NUTRIENT CRITERIA AND DESIGNATED USES FOR RESERVOIRS IN THE TRINITY RIVER BASIN

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ABSTRACT

Texas has embarked on the process of developing quantitative or numerical nutrient criteria in response to EPA's 1998 national initiative. Texas is dealing with many complex issues in developing appropriate criteria, and one is simply determining what is to be the technical basis for the criteria. EPA's proposed methodology for lakes and reservoirs was based on a percentile of data from reference systems, with no consideration of the designated uses. In contrast, the language in the Clean Water Act is fairly specific as to the relationship between designated uses and criteria. Furthermore, recent significant documents including the National Research Council's 2001 review of the TMDL program, and the General Accounting Office's 2003 review of EPA's efforts, suggest there is interest and support for developing appropriate and attainable designated uses and having criteria that are tied to those uses.

In response to the need for developing a better understanding of uses and supporting criteria, the Trinity River Authority undertook a project with the support of the Clean Rivers Program of the Texas Commission on Environmental Quality (TCEQ). The goal of the project was to explore the relations between a comprehensive list of actual uses that exist for a variety of reservoirs and attempt to develop a process for setting criteria that might be supportive or based on those uses. This paper describes the methods and results of this project performed in parallel with efforts by the TCEQ to develop numerical criteria for some reservoirs. The major study findings were:

- For the nine study reservoirs, the existing uses appeared to be supported.

- Of the major nutrients (N and P) and response variables (chlorophyll *a* and water clarity), the parameter most directly related to uses and criteria development was chlorophyll *a*.

- For reservoirs with little anthropogenic impact, it might be appropriate to set criteria to maintain the current levels of chlorophyll *a*—in effect an anti-degradation criterion.

- There is a measure of conflict in the level of use support and the concentration of chlorophyll *a*. The swimming and water supply uses are better supported by water with lower chlorophyll *a* concentration, while the sport fishing use benefits from a somewhat higher concentration. For reservoirs where there may be a need to set a chlorophyll *a* criterion lower than current levels, a method to achieve an optimal balance of use protection is needed.

- The example of the regional water planning groups, with vetted representatives of all major uses, would appear to be a good way to obtain the detailed local knowledge needed to determine the best balance for overall use support.

KEYWORDS

Nutrients, reservoirs, aquatic life use, recreation use, water supply use, eutrophication, trophic state

INTRODUCTION

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 for selected reservoirs in the Trinity River Basin. The study was supported by the Clean Rivers Program (CRP) of the Texas Commission on Environmental Quality (TCEQ).

METHODOLOGY

Nine reservoirs in the Trinity River Basin were selected for detailed study based on geographic, land use and size diversity, and data availability factors. These are shown in Figure 1. Details of the reservoirs and available data are provided in Table 1. 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 Corps of Engineers, 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.

Data were retrieved from a range of sources including the CRP, Texas Parks and Wildlife Department (TPWD) that manages the fisheries in each reservoir, approximately 40 organizations that treat and 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.

The nine study reservoirs all currently have these three designated uses in the Texas Surface Water Quality Standards. Table 2 shows the uses and the numerical criteria that are now in the

Figure 1 - Selected Reservoirs for Study

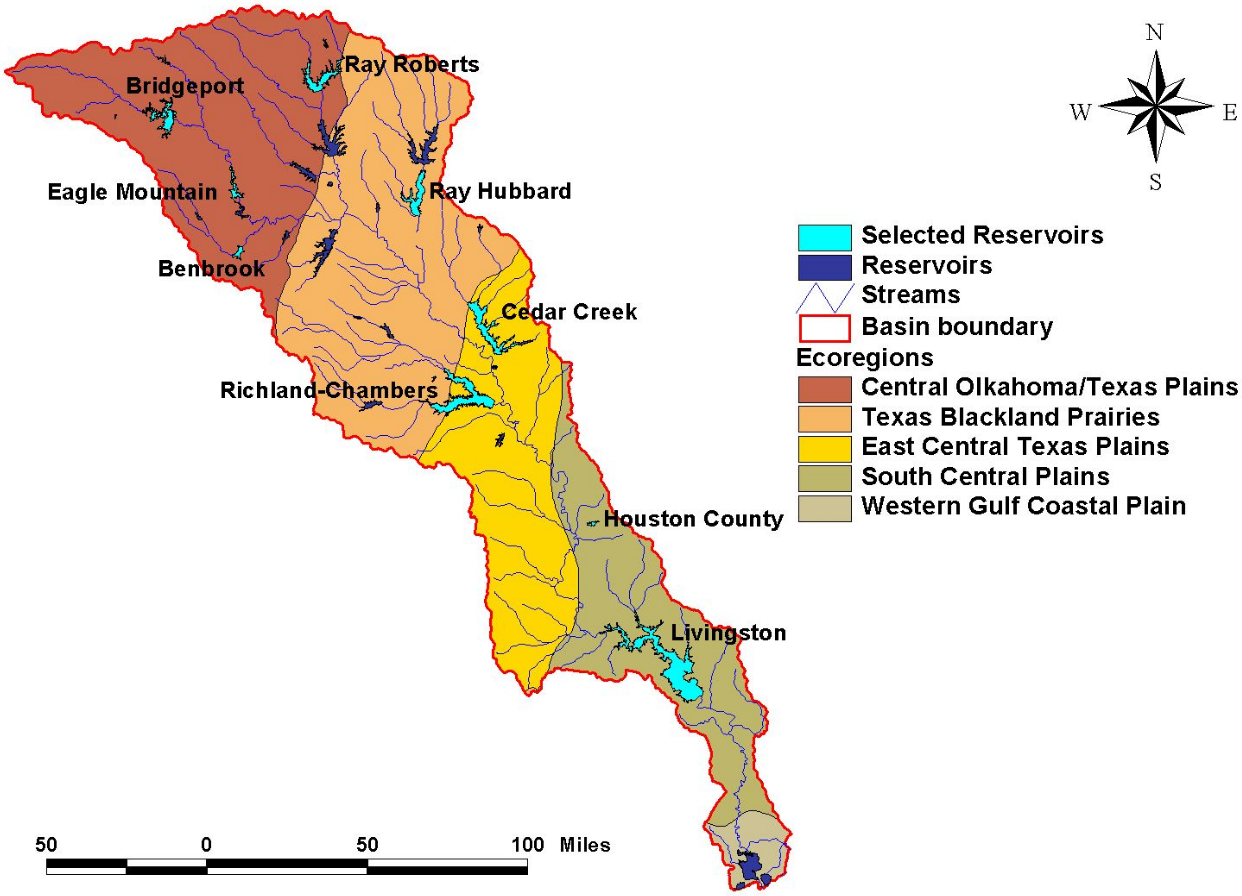


Table 1 - Study Reservoir Details

RESERVOIR	INTENDED USES			LAKE SIZE (ac) [1]	WTRSHD SIZE (mi^2) [2]	WTRSHD LANDUSE	AGE (yrs)	FEDERAL AGENCY	LOCAL CONTACT	YIELD (mgd) [3]	% YIELD FROM POINT SOURCE	EST POINT SOURCE (mgd)	WQ DATA AVLBLTY [4]	Chlorophyll *a*		TP		TCEQ TSI RANK ADJ [5]
	WATER SUPPLY	FLOOD CNTRL	RECRE-ATION											Ave (µg/L)	Num of data	Ave (mg/L)	Num of data	
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.

Table 2 - 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.

Standards. It can be seen that all reservoirs have identical designated uses and there are small differences in some of the numerical criteria. With minor departures, all of the current uses are attained by the nine study reservoirs.

The following section describes the results of the investigations into the available data on these uses, the criteria and the attainment status for the study reservoirs. In the analyses that follow, all nutrient and response parameter data are evaluated. As the study progressed it became clear that the nutrients themselves were not directly related to uses, and water clarity was affected by many things. It was concluded that chlorophyll *a* was the best parameter for assessing use support and the leading candidate for numerical criteria development.

RESULTS

These sections describe basic results and general findings under the three broad use categories.

Recreational Uses

The only recreation use now designated in the standards is Contact Recreation. The specific criteria associated with that use are for indicator bacteria. The criteria (there are two for the moment as Texas is in the process of changing from the older fecal coliform 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. The main bodies of all of the study reservoirs meet the water quality criteria for contact recreation by a comfortable margin (PBS&J, 2003).

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.

Sport fishing activities are a major component of recreational use in Texas reservoirs. For this study the sport fishing use is considered under the aquatic life category 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.

Some of this more complete list of recreational activity may be related to nutrient levels, at least to some degree. A search was made for recreation participation data in the various activities and any relation that might exist with nutrient levels. However, recreation participation data were only maintained for two reservoirs, Benbrook and Ray Roberts (USACE, 2003), and these did not differ greatly in nutrients or chlorophyll *a*.

The primary conclusion drawn from extensive literature review and local experience was that participation does not appear to be greatly affected by the level of nutrients. The main factors appear to be proximity to population centers and the availability of facilities. 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.

While the data available did not support a quantitative relation between recreational uses and the concentration of chlorophyll *a*, literature and an examination of extreme conditions suggest that more water clarity is desirable for recreational pursuits. The study being conducted through the Texas Water Conservation Association (TWCA) and participating river authorities should improve our level of understanding of this issue.

Aquatic Life Use

All of the study reservoirs are currently designated to support a "High" aquatic life use (Texas Surface Water Quality Standards, TNRCC, 2000). The criteria associated with this use are dissolved oxygen, 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 (TNRCC, 2002). Almost without exception, these criteria are attained in the study reservoirs.

The analysis focused on two major areas, fisheries and biological criteria. Biological criteria for streams, as a measure of aquatic life use 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 supplied by a freshwater stream.

The situation is fundamentally different for reservoirs that 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.

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-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.

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 Indices of Biotic Integrity (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.

Nutrients and Fishery 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 total phosphorus 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

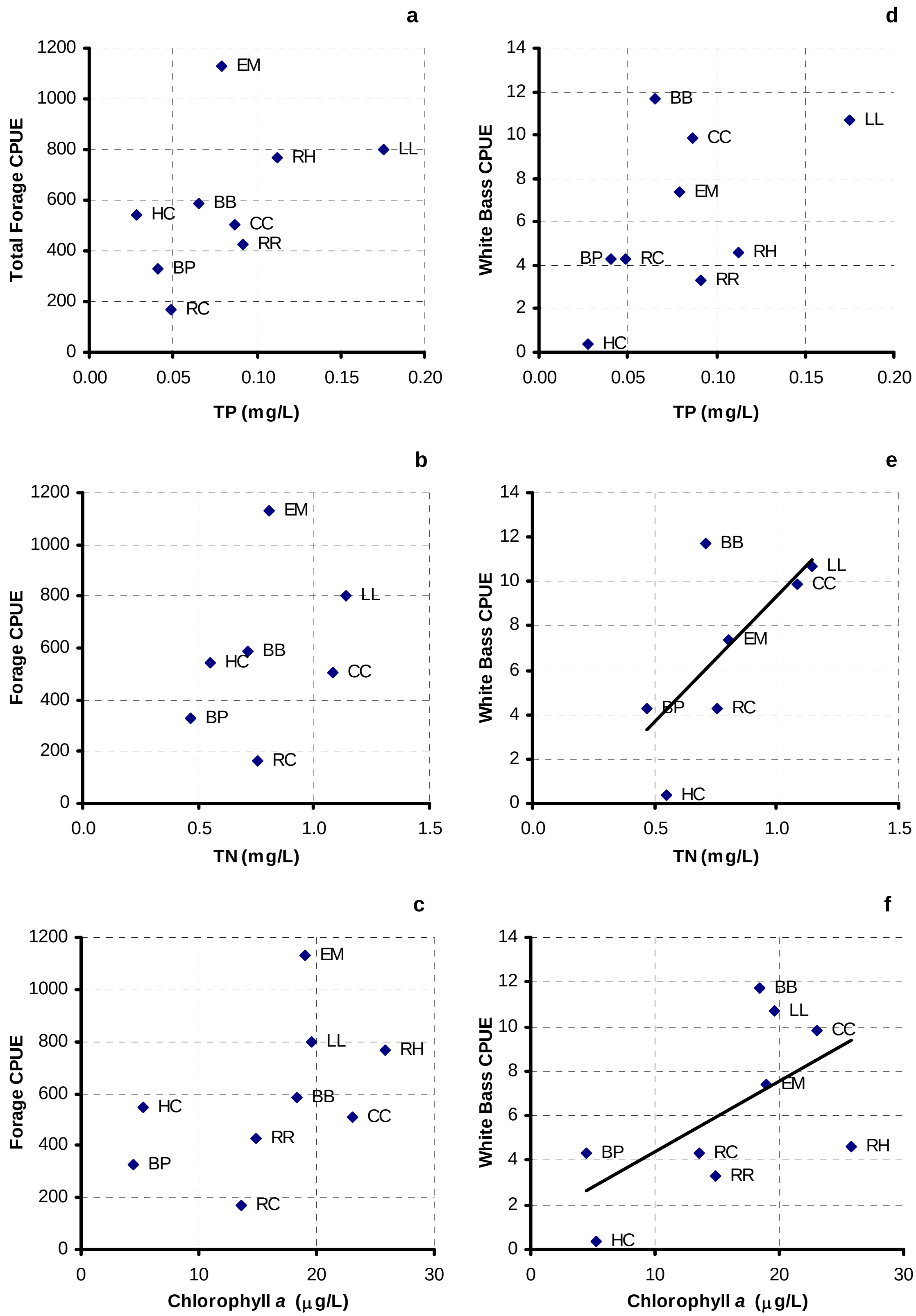
1988). The reverse of this situation is also true. Lower nutrient and chlorophyll *a* concentrations with increasingly clear water decreases fish production, which is important to note for lentic systems managed for recreational fishing.

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. Catch-per-unit-effort (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. 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, total phosphorus (TP), and total nitrogen (TN). A sampling of results is shown in Figure 2a-l.

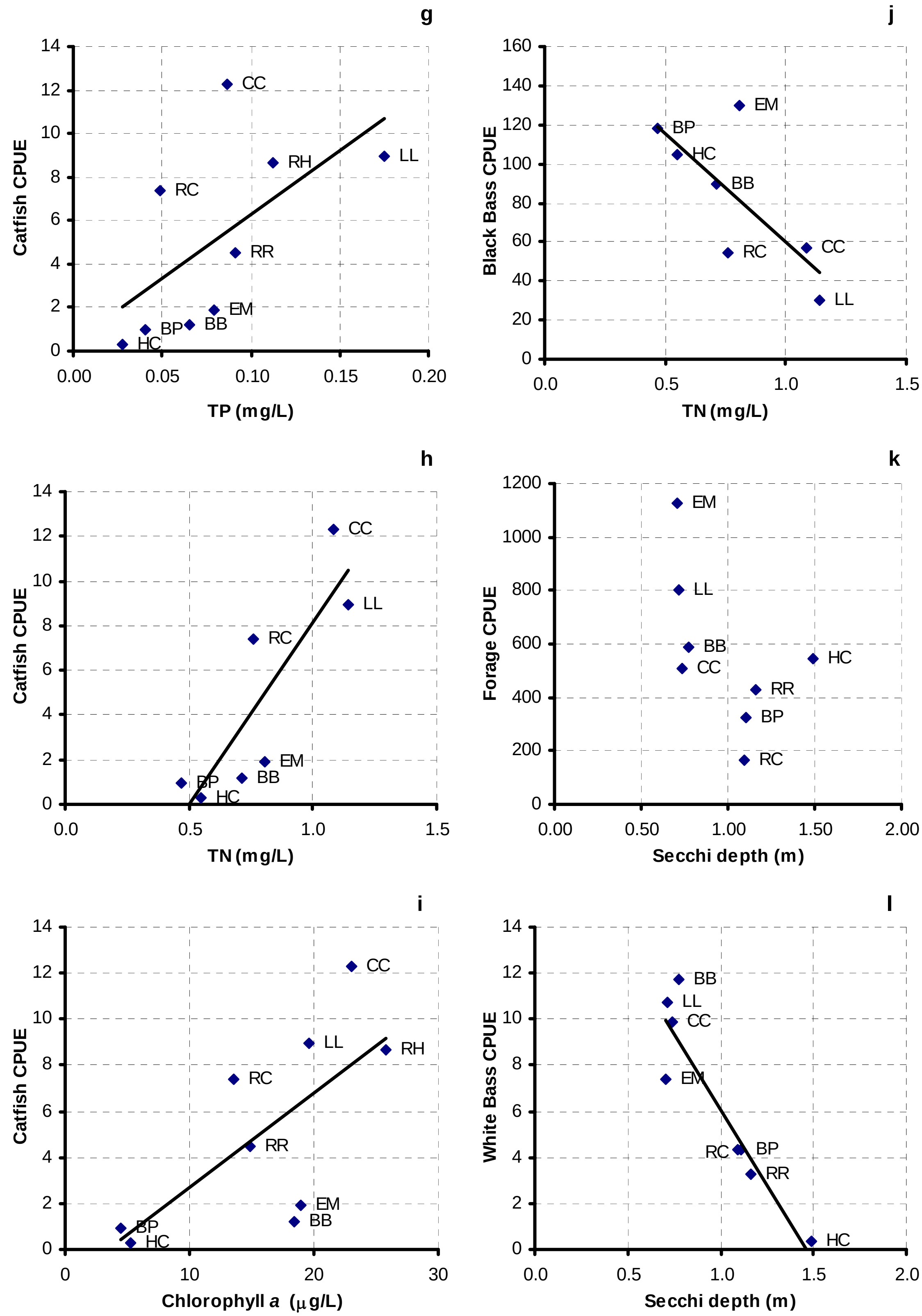
Methods for evaluating habitats in streams have been well established and are a step widely recognized for community analysis (TNRCC, 1999; EPA, 1989). However, means of quantifying reservoir physical habitat for use attainability analysis have been less well developed. To test the extent that littoral 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 3 presents the components of the PHQI developed for this project, as applied to the study reservoirs. 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.

Figure 2 – 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, Bridgepor
LL, Lower Livingston; RH, Ray Hubbard; RR, Ray Roberts; RC, Richland-Chambers.

Figure 2 – Relationship Between Fisheries Indices and Water Quality Variables (Concluded)
(Regression lines are shown when significant at 90% confidence level)



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

Table 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 Development Ratio	2	2	3	2	3	2	3	2	3
Percent Woody Cover	3	2	3	2	1	3	1	2	2
Percent Gravel or Larger	1	1	1	2	1	1	4	1	2
Score	**10**	**6**	**8**	**9**	**5**	**11**	**9**	**6**	**8**

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.

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. 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. While not evident in the study reservoirs, there is no doubt that very high levels of chlorophyll *a* can produce undesirable effects previously mentioned. 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.

Water Supply Use

All of the study reservoirs, and most of the reservoirs constructed in the nation, were built with water supply as one of the intended uses. Other important uses such as flood control and hydroelectric generation are not considered here. The water from all of the water supply reservoirs in Texas require treatment before it can be used as a potable supply by the public. The amount of treatment and the cost of that treatment can vary depending on the quality of the water. The subject of the analysis was the effect of nutrients and chlorophyll *a* on the amount of treatment required and the cost of the treatment. The most common mechanism where algae levels affect the water supply is through phytoplankton such as blue-green algae that can cause taste and odor problems.

In a survey of water suppliers in the nine study reservoirs, questions were asked as to the treatment system employed and whether there were problems encountered with taste or odor. If such problems were reported, inquiries were made as to how it was handled. Most of the respondents reported having to deal with taste and odor problems. The following adaptations or modifications 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 additional coagulant,
- Use copper sulfate for algal control,
- Use of activated carbon (granular or powdered).

In addition to these different methods, questions were also asked as to the additional cost of treatment incurred to deal with taste and odor when it was noted.

In examining the relation between reported taste and odor problems and the levels of nutrients and chlorophyll *a* in the water supply reservoirs, there was no obvious relationship. Additional analyses were conducted with detailed quantitative information on the reports of taste and odor problems and level of nutrients and algae (PBS&J, 2003). There were limited data on the observations of Geosmin and 2-methylisoborneol (MIB) that indicated a limited degree of correspondence between these taste and odor parameters and the overall concentration of chlorophyll *a*.

The investigation of relations between water supply use and the levels of chlorophyll *a* confirmed two points. One is that while there is much variability, there is some relation between higher chlorophyll *a* and additional treatment to produce a quality product. The other is that the water treatment systems are able to deal successfully with the variation and taste and odor concerns in the study reservoirs. The data reviewed does not indicate there is a chlorophyll *a* limit beyond which treatment is ineffective and the water supply use is not supported.

DISCUSSION

The analysis of use and nutrient data for nine study reservoirs yielded valuable information on a number of points. Some of the major findings were:

Use Support — All of the study reservoirs are heavily used for recreation, water supply, and support healthy aquatic life communities. By that measure, all the reservoirs supported their designated uses. Some water quality stations on arms or tributaries to the reservoirs had different values that were higher than screening values employed by the TCEQ, but the main body stations were generally lower than the screening levels.

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. 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.

Figure 3 – Theoretical Relation Between Chlorophyll *a* and Level of Use Support for Swimming & Aesthetic Appreciation

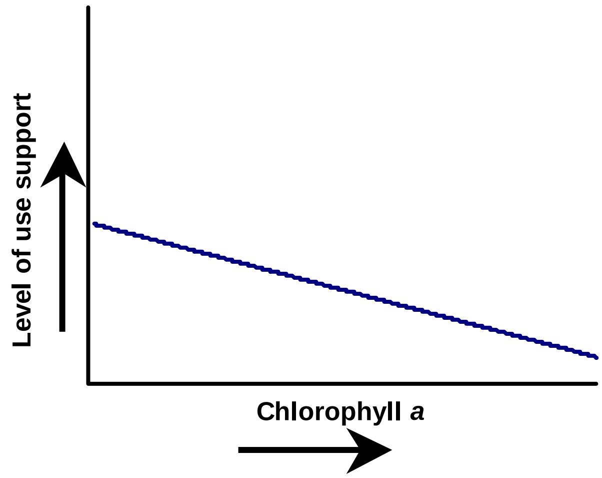
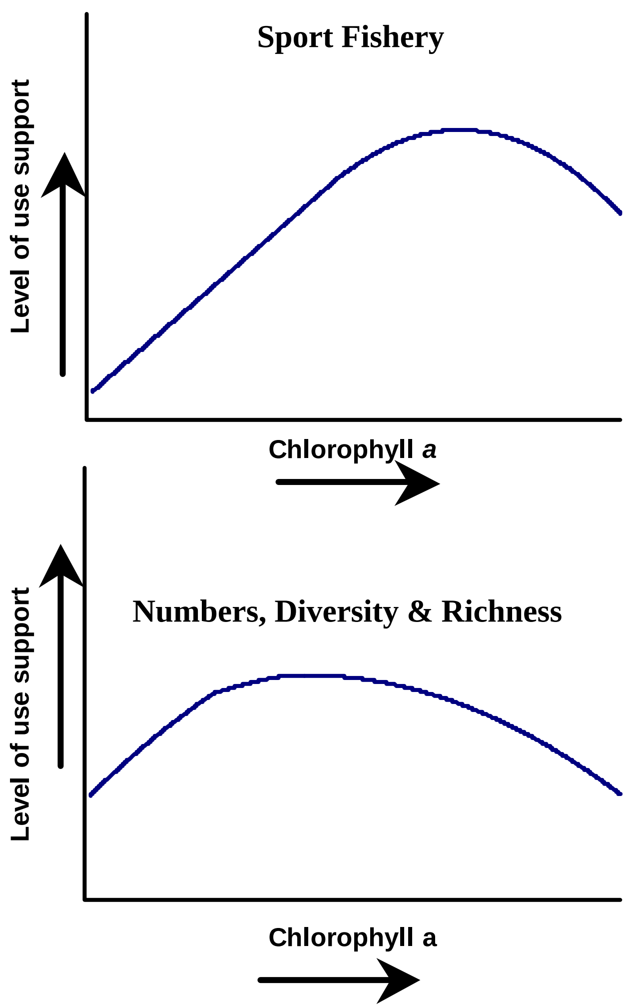


Figure 4 – Theoretical Relation Between Chlorophyll *a* and Level of Aquatic Life Support

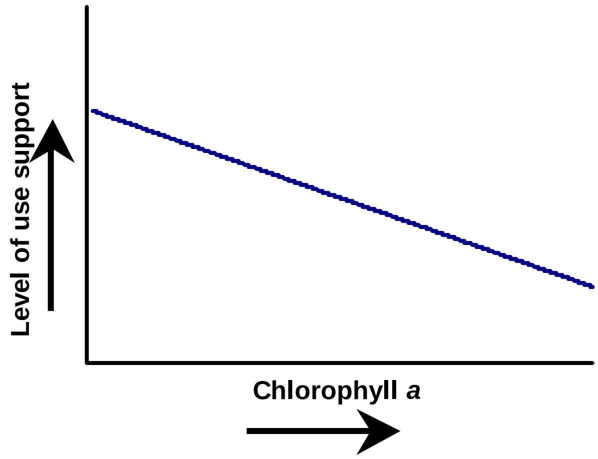


With recreation, including swimming, boating, skiing and aesthetic appreciation, it is well understood that better water clarity, as represented by lower chlorophyll *a* levels, should have a higher level of use support. This is illustrated graphically as a decline in the level of use support with higher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

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.

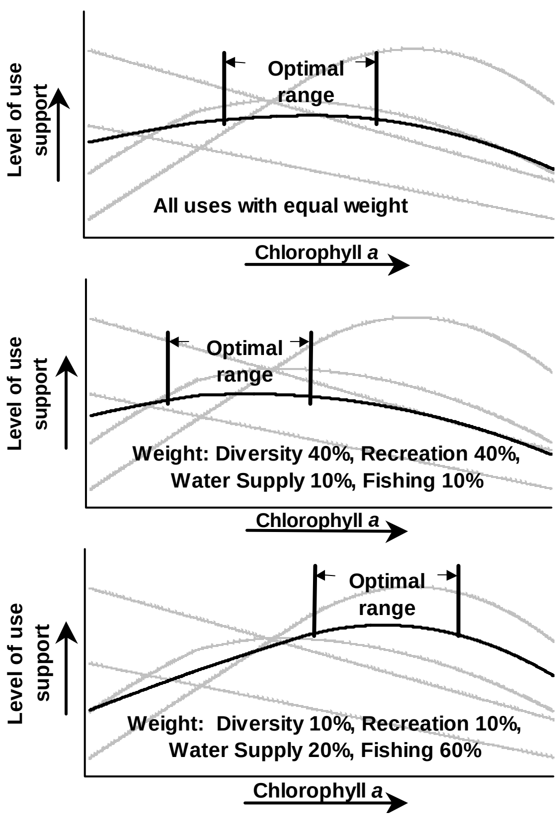
Another dimension of aquatic life use support is species diversity and richness. While we could locate no studies of reservoirs specific to this topic, biological experience suggests that species diversity or richness would probably peak at an average chlorophyll *a* level less than what would be expected 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.

Figure 5 – 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.

Figure 6 – Theoretical Relation Between Overall Level of Use Support and Chlorophyll *a*



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 specific criteria and screening levels for coves and arms to more accurately reflect their specific conditions.

CONCLUSIONS

The EPA initiative of requiring states and tribes to develop numerical nutrient criteria has spurred this analysis of use and nutrient data in the Trinity River Basin. The main conclusions are that the uses are supported by the present level of nutrients, but there is no assurance that the present levels are necessarily optimal to maximize the overall level or degree of use support. For example, some of the impacted reservoirs (those with more than 10% of their watersheds in row crop or urban use, or those having a large wastewater source) might improve the overall level of use support with reductions in nutrient inputs. Conversely, some of the less impacted reservoirs might see improved fishery and overall support with more nutrients. If the decision is made to determine an optimal level that best supports the particular mix of uses for a given reservoir, there are methods available that can achieve that end.

ACKNOWLEDGMENTS

This study was conceived by the partners in the CRP, and supported by CRP funding through the TCEQ. An important feature of the study is that it relied on water chemistry data from both the CRP and fisheries data from the TPWD. In particular we want to recognize the data and technical assistance provided by the TPWD offices in Denison, Fort Worth, Tyler and Bryan. The City of Houston also made a significant data contribution to the study. Finally, we want to recognize the efforts made by members of the Technical Steering Committee for the study. This included providing data and suggesting technical direction during the study.

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Least Impacted Reservoir Screening Method

Data Source

Land use cover data for this project covers data from 1990-1992 and was acquired from the National Landcover Characterization Dataset, which can be found on the USGS website at http://seamless.usgs.gov.

Toby Welborn of the USGS TX District (512-927-3567 twelbor@usgs.gov) can provide detailed (but not yet published) metadata.

Least Impacted Reservoir Determination

Least impacted reservoirs are those with the following characteristics. The land use characteristics must be met for both the reservoir's Area of Primary Influence or API (see below) and the reservoir's watershed. All land use percents are only in terms of total land, i.e. water acres excluded.

1. Less than 10% urban land use
   (high intensity residential, low intensity residential, urban/recreational grasses, and commercial/industrial/transportation land uses).
2. Less than 10% agriculture land use
   (orchards/vineyards, row crops, small grains, and fallow)
   (The pasture/hay land use is not included in the above groups)
3. No major domestic discharges to the watershed's segment. A major domestic is a municipal facility discharging greater than 1.0 MGD.
4. No major domestic discharges to the watershed's upstream segment(s). EPA's enviromapper was used to determine if there were major domestics (greater than 1 MGD) on the truncated upstream stream segments of the remaining list of lakes.

Determination of the API

This API is defined as the area within 1,000 feet of a reservoir and within 1,000 feet of the downstream reaches of streams entering the reservoir. The upstream boundary of a stream reach used for the API is determined by estimating 2-hour travel times (the water in the stream must reach the reservoir within 2 hours during a 2-year flood discharge). These estimates are made for each of 11 Texas hydrologic regions (Asquith and Slade, USGS Water Resources Investigation Report 96-4307).

January 23, 2004
Nutrient Criteria Development Workgroup III

Potentially Impacted Reservoirs - Urb/Ag Land Use >10%[1]		
RESERVOIR	%	COMMENTS
Aquilla Reservoir	27	
Bardwell Reservoir	28	
Brady Creek Reservoir	23	
Bryan Municipal Lake	76	
Buffalo Springs Lake	13	
Cedar Creek Reservoir [4, 6, 7]	12	
Cox Lake	12	
E.V. Spence Reservoir	17	
Eagle Mountain Reservoir [4, 7]	18	
Fin Feather Lake	82	
Granger Lake	28	
Greenbelt Reservoir	36	
Joe Pool Lake	25	
Lake Arlington	59	
Lake Arrowhead	12	
Lake Austin	16	
Lake Brownwood	11	
Lake Coleman	20	
Lake Colorado City	29	
Lake Crook	14	
Lake Fort Phantom Hill	27	
Lake Graham	23	
Lake Granbury	17	
Lake Houston	13	
Lake Kemp	19	
Lake J.B. Thomas	42	
Lake Kickapoo	13	
Lake Livingston [4, 5, 6, 7]	17	
Lake Lyndon B. Johnson	11	
Lake Mackenzie	17	
Lake Nasworthy	31	
Lake Ray Hubbard [4, 5]	23	
Lake Ray Roberts	13	
Lake Stamford	27	
Lake Sweetwater	14	
Lake Tanglewood [4, 5, 6, 7]	64	

Potentially Impacted Reservoirs - Urb/Ag Land Use >10%[1]		
Lake Texana	15	
Lake Texoma	36	
Lake Theo	14	
Lake Waxahachie	24	
Lake Weatherford	14	
Lake Whitney	40	
Lake Wichita	23	
Lake Worth	19	
Leon Reservoir	14	
Lewisville Lake	23	
Millers Creek Reservoir	17	
Navarro Mills Reservoir	32	
O.H. Ivie Reservoir	31	
Oak Creek Reservoir	17	
Palo Duro Resevoir	10	
Pat Cleburne Reservoir	14	
Pat Mayse Reservoir	16	
Proctor Lake	21	
Town Lake	67	
Twin Buttes Reservoir	13	
White Rock Lake	73	

Potentially Impacted Reservoirs - Major Domestics[2]	
RESERVOIR	COMMENTS
Belton Reservoir	
Benbrook Lake [4]	
Choke Canyon	
Falcon Lake	
Grapevine Reservoir	
Lake Anahuac	
Lake Lavon	
Lake Meredith	
Lake O' The Pines	
Lake Palestine	
Lake Tawakoni [4, 6]	
Lake Tyler east	
Lake Waco [4, 5]	
Possum Kingdom Reservoir	
Richland-Chambers Reservoir [4,5]	
Toledo Bend Reservoir [4, 6]	
White River Lake	

Least Impacted Reservoirs[3]	
RESERVOIR	COMMENT
Amistad Reservoir	
B. A. Steinhagen Reservoir	
Caddo Lake	
Canyon Lake	
Diversion Lake	
Ellison Creek Reservoir	
Farmers Creek (Nocona Lake)	
Houston County Lake	
Hubbard Creek Reservoir	
Inks Lake	
Lake Amon G. Carter	
Lake Bob Sandlin	
Lake Bridgeport	
Lake Buchanan	
Lake Cherokee	
Lake Cisco	
Lake Conroe	
Lake Corpus Christi	
Lake Cypress Springs	
Lake Fork Reservoir	
Lake Georgetown	
Lake Jacksonville	
Lake Limestone	
Lake Marble Falls	
Lake Mexia	
Lake Murvaul	
Lake Palo Pinto	
Lake Travis	
Lake Tyler	
Medina Lake	
O.C. Fisher Reservoir	
Red Bluff Reservoir	
Sam Rayburn Reservoir	
Somerville Lake	
Stillhouse Hollow Lake	
Wright Patman Lake [4, 7]	

Footnotes

1	Number following lake name is % of urban and agricultural land use within the 2-hour travel time of reservoir and/or upstream segment
2	Major domestics (>1MGD) discharge to reservoir and/or upstream segment
3	Reservoirs with % of urban and agricultural land use less than 10% and with no major domestics
4	Reservoirs with secondary concerns for chlorophyll a from the 305B report
5	Reservoirs with secondary concerns for chlorophyll a & NO3 + NO4 from the 305B report
6	Reservoirs with secondary concerns for chlorophyll a & Orthophosphorus from the 305B report
7	Reservoirs with secondary concerns for chlorophyll a & total phosphorus from the 305B report