lines are shown when significant at 90% confidence level)



CC, Cedar Creek; EM, Eagle Mountain; HC, Houston County; BB, Benbrook; BP, Bridgeport; LL, Lower Livingston; RH, Ray Hubbard; RR, Ray Roberts; RC, Richland-Chambers.

FIGURE 5-1 (CONCLUDED)
RELATIONSHIP BETWEEN FISHERIES INDICES AND WATER QUALITY VARIABLES
(Regression lines are shown when significant at 90% confidence level)



CC, Cedar Creek; EM, Eagle Mountain; HC, Houston County; BB, Benbrook; BP, Bridgeport; LL, Lower Livingston; RH, Ray Hubbard; RR, Ray Roberts; RC, Richland-Chambers.

TABLE 5-1
CORRELATIONS BETWEEN FISHERIES INDICES AND
WATER QUALITY VARIABLES AND PHYSICAL HABITAT

	R^2 [1]					
	TP	**TN**	**Chl *a***	**TSS**	**Secchi**	**PHQI** [2]
CPUE						
Forage	0.23	0.12	0.24	**0.36**	(-)0.29	*
White bass	0.28	**0.47**	**0.36**	0.29	**(-)0.86**	*
Crappie	(-)0.10	(-)0.01	0.00	(-)0.10	0.00	(-)0.01
Catfish	**0.36**	**0.72**	**0.47**	0.18	(-)0.20	(-)0.23
Black bass	(-)0.12	**(-)0.55**	0.00	0.00	0.06	0.21
PSD						
White bass	(-)0.03	(-)0.07	0.02	(-)0.01	0.01	*
Crappie	0.18	0.01	0.32	**0.44**	0.21	0.00
Catfish	0.27	0.26	0.15	0.13	0.15	0.22
Black bass	0.04	0.25	0.00	0.00	0.00	0.00
Wr						
Black bass	**0.38**	0.39	**0.36**	0.33	(-)0.26	*

[1] Bold values mean a regression slope between the variables are significant at 90% confidence level. Negative sign means inverse relationship.
[2] Physical Habitat Quality Index.
* Not calculated

heavily utilize forage fish, it would appear that their abundance would have responded favorably to increased forage abundance. Discussions in Sections 5.3.2 and 5.4 provide some possible explanations.

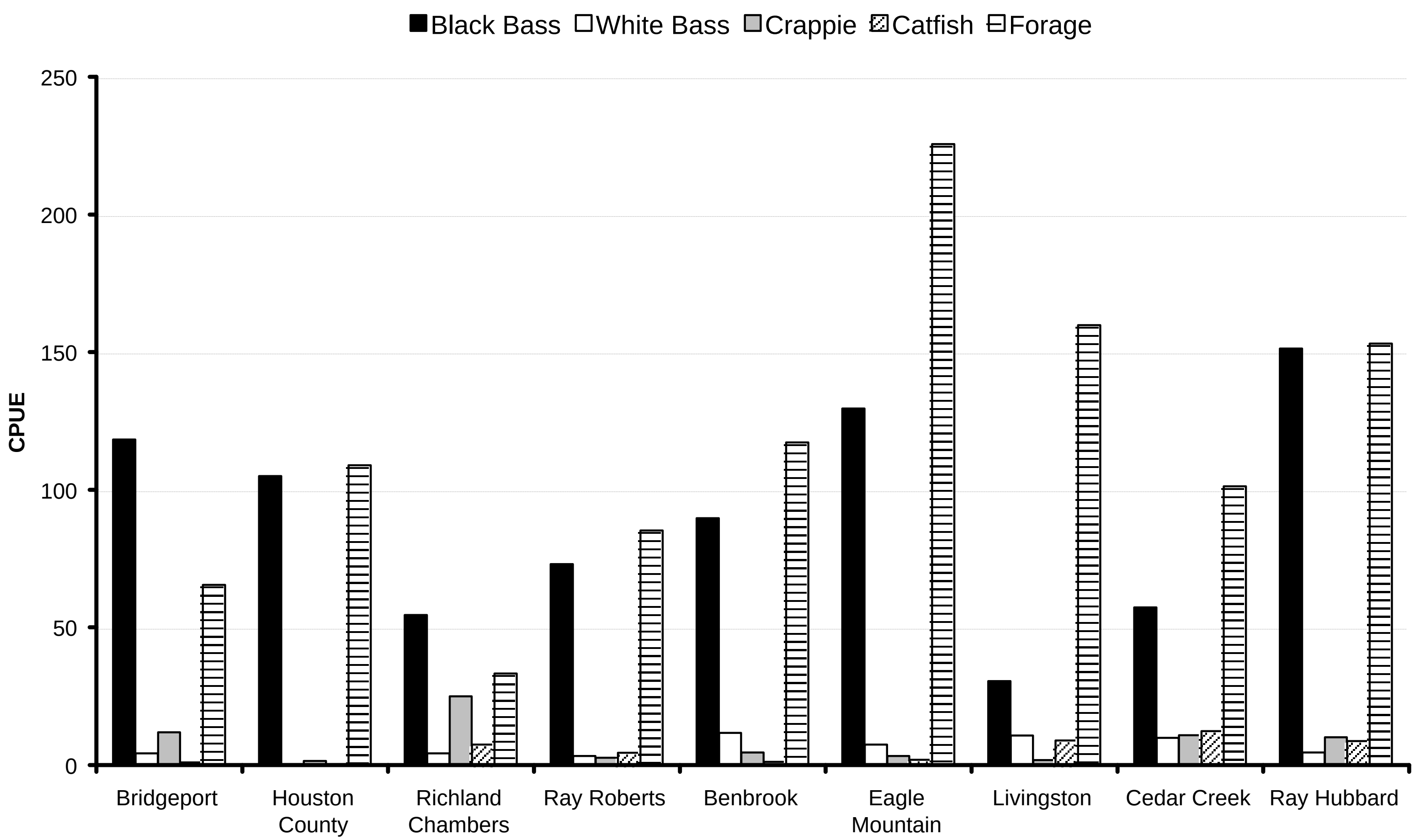
Figure 5-2 provides another way to compare fish abundance and highlight the effects of sampling methods in the study reservoirs, using available CPUE data. The data for each fish community are plotted, and the reservoirs ordered according to chlorophyll *a* concentrations in ascending order from left to right. As previously mentioned, some of the catch rates for different species are not comparable, resulting in the appearance of wide disparity between certain groups of fish. Catch rates of black bass and forage fish are somewhat comparable because both groups of fish were collected by boat electrofishing. Since electrofishing is an active capture technique and is an effective tool for sampling shallow, shoreline areas, it often results in the capture of relatively large numbers of small fish. White bass and catfish were collected using gill nets and crappie were collected using frame nets, which are passive capture techniques that are biased against smaller individuals. Gill nets and frame nets often yield much smaller numbers of fish than those collected by electrofishing. The difference in sampling methods produces a major difference in CPUE between fish communities that may not actually exist.

Secchi depth appeared to predict white bass abundance quite well. There was a marked decline in abundance in reservoirs with better water clarity that was closely correlated (r^2 of 0.86 for the study reservoirs). Forage and catfish abundance also declined with increasing water clarity but were less significantly correlated (r^2 = 0.28 and 0.20). Black bass and crappie abundance increased slightly with increasing water clarity, but were poorly correlated (r^2 = 0.06 and 0.01). Secchi depth is typically correlated (negatively) with chlorophyll *a* concentration. It was suspected non-algal turbidity common to these reservoirs might have confounded this relationship. However, the abundance of white bass, forage, and catfish were in line with those parameters, suggesting similar proportions of non-algal turbidity in each of the reservoirs. Response of fish communities to TSS appeared to parallel their relationship with chlorophyll *a*.

Another fisheries measure is the weight ratio (Wr). It is an indication of the condition of the fish (how well fed) based on their weight relative to their length. Study reservoir results are shown in Figure 5-1. Largemouth bass demonstrated a consistent, but poorly correlated (r^2 range of 0.06 to 0.13) relationship with chlorophyll *a* and nutrients. Condition tended to increase with increasing nutrients and chlorophyll *a* with a slight decrease with increasing water clarity. This relationship was also seen for the sub-adult and adult segments of the populations. Increase in body condition can be expected with increasing fertility and decreasing water clarity associated with algal turbidity.

PSD (Proportional Stock Density) for all species did not demonstrate any noticeable trends. PSD is probably only a moderately fair indicator, at best, of community responses to fertility. Reservoirs that are regulated by statewide minimum size limits and have high angler harvest tend to have low PSDs for recreational species. Degree of angler harvest influences the number of individuals larger than stock size.

FIGURE 5-2
COMPARISON OF FISH CPUE IN STUDY RESERVOIRS



5.3.2 Physical Habitat and Fish Communities

While fundamental principals support predictable relationships between nutrients and fish communities, those relationships were not easily defined for black bass and crappie. These species, as well as others, such as various sunfishes and catfishes, have at least some dependency on physical habitat (USFWS, 1985, 1984a and b, and 1982a, b, c, d and e). As such, diversity and abundance of various species in lakes and reservoirs are supported by the complexity of the littoral zone (Weaver et al., 1996; Dibble et al., 1996). The term complexity is used to describe features such as coves and variations in the shoreline as well as rock or structures that produce vertical roughness. Increased littoral complexity typically improves shoreline habitat utility and offers protection for cover-dependent species. All other things being equal, increased complexity should support fish populations and be correlated with fish abundance. We wanted to determine if abundance of certain species might have been less dependant on nutrients and more dependant on available physical habitat. This might help explain some of the differences in catch rates that were seemingly inconsistent with expectations.

Methods for evaluating habitats in streams have been well established and are a step widely recognized for community analysis (TNRCC, 1999; EPA, 1986). However, means of quantifying reservoir physical habitat for use attainability analysis have been less well developed. To test the extent that littoral habitat may play in affecting the abundance of cover-dependant species, we compared abundance to a measure of littoral habitat that we identify as a Physical Habitat Quality Index (PHQI). The intent with this index was not to develop an all-inclusive measure of physical habitat, but rather to capture important key physical habitat features that are likely to affect cover-dependant species. These features included percent aquatic vegetation (submerged and emergent), shoreline development ratio (SDR). The SDR is the ratio of actual shoreline length to the shoreline length of a circular reservoir of the same area, and is not related to the amount of docks or piers. Other parts of the PHQI are percent woody cover, and percent gravel or larger substrate in the reservoir. Table 5-2 presents the components of the PHQI developed for this project. A preliminary review by TPWD biologists concurred that it captures the most important habitat features for reservoirs. It has been submitted to David Terry of TPWD, Inland Fisheries Division, for formal review with the hope that it can gain acceptance and evolve into a widely used method of reservoir habitat characterization.

Habitats of reservoirs are routinely assessed by TPWD and are broken down by percentage of cover type. Each district reports habitat types and abundance somewhat differently, but the data are largely comparable. In cases where data were not directly comparable, relatively minor assumptions were made to provide consistency between data sets. Habitat data were collected during the same general timeframe that the fisheries data were collected (1996 to 2002).

Each of the habitat features was ranked as a metric to provide a qualitative score for each reservoir (Table 5-3). Metric scores and weighting were somewhat subjective, but were largely derived from established metrics for streams and observations made by previous researchers. Importance of various

TABLE 5-2
PHYSICAL HABITAT QUALITY INDEX

Habitat Parameter	Scoring Category									
Percent Total Aquatic Vegetation [1]	No aquatic vegetation	>0 - 5%	>5% - 10%	>10% - 15%	>15% - 20%	>20% - 30%	>30% - 40%	>40% - 50%	>50% - 75%	75% - 100%
Score	**0**	**1**	**2**	**3**	**4**	**5**	**4**	**3**	**2**	**1**
Shoreline Development Ratio [2]	1 to 2	>2 to 4	>4 to 10	>10 to 20	>20					
Score	**0**	**1**	**2**	**3**	**4**					
Percent Woody Cover	0	>0 to 10%	>10% to 25%	>25% to 50%	> 50%					
Score	**0**	**1**	**2**	**3**	**4**					
Percent Gravel or Larger	0	>0 to 10%	>10% to 25%	>25% to 50%	>50%					
Score	**0**	**1**	**2**	**3**	**4**					

[1] Submerged and emergent vascular plants.
[2] Ratio of actual shoreline to circumference of circle with same area.

TABLE 5-3
PHYSICAL HABITAT QUALITY INDEX RESULTS FOR STUDY RESERVOIRS

Habitat Parameter	**Houston County**	**Livingston**	**Richland Chambers**	**Ray Hubbard**	**Cedar Creek**	**Ray Roberts**	**Bridgeport**	**Benbrook**	**Eagle Mountain**
Percent Total Aquatic Vegetation	4	1	1	3	0	5	1	1	1
Shoreline Developm	2	2	3	2	3	2	3	2	3
Percent Woody Cove	3	2	3	2	1	3	1	2	2
Percent Gravel or La	1	1	1	2	1	1	4	1	2
Score	**10**	**6**	**8**	**9**	**5**	**11**	**9**	**6**	**8**

habitat features to each species were obtained from the Habitat Suitability Index Models developed by the USFWS (1984a and b, 1982a, b, c, d, and e). Measures of percent woody cover and percent gravel or larger were similar the TNRCC (1999) habitat evaluation protocol for streams. The SDR is a measure of the shape of a water body and is an indicator of the potential amount of littoral zone (Nielson and Johnson, 1985). A circular reservoir will have a SDR of 1 and the greater the irregularity of the shoreline, the greater the SDR. To normalize data for scoring, an upper SDR of 20 was selected based upon the approximate maximum shoreline development expected for Texas reservoirs. Woody cover, gravel or larger substrate, and SDR were weighted evenly with scores ranging from 0 to 4.

Aquatic vegetation was weighted slightly heavier (0 to 5) due to its inherent importance in community structure and function (Dibble et al., 1996; Weaver et al., 1996; Allen and Tugend, 2000). The relationship between coverage of aquatic vegetation and community benefits is not linear. Too much coverage may result in problems such as community homogeneity, poor water quality, or poor growth (Allen and Tugend, 2000; Maceina and Shireman, 1982). Too little aquatic vegetation limits littoral cover and reduces recruitment of juvenile fish (Smart and Dick, 1999). Durocher et al. (1984) demonstrated that largemouth bass recruitment and standing crop increased with increasing submerged aquatic vegetation, up to 20% coverage. They suggested that submerged aquatic vegetation would begin to have a negative impact at densities somewhere above 20%. From these studies, there appears to be an ideal range of coverage of aquatic vegetation. We used 20% to 30% coverage as the optimum, where ranking scores decreased on either side of that range.

Results indicate that physical habitat was variable across the study reservoirs. PHQI scores ranged from 5 (Cedar Creek Reservoir) to 11 (Lake Ray Roberts) (Table 5-3). A comparison was made between physical habitat and abundance of black bass, crappie, and catfish. According to the Habitat Suitability Models (USFWS, 1984a and b and 1982a, b, c, d, and e), physical habitat is very important to those species. It was found that black bass abundance tended to increase with increasing habitat quality but was only slightly correlated ($r^2 = 0.21$). The highest CPUE (151) came from Lake Ray Hubbard, which had a PHQI score of 9 while to lowest CPUE (30) came from Lake Livingston, which had a PHQI score of 6. Lake Ray Hubbard probably supports high abundance of largemouth bass due to the presence of aquatic plants, particularly *Hydrilla* (Rafe Brock, personal communication, 2003). Total coverage of aquatic vegetation on this reservoir was 14%, which was relatively high compared to the other study reservoirs. On the other hand, Lake Ray Roberts had the highest coverage of aquatic vegetation (27%), but had a mean CPUE of only 73. The lowest abundance of black bass came from reservoirs (Livingston, Richland-Chambers, and Cedar Creek) with the lowest abundance (0–5%) of aquatic vegetation.

Crappie abundance demonstrated no noticeable relationship with habitat quality ($r^2 = 0.01$). The highest crappie CPUE (25) came from Richland-Chambers Reservoir that had a PHQI score of 8 while the lowest CPUE (2) came from Houston County Lake that had a PHQI of 10. While the data may indicate that crappie abundance relates little to trophic state and physical habitat quality, it is possible that the data do not accurately reflect populations. The TPWD has recognized that crappie sampling with frame nets has been difficult and inconsistent both spatially and temporally. Thus, it is possible that relationships do exist, but are not easily discerned with available data.

Catfish abundance appeared to decrease with increasing habitat quality ($r^2 = 0.23$). The highest CPUE (12) came from Cedar Creek Reservoir that had the lowest PHQI score of 5, while the lowest CPUE (<1) came from Houston County Lake that had a PHQI score of 10. It is very possible that a relationship exists for the study reservoirs between degree of physical habitat and/or water clarity and black bass predation on catfish. While catfish are somewhat dependent on cover for spawning and recruitment, black bass will often predate on small catfishes. Under conditions favorable to black bass feeding habits, such as good water clarity and abundant physical habitat, black bass can predate heavily on catfishes. We found that Houston County Lake had the lowest abundance of catfish, the second highest PHQI score, greatest water clarity, and a relatively abundant black bass population with a substantial proportion of the population of adult size (PSD about 45). On the other hand, Cedar Creek Reservoir had the highest catfish abundance, the poorest PHQI score, the next to lowest water clarity, and a sparse black bass population. As a result, while fertility is probably important to catfish, various community interactions might be important as well.

There is no doubt that defined relationships exist between physical habitat and some fish communities. However, due to the preliminary nature of the PHQI and the many other factors affecting reservoir conditions, it was not expected that the habitat index would explain all of the relationships. Nevertheless, analysis of physical habitat should be an integral part of measuring trophic changes in reservoirs.

5.4 ANGLER USE

All of the study reservoirs are used by anglers for recreational fishing. Some commercial fishing may exist, but is only a small part of the fisheries use and is not considered further. The degree of angler utilization of particular species is variable and depends highly on the quality of those fisheries in each reservoir. The TPWD conducts creel surveys on selected reservoirs to obtain angler-use and harvest data. However, the number of such surveys was very limited which made it impossible to draw conclusions based on angler use.

The TPWD maintained Annual Reports of Tournament Surveys during the mid to late 1990’s. These reports tracked the success and popularity of black bass tournament fishing for reservoirs across the state. Of the study reservoirs, Richland-Chambers, Cedar Creek, Ray Roberts, Ray Hubbard, and Livingston appear to be somewhat important to tournament anglers. Popularity of reservoirs for tournaments is not only a function of the quality of the fisheries, but is also dictated by accommodations, reservoir size, and length and creel limits. Even though a black bass fishery may be popular, if the reservoir is not conducive for tournaments, then it may not rank as a popular tournament location. The finding that the five reservoirs mentioned above were popular for tournament fishing is suggestive of a good fishery, but should not be interpreted to mean that the other study reservoirs were necessarily less desirable.

In summary, the study reservoirs are all used by anglers to a substantial degree. But participation data are not sufficiently uniform to determine quantitative measures of use.

5.5 ADDITIONAL DISCUSSION OF RELATIONSHIPS

From the analysis of available TPWD fishery data it was possible to identify trends and relationships, although mostly weak, between some nutrient variables in the study reservoirs. Other variables, that would seemingly be correlated based on known fisheries and limnological interactions, did not appear to demonstrate any noticeable relationships. When considering the wide variability in reservoir characteristics that exist throughout limnological studies, the study reservoirs were not all that different in terms of morphometry and trophic conditions. Using measures of chlorophyll *a* in the TSI (range = 0 to 100) developed by Carlson (1977), all of the study reservoirs ranked from just less than 50 to just over 60. This suggests that the study reservoirs only account for approximately 10 to 20% of the trophic variability that could be potentially observed. This range also indicates that each reservoir can be loosely characterized as mesotrophic. Their similarities may, in part, explain why only weak relationships between fish communities and trophic state were observed. Ney (1996) points out that TP and chlorophyll *a* are very strong predictors of fish standing crop, with highly correlated, positive relationships existing between increasing phosphorus and chlorophyll *a* and standing crop. However, those data were drawn from reservoirs of significant trophic differences. Our inability to demonstrate similar relationships with a high level of statistical confidence may have simply been a matter of resolution.

Another important consideration is the role of variables that were not fully explored in this study. Numerous biotic, abiotic, and anthropogenic impacts, not directly related to nutrients, probably contributed to fish-communities structure in the study reservoirs. Water level fluctuations can have a real and a perceived effect on populations. Low water levels reduced available habitat during certain years in some of the reservoirs that resulted in reduced spawning and recruitment success. On the other hand, increased water levels observed since 1996 probably improved spawning and recruitment. However, sampling (especially shoreline sampling) during water-level extremes might explain some population variability. When reservoir levels are low, fish tend to change their behavior and distribution to adjust to decreasing littoral habitat, often moving out of reach of shoreline sampling efforts.

As previously discussed, fish community interactions are also important to consider. Predatory species may greatly influence prey abundance as well as abundance of other predatory species. Successful stocking of predatory species increases abundance of that species, and can also reduce abundance and/or change the size-distribution of prey species. This interaction may be continued down the food chain to one degree or another. Carpenter et al. (1985) postulated that a cascading effect might occur as far down as the plankton level due to changes at the top of the food chain. With this in mind, predator harvest by anglers or the stocking of predatory species may not only change community structure by directly changing the predatory population, but perhaps affect other trophic levels to a degree.

Sampling techniques and variability were also considered. Certain species are more easily sampled than others and sampling efficiency can be influenced by any number of factors, such as water clarity, habitat presence, time of year, and fish behavior. The best example of how this may be the problems associated with obtaining data representative of crappie populations that was previously discussed. Another problem faced was the low number of sampling events available in the data analysis. A choice was made to use only samples obtained from randomized sampling that was implemented in about 1996. As the database increases with future sampling events, higher confidence levels should be obtained.

In summary, study results indicate that nutrient concentrations have not adversely impacted the recreational fisheries in the study reservoirs. Data generally indicate that reservoirs with higher nutrient and chlorophyll *a* concentrations support increased abundance of most target species over reservoirs with lower nutrient and chlorophyll *a* concentrations. Previous studies demonstrate that maximum fish standing crop probably occurs at nutrient and chlorophyll *a* levels much higher than those observed in this study (see Section 5.3).

However, these results do not include non-target species, some of which may be sensitive to symptoms of eutrophication. Neither data nor processes are available to aid in determining the role of or ecological importance of non-target species in reservoir environments and community evaluations. Future studies and criteria development should investigate the role of these species and "indicators" in assessing reservoir fish community health.

5.6 POTENTIAL USER CONFLICTS

The technical pursuits of limnologists and fisheries scientists largely overlap, but their focus and objectives have traditionally been somewhat divergent. Limnologists are often involved in development of water quality policies while fisheries biologists are most often associated with recreational fisheries management. As a result, recreational fisheries management has traditionally not played a role in water quality policy development in Texas. In a sense, both represent user groups that are significant stakeholders in reservoir use.

As discussed in Section 4.0, public perception of algal turbidity can be somewhat variable due to regional differences. As such, there are probably different thresholds that trigger concern over eutrophication by different users in different areas. While a threshold has yet to be determined for Texas reservoirs, it is probably safe to assume that it lies well below what is needed for maximum fish production. This, in turn, suggests the potential for differences in user goals.

Ney (1996) cites a number of case studies where the effects of reduced nutrient loading resulted in detrimental impacts to recreational fisheries. There are, however, some obvious trade-offs between reduced eutrophication and improved habitat. These trade-offs may include reducing hypoxia in the hypolimnion and improving water clarity necessary for SAV, an important component of habitat for cover-seeking species. Ney (1996) went on to suggest that a logical first step in optimizing nutrient management in multiple-use reservoirs may be to answer two questions:

(1) how low must the nutrients be to avoid undesirable algal production?; and

(2) how high must the nutrients be to sustain good fishing?

Maceina et al. (1996) addressed this question in a study of black bass and crappie fisheries in Alabama. Results of their study indicated that chlorophyll *a* concentrations >15 ug/L generally resulted in water transparencies less than 120 cm, which was considered less appealing to non-angler users. They found that reduction in chlorophyll *a* concentrations to 10–15 ug/L was not necessarily detrimental to those fisheries. As such, chlorophyll *a* concentrations between 10 ug/L and 15 ug/L might be an appropriate range for satisfying angling and non-angling users in Alabama.

Due to the high degree of angling and non-angling uses of the study reservoirs, variations in use-attainment goals exist. Thresholds for public perception of eutrophication in Texas have not been well defined, but those expectations are somewhat predictable. Within the variability of user perception from region to region or reservoir to reservoir, non-angler users generally share the same desire for clear water. Recreational fisheries and anglers have adapted to existing reservoir conditions. Anglers generally accept that each reservoir is unique in terms of its physical and chemical attributes. As a result, reservoir fisheries can be unique, providing a variety of fishing experiences. Even though differences in fisheries and angler use exist, the TPWD does not have a classification system for reservoir fisheries. Shifts in trophic state, such as those caused by nutrient-reduction efforts, or, conversely, increases in eutrophication, might result in changes in recreational fisheries. Depending on the circumstances, these changes may be to the benefit or detriment of anglers. However, without a bench-mark for recreational fisheries, it will be difficult to answer the question of: how fertile does a reservoir need to be to sustain good fishing? We believe to answer this question, it is important to first classify existing fisheries uses and angler expectations.

6.0 WATER SUPPLY

All of the study reservoirs, and most of the significant reservoirs in the basin, were constructed with water supply as an intended use. In some cases this is limited to irrigation supply, but in most cases the intended use is as a public water supply. The water quality criteria that are now associated with this use include TDS, chlorides and sulfates, along with some drinking water parameters. All of these criteria are attained on study reservoirs. There currently are no criteria for nutrients, but there is a general recognition that at some level nutrients may impact the ability of a reservoir to support the water supply use. This section explores the relation between nutrient levels and the degree to which the water supply use is supported.

Surface waters normally have a range of dissolved and suspended constituents that must be treated or removed before the water can be distributed as potable in a public water supply system. The amount of treatment required can vary substantially. At one extreme, the lakes in New England and upstate New York, that supply water to the City of New York, typically require no treatment except chlorination. The other end of the spectrum might be river water during a high flow event, where the water has a dark brown color and a large amount of organic and inorganic debris. In this case a higher level of treatment may be needed.

The water supply reservoirs in the Trinity basin are intermediate, with the water requiring treatment, but less than is needed for some water supplies. Surface water treatment typically consists of the addition of a coagulant to facilitate the formation of particulate matter, settling and/or filtering to remove the bulk of particulate matter, and then disinfection. There are many variations within this general treatment description, depending on the particulars of the water supply, and the individual design employed.

Water supply reservoirs are dynamic systems, responding to changes in inflows and seasonal changes in the aquatic ecosystem. The aquatic ecosystem includes microscopic plants and animals (ranging in size from the sub-micron level up to several millimeters) the attached and free floating algae and vascular plants, organisms that live in the sediment, and a range of larger animal life. Aquatic ecosystems change constantly maintaining a form of dynamic equilibrium, responding to both external changes (inflows, nutrients, temperature, wind mixing) and internal population dynamics. As different components of the micro and macroscopic system become more or less dominant, there can be changes needed in the type or level of water treatment needed to produce a consistent, high quality product. This is the routine situation faced by water suppliers that rely on surface waters, whatever the level of nutrients.

Parameters that typically change with time in a reservoir include suspended solids content (suspended sediment as well as microscopic plants and animals), dissolved solids content including both organic and inorganic parameters, color (from tannins leached from trees as well as microscopic plants), taste, and odors (from the same suite of variables). Experienced operators of water treatment plants have learned the nuances of their particular water supply and treatment system, and developed means to accommodate changes in the water supply that are appropriate to their system.

While many parameters can affect the treatment required for a raw water supply, the subject of this analysis is nutrients, primarily nitrogen and phosphorus. While there are some nutrient components that directly relate to water suitability (e.g., the nitrate-N limitation of 10 mg/L), these are almost never a concern. The most common mechanism where nutrient levels in the supply have the potential to affect potable quality appears to be through phytoplankton such as a blue-green algae, that may respond to a particular nutrient condition. These organisms can cause taste and odor problems.

6.1 SURVEY OF WATER SUPPLIERS

In a survey of the study reservoir water suppliers, questions were asked as to the treatment system employed and whether there were problems encountered with taste or odor. If such problems were reported, suppliers were asked how it was handled. See Appendix A for a full record of the survey results.

Most of the respondents reported having to deal with taste and odor problems to some degree. The following adaptations or modifications to the routine treatment measures were reported by one or more of the respondents:

- Drawing water from different levels of the lake (requires a multi-level intake structure or alternate intake),
- Use of oxidizing agents such as chlorine, chlorine dioxide, chloramines, ozone, or permanganate on the raw water prior to the routine treatment steps,
- Use of additional coagulant,
- Use of copper sulfate for algal control,
- Use of activated carbon (granular or powdered).

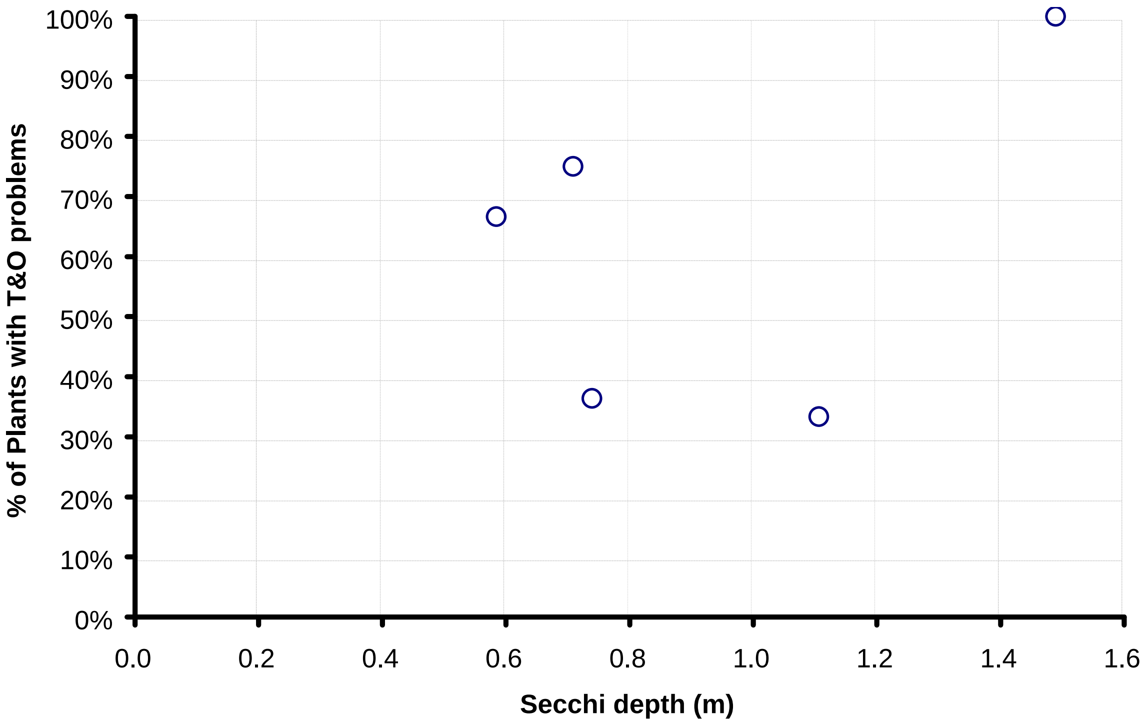
In addition to these different methods, suppliers were asked as to the additional cost of treatment incurred to address taste and odor problems.

6.2 ANALYSIS OF SURVEY DATA

The first step in the analysis of the data was to determine the relationships between ambient levels of nutrients and chlorophyll *a* and the incidence of reports of taste and odor problems. This was complicated because water intakes and treatment units in the metroplex are typically larger and drew water from several reservoirs, typically in series. The number of discreet suppliers in each reservoir and the number that reported problems are shown in Table 6-1.

In examining the relation between reported taste and odor problems and the levels of nutrients and chlorophyll *a*, there was no obvious relationship. Figure 6-1 shows plots of the frequency of reported problems in the study reservoirs along with the average levels of nutrient parameters. It can be seen that little direct relationship between nutrients and problems is apparent.

FIGURE 6-1
RELATIONSHIP BETWEEN PERCENTAGE OF PLANTS WITH TASTE & ODOR PROBLEMS AND WATER QUALITY PARAMETERS



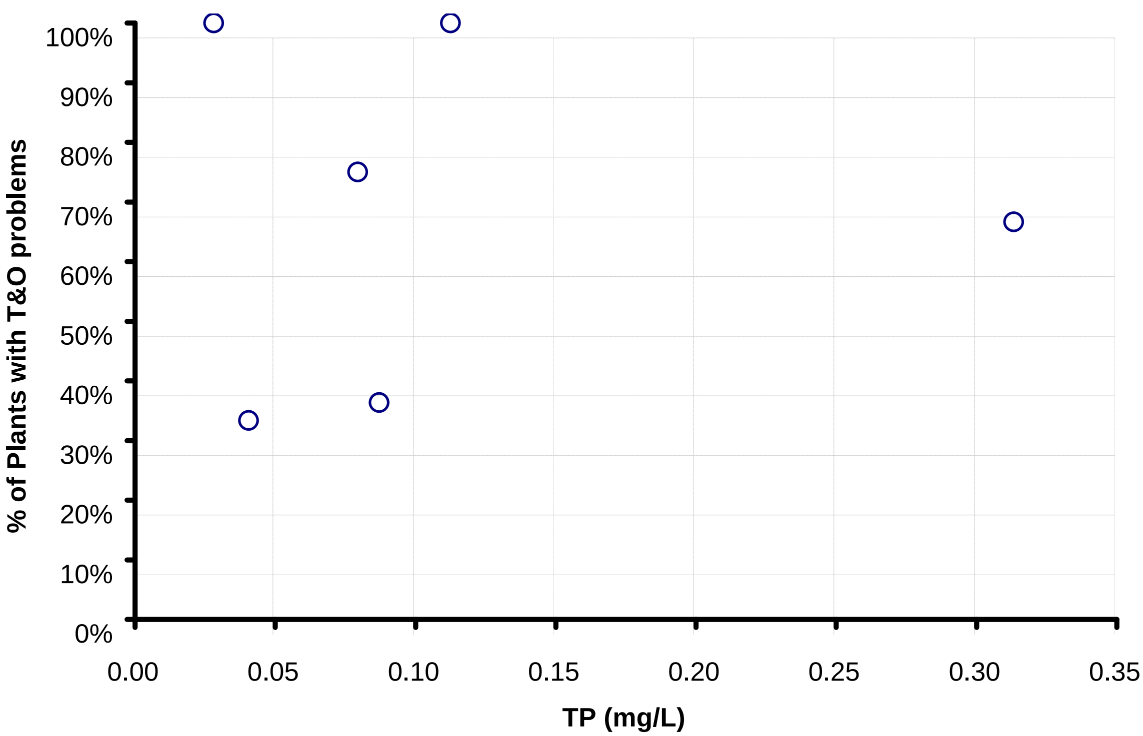
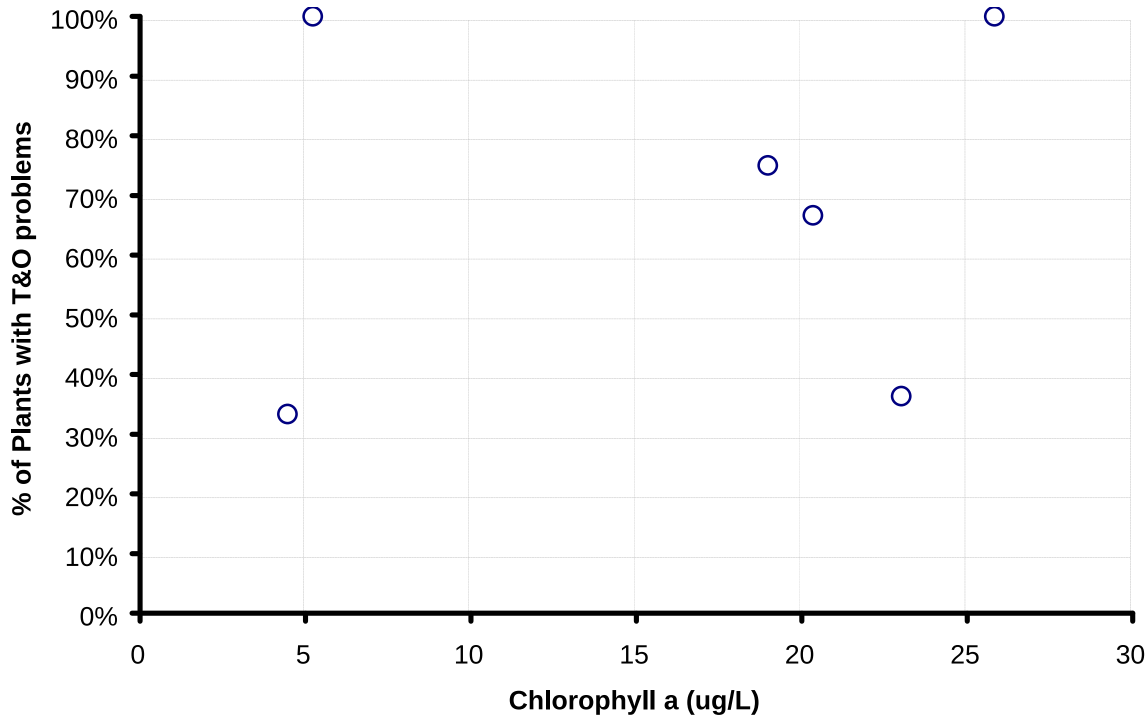


FIGURE 6-1 (CONCLUDED)
RELATIONSHIP BETWEEN PERCENTAGE OF PLANTS WITH TASTE & ODOR PROBLEMS AND WATER QUALITY PARAMETERS



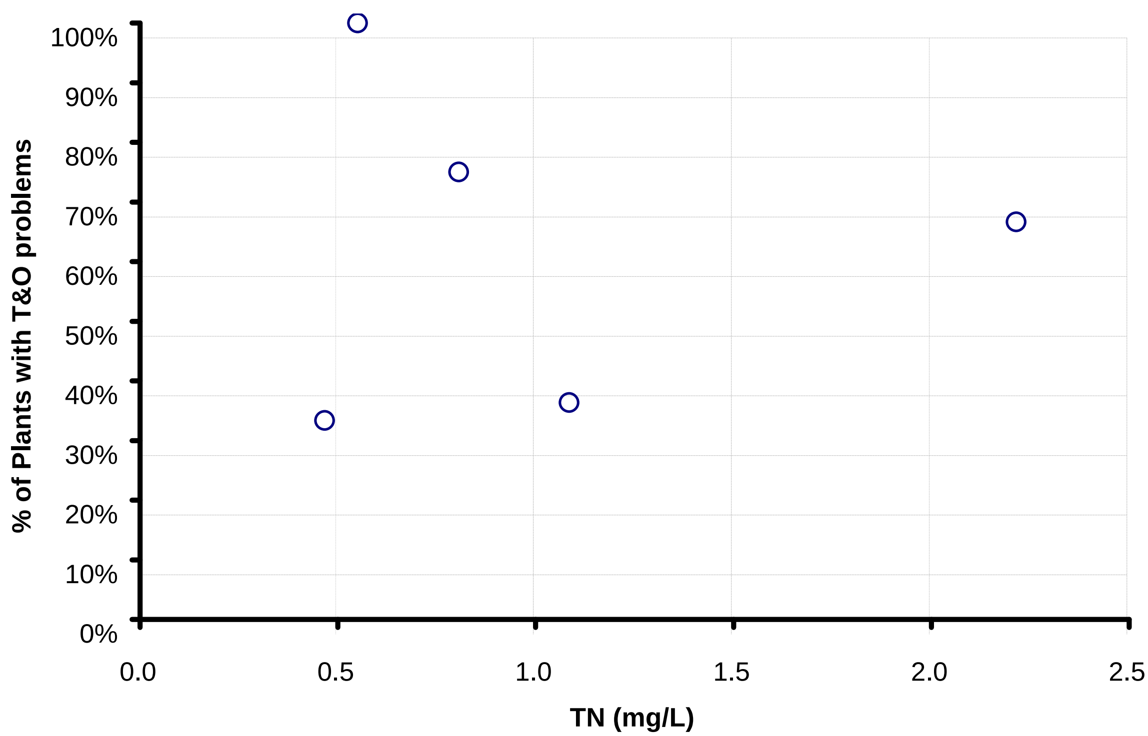


Table 6-1
Number of Water Suppliers with
Taste and Odor Problems

Reservoir	Number of Suppliers	Number with Taste & Odor Problems
Benbrook	0	N/A
Bridgeport	6	2
Cedar Creek	11	4
Eagle Mountain	4	3
Houston County	1	1
Livingston	6	4
Ray Hubbard	1	1
Ray Roberts	0	NA
Richland Chambers	0	NA

[1] Do not include suppliers with multiple sources .

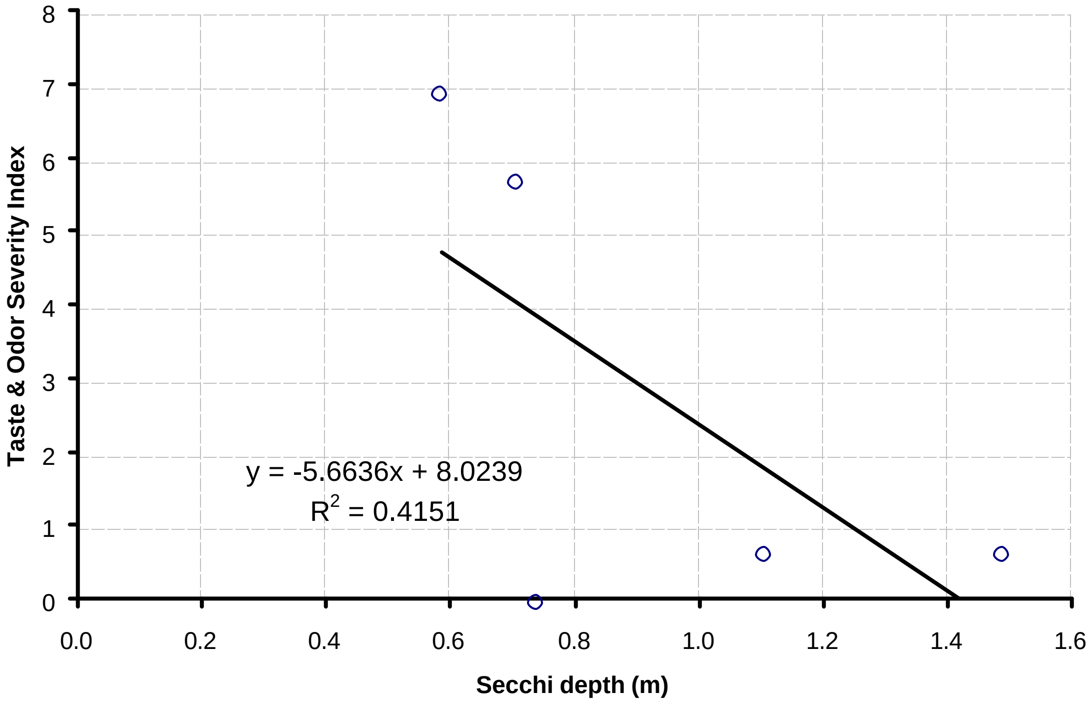
In an attempt to further investigate the relationship, considerable effort was invested in developing an index of taste and odor problems from the available data. This index was defined as a product of the duration a problem was reported to exist, expressed as a fraction of a year, times the amount of money spent to address the problem ($/volume of water treated). The index was calculated for each plant and an average index was obtained for each reservoir, excluding those plants that take water from multiple sources. As shown in Figure 6-2, this index gave some indication of a relationship with nutrients, chlorophyll *a* and Secchi depth.

Although the above index appears to give somewhat reasonable results, it is not a satisfactory measure of the degree of the taste and odor problem. The main difficulty is that there are a number of technologies for treating taste and odor problem with different cost structures. Therefore, the taste and odor treatment costs of two plants with different technologies do not provide a direct comparison of the severity of the problem each plant is facing. One particular example is the Tolosa Plant that takes water from Cedar Creek Reservoir. It uses an unconventional package plant. The beads in the clarifier apparently helps to control taste and odor and there is no additional cost to address the problem. Another issue is how good the water at the treatment plant represents the water in the reservoir. For example, as discussed in the next section, some of the plants that use Lake Livingston as a source are diverting water from locations remote from the lake.

6.3 CITY OF HOUSTON DATA

The City of Houston is a major user of water from Lake Livingston, although it not withdrawn directly. Before the water is received at Houston treatment plants it first is released from Lake Livingston and is diverted from the Trinity River near Dayton about 50 miles south of the dam. Some of the water in the river at that point is from the watershed below Lake Livingston. The diverted water is conveyed through a

FIGURE 6-2
RELATIONSHIP BETWEEN TASTE & ODOR SEVERITY INDEX AND WATER QUALITY PARAMETERS



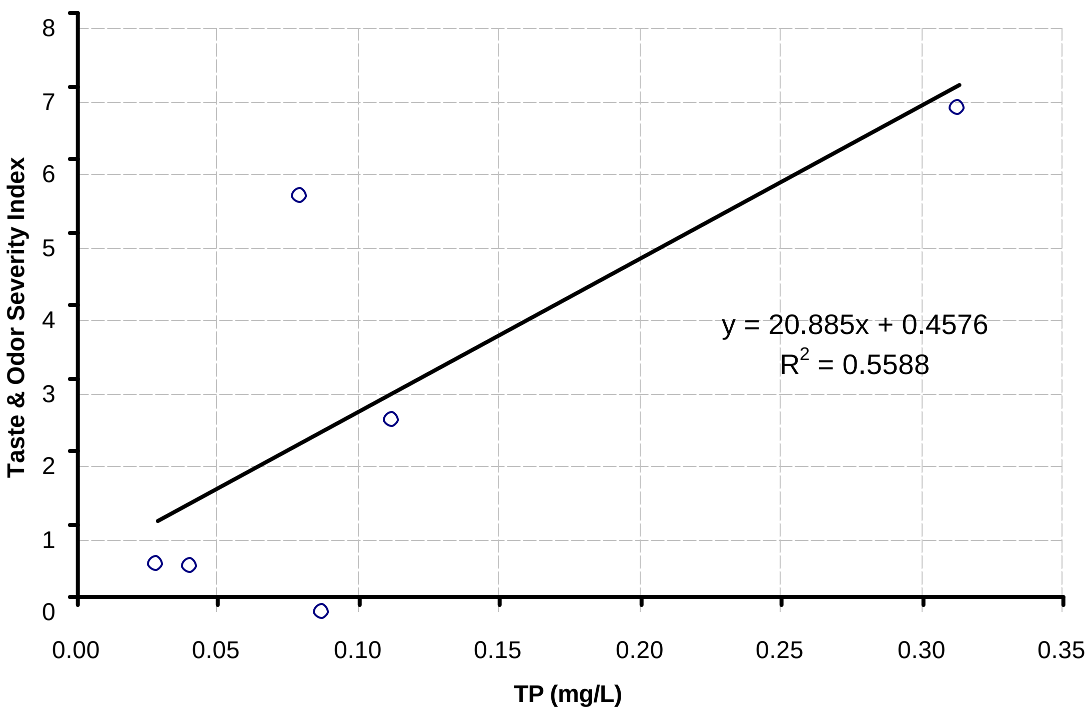
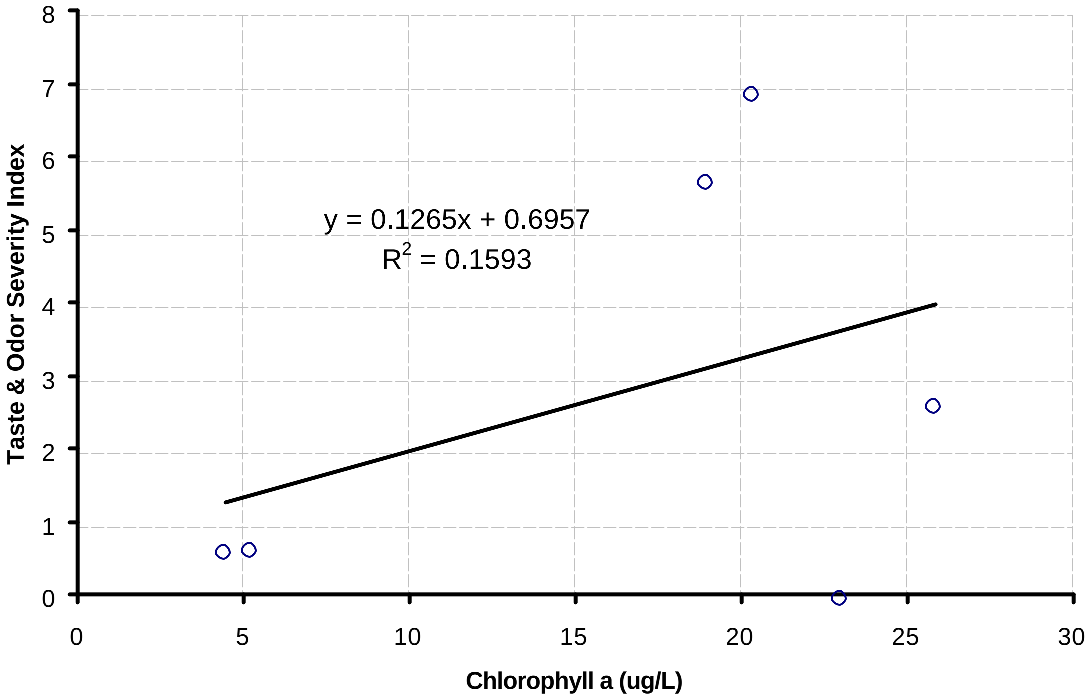
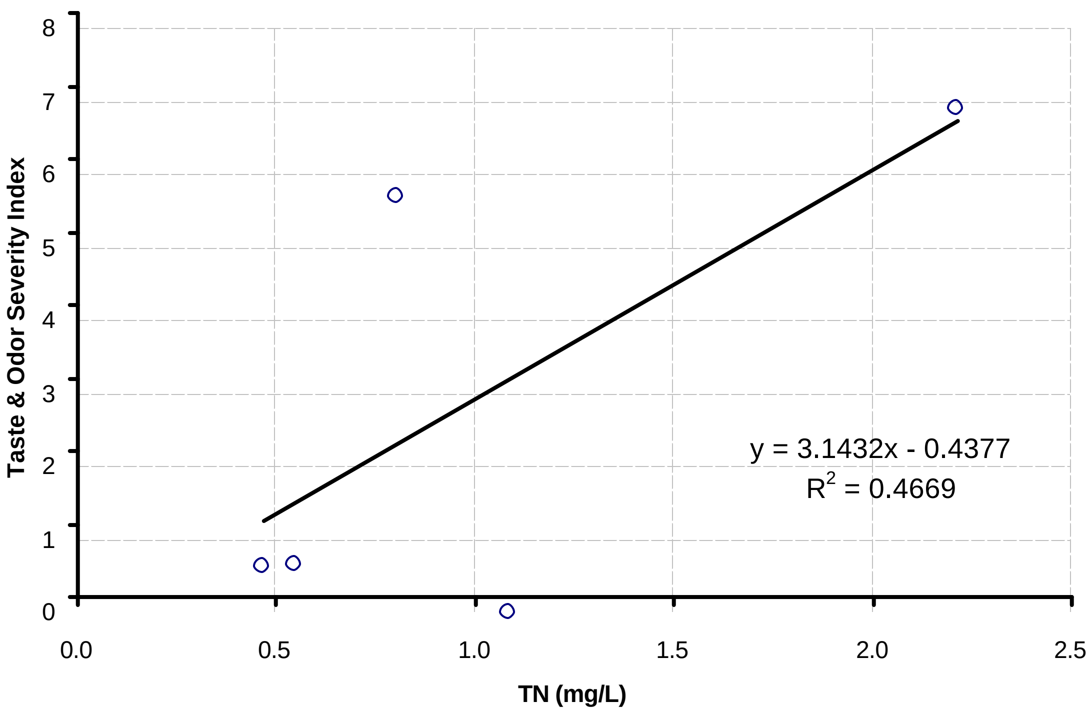


FIGURE 6-2 (CONCLUDED)
RELATIONSHIP BETWEEN TASTE & ODOR SEVERITY INDEX AND WATER QUALITY PARAMETERS





canal to the Lynchburg Reservoir in east Houston, a distance of about 60 miles, and then pumped via pipelines more than 10 miles long to either of two plants, the East Water Purification Plant or the Southeast Water Treatment Plant. A further modification is that the water is typically chlorinated before being pumped from the Lynchburg Reservoir to the plants. Because the distance between Lake Livingston and the Houston water treatment plants is so large, and the opportunities for change so great, it is arguable whether it is actually Lake Livingston water that is being treated.

At the same time, the City of Houston provides a unique study resource in that it is one of the few water treatment operators that maintains records of nutrient concentration, algae counts, and customer reports of problems. With the recognition of transport differences, these data provide a quantitative measure of the problems that may be useful in assessing the relationship between use support and nutrient levels. The data discussed below were provided by Jim Greenlee of the City of Houston.

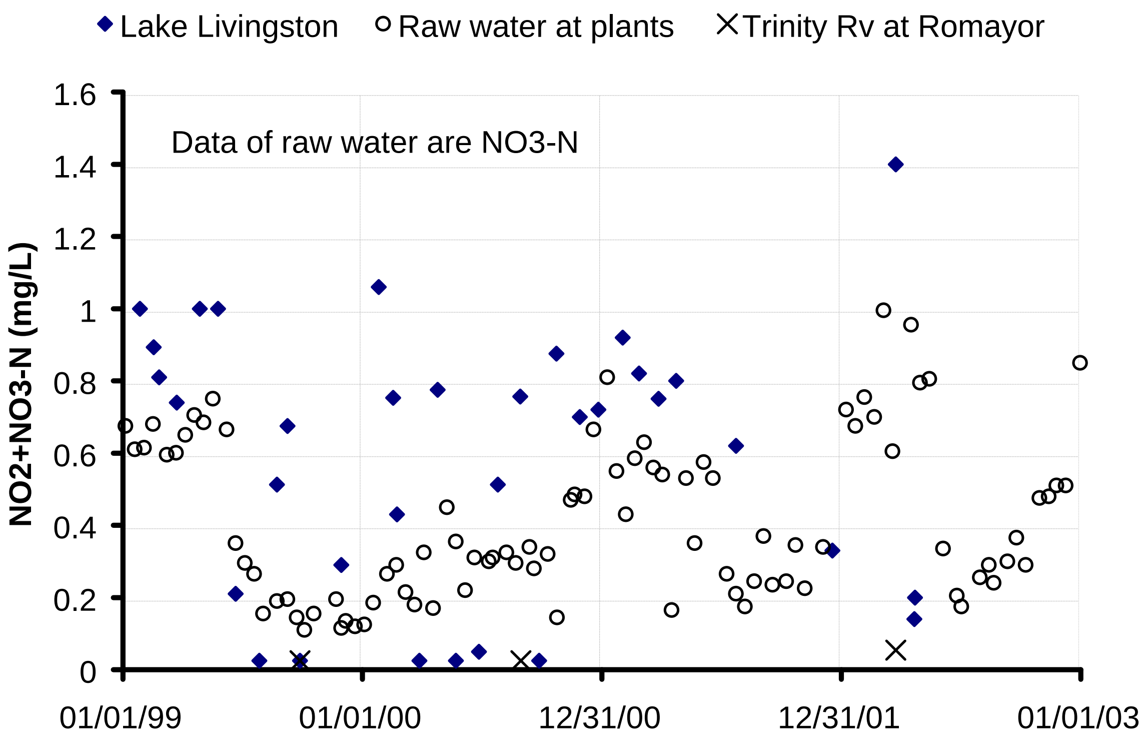
The data provided by the City of Houston were collected from East Water Purification Plant I and Plant III. The plant operator noted that there was very little difference in the raw water at the two plants. Therefore, data of the two plants were averaged for the following analysis. This water is mainly from the Trinity system but also includes 10 to 20% of the water from Lake Houston.

The first step in the analysis of the Houston data was to compare the nutrient observations over time with those obtained by the TRA on Lake Livingston and also those observations made in the river at Romayor. Note that the Houston data followed conventional laboratory methods but was not collected and analyzed under a CRP Quality Assurance Project Plan (QAPP) like that followed by the TRA data. Figure 6-3 shows the PO_4-P and NO_2+NO_3-N concentrations for the various data sources over time. River data at Romayor are few but appear to be consistent with the lake data. With the PO_4-P data it appears that the Lake Livingston data are substantially lower than the raw water at the plants. With the NO_2+NO_3-N, there does not seem to be significant difference between the Lake Livingston data and the raw water data.

The next comparison was between the algae counts measured and the PO_4-P levels at the plants. The algae counts are reported to be single units of algae, and include some clumped cells and some cell fragments, but nevertheless represent a good relative measure of algae concentration. The algae counts were provided as monthly data while the dates of sampling were provided for the PO_4-P data. Monthly averages of the PO_4-P data are compared with algae counts in Figure 6-4. There does not appear to be a correlation between the PO_4-P level and the algae counts.

Monthly numbers of complaints reported to the City of Houston are tabulated in Table 6-2. These include reports of taste, dirt (suspended particulates), rusty appearance, color and odor. These are reports for the entire water system, including the roughly 30% of the system served by groundwater. Also, 10 to 20% of the water supply is from Lake Houston, which has somewhat higher nutrient levels than Lake Livingston. These differences mean that the record of water problem reports is not uniquely associated with Lake Livingston water, but there is nevertheless useful information.

FIGURE 6-3
COMPARISON OF NUTRIENT LEVELS FOR VARIOUS DATA SOURCES



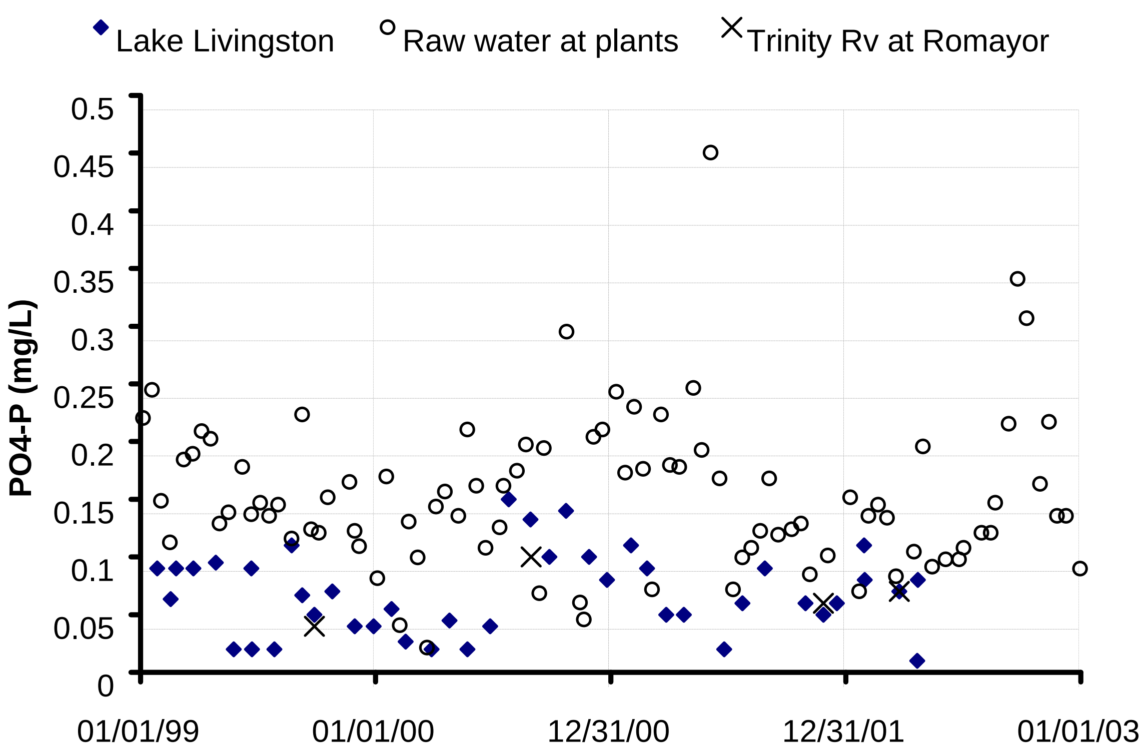


FIGURE 6-4
RELATIONSHIP BETWEEN ALGAE COUNTS AND PHOSPHATE IN CITY OF HOUSTON RAW WATER

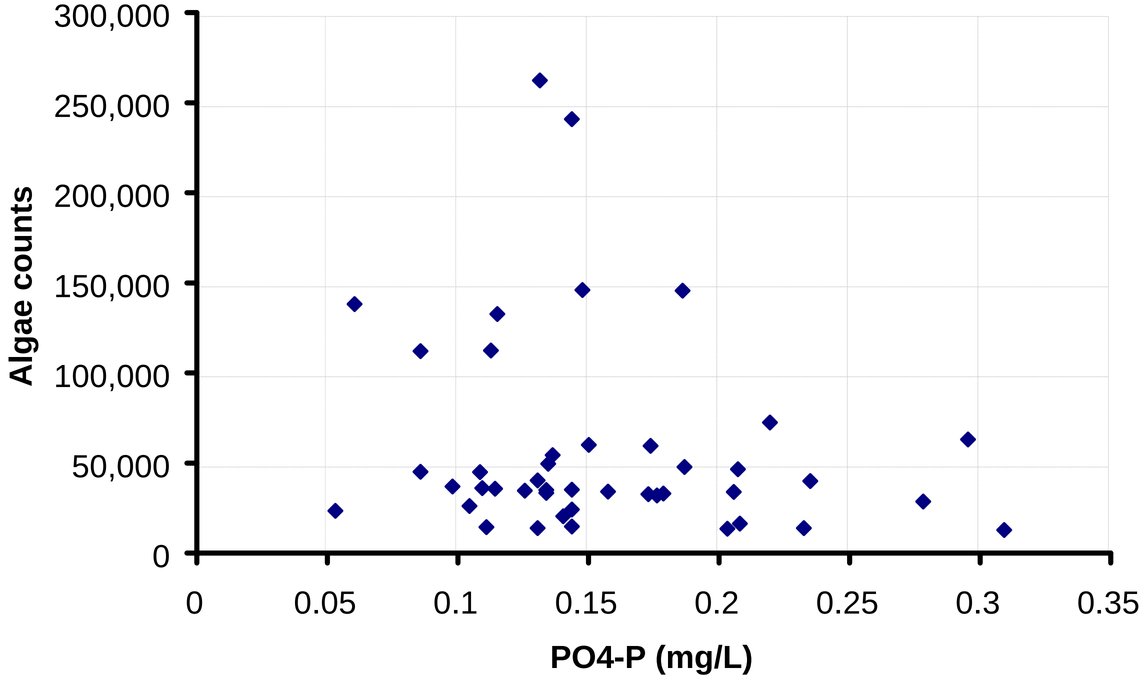


TABLE 6-2
NUMBER OF COMPLAINTS REPORTED TO THE CITY OF HOUSTON

Date	Reason for complaint					TOTAL
	Bad taste	Dirty water	Rusty water	Water has color	Water odor	
Sep-00	3	9	16	32	49	109
Oct-00	4	13	14	75	106	212
Nov-00	11	10	19	56	49	145
Dec-00	9	12	12	70	34	137
Total	27	44	61	233	238	603
Jan-01	15	23	31	101	42	212
Feb-01	11	25	17	102	48	203
Mar-01	16	20	24	102	57	219
Apr-01	7	13	37	115	52	224
May-01	13	15	20	70	45	163
Jun-01	31	23	9	89	64	216
Jul-01	49	14	26	65	111	265
Aug-01	69	25	14	76	111	295
Sep-01	16	15	11	57	77	176
Oct-01	20	18	22	67	78	205
Nov-01	15	12	16	58	46	147
Dec-01	20	9	19	52	46	146
TOTAL	282	212	246	954	777	2471
Jan-02	19	18	19	101	52	209
Feb-02	16	14	16	102	27	175
Mar-02	7	17	39	110	32	205
Apr-02	12	10	14	103	37	176
May-02	33	10	13	89	73	218
Jun-02	28	21	30	88	63	230
Jul-02	20	9	23	69	56	177
Aug-02	21	13	27	86	70	217
Sep-02	24	24	34	107	83	272
Oct-02	17	15	27	86	55	200
Nov-02	11	25	18	58	34	146
Dec-02	17	8	27	102	49	203
TOTAL	225	184	287	1101	631	2428
GRAND TOTAL	534	440	594	2288	1646	5502

The first point to note is that the number of complaints of each type appears to be relatively constant month to month. In contrast to the constant complaint rate, the concentrations of nutrients and algae in the plant intakes is documented to vary substantially over the period of record. This suggests that the relationship between nutrients and complaints with treated water may not be strong, or it is complex.

For example, reports of bad taste and odor complaints are compared with algae counts in Figure 6-5. Again, there does not appear to be a correlation between the number of complaints and the algae counts. The lack of correlation is not too surprising. Some of these complaints were probably due to factors other than taste and odor caused by algae.

6.4 DATA ON TASTE AND ODOR COMPOUNDS

The most commonly reported taste and odor compounds are Geosmin and 2-methylisoborneol (MIB). These compounds are naturally occurring and produced by some species of blue-green algae as metabolic by-products. They cause earthy-musty taste and odor in water. Sensitive individuals can detect Geosmin and MIB between five and ten parts per trillion, or nanogram per liter (ng/L). These compounds do not pose a health hazard, but are a quality concern.

TRA and CRP partners have been collecting Geosmin and MIB data since the late 1980s. Table 6-3 shows a summary of these data. The data show considerable variation between stations on the same water body, with a significant number of observations below detection limits and some maximum values above 100 ng/L. At most of the stations, about 30–50% of the Geosmin data and about 10–20% of the MIB data are above 5 ng/L, an approximate threshold for detection by sensitive individuals. It appears that the potential for taste and odor problems in the raw water is not uncommon at these locations.

The data in Table 6-3 are arranged with the reservoirs with the highest concentrations at the top of the table and lower concentration reservoirs at the bottom. Note that the stations at the bottom of the table are stream rather than reservoir stations. There is some correlation between average chlorophyll *a* data and average Geosmin and MIB data, but it is not a strong relationship.

6.5 ANALYSIS AND DISCUSSION

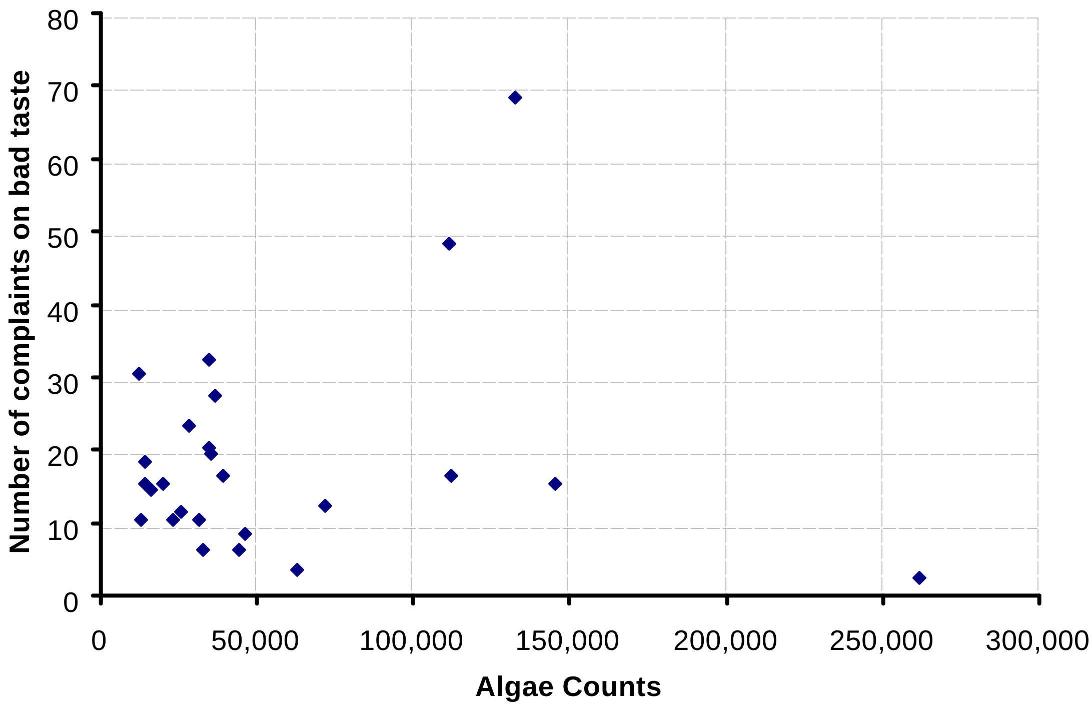
This investigation of the relations between water supply use and the levels of nutrients confirms two fundamental points. One is that while there is a great deal of variability, there is some relation between higher nutrient and chlorophyll levels and the requirements for water treatment to produce a quality product. The other fundamental point is that in almost all cases the water treatment system is capable of dealing with the variation experienced in the study reservoirs.

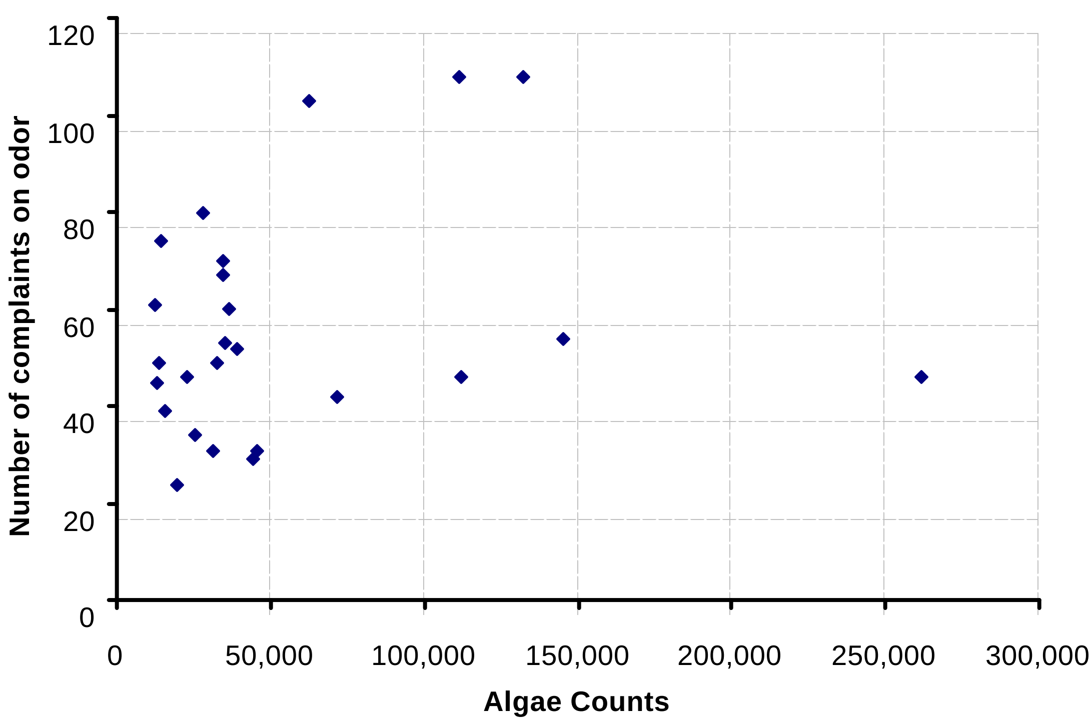
TABLE 6-3
SUMMARY OF GEOSMIN AND 2-METHYLISOBORNEOL DATA

Station ID	Location	Data period		Geosmin (ng/L)							2-Methylisoborneol (ng/L)						
		start	End	Num of data	% nondetect	% > 5	Mean	Stdev	Max	Min	Num of data	% nondetect	% > 5	Mean	Stdev	Max	Min
10998	L RAY HUBBARD NR DALLAS WATER INTAKE	05/13/92	10/02/02	68	29%	49%	12.5	19.5	109.0	0	67	48%	22%	5.8	15.1	119.7	0
17829	LAKE RAY HUBBARD AT MIDLAKE	04/14/92	10/02/02	70	33%	53%	12.4	18.8	121.9	0.015	70	49%	24%	5.2	8.7	48.9	0
16829	LAKE RAY HUBBARD AT SH66	05/13/92	10/02/02	66	26%	48%	12.1	36.9	299.5	0.015	67	57%	12%	2.5	2.4	11.3	0
16809	LAKE RAY HUBBARD AT IH30	05/13/92	10/02/02	67	28%	57%	11.1	18.4	134.6	0.015	67	52%	25%	4.2	5.3	23.1	0.02
10437	LAKE TAWAKONI AT SH 276	05/13/92	10/03/02	71	28%	52%	11.6	17.0	107.7	0.6	71	52%	15%	3.5	4.6	26.6	0.1
10434	LAKE TAWAKONI NEAR DAM	05/13/92	10/03/02	70	34%	49%	11.6	18.6	114.9	0.8	70	43%	20%	6.9	19.0	148.9	0
17835	LAKE TAWAKONI AT THE INTAKE	05/13/92	10/03/02	71	28%	62%	10.7	16.0	105.6	0.7	71	42%	24%	3.9	4.2	24.6	0.02
17836	LAKE TAWAKONI SABINE RIVER AR	05/13/92	10/03/02	69	32%	52%	9.3	9.8	50.7	0.95	70	54%	11%	2.5	2.2	10.3	0
16824	RAY ROBERTS LAKE AT CR3002	05/11/88	10/30/02	96	48%	27%	9.5	22.0	176.6	0	96	60%	15%	3.7	6.2	42.0	0
17834	RAY ROBERTS LAKE AT DWU INTAK	05/11/88	10/30/02	100	48%	26%	7.2	12.6	73.1	0	100	56%	15%	4.8	8.8	68.0	0.02
11076	L RAY ROBERTS ISLE DU BOIS AR	05/11/88	10/30/02	98	41%	33%	7.2	9.7	50.6	0	98	58%	22%	4.9	7.5	49.4	0
13875	GRAPEVINE LAKE SITE BC	04/13/92	10/10/02	72	43%	29%	6.5	15.8	117.9	0.015	72	49%	24%	4.2	5.2	23.4	0
17828	GRAPEVINE LAKE AT MARINA	06/06/88	10/10/02	93	54%	27%	5.2	6.9	37.1	0.015	93	58%	15%	4.1	6.2	39.4	0
17827	GRAPEVINE LAKE AT DWU INTAKE	05/10/88	10/10/02	96	57%	25%	5.1	9.8	86.0	0	96	58%	15%	3.8	5.2	24.8	0
11027	LEWISVILLE LK HICKORY CK IH35	05/10/88	10/10/02	96	46%	30%	6.1	9.4	53.0	0	96	61%	18%	4.4	8.3	68.0	0.02
11026	LEWISVILLE LAKE, ELM FORK ARM	05/10/88	10/10/02	98	54%	21%	6.1	14.5	108.0	0	97	63%	11%	3.3	5.5	47.6	0
17830	LEWISVILLE LK AT LITTLE ELM C	05/10/88	10/10/02	96	51%	20%	5.5	8.5	47.0	0.015	95	64%	9%	2.8	2.8	15.6	0
15685	LAVON LAKE SITE AC	04/23/97	04/17/01	18	56%	33%	5.7	6.9	24.9	0.95	18	83%	17%	5.0	9.0	36.3	0.7
16438	ELM FORK AT DWU INTAKE	05/11/93	10/01/02	63	40%	21%	4.8	6.7	41.0	0.015	63	48%	24%	4.0	4.1	17.2	0
11031	ELM FORK TRINITY R. AT FM 207	04/19/01	04/19/01	1	100%	0%	2.0		2.0	2	1	100%	0%	2.1		2.1	2.1
16437	ELM FORK BELOW LAKE LEWISVILL	05/10/00	05/10/00	1	100%	0%	1.5		1.5	1.45	1	100%	0%	0.7		0.7	0.7
17849	SKI LAKE NEAR INTAKE	05/12/93	10/01/02	60	37%	17%	3.1	2.5	13.0	0.015	61	46%	26%	5.0	7.5	40.1	0
14485	DENTON CREEK AT US 377	date missing		1	100%	0%	1.4		1.4	1.4	1	100%	0%	1.6		1.6	1.55

Note:
Nondetects have been replaced with half the reporting limits for calculating the statistics.

FIGURE 6-5
RELATIONSHIP BETWEEN NUMBER OF COMPLAINTS AND ALGAE COUNTS
IN CITY OF HOUSTON RAW WATER





The data reviewed in the Trinity River basin does not indicate a chlorophyll *a* limit beyond which water treatment is ineffective and the water supply use is not supported. On the other hand, the marginally higher cost of water treatment with higher chlorophyll *a* levels may be a suitable justification for setting a chlorophyll a limit or criterion. The topic of criteria setting is addressed in more detail in the next section.

7.0 ANALYSIS OF NUTRIENT-USE RELATIONS

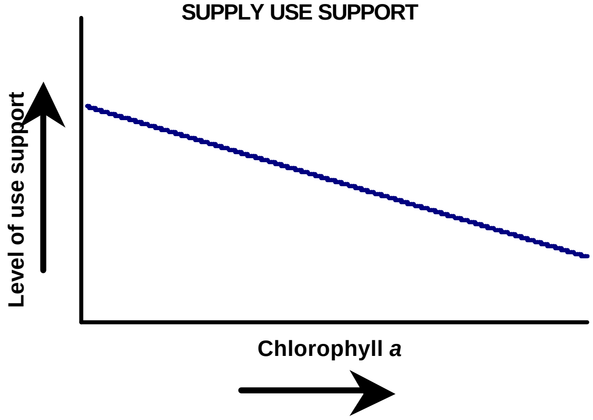
The previous sections have reviewed the various uses and the relationships that exist with chlorophyll *a* and nutrients in the study reservoirs. The relationships are complex, but in general, all of the study reservoirs support water supply, aquatic life propagation, and recreational uses, as evidenced by high levels of public activity. However, this statement must be qualified. If the basis for judging use support is the statewide 85th percentile screening levels, most of the study reservoirs have monitoring stations with higher values. Frequently, these stations are in coves or arms of the reservoirs that are substantially different from the main body and may need to be analyzed independently. This section summarizes the major findings and attempts to integrate the results in a way that may be useful for development of numerical criteria.

A key point in the question of criteria development is: Should the criteria be for specific nutrients or for response variables, such as chlorophyll *a* or water clarity? As previously discussed, the relationships between nutrients, nutrient-response parameters and various reservoir uses are complex. Identifying discernable patterns or relationships is difficult in some cases. Existing water quality monitoring efforts for the study reservoirs are good, and data on nutrient concentrations, chlorophyll *a* and water clarity are abundant, providing a good basis for analysis. In studies of reservoirs that are free of non-algal turbidity or significant trophic interactions, the relationship between nutrients and algal growth is well established and the link between nutrients and use impairment may be straightforward. As for the study reservoirs, as well as many east Texas reservoirs, ambient nutrient concentrations tend to be a poor measure of use impairment. Suspended sediments and tannic staining are common in this region and often prevent excessive plant growth through shading, which can result in relatively high nutrient concentrations without the undesirable effects of high algae concentrations. Similarly, due to the role non-algal turbidity plays in these reservoirs, water clarity may not be a good indicator of use support. Chlorophyll *a* is probably the best indicator of use support since it is a direct measure of algae concentration, which is the most prominent response variable associated with nutrients and use impairment. For this study, chlorophyll *a* is selected as the primary parameter for determining use support and the leading candidate for numerical criteria development.

7.1 WATER SUPPLY

Providing a reliable water supply was the primary reason these reservoirs were constructed. All of the study reservoirs are heavily used for public water supply (both directly and indirectly) and provide an important service to residents of the basin. The experience explored in this study indicates that reservoirs with a higher concentration of chlorophyll *a* supply waters that require a somewhat higher level or cost of water treatment, and possibly a greater number of user complaints regarding taste or odor. This basic relation is illustrated conceptually in Figure 7-1. The theoretical level of use support is shown to decline as the concentration of chlorophyll *a* increases, simply because more treatment may be required. However, the study data on this point are by no means definitive. Another key point is that for the study

FIGURE 7-1
THEORETICAL RELATION BETWEEN
CHLOROPHYLL *a* AND LEVEL OF WATER
SUPPLY USE SUPPORT



reservoirs the differences in water treatment requirements appear to be well within the ability of the water suppliers to accommodate with process adjustments. It is not a question of whether the use is "supported" or "not supported," but rather a cost differential that may or may not be significant in particular situations.

Questions of cost differentials must include aspects such as efficiency and equity as well as ability to pay. In some cases it may be less costly to treat drinking water to a higher level than it would be to achieve the same end by removing nutrients from a reservoir. The questions of who benefits and who pays will always be integral to such decisions.

7.2 AQUATIC LIFE

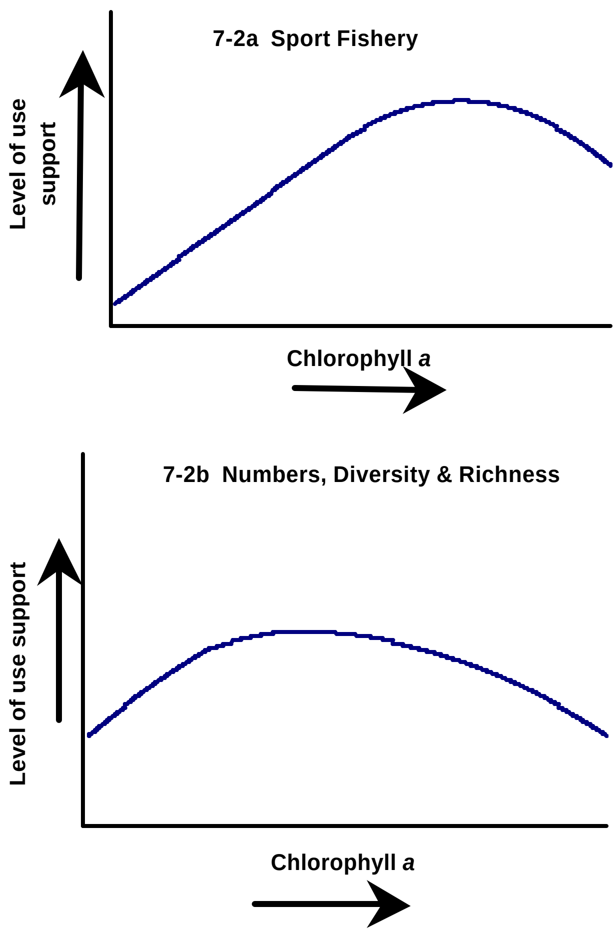
All of the study reservoirs provide habitat and support healthy aquatic ecosystems, with no indication of eutrophication-related problems. The characteristics of the aquatic ecosystems are different as a result of many factors including size, physical habitat, water quality conditions, and fisheries management measures. The reservoirs have different concentrations of chlorophyll *a*, and these differences can affect the biota and favor one species or functional group of species over another. However, this same statement can be made of a wide range of physical differences between reservoirs.

The approach of analyzing the relationships by applying measures of aquatic community integrity is underdeveloped at this time for reservoirs. Because reservoirs can be very different in and among themselves and they do not serve the same function as natural aquatic habitats, existing assessment protocols would hardly apply. Data are abundant for species important to recreational fishing and there will likely be a wealth of similar data in years to come. This will probably provide the grounds for assessments based on achieving angling uses and less on the role of reservoirs as "natural" communities. The use of community structure measures is quite plausible, but this approach will need to carefully consider existing data sources and future biological collection techniques.

In general, reservoirs that exhibit poor water quality, shallow hypoxic zones, and fish kills as a result of eutrophication are not likely to be favored by anglers. However, in mesotrophic reservoirs, reducing nutrients may act to the detriment of fisheries resources. Reservoirs that have low nutrient concentrations and are exceptionally clear, which are goals common to non-angling users, do not support a high degree of fish productivity. It is clear that the recreational fisheries use requires higher chlorophyll *a* concentrations than might be desired by non-angler users. This potentially sets the stage for conflicts among user groups in relation to reservoir management objectives.

While not evidenced in the study reservoirs, there is no doubt that very high levels of chlorophyll *a* can produce undesirable effects such as an expanded area of hypoxic conditions and limited species diversity. Conversely, very low chlorophyll *a* levels can have negative effects on population levels and also cause shifts in species composition. In the mesotrophic conditions exhibited by the study reservoirs, there does not appear to be an indication of significant adverse effects in either direction. However, the possibility of adverse effects needs to be recognized because the details of community structure in these systems have yet to be studied.

FIGURE 7-2
THEORETICAL RELATION BETWEEN CHLOROPHYLL *a* AND LEVEL OF AQUATIC LIFE USE SUPPORT



For the most economically important dimension of aquatic life, the fishery use data indicate that in the range observed in this study, higher chlorophyll *a* levels provide a stronger recreational fishery. This is illustrated in Figure 7-2a where higher concentrations of chlorophyll *a* support a higher level of use support for important recreational species. Clearly the upward slope shown on the illustration is not without limit. While not evident in the study reservoirs, there is no doubt that very high levels of chlorophyll *a* can produce undesirable effects previously mentioned. This effect is illustrated in Figure 7-2a by a decrease in fishery use at higher levels of chlorophyll *a*.

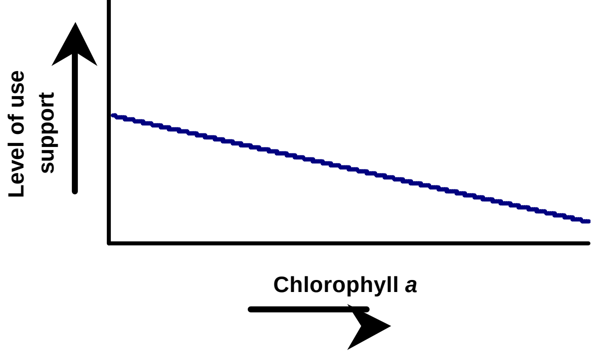
While we could locate no studies of reservoirs specific to this topic, biological experience suggests that species diversity or richness would probably peak at an average chlorophyll *a* level less than what would be expected for maximum recreational fishery production. Species that have sensitive life stages or narrow habitat requirements might disappear with higher chlorophyll *a* levels. Very low chlorophyll *a* levels can have negative effects on recreationally important species, and also impact species diversity and richness. The theoretical relationship between average chlorophyll *a* level and species diversity and richness is illustrated with a line on Figure 7-2b.

7.3 RECREATION

All of the study reservoirs are widely used by the public for various forms of recreation. For this study, the major recreational activity, fishing, was considered with aquatic life. The recreation use considered here is focused on water sports and aesthetic appreciation. While standards exist for the protection of human health from pathogens while engaged in contact recreation (swimming or related activities where water ingestion is anticipated), the idea of use impairment based on public perception of water quality has not been addressed in Texas. Most who live near reservoirs or who use reservoirs for recreation share a common desire for clean water, free of nuisance plant growth or odor problems. Because public recreation and property ownership have significant economic, social, and political ramifications, it is probably important to capture those perceptions in criteria development.

A limitation of the study is that data on recreational uses are not sufficient for a quantitative investigation. It is reasonable to expect that most of the non-fishing recreational users would support the concept of crystal clear water. However, that situation does not exist in the Trinity River basin because of natural color and sediment-induced turbidity. Literature suggests that those who use the reservoirs for swimming are probably going to be the user group most sensitive to the symptoms of eutrophication or higher chlorophyll *a* levels. However, their level of sensitivity is likely to differ between regions or even between reservoirs, depending on the types of conditions to which they are accustomed. It is also evident that the types and extent of uses are strongly driven by reservoirs' physical nature and proximity to metropolitan areas. Thus, users are likely to give little weight to water clarity relative to convenience. This, in turn, suggests that use may be more of a function of supply and demand rather than the actual quality of the resource. As the demand for a limited resource continues to grow, the tolerance for less water clarity will likely grow as well.

FIGURE 7-3
THEORETICAL RELATION BETWEEN CHLOROPHYLL *a* AND LEVEL OF USE SUPPORT FOR SWIMMING & AESTHETIC APPRECIATION



While quantitative data are not available, it is clear that there is no single value for chlorophyll *a* that defines the boundary between use support and non-support. Literature and common sense suggest that as the level of chlorophyll *a* increases, the degree of water sport and aesthetic appreciation use support will decrease. This is conceptually illustrated in Figure 7-3. However, the theoretical nature of this relation needs to be appreciated and the practical considerations of proximity and choice need to be recognized. The survey data being collected by members of the TWCA (2003) in the next two years will provide important information to aid in understanding the relations.

7.4 ANALYSIS AND INTEGRATION

From the above there is no clear limiting or threshold value for chlorophyll *a* levels to support uses and there is a difference in direction of effects of chlorophyll *a* with the uses considered. Furthermore, the mix or level of activity for the various uses can be expected to be different with each reservoir.

At this time the data would suggest that the existing levels of chlorophyll *a* are "acceptable" but not necessarily optimal to best satisfy the competing uses. For each reservoir it is the level to which the existing uses have adapted, rather than the best level to support the uses. To achieve what might be viewed as optimal for existing and reasonable potential uses will require some mechanism for the competing uses to be represented and balanced in a rational and structured fashion.

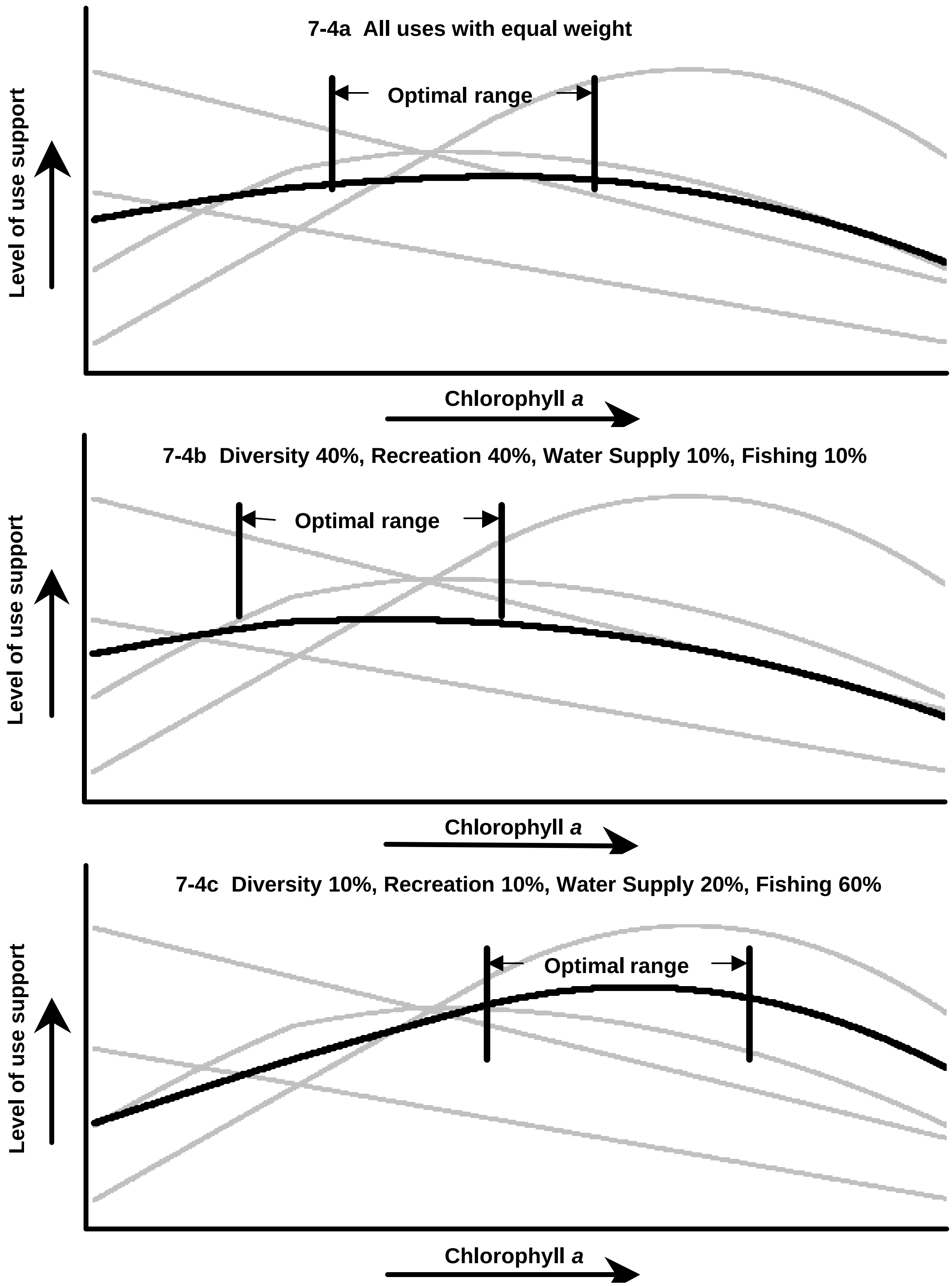
There are mathematical means of determining the optimal average concentration of chlorophyll *a*, provided the relations between use support and average chlorophyll *a* are known, and the relative weight to assign to each use is accepted. If these were known for a given reservoir, an optimal level could be computed using standard linear optimization techniques. An example is shown in Figure 7-4 for different mixes of uses, using the theoretical use-support and chlorophyll *a* relations described. In Figure 7-4a, all uses are given equal weight. In Figure 7-4b, the diversity-richness and recreation uses are each given 40% of the total (together they have 80%) and water supply and fishing are given 10% each. The calculated optimum is moved to a lower chlorophyll *a* value. In Figure 7-4c, the weights assigned are 60% fishing, 20% water supply, and 10% each for diversity-richness and recreation. This shifts the optimal value up.

This example illustrates the mathematical relationships inherent in optimization. Clearly, the data and equations needed to implement this mathematical optimization do not exist for Trinity basin reservoirs in quantitative form. But while the data do not exist quantitatively, there is qualitative knowledge of the relationships and weights, at least for the more studied reservoirs. Deciding what is the best choice with qualitative information can be done. It is exactly the type of decision that individuals make routinely. For example, an individual purchasing a car will balance needs for size, style, cost, etc., and give more weight to some aspects than others in making a selection. While the cost is quantitative, the other important aspects in the decision are qualitative. Qualitative judgments are made in selecting a candidate to support for elected office, and governments follow a similar process in evaluating policy alternatives where some aspects are only partly understood.

7.5 SELECTING CRITERIA

The above discussion addresses the findings of this study on uses and the primary nutrient-related response variable, chlorophyll *a*. It describes a process for obtaining a quantitative criterion best related to actual uses. This section addresses the process of selecting numerical nutrient criteria.

FIGURE 7-4
THEORETICAL RELATION BETWEEN OVERALL LEVEL OF USE SUPPORT AND CHLOROPHYLL a



The topic here is setting numerical criteria in the Texas Surface Water Quality Standards. The process of revising the standards is lengthy, involving draft publication, public comment, responses to comments, administrative action by the Commission, and finally approval by the EPA. This document only focuses on the technical process of developing the draft to the stage of publication.

There are a number of ways in which numerical chlorophyll *a* criteria could be calculated and developed. Some methods are briefly described below, including the method the TCEQ is currently employing, EPA's proposed method, and variations that focus on the use support concept.

As a practical matter, whatever method is employed it is unlikely that major increases in chlorophyll *a* will be allowed for any large public multi-use reservoir, simply because of the anti-degradation policy. The main activity in determining numerical chlorophyll *a* criteria will thus be in identifying where reductions are needed and how large these reductions need to be to support the expected uses.

An important consideration with the process of determining a numerical chlorophyll *a* criterion is the need to incorporate how attainment is to be evaluated. The high degree of natural variability in chlorophyll *a* levels from month to month, year to year, and in different parts of the same reservoir on the same day need to be considered and reflected in any criteria that are ultimately selected.

The method that TCEQ is considering is to set the criterion at the mean of at least 10 historical observations plus an amount such that there will be less than a 5% chance that another 10 or more samples obtained from the same population will not exceed the criterion. This is the same procedure that was followed in developing the existing TDS, Chloride and Sulfate criteria. It is a procedure that works reasonably well in practice for dissolved parameters. Because it is based on existing monitoring data, it can function to prevent degradation.

One difference that should be recognized is that chlorophyll *a* can respond rather dramatically to differences in nutrient levels and weather conditions. Since freshwater inflows associated with rain events represent the bulk of nutrient inputs to most reservoirs, the difference in nutrient inputs between a wet and a dry year can be very dramatic. With large changes in nutrient inputs comes the potential for very large chlorophyll *a* concentration responses. Conversely, nutrient concentrations and chlorophyll *a* levels can be very low in dry years. This inherent variability combined with the potential for dramatic response in chlorophyll *a* levels to relatively minor changes in nutrient concentrations suggests the need for a method to normalize reservoir inflow and weather data in the process of determining attainment. This would have the effect of reducing variability produced by weather conditions. If implemented effectively, it would give the chlorophyll *a* criteria a better chance at targeting meaningful differences while reducing the likelihood of false responses to wet-dry year variations. Many details would need to be worked out to implement this idea, and it is not the subject of this study. It is noted here simply to indicate its importance and that it should be considered in the future.

Another important point in using the proposed TCEQ or any similar method will be to keep separate the main body stations from those on arms or coves of a reservoir. Experience has shown that these tributary arms or coves can be very different from the main body of the reservoir in physical as well as water quality conditions. The focus should be developed initially for the main body of each reservoir. Separate analyses may need to be developed for selected arms and coves as appropriate, but only with a detailed knowledge of the particular circumstances and data from those areas.

The first method for setting criteria is that used historically, where agency staff determine a level that they believe to be protective and achievable. If no major objections or problems are found in the public review process, these staff recommendations are incorporated into standards. Where there is no specific tie to protecting a use, this determination has been based on the upper range of existing ambient levels. The TDS, sulfate and chloride criteria are an example. Such criteria are in effect "anti-degradation" criteria because they are based on the upper range of existing data. If something causes the concentration in question to increase significantly, these criteria become a tool that could be used to take corrective action.

As currently being implemented by the TCEQ, reservoirs are grouped into two sets, Less Impacted (LI) and Impacted (I), where LI reservoirs are assumed to be meeting their designated uses. The basis for selecting the LI is there being relatively low levels (less than 10%) of agriculture and urban development or major WWTPs in the watersheds. Reservoirs categorized as LI would receive numeric criteria based upon the water body specific confidence interval about the mean of at least 10 observations described above. Since it will have been postulated that these reservoirs are already meeting their uses (because there is little human activity and impact that could be corrected), an anti-degradation type approach is consistent. Procedures are not yet defined for impacted reservoirs. However, that is the topic that is likely to receive the greatest interest in the future.

A second method of numerical nutrient criteria selection is that proposed by EPA. It consists of setting a criterion based on a selected percentile of data in broad ecoregions. That method might be described as protective in that it produces numerical results that are very low. However, the values produced are so low that they are completely unachievable in Texas. Besides ignoring uses, the main limitation on the method is that simply being in the same ecoregion does not generate a useful degree of common conditions. For example, one ecoregion, "Great Plains Grass and Shrublands" is common in both Texas and North Dakota. However, this does not mean conditions are common to reservoirs in the ecoregion of the two states. In fact, conditions are radically different for a variety of reasons. At the present time, this method is not being considered. However, it remains as a "hammer" that EPA can impose if states do not adopt more reasonable criteria.

Assuming that the EPA method continues to be viewed as unworkable, and that the TCEQ method of dealing with LI reservoirs is accepted, the major issue will be how to deal with the larger group of "I" reservoirs. This will be the greatest technical challenge.

Reservoirs that have somewhat more human activity in their watersheds may or may not show signs of impact or lack of use support. Certainly a large population or heavy human use carries the potential for correctable impact, while the absence of significant human activity makes the possibility of finding a correctable human impact small. In that sense the level of human activity is a useful indicator. However, that dimension is not determinative when the reservoirs in question are man-made structures serving a unique mix of uses, some of which benefit from human inputs.

There would appear to be a major policy question of specifying the goal of criteria development. Two broad approaches are noted. One path would be to have the goal to make conditions in the "I" reservoirs like those in the LI group that have some geographic similarities. This is an importation of the EPA method with all its attendant flaws, and with no consideration of uses. While the method has technical limitations, it does have some appeal in that it would be making the goal one of minimizing human effects. The other approach described in previous sections would be to make the goal to optimize the overall level of use support for each reservoir and not focus on trying to minimize human effects unless they adversely affect the optimal balance of uses. Building a consensus on this policy choice will be an important step in the overall process that will greatly affect the final outcome.

Whatever policy is pursued, a time will come when criteria for more impacted reservoirs will be addressed. Two possible approaches are suggested.

- The "I" reservoirs could be listed on the concerns list during the preceding water quality assessment and enter a stakeholder-driven process to determine if uses were being met. If they were being met, the reservoir would receive a numeric criterion based upon the confidence interval approach similar to that used for the LI reservoirs. If uses were not being met it would be slatted for criteria development using a combination of stakeholder input, monitoring and modeling.

- Go directly to numerical criteria development to optimize the overall level of use support. A way to do this is to follow the model of the regional water planning groups established by the Texas Water Development Board. In this example, representatives were appointed by the TWDB for each major stakeholder or interest in the basin. These representatives or stakeholders had the responsibility in a public forum to assess the specific water needs and supplies and to develop a consensus on plans for meeting future waters needs. In a similar manner, the TCEQ could appoint representatives of each major use (e.g., swimming, fishing, water supply) as well as the overall health of the system, and charge them to jointly determine a target chlorophyll *a* level or range that would be near optimal to maximize the overall level of use support for one or more reservoir in a region. This would be following the optimization concept illustrated in Figure 7-4. One would expect different optimal ranges to be obtained on different reservoirs with different mixes of uses.

Either of these two methods would only apply to a subset of reservoirs where a chlorophyll *a* reduction is considered. Both involve stakeholders and attempt to negotiate an optimal balance of uses. The second would formalize regional stakeholder groups that could deal with several reservoirs in the same general geographic area, while the first would form *ad hoc*, water body specific stakeholder groups.

The use of such stakeholder groups, whether regional or water body specific, may only be appropriate to a small number of reservoirs where there are strong competing uses and significant economic and environmental stakes. In those situations a stakeholder driven method offers a real chance to find a criterion that has a technical basis and broad support among different user groups.

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Appendix A

Survey of Water Suppliers

TABLE A-1
SURVEY OF WATER SUPPLIERS

RESERVOIR	TREATMENT PLANTS	PLANT ADDRESS	CONTACT	PHONE NO.	ENTITIY	USES	INTAKE LOCATION	INTAKES	LEVELS OF INTAKES	USE OF LEVELS FOR TASTE & ODOR CONTROL	SOURCES OF TASTE AND ODOR PROBLEMS	TIMES OF THE YEAR	TECHNOLOGIES OR CHEMICALS TO COMBAT TASTE & ODORS	VARIATION IN TREATMENTS	COST	GAL. TREATED (annual avg.)	REMARK
Benbrook	Benbrook Treatment Plant	On Shady River Court in Benbrook	Mitch Rivers	817-249-1250	Benbrook Water and Sewar Authority	City of Benbrook	North part of Benbrook	one	3 levels	Middle level is used when algae are dying although the top level is preferred because there is more dissolved oxygen.	algae	Oct to Feb or March	Granular Activated Carbon, copper sulfate, chlorine dioxide	vary dosages of copper sulfate and chlorine dioxide, replace filters in 1.5 to 2 yrs.	$96,000 every 2 yrs. for cost of GAC in filters, and in August 2002, the cost of copper sulfate was $1900	3.5 MGD	Lake Benbrook is supplied with water from Cedar Creek and Richland Chambers. Chlorine dioxide is used to disinfect, but it is not strong enough to treat geosmin.
Benbrook	Rolling Hills Treatment Plant	2500 SE Loop 820 in Fort Worth	Wayne Seals	817-293-5036	City of Fort Worth	mainly for Fort Worth, regional supplier too	The TRWD intake in Benbrook is located at the dam.	one	several levels, the elevation at the bottom of the pump bowl for the Benbrook station is elevation 670, and the bottom level is the most used	The bottom level is the most used.	algae, muddy water with turnovers	all year, mostly summer	Powdered Activated Carbon	Powdered Activated Carbon used throughout the year	$7.83/MG	64 MGD	The Rolling Hills Plant takes water from Benbrook, Cedar Creek, and Richland Chambers usually at the same time.
Benbrook	TRA Tarrant County Water Plant	11201 Mosier Valley Rd. in Fort Worth	Sid McCain, Bill Smith	817-267-4226	TRA	municipal, Bedford, Euless, Colleyville, parts of Grapevine and Richland Hills	NE side of Lake Arlington, near the dam The intake location at Benbrook that supplies the pipe taking water from Benbrook to Lake Arlington is located at the dam.	one	The intake at Lake Arlington has several levels but not used according to TO. Lake Arlington is supplied with water from Benbrook. At Benbrook, the elevation of the bottom of the pump bowl is 670. The bottom elevation is the most used.	The bottom level is the most used.	algae	early spring/Dec. and Jan.	Chlorine dioxide and PAC for TO control	Chlorine dioxide and PAC are used seasonally when algae is a problem	$62,600 to $85,400 per year	28 MGD	The plant intakes water from Lake Arlington, but Lake Arlington is supplied with water from Benbrook, Cedar Creek, and Richland Chambers. The cost of TO control varies because PAC is used 60 to 90 days in a year. This cost includes the usual cost of sodium chlorite to make chlorine dioxide of $17,000 per load. PAC costs 38 cents per pound, and they feed about 2,000 lbs per day. Lake Arlington is a warm lake because of the Handley power plant owned by Exelon, but water from Cedar Creek and Richland Chambers has high nutrients because there is a lot of farmland near these reservoirs.
Bridgeport	Walnutt Creek Specialty District	201 Twin Hills Rd. in Bridgeport	Mike Holloway	940-683-2347	Walnut Creek Specialty District	municipal use, for more than 4,000 rural homes	East side of lake in Twin Hills area	one	three levels	Cooler water 20 feet below has less taste and odor	algae	spring and summer	not specifically, anthracite coal in filters helps to trap some geosmin and pre-chlorination oxidizes the algae	may increase pre-chlorination and lower filtration rates to remove particles better	no direct cost	2 MGD	Mr. Holloway mentioned that there are some complaints about taste and odor because the treatment is not completely effective although chlorine and anthracite coal filters are used.
Bridgeport	Bridgeport Treatment Plant	171 Private Rd. in Bridgeport	Lee Dennis	940-683-2230	City of Bridgeport	municipal for City of Bridgeport	At the dam	one	one	NA: only one level used	algae, manganese, and iron	algae: summer and some in fall//small amounts of manganese and iron present for a few days because of the rate at which water is treated from this same level by the Cities of Bridgeport and Decatur as well as West Wise Rural Water Supply Corporation	pre-chlorination, permanganate, Powdered Activated Carbon	vary chlorine and permanganate dosages	has varied from $500 to $5000 a summer for permanganate and chlorine use	2 MGD	The cities of Bridgeport and Decatur as well as West Wise Rural Water Supply Corportation use the same level of the same intake at the dam.
Bridgeport	Runaway Bay Plant	805 US Hwy 380 in Runaway Bay	David Wilson	940-575-2210	City of Runaway Bay	municipal for Runaway Bay	SW side of Bridgeport, near Runaway Bay	one	one, seven feet deep	NA: only one level used	no taste and odor problems	NA	NA	vary amounts of caustic soda and polymer used	NA	300,000 gpd	
Bridgeport	Royce W. Simpson Water Treatment Plant	800 Water Plant Rd in Decatur	Doyle Green	940-627-5289	City of Decatur	municipal for Decatur	At the dam	one	one	Plant uses only the bottom level	some algae but no taste and odor due to algae	July and August	chlorine to kill algae and treat for Fe and Mn and H_2S	raise chlorine levels at least 3 times more in July and August than other parts of year	cost of chlorine increases in July and August about 3 times more than usual	1.6 MGD	The cities of Bridgeport and Decatur as well as West Wise Rural Water Supply Corportation use the same level of the same intake at the dam. Plant has little problems due to algae; other taste and odor problems are due to manganese, iron, and hydrogen sulfide.
Bridgeport	West Wise Rural Water Supply Corportation	Near Bridgeport Dam	James Wood	940-683-5507	West Wise Rural Water Supply Corp.	municipal serving Chico, TX	Directly in front of dam	one	one level	NA: one level	iron, manganese, and hydrogen sulfide	summer	pre-chlorination, permanganate	use permanganate during the summer	$120/MG	450,000 gpd	The cities of Bridgeport and Decatur as well as West Wise Rural Water Supply Corporation use the same level of the same intake at the dam. The use of aeration equipment in 2003 is expected to greatly reduce the cost of taste and odor control.
Bridgeport	Sid Richardson Scout Ranch Water Treatment Plant	Plant is located in the Scout Ranch, mailing address: 183 Eagle's Trail Jacksboro, TX	Joe Newton	940-575-4243	Sid Richarson Scout Ranch	for the Scout Ranch only (drinking, bathing, etc.) No water is withdrawn for irrigation	West side of Bridgeport, north of Stripling Island	one, floating pump station	floating pump station rises and falls with the lake elevation, water is withdrawn 5 feet below its surface	NA: floating pump station and no TO problems	no taste and odor problems, water of good quality, no problems with algae or other sources	NA	treatment involves chlorination, coagulation, flocculation, and sedimentation	vary amount of coagulant (alum) used and amount of chlorine gas (more in summer)	NA	winter 15k gpd, summer 30k gpd	The Ranch treats water all year, but not every day especially in the winter.

TABLE A-1
SURVEY OF WATER SUPPLIERS

RESERVOIR	TREATMENT PLANTS	PLANT ADDRESS	CONTACT	PHONE NO.	ENTITIY	USES	INTAKE LOCATION	INTAKES	LEVELS OF INTAKES	USE OF LEVELS FOR TASTE & ODOR CONTROL	SOURCES OF TASTE AND ODOR PROBLEMS	TIMES OF THE YEAR	TECHNOLOGIES OR CHEMICALS TO COMBAT TASTE & ODORS	VARIATION IN TREATMENTS	COST	GAL. TREATED (annual avg.)	REMARK
Bridgeport	South Holly Plant	1500 11th Ave. Fort Worth	Jerry McMillion	817-871-8254	City of Fort Worth	Fort Worth and 28 other cities	Both intakes are in Lake Worth: one is 100 yds into the lake from the toe of the dam, the other is at the toe of the dam	two intake structures, the North and South Holly Plants share the same intake structures	2, about same level	NA: not much difference between levels	algae, natural "fishy" taste	all year but mostly spring and fall	Powdered Activated Carbon	Vary the dosage of Powdered Activated Carbon, Powdered Activated Carbon is used when needed	$7.40/MG	50 MGD	The South Holly Plant takes water directly from Lake Worth; the water flows from Lake Bridgeport to Eagle Mountain and then to Lake Worth. It takes water from the Clear Fork of the Trinity River during high demand periods (from mid-summer to mid-fall). The plant operators call the Army Corp of Engineers to tell them how much water to release from Lake Benbrook to the Clear Fork during this period. When using water from Clear Fork, the South Holly Plant receives water from 5 different sources. Lake Worth and Clear Fork are the main sources, but the water from Clear Fork is a mixture of Richland Chambers, Cedar Creek, Benbrook, and the Clear Fork of the Trinity River. Add that to the Lake Worth water and you have 5 different sources. Each with its own unique characteristics and its own sources for taste and odor. Water from Benbrook also has Cedar Creek and Richland Chamber water because the TRWD pipe lines supply Benbrook with more water.
Bridgeport	North Holly Plant	920 Fornier in Fort Worth	Jerry McMillion	817-871-8254	City of Fort Worth	Fort Worth and 28 other cities	Both intakes are in Lake Worth: one is 100 yds into the lake from the toe of the dam, the other is at the toe of the dam	two intake structures, the North and South Holly Plants share the same intake structures	2, about same level	NA: not much difference between levels	algae, natural "fishy" taste	all year but mostly spring and fall	Powdered Activated Carbon	Vary the dosage of Powdered Activated Carbon, Powdered Activated Carbon is used when needed	$7.40/MG	50 MGD	The North Holly Plant takes water from Lake Worth, and the water travels from Bridgeport to Eagle Mountain and then to Lake Worth.
Cedar Creek	Rolling Hills Treatment Plant	2500 SE Loop 820 in Fort Worth	Wayne Seals	817-293-5036	City of Fort Worth	mainly for Fort Worth, regional supplier too	The intake is north of the spillway and discharge channel on the west side of the lake. It is located south of Don's Port marina.	one intake	2 levels: bottom intake (elevation from 266.5 to 278.5) top intake (elevation 302 to 314)	No, taste and odor is not considered	algae, muddy water with turnovers	all year, mostly summer	Powdered Activated Carbon	Powdered Activated Carbon used throughout the year	$7.83/MG	64 MGD	The Rolling Hills Plant takes water from Benbrook, Cedar Creek, and Richland Chambers usually at the same time.
Cedar Creek	City of Trinidad Plant	On North Line Rd. in Trinidad	Matt Booker	903-778-2724	City of Trinidad	municipal for Trinidad	South end of lake, at the dam	one	one level	NA: only one level	algae, reduced chlorine for less chlorine taste	summer	prechlorinate and copper sulfate with alum during coagulation. Liquid chemicals are used. A mixture with 50% alum and 1% copper sulfate is used. About 20 gallons are used a day.	more chlorine needed in summer, more coagulant chemicals needed in winter	1cent more per lb to use alum with copper sulfate. Mr. Booker does not know how many pounds of copper sulfate go into the liquid mixture. About 20 gallons are used a day of the 50% alum mixture with 1% copper sulfate.	260,000 gpd	A pipe line takes water from Cedar Creek to the City of Trinidad private lake from which water is pumped.
Cedar Creek	John F. Kubala Water Treatment Plant	7001 Hwy 287 in Arlington	Chuck Volkes	817-478-5702	City of Arlington	municipal for Arlington	The plant uses two taps on the TRWD pipe lines carry water from Richland Chambers and Cedar Creek. The intake is north of the spillway and discharge channel on the west side of Cedar Creek. It is located south of Don's Port marina.	one at each lake	2 levels: bottom intake (elevation from 266.5 to 278.5) top intake (elevation 302 to 314)	NA: taste and odor is not considered	algae	summer	ozonation	ozone is used all year as primary disinfectant and for taste and odor control	$5.25/MG plus cost of elec. $6.54/MG	40-50 MGD	Before ozone began to be used,the plant spent about $750,000 per year on PAC. The other Arlington plant treats water from Lake Arlington.
Cedar Creek	Beachwood Estates	Subdivision of Beachwood Estates near Tool, TX	Joyce Hubbard	903-451-3204	Tecon Water Supply Co.	residential for subdivision of Beachwood Estates	West side of lake, near spillway, south of Tool, TX	one	one level	NA: one level	no taste and odor problems	NA	no treatment for taste and odor	vary amount of coagulant (alum) used	NA	100,000 gpd	
Cedar Creek	Carolynn Estates	Subdivision of Carolyn Estates near Mabank	Joyce Hubbard	903-451-3204	Tecon Water Supply Co.	residential for subdivision of Carrollin Estates	East side of lake near Mabank, TX	one	one level	NA: one level	no taste and odor problems	NA	no treatment for taste and odor	vary amount of coagulant (alum) used	NA	150-200,000 gpd	
Cedar Creek	Cherokee Shores	Subdivision of Cherokee Shores near Mabank	Joyce Hubbard	903-451-3204	Tecon Water Supply Co.	residential for subdivision of Cherokee Shores	East side of lake near Mabank, TX	one	one level	NA: one level	no taste and odor problems	NA	no treatment for taste and odor	vary amount of coagulant (alum) used	NA	150-200,000 gpd	
Cedar Creek	McKay Water Treatment Plant	100 Enchanted Dr.	Arthur Black	903-887-3241	East Cedar Creek Municipal Water District	municipal for parts of the Towns of Payne Springs and Enchanted Oak	Mid-length of lake, near Seminole Loop Rd. (b/w Payne Springs and Enchanted Oaks)	one	three levels	No, the level used does not make a difference	no taste and odor problems	Algae grows in the summer, but Mr. Black says that the there are no taste and odor problems due to algae or other sources.	standard treatment includes pre-chlorination and particulate removal	vary amount of chlorine and coagulant used	NA	328,000 gpd	

TABLE A-1
SURVEY OF WATER SUPPLIERS

RESERVOIR	TREATMENT PLANTS	PLANT ADDRESS	CONTACT	PHONE NO.	ENTITIY	USES	INTAKE LOCATION	INTAKES	LEVELS OF INTAKES	USE OF LEVELS FOR TASTE & ODOR CONTROL	SOURCES OF TASTE AND ODOR PROBLEMS	TIMES OF THE YEAR	TECHNOLOGIES OR CHEMICALS TO COMBAT TASTE & ODORS	VARIATION IN TREATMENTS	COST	GAL. TREATED (annual avg.)	REMARK
Cedar Creek	TRA Tarrant County Water Plant	11201 Mosier Valley Rd. in Fort Worth	Sid McCain, Bill Smith	817-267-4226	TRA	municipal, Bedford, Euless, Colleyville, parts of Grapevine and Richland Hills	The plant's intake structure is at the NE-end of Lake Arlington, near the dam. Lake Arlington receives water from Cedar Creek. At Cedar Creek, the intake is located north of the spillway and discharge channel (west side of CC), south of Don's Port marina.	one	At Lake Arlington, the intake has several levels, but they are not used according to TO. Lake Arlington is supplied with water from Cedar Creek. At Cedar Creek there are 2 levels (bottom intake's elevation range is 266.5 to 278.5, top intake's elevation range is 302 to 314).	No, taste and odor is not considered by TRA plant or by TRWD.	algae	early spring/Dec. and Jan.	Chlorine dioxide and PAC for TO control	Chlorine dioxide and PAC are used seasonally when algae is a problem	$62,600 to $85,400 per year	28 MGD	The plant intakes water from Lake Arlington, but Lake Arlington is supplied with water from Cedar Creek, Richland Chambers, and Benbrook. The cost of TO control varies because PAC is used 60 to 90 days in a year. This cost includes the usual cost of sodium chlorite to make chlorine dioxide of $17,000 per load. PAC costs 38 cents per pound, and they feed about 2,000 lbs per day. Lake Arlington is a warm lake because of the Handley power plant owned by Exelon, but water from Cedar Creek and Richland Chambers has high nutrients because there is a lot of farmland near these reservoirs.
Cedar Creek	Plants 1 & 2	99 Sunset Blvd.	Kirk Kebodeaux	903-489-0091	City of Star Harbor	municipal for Star Harbor/ water is drawn but not treated to irrigate golf course	South end of lake, in the area of the lake down the street from the WT plants, Star Harbor is the southernmost city along Cedar Creek before the dam. One intake is 800 feet from the shore, and the other is 1000 feet from the shore.	each plant has one	one level	NA: intake is not adjustable, only one level used	no taste and odor problems, occasionally there is a sulphurous smell in the summer, no need to treat for taste and odor control	NA	Standard treatment involves disinfection with Miox, which stands for mixed oxidants including hypochlorous ions.	Raw water is mostly consistent, only volume of water to treat changes	NA	winter 30k gpd, summer 125k gpd	Construction of Plant 2 ended in January of 2003, and it is the only plant in use now. Plant 1 is for sale.
Cedar Creek	Tool Plant	Macon Rd. in Tool, TX	Chuck Webb	903-432-4940	West Cedar Creek Municipal Utility District	municipal for the district	West side of lake, in Don's Port area, near Macon Rd The lake is about 30 feet deep in this area.	one	3 levels	The middle level is used the most, and this also helps for tastes and odors.	algae	summer	Pre-chlorination is used when algae is a problem. Miox (mixed oxidants) is used all year to disinfect.	Pre-chlorinate for about two months when algae is a problem. Adjust amountof coagulant used.	The cost of pre-chlorinating is not significant (small dosages used for about 2 months).	4-500,000 gpd	The treated water at the Tool Plant still has some tastes and odors due to algae although pre-chlorination helps to reduce them.
Cedar Creek	Tolosa Plant	Conty Line Rd. in Tolosa	Chuck Webb	903-498-4804	West Cedar Creek Municipal Utility District	municipal for the district	near County Line Rd on the west side of the lake, about 100 yards from shore, the lake is about 14 feet deep in this area	one	3 levels	No, but the top level is almost always used	algae	summer	The clarifier also has beads that act like filter media; they adsorb agents that cause foul tastes and odors. The mixed media filters also help control TO.	Vary amount of coagulant used.	Depends on the cost of the technology that is used year round, when algae is not a problem too. The beads in the clarifier also help for taste and odor control, but they have not been replaced in three years since they were first used. They are cleaned periodically. Taste and odor control involves the use of beads and the filters. Mr. Webb said that there is not a specific cost for taste and odor control because filters are standard and the beads in the clarifier are used all year even when there are not taste and odor problems.	800,000 gpd	Ms. Sanders said that both the Tool and Tolosa plant have problems due to algae, but the treatment varies at each plant. The treatment at the Tolosa Plant controls tastes and odors better than at the Tool Plant. The Tolosa plant is considered by TCEQ to be an unconventional packaged plant designed by USFilter. One of the main differences is the use of beads in the clarifier that also help to control tastes and odors. The treatment at the Tolosa plant helps the treated water not to have taste and odor problems.
Cedar Creek	City of Mansfield Plant	707 Pleasant Ridge Ct in Mansfield	Bud Erwin	817-477-2248	City of Mansfield	municipal	The intake is north of the spillway and discharge channel on the west side of the lake. It is located south of Don's Port marina.	2 taps on TRWD pipe lines	2 levels: bottom intake (elevation from 266.5 to 278.5) top intake (elevation 302 to 314)	No, taste and odor is not considered	algae, some times if have low DO	late spring to fall	Granular Activated Carbon filters	Granular Activated Carbon filters work well, replaced after 24 to 30 months	$106,000 per year, cost of the lease on Granular Activated Carbon filters per year.	6 MGD	Mr. Erwin says that the GAC filters work well to remove organics.
Cedar Creek	City of Kemp Plant	Off Hwy 175 in Kemp	Joe Vallirreal	903-498-3191	City of Kemp	municipal for Kemp	The pumps are about 3 miles into the lake. East side of lake, near Kemp, SE of the intersection between Hwy 175 and Hwy 274.	2 pumps used	2 pumps are located at same level	NA: only one level for both pumps	algae	summer	Granular Activated Carbon filters,prechlorination	vary amount of chlorine used	NA, no cost specific for taste and odor problems	275,000 gpd	
Cedar Creek	City of Mabank	2200 W Main (Hwy 334) in Gun Barrel City	Tim Whitley	903-887-1328	City of Mabank	municipal for Mabank and other towns	NE of Chamber Isle and north of Hwy 334, 150 feet into the lake	two, 20 feet apart	each uses only one level, one is 20 feet deep, the other 25 feet deep	NA: each intake is located at one level	no taste and odor problems due to algae, lake turnovers may cause some	NA	chlorine (gas), may use chloramines in the future	vary amount of coagulant (alum) used	NA	range: 900,000 gpd to 2 MGD	

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SURVEY OF WATER SUPPLIERS

RESERVOIR	TREATMENT PLANTS	PLANT ADDRESS	CONTACT	PHONE NO.	ENTITIY	USES	INTAKE LOCATION	INTAKES	LEVELS OF INTAKES	USE OF LEVELS FOR TASTE & ODOR CONTROL	SOURCES OF TASTE AND ODOR PROBLEMS	TIMES OF THE YEAR	TECHNOLOGIES OR CHEMICALS TO COMBAT TASTE & ODORS	VARIATION IN TREATMENTS	COST	GAL. TREATED (annual avg.)	REMARK
Cedar Creek	Brookshire Water Treatment Plant	161 Harmon Rd. in Gun Barrel City	Arthur Black	903-887-3241	East Cedar Creek Municipal Water District	Municipal, parts of Mabank and Gun Barrel City	Mid-length of lake South of Gun Barrel City and north of Payne Springs, near the shore where Welch Ln. ends.	one	three levels	No, the level used does not make a difference	no taste and odor problems	Algae grows in the summer, but Mr. Black says that the there are no taste and odor problems due to algae or other sources.	standard treatment includes pre-chlorination and particulate removal	vary amount of chlorine and coagulant used	NA	746,000 gpd	
Eagle Mountain	Eagle Mountain Plant	6801 Bowman Roberts Rd. in Fort Worth	Todd Burleson	817-238-9977	City of Fort Worth	Fort Worth and its suburbs	SE corner of lake	one	2 levels, used simultaneously	No, not considered, both valves are usually open at the same time	algae	spring and summer more	ozonation	Vary ozone dosage a little but ozone is used all year as a primary disinfectant. Ozone has the added benefit of controlling taste and odors.	$11.50/MG	42 MGD	
Eagle Mountain	City of Azle Plant	1500 Lake View Dr. in Azle	Bobby Langston	817-444-3751	City of Azle	municipal use for Azle	SW side of lake, about 1500 ft from shore	one	3 levels	The upper and middle layers are used when dissolved oxygen is low at the bottom layer. All three levels are used at different times to avoid more turbidity.	algae	summer	chlorine, potassium permanganate and PAC	vary dosages of permanganate and chlorine	$6, 250 average cost to use PAC and potassium permanganate	2 MGD	
Eagle Mountain	Community Water Supply	12190 Liberty School Rd. Mapsco 15D	David Shearer	817-444-5731	Community Water Supply	water supply for rural homes	Northwest corner of lake, near the shore where Peden Rd. ends (Mapsco 15D)	one	2 levels, ten feet apart	No, not much difference between levels	algae	summer	PAC	use PAC in the summer as needed and vary dosages of other chemicals	$500 to $1000 per summer	400,000 gpd	The intake is along the shore where the algae accumulates more.
Eagle Mountain	City of Springtown Plant	on Peden Rd. near Community Water Supply Water Treatment Plant	Gene Edmondson	817-444-6031	City of Springtown	municipal for Springtown and Reno, TX	Northwest corner of lake, about 50 yards into the lake.	one	The pipe is slotted. Water flows in from all slots.	NA: operators do not close some slots, all are open at the same time	no taste and odor problems, although there is algae growth	summer	PAC was used years ago. Pre and post chlorination, coagulant, and caustic soda used.	Do not treat for taste and odor control. Vary dosages of other chemicals.	NA	2-300,000 gpd	The intake is located about 50 yards from the shore. Mr. Edmondson says that the they have not had a need to treat for taste and odor in years.
Eagle Mountain	City of River Oaks	1900 Nancy Lane in Riiver Oaks	Marvin Gregory	817-626-5421	City of River Oaks	municipal, City of River Oaks	located in Lake Worth at the dam, north of the intakes used by the North and South Holly Plants of Fort Worth	one intake structure	2 16" pipelines extend into the lake, about same level (20 and 25 feet deep). The water is siphoned from the Lake over the dam and the 16-inch transmission mains gravity flow it to the raw water pump house located on the plant site.	NA: not much difference between levels	algae is an occasional problem	summer	Powdered Activated Carbon, pre and post chlorination	Powdered activated carbon is used when needed	Minimal, only use about 200 lbs of carbon per year	15 MGD	River Oaks intake is in Lake Worth, and Lake Worth receives water flow from Bridgeport and Eagle Mountain.
Eagle Mountain	South Holly Plant	1500 11th Ave. Fort Worth	Jerry McMillion	817-871-8254	City of Fort Worth	Fort Worth and 28 other cities	Both intakes are in Lake Worth: one is 100 yds into the lake from the toe of the dam, the other is at the toe of the dam	two intake structures, the North and South Holly Plants share the same intake structures	2, about same level	NA: not much difference between levels	algae, natural "fishy" taste	all year but mostly spring and fall	Powdered Activated Carbon	Vary the dosage of Powdered Activated Carbon, Powdered Activated Carbon is used when needed	$7.40/MG	50 MGD	The South Holly Plant takes water directly from Lake Worth; the water flows from Lake Bridgeport to Eagle Mountain and then to Lake Worth. It takes water from the Clear Fork of the Trinity River during high demand periods (from mid-summer to mid-fall). The plant operators call the Army Corp of Engineers to tell them how much water to release from Lake Benbrook to the Clear Fork during this period. When using water from Clear Fork, the South Holly Plant receives water from 5 different sources. Lake Worth and Clear Fork are the main sources, but the water from Clear Fork is a mixture of Richland Chambers, Cedar Creek, Benbrook, and the Clear Fork of the Trinity River. Add that to the Lake Worth water and you have 5 different sources. Each with its own unique characteristics and its own sources for taste and odor. Water from Benbrook also has Cedar Creek and Richland Chamber water because the TRWD pipe lines supply Benbrook with more water.
Eagle Mountain	North Holly Plant	920 Fornier in Fort Worth	Jerry McMillion	817-871-8254	City of Fort Worth	Fort Worth and 28 other cities	Both intakes are in Lake Worth: one is 100 yds into the lake from the toe of the dam, the other is at the toe of the dam	two intake structures, the North and South Holly Plants share the same intake structures	2, about same level	NA: not much difference between levels	algae, natural "fishy" taste	all year but mostly spring and fall	Powdered Activated Carbon	Vary the dosage of Powdered Activated Carbon, Powdered Activated Carbon is used when needed	$7.40/MG	50 MGD	The North Holly Plant takes water from Lake Worth, and the water travels from Bridgeport to Eagle Mountain and then to Lake Worth.
Houston County	Houston County Water Control District No. 1	In Latexo, TX	John Chenette	936-554-3985	Houston County WCID No. 1	municipal and industrial	NE end of lake	one, north end of lake	two, but mainly use one	No, not much difference between levels	algae	summer to fall	copper sulfate, chloramines	do not use copper sulfate when algae is not a problem	$1.31/MG	1.8 MGD	The cost estimate was done using $500 since Mr. Chenette said they spend about $400 or $500 a year on copper sulfate.
Livingston	Livingston Water Plant	4253 FM 350 South Livingston, TX 77351	John Ackerman	936-967-4495	City of Livingston	municipal for Livingston and prison unit	450 feet into the lake, plant is less than a mile away from intake	3 pumps in same are of lake	3 levels, about 3' intervals between pumps	TO not considered, different levels useful for changing lake elevations	algae problem is small	summer	chlorine dioxide at the intake, chlorine	use chlorine dioxide all year, vary dosages of chlorine and coagulant	$.05/MG plus cost of equipment use	2 MGD	Mr. Ackerman states that chlorine dioxide works well, and that there are no complaints from residents of Livingston.

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RESERVOIR	TREATMENT PLANTS	PLANT ADDRESS	CONTACT	PHONE NO.	ENTITIY	USES	INTAKE LOCATION	INTAKES	LEVELS OF INTAKES	USE OF LEVELS FOR TASTE & ODOR CONTROL	SOURCES OF TASTE AND ODOR PROBLEMS	TIMES OF THE YEAR	TECHNOLOGIES OR CHEMICALS TO COMBAT TASTE & ODORS	VARIATION IN TREATMENTS	COST	GAL. TREATED (annual avg.)	REMARK
Livingston	Westwood Shores Water Plant	75 Cottonwood in Westwood Shores	Mark Huffman	936-594-3411	Westwood Shores Municipal Utility District	municipal for Westwood Shores	North end of lake. Plant is on Cottonwood in Westwood Shores	2 intakes north end of lake	2 pumps are at different levels	no taste and odor problems, and 5 feet difference between pumps	do not have taste and odor problems	none	NA	NA	NA	150,000 gpd	
Livingston	Waterwood Treatment Plant	On Hwy 980 b/w Huntsville and Livingston	Joe Myers	936-891-5640	Waterwood Municipal Utility District No. 1	residential, one commercial bldg.	North of subdivision of Waterwood, where Browns Creek flows into Livingston, 300 yards off shore	one intake	2 levels	Water characteristics are the same at both levels only 2 feet apart	algae (once in the past 20 years)	NA	Powdered Activated Carbon if needed	NA	NA	170, 000 gpd	
Livingston	Southeast Water Treatment Plant	3100 Genoa-Red Bluff Rd in Houston	Jim Greenlee	713-330-2512	City of Houston	Houston and wholesale to 12 communities	At the dam in Lynchburg Reservoir. Water from Livingston travels 50 miles in the Trinity R. before it is diverted to the Lynchburg Reservoir by a canal.	one	one level (shallow reservoir)	NA: one level	algae, fungi, not considered a large problem. Complaints vary including complaints about rusty-yellow color, taste and odor, particles.	algae in the summer, but receive complaints at different times of the year.	Chloramines, PAC has been used about 6 times in 15 years	Vary dosages of coagulant (ferric sulfate) to comply with turbidity and total organic standard	$150,000 to use PAC for about two weeks for both plants, PAC used 6 times in 15 years	100 MGD	12-mile pipeline delivers water to plant from Lynchburg Reservoir. Mr. Greenlee does not consider the taste and odor problems to be a big problem. They may be due to algae. At least half of the complaints are not related to taste and odor.
Livingston	East Water Purification Plant	2300 Federal Rd Houston 77015	Jim Greenlee	713-330-2512	City of Houston	Houston and wholesale to 12 communities	At the dam in Lynchburg Reservoir. Water from Livingston travels about 50 miles in the Trinity R. before it is diverted to the Lynchburg Reservoir by a canal.	one intake	one level (shallow reservoir)	NA: one level	Algae and fungi grow in the summer, but not considered a large problem. Complaints for taste and odors but also for rusty-yellow color and particles.	algae in the summer, but receive complaints at different times of the year.	Chloramines, PAC has been used about 6 times in 15 years	Vary dosages of coagulant (alum) to comply with turbidity and total organic standards	$150,000 to use PAC for about two weeks for both plants, PAC used 6 times in 15 years	220-225 MGD	14-mile pipeline delivers water from Lynchburg Reservoir. The East Plant also treats 25 MGD of water from Lake Houston. Water from Lake Houston travels 12 miles in an open canal before it reaches the plant. Mr. Greenlee does not consider that the plants have a large taste and odor problem, which may be due to algae. About half of the complaints are not related to taste and odor.
Livingston	Trinity County Regional Water Supply System	Near Hwy 19 and Bell Rd (before the Hwy 19 bridge that crosses the Lake Livingston)	Steve Lee	936-594-5349	TRA	municipal, whole sells water to Trinity, Groveton, Westwood Shores MUD, Glendale, Riverside, and Trinity Rural Water Supply Corporation.	On both sides of a small peninsula; the wells are 2 miles away from the plant.	Series of 18 wells.	NA, the wells are located in sand/gravel bed of the shore	NA, no taste and odor problems using the wells	no taste and odor problems, filters remove the small amounts of manganese and iron, no foul tastes and odors due to algae	NA	Chlorination, Aeration equipment, filtration, and fluoridation	Vary chlorine dosages	NA	900,000 gpd	Water from Lake Livingston is collected through 18 wells on the Trinity shoreline of the lake. The water does not have foul tastes and odors. The sand/gravel bed also helps reduce turbidity. This plant does not have coagulation, flocculation, and sedimentation processes.
Livingston	Huntsville Water Treatment Plant	in Huntsville	Keith Bass	936-295-9388	City of Huntsville	municpal for Huntsville, two prison units, some water after leaving the clarifer is sent to an industrial power plant	From the Trinity River before reaching Livingston	one intake	2 levels	No, five feet difference between levels (15 and 20 feet deep)	algae and actinomycetes	April to October but more in August and September	chlorine dioxide is used for TO control	Vary the dosage of chlorine dioxide	$70-75,000 per year for chlorine dioxide, therefore about $.05/MG based on cost of $70,000	10 MGD	The Huntsville Plant intakes water from the Trinity River before reaching Livingston.
Ray Hubbard	East Side Plant	405 Long Creek Rd. Sunnyvale, TX 75182	Bob Parland	214-670-0919	City of Dallas	municipal	SW corner of Ray Hubbard	one	two	No, with lake mixing, there is no difference in taste and odor between the two levels.	algae	from July to end of warm weather	Powdered Activated Carbon	Powdered Activated Carbon used only during times of algae growth	$8/MG	75 MGD	
Ray Roberts	Lewisville Water Treatment Plant	Spencer Rd in Denton	Tim Fisher	940-349-7190	City of Denton	municipal	In Hickory Creek (in SW part of Lake Lewisville)	one	2 levels	No, taste and odor is not considered, take from lower level just to avoid buildup	algae	late summer through Jan.	permanganate, Powdered Activated Carbon	use Powdered Activated Carbon only during worst algae periods	About $50,000 a year on powder activated carbon	14 MGD	There is not a water plant that treats directly from Lake Ray Roberts; Lake Lewisville receives water from Ray Roberts and the Trinity River . Denton is building a plant that will treat water directly from Ray Roberts; this plant will open in the spring of 2003.
Ray Roberts	City of Lewisville Treatment Plant	1400 N Cowan in Lewisville	Carol Bassinger	972-219-3510	City of Lewisville	municipal for Lewisville	Both intakes are at the dam	Two// The older intake structure has 5 pumps at different levels. The new intake structure is shared with the Upper Trinity Regional Water District, and it has 3 levels.	5 levels, 3 levels	At the intake structure owned by City of Lewisville, tastes and odors are not considered; the pumps used depend on lake elevations. The Upper Trinity Regional Water District decides which level Lewisville will use at the new intake structure.	algae	summer	PAC at one intake	Use PAC only in the summer	$3,500 per summer	14 MGD	There is not a water plant that treats directly from Lake Ray Roberts; Lake Lewisville receives water from Ray Roberts and the Trinity River . Lake Ray Roberts is about 15. 5 miles away from Lake Lewisville.
Ray Roberts	Upper Trinity Regional Water District Plant	300 Treatment Plant Rd. in Lewisville	Hector Ortiz	972-489-2221	Upper Trinity Regional Water District	municipal use for cities in Denton County	At the dam of Lake Lewisville	one	four levels, the top one is mostly always used	No, taste and odor is not considered	algae	summer and other warm parts of the year	Ozone and granular activated carbon in the filters	Use more ozone to treat warmer water	$10-15/MG	11-12 MGD	There is not a water plant that treats directly from Lake Ray Roberts; Lake Lewisville receives water from Ray Roberts and the Trinity River . Mr. Ortiz mentioned that in the summer we can better notice the difference in taste between the water treated by UTRWD and by the City of Lewisville because ozone controls tastes and odors better.

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Richland Chambers	Winkler Water Supply																No response to survey requests.
Richland Chambers	Rolling Hills Treatment Plant	2500 SE Loop 820 in Fort Worth	Wayne Seals	817-293-5036	City of Fort Worth	mainly for Fort Worth, regional supplier too	Near 200 SE County Rd 3250, west of Hwy 309 and northeast of Hickey Island	one intake	The intake structure uses 2 levels at Richland Chambers. The bottom level has an elevation range of 266 to 280, and the top level's range is 291 to 305.	No, taste and odor is not considered	algae, muddy water with turnovers	all year, mostly summer	Powdered Activated Carbon	Powdered Activated Carbon used throughout the year	$7.83/MG	64 MGD	The Rolling Hills Plant takes water from Benbrook, Cedar Creek, and Richland Chambers usually at the same time.
Richland Chambers	John F. Kubala Water Treatment Plant	7001 Hwy 287 in Arlington	Chuck Volkes	817-478-5702	City of Arlington	municipal for Arlington	Near 200 SE County Rd 3250, west of Hwy 309 and northeast of Hickey Island	one at each lake	The intake structure uses 2 levels at Richland Chambers. The bottom level has an elevation range of 266 to 280, and the top level's range is 291 to 305.	No, taste and odor is not considered	algae	summer	ozonation	ozone is used all year as primary disinfectant and for taste and odor control	$5.25/MG plus cost of elec. $6.54/MG	40-50 MGD	Before ozone began to be used,the plant spent about $750,000 per year on PAC. The other Arlington plant treats water from Lake Arlington.
Richland Chambers	City of Mansfield Plant	707 Pleasant Ridge Ct in Mansfield	Bud Erwin	817-477-2248	City of Mansfield	municipal	Near 200 SE County Rd 3250, west of Hwy 309 and northeast of Hickey Island	2 taps on TRWD pipe lines	The intake structure uses 2 levels at Richland Chambers. The bottom level has an elevation range of 266 to 280, and the top level's range is 291 to 305.	No, taste and odor is not considered	algae, some times if have low DO	late spring to fall	Granular Activated Carbon filters	Granular Activated Carbon filters work well, replaced after 24 to 30 months	$106,000 per year, cost of the lease on Granular Activated Carbon filters per year.	6 MGD	Mr. Erwin says that the GAC filters work well to remove organics.
Richland Chambers	TRA Tarrant County Water Plant	11201 Mosier Valley Rd. in Fort Worth	Sid McCain, Bill Smith	817-267-4226	TRA	municipal, Bedford, Euless, Colleyville, parts of Grapevine and Richland Hills	The plant uses water from the NE-end of Lake Arlington; the intake is near the dam. Lake Arlington is supplied with water from Richland Chambers. At RC, the intake is located near 200 SE County Rd 3250, west of Hwy 309, northeast of Hickey Island.	one	At Lake Arlington, the intake has several levels, but they are not used according to TO. Lake Arlington is supplied with water from Richland Chambers using 2 levels. The bottom level's elevation range is 266 to 280, and the top level's is 291 to 305.	No, taste and odor is not considered	algae	early spring/Dec. and Jan.	Chlorine dioxide and PAC for TO control	Chlorine dioxide and PAC are used seasonally when algae is a problem	$62,600 to $85,400 per year	28 MGD	The plant intakes water from Lake Arlington, but Lake Arlington is supplied with water from Cedar Creek, Richland Chambers, and Benbrook. The cost of TO control varies because PAC is used 60 to 90 days in a year. This cost includes the usual cost of sodium chlorite to make chlorine dioxide of $17,000 per load. PAC costs 38 cents per pound, and they feed about 2,000 lbs per day. Lake Arlington is a warm lake because of the Handley power plant owned by Exelon, but water from Cedar Creek and Richland Chambers has high nutrients because there is a lot of farmland near these reservoirs.