INVESTIGATIONS INTO THE RELATIONSHIP BETWEEN WATER-COLUMN ALGAL CONCENTRATIONS AND USER PERCEPTIONS OF THE SUITABILITY OF LAKE LIVINGSTON FOR RECREATION AND AESTHETIC ENJOYMENT

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Executive Summary

The goal of this study was to determine if user perceptions of the suitability of Lake Livingston for recreational and aesthetic enjoyment are related to water quality. Specifically, the study tested the hypothesis that user perceptions would become less favorable as concentrations of algae increased.

To accomplish this, water quality samples were collected simultaneous to the administering of surveys to individuals recreating on the reservoir. Surveys and water quality data were collected over the spring and summer of 2003 and 2004 at two locations on Lake Livingston; one in the headwaters and one in the main body.

Analyses of water quality data indicate that Lake Livingston is a hypereutrophic reservoir with high concentrations of nutrients, algae and suspended solids. Algal growth was determined to be light limited. The headwater site demonstrated a relationship between suspended solids and inflows to the reservoir.

Analyses of surveys indicated that users could perceive changes in algal concentrations. However, this relationship was found to be valid only through the mid point of the survey's gradient-response scores; users were disinclined to answer with either D or E, the two most extreme responses in terms of the degree of greenness of the water.

No significant relationships could be found between algal concentrations and user perception of the suitability of the reservoir to support recreation and aesthetic enjoyment. Significant relationships were found however, between user perceptions and concentrations of suspended solids. As concentrations of suspended solids increased, users' responses became less favorable. This relationship was found to be true for all three species of suspended solids: total, volatile and inorganic.

The results of this study found no evidence to support the hypothesis that users' perceptions of Lake Livingston for recreation and aesthetic enjoyment are related to algal concentrations. This is believed to be due to the greater influence of non-algal turbidity on water clarity. Accordingly, there is no evidence of algal-induced use impairment and therefore no support for the development of numeric nutrient or chlorophyll-a criteria to protect the contact recreation use. In addition, there is no evidence to support the notion that numeric nutrient or chlorophyll-a criteria would increase user satisfaction.

Introduction

The U.S. Environmental Protection Agency (EPA) has directed the states to develop numerical criteria for nutrients in surface waters. Each state was required to demonstrate significant progress in this regard by December 2004. In response to this requirement, the Texas Commission on Environmental Quality (TCEQ) has committed to issue draft numerical nutrient criteria for major reservoirs.

The Clean Water Act specifies that water quality standards should be based upon the protection of identified uses. Unfortunately, there is little research that documents quantifiable relationships between the effects of excess nutrients and impacts on uses. In most Texas reservoirs, recreational use is a primary use. This is despite the fact that the majority of Texas reservoirs were not specifically built for recreation. However, no research has been identified that relates impacts attributable to nutrients to recreational use impairment in Texas reservoirs (PBS&J, 2002).

The objective of this study is to determine if relationships exist between perceptions of recreational users regarding the suitability of Lake Livingston for recreation and chlorophyll-a concentrations. Additionally, should relationships be found to exist, efforts would be explored as to how to quantify them.

Lake Livingston is located in the lower reaches of the Trinity River. It is the largest reservoir within the Trinity basin with a surface area of 83,277 acres and a volume of 1,741,867 acre-feet. The primary uses of Lake Livingston are drinking water supply and recreation (e.g. fishing, boating, jet-skiing, etc...). Average summer chlorophyll-a concentrations are approximately 20.2 ug/L with average summer total phosphorus concentrations of 306 ug/L.

Fundamentally, the study design is based upon coupling user surveys regarding the suitability of the reservoir for recreation with analyses of water chemistry data collected simultaneous to the surveys.

Study Design

The study design is based upon similar studies conducted in several other States (Heinskey & Walker, 1988; Smeltzer & Heinskey, 1990). Borrowing from these previous studies, the study design was created by a group of professionals from Texas water agencies, with direct input from Dr. William Walker. Participating agencies included Alan Plummer and Associates, Inc, the Brazos, Guadalupe-Blanco, Lower Colorado , Sabine, San Antonio and Trinity River Authorities, and the Tarrant Regional Water District.

Station Locations

Two locations were identified on Lake Livingston: station 10911 at the US 190 bridge and 10899 at the Lake Livingston State Park (Figure 1). Samples for analysis of water quality variables were collected by boat near shore at these locations while surveys were administered on shore.

Water quality conditions at station 10911 are representative of headwater conditions. Algal concentrations, based upon historical data, are typically high at this location. In contrast, station 10899 is located in the main pool of the reservoir. Algal concentrations at this site are typically much lower than at station 10911. These two disparate locations were selected in order to maximize the range of algal concentrations under which surveys were administered. Having a broad range of algal conditions is paramount to determining changes in user perceptions based upon algal concentrations.

Water Quality Sampling

Sampling was conducted at two locations twice per month from June through September of 2003 and April through September of 2004. Samples were to be collected two weeks apart, however this was not always possible. Sampling was not conducted immediately after rain events. Water quality sam-

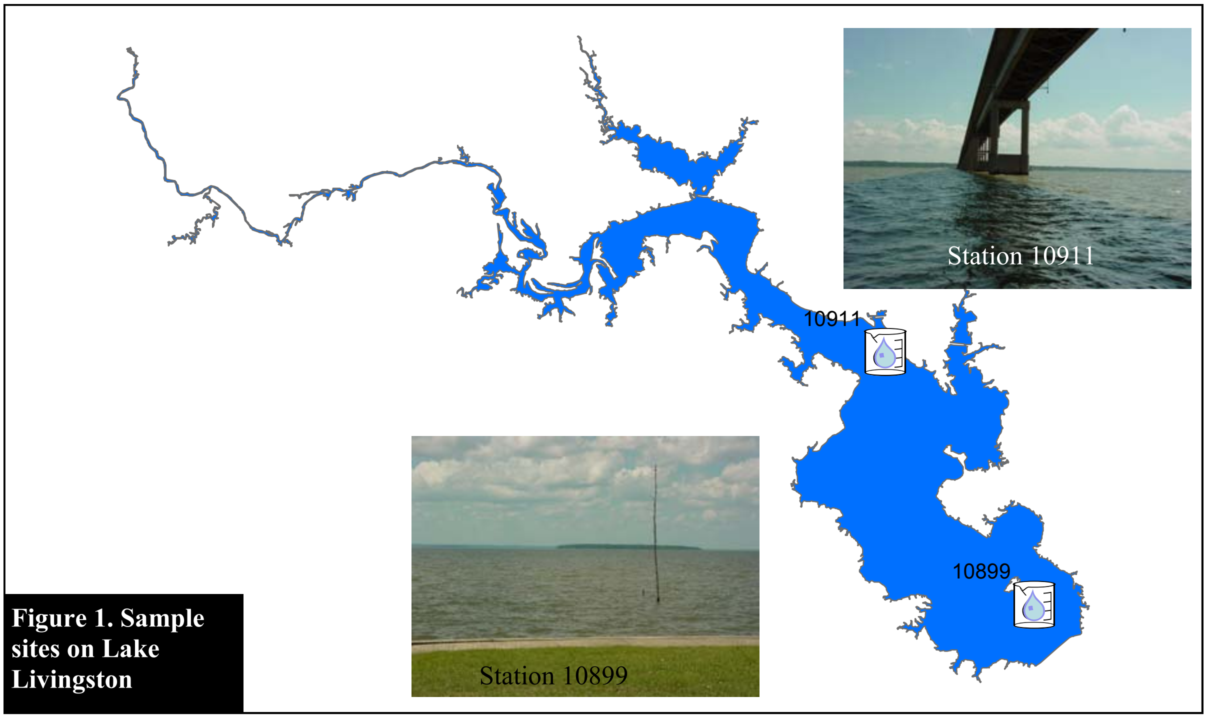

Figure 1. Sample sites on Lake Livingston

ples were analyzed for nitrogen, phosphorus, chlorophyll-a, turbidity, and suspended solids (see Table 1 for a complete list). Samples were composited from depths of 0.3, 1, and 2 meters.

Chlorophyll-a samples, used as a surrogate for algae, were collected in duplicate during each sampling effort. One set (including additional duplicates at a rate of 50%) was field filtered, frozen and submitted to the LCRA Environmental Laboratory for analysis. The second set was not field filtered or frozen, and was analyzed at the Lake Livingston Project laboratory. Field measurements were recorded for dissolved oxygen (DO), temperature, pH, Secchi disc depth, and specific conductivity.

Table 1. Water Quality Variables Analyzed

Algae	Nutrients	Clarity
Chlorophyll-*a*	Nitrate	Suspended Solids, Total
Pheophytin	Nitrite	Suspended Solids, Volatile
	Total Kjeldahl	Turbidity
	Phosphorus, Total	

All samples were collected and analyzed according to standardized procedures as detailed in Appendix J of the Trinity River Authority of Texas Quality Assurance Project Plan, Revision 2, dated November 1, 2003.

Surveys

On each day that water quality samples were collected, surveys were administered to individuals recreating in the immediate vicinity. Surveys were administered to at least five recreators per site. In addition, two members of the LLP field staff completed surveys at each of the two sampling sites. In this manner, a minimum of seven surveys were completed per site.

The user survey is designed to document the user's opinion of the physical condition of the waterbody based on its appearance and the level of algal growth on that day and to document the user's perception of how suitable the water conditions are for recreational use and aesthetic enjoyment.

The survey consisted of five basic questions (Figure 2). Questions 1 and 2 are designed as gradient responses to gage the degree to which recreators perceive the water as green (question 1) and is suitable for recreation and aesthetic enjoyment (question 2). There are five possible responses for both. For question 1, the answers range from a. "*no algae present (beautiful water conditions)*" to e. "*extremely high algae levels with floating scum or foul odor (recreation and aesthetic enjoyment nearly impossible)*." For question 2, the answers rage from a. "*beautiful, could not be any nicer*," to e. "*swimming and aesthetic enjoyment of the lake is nearly impossible.*" Question 3 is a follow-up to question 2, and attempts to determine if perceived impairment is caused by algae or non-algal turbidity. Question 4 documents the frequency with which the individual recreates at the reservoir while the fifth and final question determines the user's primary recreational activity.

Survey data results were compiled,

Recreational Use Survey

Reservoir ______________________________ ***Date*** ________________

Site __________________________________ ***Time*** ________________

1) Please circle the one response that best describes the physical condition of the lake water today:

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

2) Please circle the one response that best describes your perception of how suitable the lake water is for recreation and aesthetic enjoyment today:

a) Beautiful, could not be any nicer
b) Very minor aesthetic problems; excellent for swimming, boating enjoyment
c) Swimming and aesthetic enjoyment slightly impaired
d) Desire to swim and level of enjoyment of the lake substantially reduced
e) Swimming and aesthetic enjoyment of the lake nearly impossible

3) If you circled c, d, or e in Question No. 2 above, please indicate the factor that most affected your answer:

a) Muddiness
b) Algae/greenness
c) Other (please specify) ____

4) How many times a year do you visit the lake? (Circle one response)

a) Permanent resident
b) More than six times per year
c) Two to six times per year
d) Typically every year
e) This is my first visit

5) Please circle the activity that best describes your primary activity <u>today</u>:

a) Swimming ***d) Skiing/Windsurfing***
b) Fishing ***e) On-Shore Activity (camping, picnicking, etc.)***
c) Boating ***f) Other or non-recreational (please specify)***

____

Survey Code No. __________

Official Use Only

Figure 2. User survey.

computerized and reviewed for accuracy on a 100% basis. User responses were then compared to corresponding water chemistry measurements. Comparisons included analyses of frequency distribution graphs of user responses for questions one and two v. water quality parameters, and analyses of variance to test for differences among user responses. Analyses were also conducted to determine if various recreational activities are more or less sensitive to water quality conditions and if user perceptions are a function of the frequency of visitation to the lake.

In addition, simple and multivariate regression analyses of water quality variables, including flow, were performed to test for relationships and to determine to what extent turbidity is a function of algal v. non-algal suspended solids.

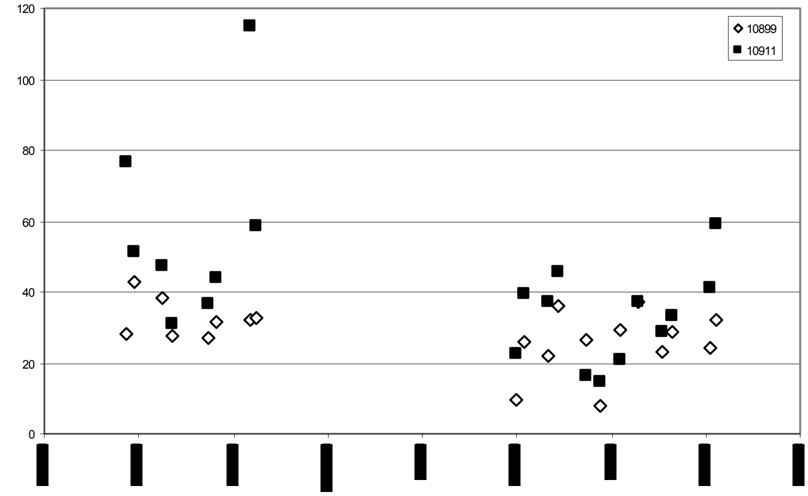

Figure 3. Chlorophyll-a v. time. The lower chlorophyll-a values recorded during the spring and summer of 2004 are believed to be the result of higher inflows experienced during that timeframe.

Results

Water Chemistry Analyses

Sampling conditions during the course of this study included a typical year in terms of precipitation and temperature (2003) and an extremely wet and mild year (2004). This provided data over a range of conditions, which, while introducing potentially confusing data, can also facilitate comparison of variables and make relationships more easily detectible.

Chlorophyll-a values ranged from 7.8 ug/L to 115 ug/L (Figure 3). Concentrations where generally higher at site 10911 and were higher in 2003 than in 2004. Both of these observations conform to expectations given that 10911 is in the headwaters of the lake and that the lower inflows of 2003 were associated with lower levels of non-algal turbidity; a fact which increased the amount of light available for algae.

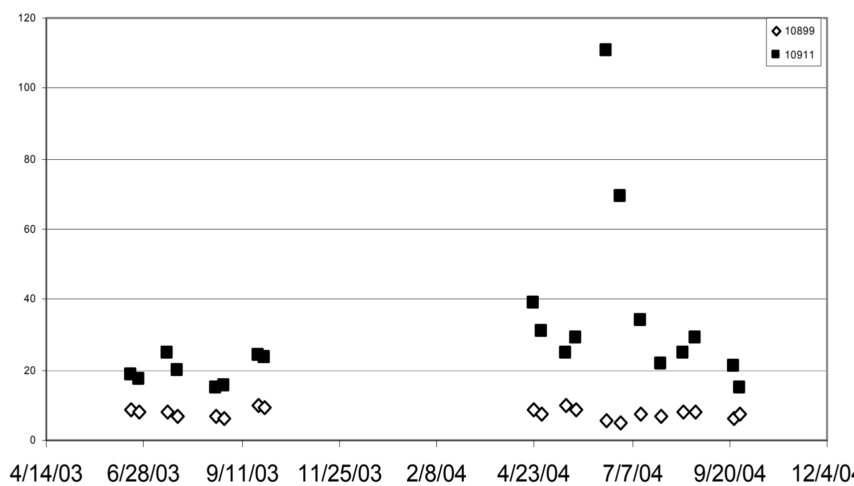

Figure 4 . TSS v. time. The higher TSS values recorded during the spring and summer of 2004 are believed to be the result of higher inflows experienced during that time frame.

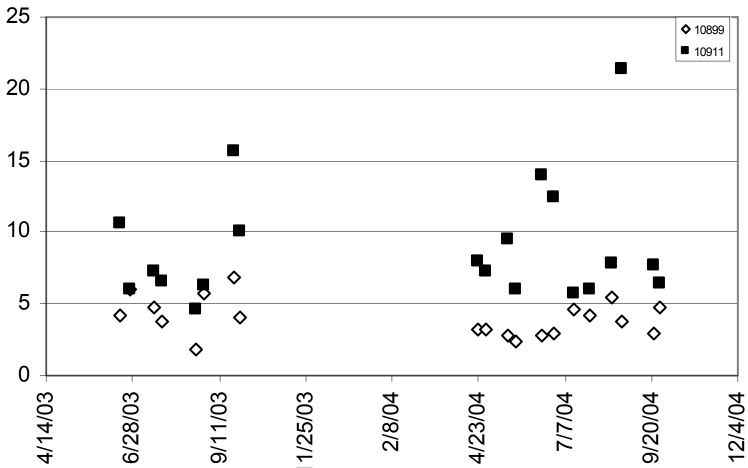

Figure 5. VSS v. time.

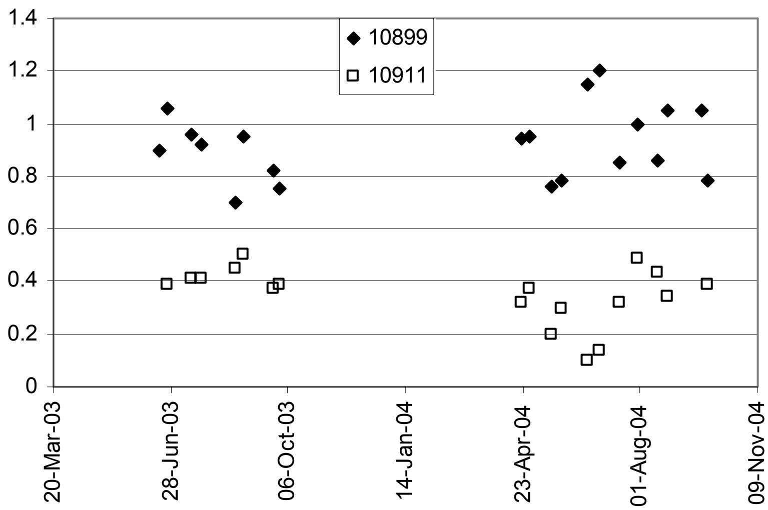

Figure 6. Secchi depth v. time.

TSS and VSS concentrations were also higher at site 10911 than 10899 (Figures 4 and 5). At station 10911, concentrations of both TSS and VSS were higher in the second year of sampling (2004). This can be directly linked to the increased flow volumes of that year, which brought suspended solids into the lake.

Secchi depth measurements were consistently greater at site 10899 than 10911 (Figure 6). This is typical of reservoirs, which tend to have greater clarity in the main pool towards the dam after suspended solids have had a chance to settle out.

Visually, it appears that clarity was greater in 2003 at site 10911 than in 2004, again a result of the higher flows of the latter year. No difference in Secchi depth is apparent between years at station 10899.

As had been expected, site 10911 was found to have higher concentrations of both inorganic and organic suspended solids and chlorophyll-a as compared to site 10899.

Relationships Among Water Quality Variables

Simple and multivariate regression analyses were conducted in order to characterize any existing relationships between chlorophyll-a, suspended solids and Secchi depth.

Multivariate regression analysis revealed that Secchi depth was significantly and negatively related to both ISS and VSS at both

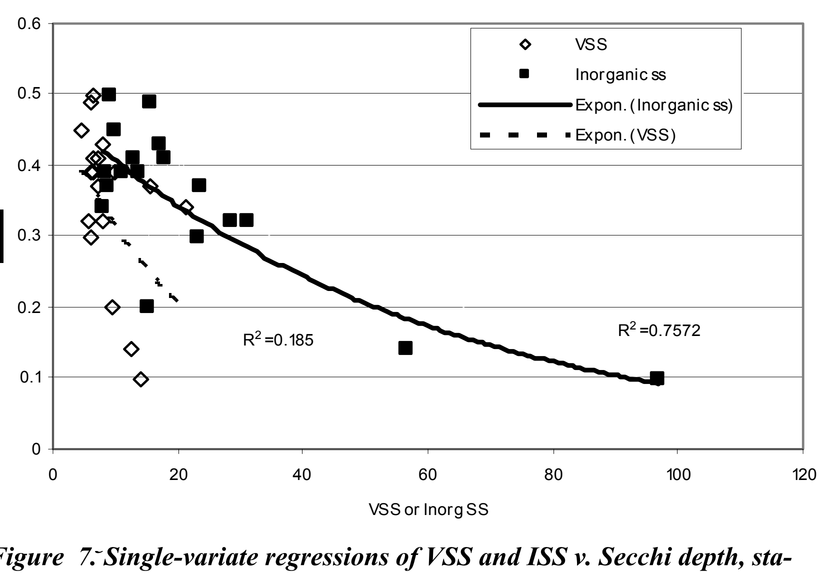

Figure 7. Single-variate regressions of VSS and ISS v. Secchi depth, station 10911.

station 10911 (Table 2) and at station 10899. Figure 7 shows the results of simple linear regressions between ISS and Secchi depth and VSS and Secchi depth at station 10911. Note the good fit of the regression line between ISS and Secchi depth in the simple regression analysis (R^2 is 0.76) and the high-significance of the p-value in the multivariate regression analysis. The relatively poor R2 in the remainder of the relationships indicates that, although a significant relationship exists, there is a tremendous amount of variability in Secchi depth that cannot be explained by TSS and VSS alone.

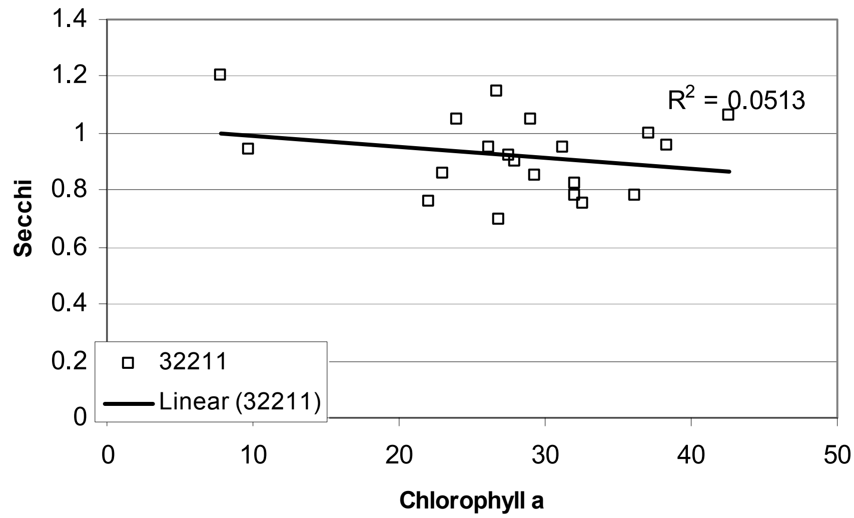

Figure 8. Simple regressions of chlorophyll-a v. Secchi depth, station 10899.

Table 2. Results of Multivariate Regression Analysis of VSS and ISS v. Secchi depth.

	Coefficients	Standard Error	*t*-Stat	P– value
Intercept	**1.367668**	0.145313	9.411892	3.736E-08
VSS	**-0.049813**	0.023309	-2.137019	**0.0474255**
Inorg. Ss	**-0.068251**	0.018662	-3.657228	**0.00195085**

Simple regressions were also performed between chlorophyll-a and Secchi depth (Figures 8 & 9). The relationship between Chlorophyll-a was not found to be significant at the alpha = 0.10 level for either site; p values were 0.34 for 10899 and 0.15 for site 10911. It is interesting to note that, at 0.15, the p value for site 10911 was close to significance, however the slope of the regression was positive. In other words, as chlorophyll-a concentrations increase at site 10911, so does secchi depth. This is of course counter to conventional wisdom, which says that as chlorophyll-a increases, clarity decreases. The reason for the positive slope at 10911 is that light is limiting to algal growth at that location. So as total suspended solids decrease, say during a long period of dry weather, clarity increases. As the clarity increases, there is more light available for algal cells, which then grow, increasing chloro-

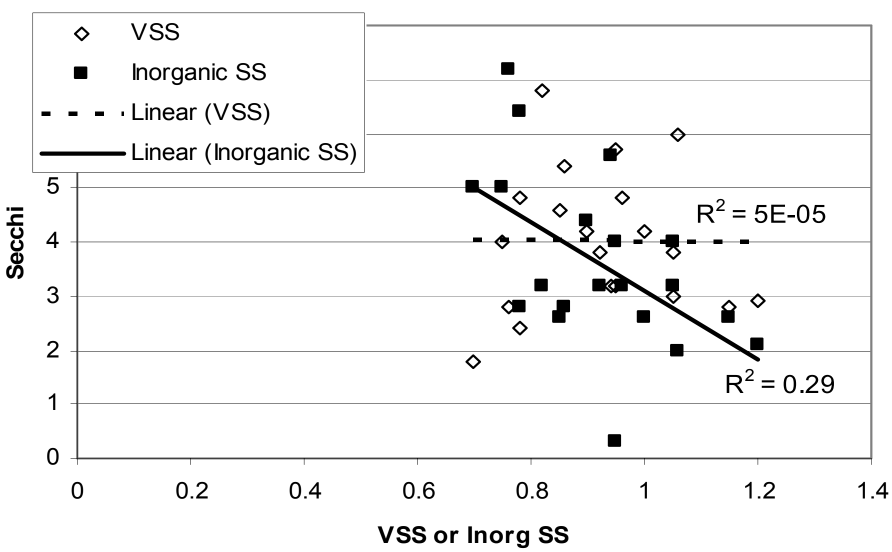

Figure 9. Single-variate regressions of VSS and ISS v. Secchi depth, station 10899.

Table 3. Results of Multivariate Regression Analysis of VSS and ISS v. Secchi depth, station 10899.

	Coefficients	Standard Error	*t*-Stat	P– value
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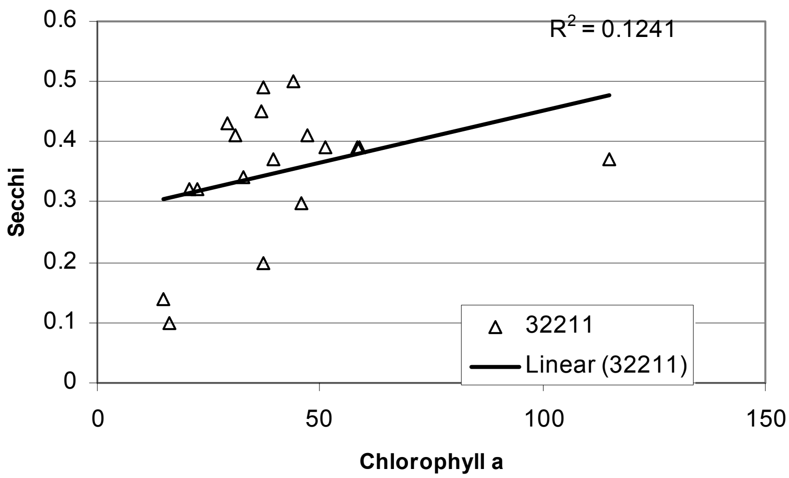

Figure 10. Chlorophyll-a v. Secchi. Note the positive slope indicating that Secchi depth (i.e. clarity) increases as chlorophyll-a concentrations increase.

phyll-a. Although increasing concentrations of algae decrease clarity through shading, the increase in clarity resulting from the decrease in suspended solids more than offsets this. It seems plausible that at some point the density of algal cells would cancel out the increase in clarity from the decrease in suspended solids. Indeed there is evidence of such a phenomenon occurring when chlorophyll-a concentrations reached 115 ug/L in the summer of 2004.

Influence of Flow on Water Quality Parameters

Four water quality parameters were analyzed to look for relationships with monthly averaged flow: chlorophyll-a, TSS, VSS and inorganic SS (ISS). Flow measurements were obtained from USGS gage 08065350; Trinity River near Crockett, Texas. Monthly flow values were determined by averaging daily average flows at that site. Monthly averages were used in lieu of discrete measurements or daily averages in order to better account for travel time and lag effects.

It is reasonable to expect relationships between flow and chlorophyll-a and suspended solids to differ between sites. Accordingly, multiple regressions of each water quality variable against flow were performed, allowing separate intercept and slope terms for the two sites (10899 and 10911). Site 10911 had higher mean values for all parameters.

Multiple regressions of the raw data were done first, but are not reported here because all had problems of heteroscedasticity and skew in the residuals, which violates the assumptions of the analysis. To remove these problems, the natural log transformation was used. Multiple regression of natural logs had no residual problems and had better fit (i.e. higher R^2).

The fitted regression model for chlorophyll-a (Tables 4 and 5 and Figure 8) indicates that chlorophyll-a is a decreasing function of flow, with a much stronger relationship for site 10911, where chlorophyll-a is generally higher. The R^2 value was 0.337.

TSS – The fitted regression model indicates that TSS is an increasing function of flow at site 10911, where TSS is generally higher, but is essentially unrelated to flow at site 10899. R^2 was 0.867.

Table 4. Table of Coefficients for Average Monthly Flow v. Chlorophyll-a

Term	Coefficient	Std Error	t	P
Intercept 10899	3.464	0.154	22.46	<0.001
Intercept 10911	4.036	0.157	25.75	<0.001
Slope 10899	-0.000029	0.0000216	-1.35	0.18
Slope 10911	-0.000068	0.0000217	-3.13	0.003

Table 5. Table of Results of Analysis of Variance

	SS	df	MS	F	P
Regression	3.182	3	1.061	6.27	0.001
Residual	6.255	37	0.169		
Total	9.436				

VSS – The fitted regression model indicates

Table 6. Table of Coefficients for Average Monthly Flow v. Total Suspended Solids

Term	Coefficient	Std Error	t	P
Intercept 10899	2.077	0.104	19.95	<0.001
Intercept 10911	2.776	0.106	26.24	<0.001
Slope 10899	-0.000010	0.000015	-0.70	0.49
Slope 10911	0.000084	0.000015	5.72	<0.001

Table 7. Table of Results of Analysis of Variance For Total Suspended Solids.

	SS	df	MS	F	P
Regres-sion	18.51	3	6.17	80.14	<0.001
Residual	2.85	37	0.077		
Total	21.36				

that VSS is a weakly increasing (non-significant) function of flow at site 10911, where VSS is generally higher, but is essentially unrelated to flow at site 10899. Tables of coefficients and the analysis of variance follow. R^2 was 0.572. Because these flow relationships differ from those seen for chlorophyll-a, these results suggest that VSS might contain much organic matter that is not algal, such as detritus or bacteria.

Table 8. Table of Coefficients for Average Monthly Flow v. Volatile Suspended Solids

Term	Coefficient	Std Error	t	P
Intercept 10899	1.485	0.134	11.08	<0.001
Intercept 10911	1.929	0.136	14.16	<0.001
Slope 10899	-0.000022	0.000019	-1.16	0.25
Slope 10911	0.000031	0.000019	1.65	0.11

Table 9. Table of Results of Analysis of Variance For Volatile Suspended Solids.

	SS	df	MS	F	P
Regres-sion	6.318	3	2.106	16.49	<0.001
Residual	4.725	37	0.128		
Total	11.04				

ISS – The fitted regression model indicates that ISS is an increasing function of flow at site 10911, where ISS is generally higher, but is essentially unrelated to flow at site 10899. Tables of coefficients and the analysis of variance follow. R^2 was 0.718.

Table 10. Table of Coefficients for Average Monthly Flow v. Inorganic Suspended Solids

Term	Coefficient	Std Error	t	P
Intercept 10899	0.994	0.222	4.49	<0.001
Intercept 10911	2.211	0.225	9.81	<0.001
Slope 10899	0.000022	0.000031	0.70	0.49
Slope 10911	0.000101	0.000031	3.25	0.002

Table 11. Table of Results of Analysis of Variance For Total Suspended Solids.

	SS	df	MS	F	P
Regression	32.91	3	10.97	31.43	<0.001
Residual	12.92	37	0.3491		
Total	45.83				

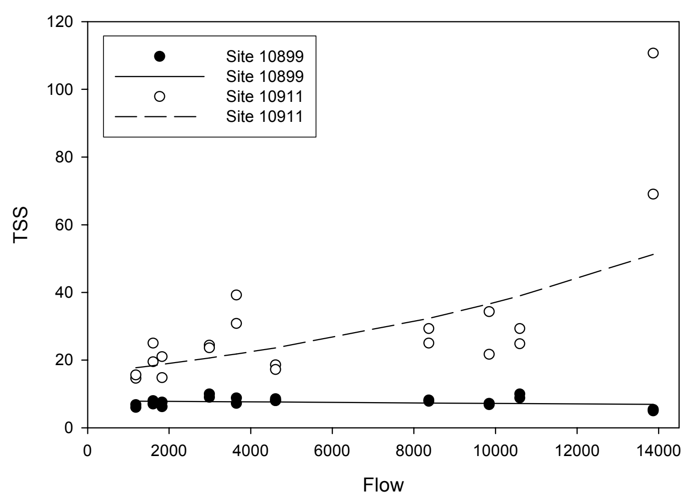

Figure 11. TSS v. flow. TSS appears to be positively related to flow at site 10911, but does not appear to be related to flow at

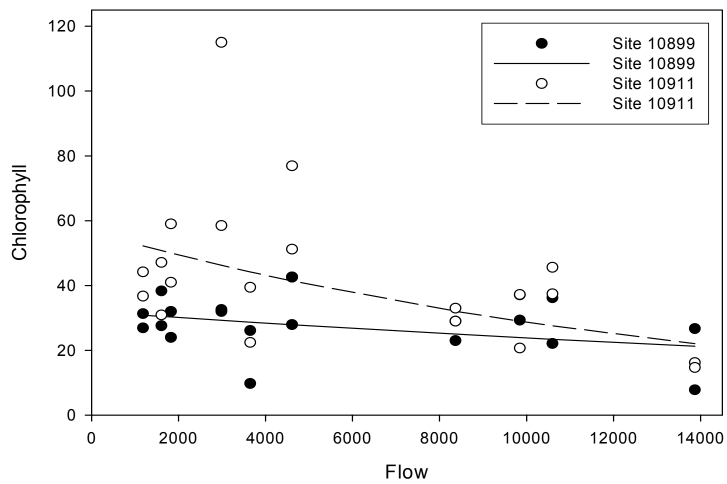

Figure 12. Chlorophyll-a v. flow. Chlorophyll-a appears to be negatively related to flow at both sites.

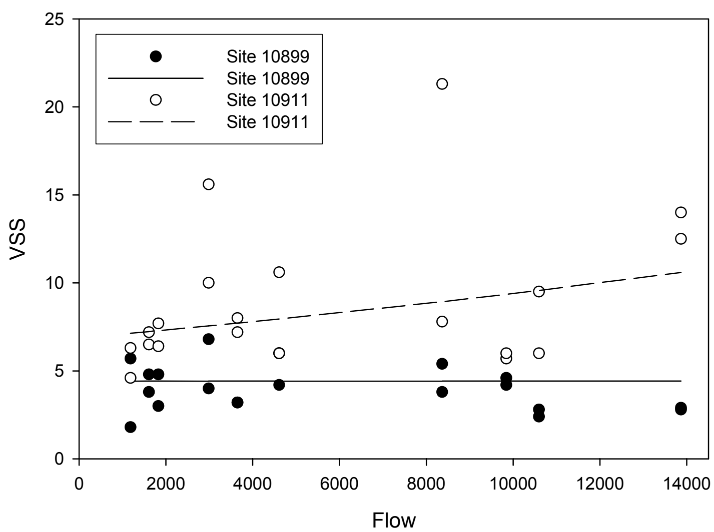

Figure 13. VSS v. flow. VSS appears to be positively related to flow at site 10911, but does not appear to be related to flow at site 10899.

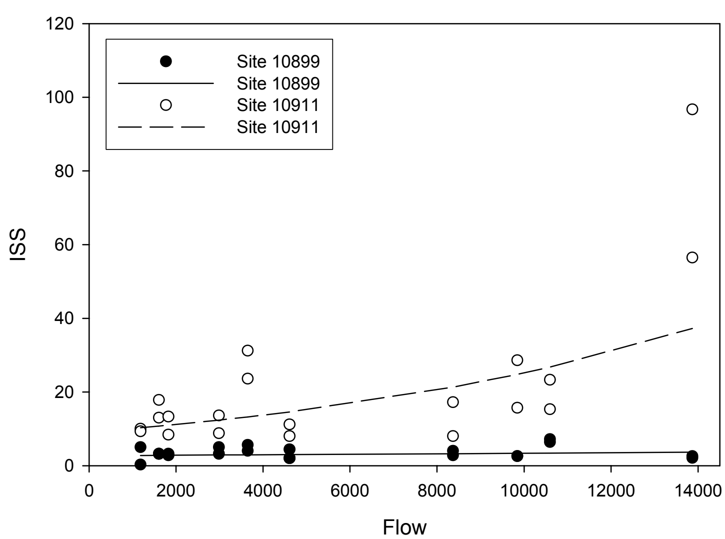

Figure 14 . ISS v. flow. ISS appears to be positively related to flow at site 10911, but does not appear to be related to flow at site 10899.

Survey Results

Through the course of the two years the study was conducted, a total of 156 surveys were collected; 83 at site 10899 and 73 at site 10911.

Analysis of results involved two states: analyzing frequency distribution graphs and performing statistical analyses. The frequency distribution graphs are useful for detecting strong, general trends. Because statistical analyses are more precise and can yield definitive answers regarding relationships, this was the preferred method of analysis.

Frequency distribution Graphs

Frequency distribution graphs were created by determining the number of A, B, C, D or E responses given for questions 1 and 2 at a given site. Those counts were then graphed against the concentrations of chlorophyll-a with which they corresponded. (Figures 15,16, 17 and 18).

All things being equal, it would be expected that, as concentrations of chlorophyll-a increase, the number of unfavorable responses would increase. There is some evidence for this with question 1 (perception of the greenness of the water) at station 10911, however the number of D and E responses do not follow the expected pattern.

Similarly, there is no apparent connection between chlorophyll-a concentrations and responses for question 2, which tests user perception of the suitability of the reservoir for recreational suitability and aesthetic enjoyment.

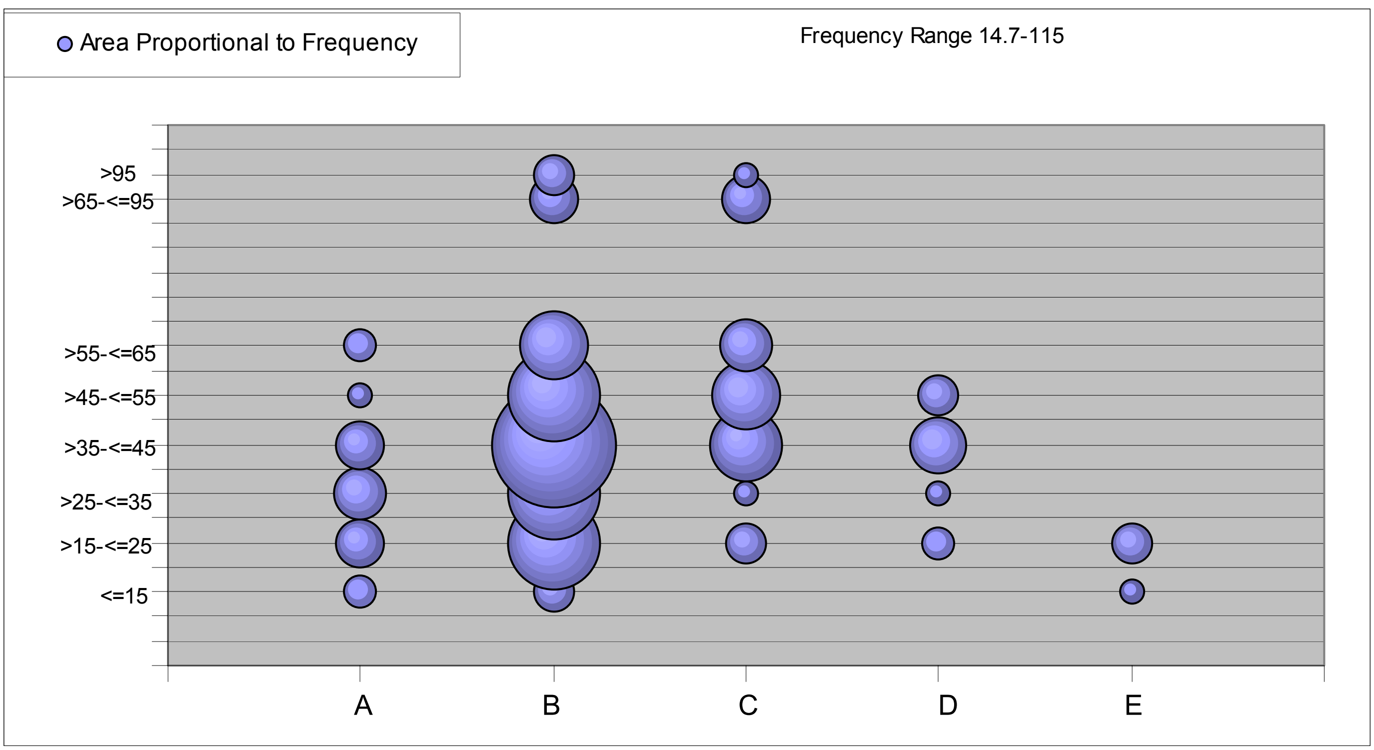

Figure 15 . Frequency distribution graph comparing the frequency of responses to question 1 corresponding concentrations of chlorophyll-a at site 10911.

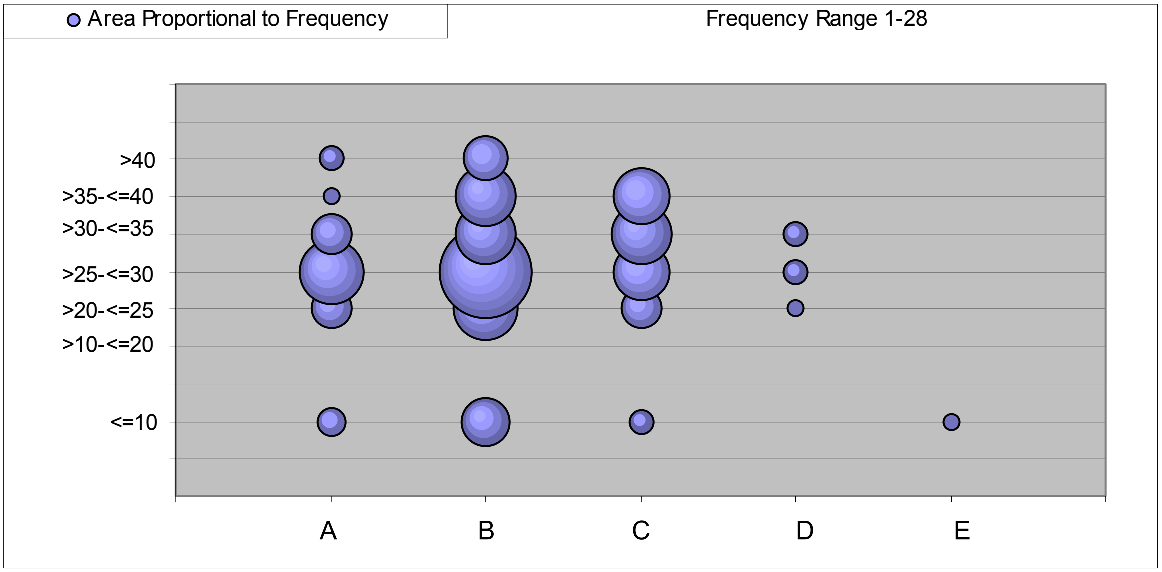

Figure 16 . Chlorophyll-a concentrations associated with question 1 responses at site 10899.

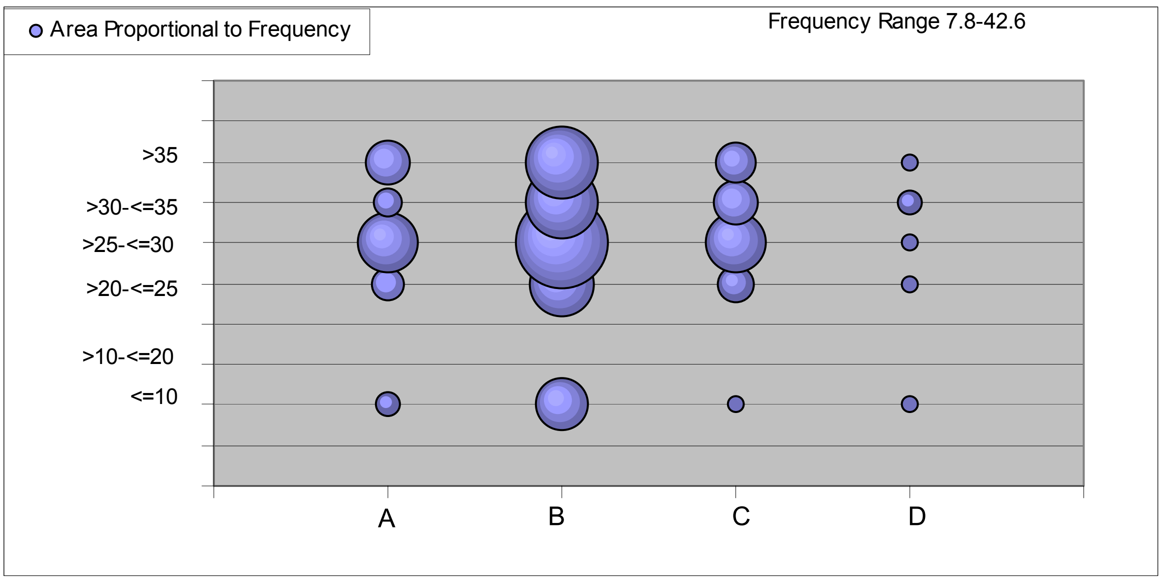

Figure 17 . Chlorophyll-a concentrations associated with question 2 responses at site 10899.

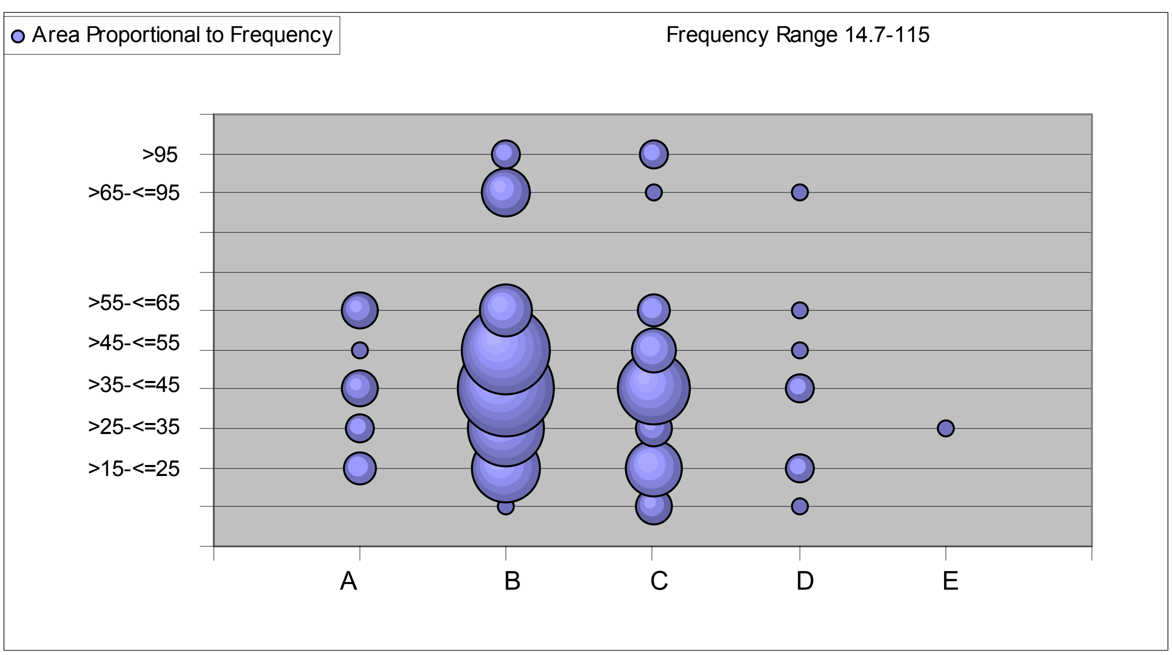

Figure 18 . Chlorophyll-a concentrations associated with question 2 responses at site 10911.

Comparing Water Quality Parameters among Groups of Respondents with Different Responses to Questions 1 and 2

In this report, four water quality parameters were analyzed to look for differences among respondents with different responses to questions 1 and 2 on the user survey for Lake Livingston. The four parameters analyzed are chlorophyll-a, TSS, VSS and inorganic SS (ISS). For each respondent, their survey data are matched with water quality data on these parameters, and then Analysis of Variance (ANOVA) is used to see whether mean parameter values differ in groups reporting different responses for the two survey questions.

For each parameter, a one-way ANOVA was done with a water quality parameter as the response variable, and the different responses to question 1 or question 2 as the independent grouping variable. Then, a two-way factorial ANOVA was done to examine whether the relationship between water quality parameters and responses to these questions differed between contact recreation users or other user types. Finally, a two-way factorial ANOVA was done to examine whether the relationship between water quality parameters and responses to these questions differed between the two sites examined in Lake Livingston. This was done because in early exploration of the data, large site differences were apparent in water quality parameters, and it appeared that the relationship to survey responses might also differ between sites.

In all analyses, there was strong "heteroscedasticity," i.e. differences in variance between the groups being analyzed. Such differences violate the assumptions of ANOVA, but do not necessarily affect the results of the analysis. In addition to analyzing raw data, data transformed to natural logarithms were analyzed. This transformation removed problems of heteroscedasticity, and usually the results of the analysis were unchanged. Therefore, only the original analyses of raw data are reported here, unless there are differences in the results after transformation to natural logarithms.

Due to large differences in sample size between groups defined by responses to survey questions, software capable of handling badly unbalanced data was used (Statistica); nevertheless, significance tests could not be done for some effects. It was always possible to test for differences in water quality between groups defined by survey responses, and to test the interaction term involved in examining whether this relationship differed between user types (contact recreation v. other) or site. It was not always possible to test significance of the direct relationship between water quality parameters and either user type or site. However, all ANOVA analyses were followed by post-hoc contrast analyses to test for pairwise differences between various means, permitting some analysis of differences between sites and user types. Many contrast analyses are available. Tukey's HSD was used here because it is appropriate for analyses with interactions, is reasonably conservative when many contrasts are involved, and is easy to implement. Due to the conservative nature of this technique, there were cases where the ANOVA detected a significant effect, but the contrast analysis found no corresponding pairwise differences among groups.

Some hypotheses can be stated in advance of the analysis, based on intuition and previous studies of water quality and user perceptions. Question 1 concerns user perceptions of how much algae are present. Going from response A to E, one would expect chlorophyll-a concentrations to increase. TSS and VSS are more weakly related to algal abundance than chlorophyll-a, but might also be expected to increase going from response A to E for question 1. It is more difficult to generate an expectation for ISS. Conceivably, inorganic turbidity could be visually confused with algal turbidity, so that again increases from response A to E would be expected.

However, it is also possible that a reduction in ISS, when algae are abundant, could make their visual signal more apparent, so that decreases going from response A to E could occur, or perhaps more complex relationships could occur. Question 2 concerns users perceptions of suitability of the lake for recreation and aesthetic enjoyment. Going from response A to E, increase of all four water quality parameters would be expected. If contact recreation users are especially sensitive to water quality, one would expect these relationships to be steeper among this user group, as opposed to others. Also, “negative” perceptions (i.e. responses C to E) would occur at lower levels of these water quality parameters for contact recreation users, versus other users, if contact users have lower absolute thresholds at which they perceive water quality to be impaired.

Simple Analysis of Water Quality in Relation to Question 1

The table below (Table 12) summarizes results of the ANOVA’s comparing means of water quality parameters in relation to response to question 1.

For chlorophyll-a, mean levels were significantly different among response groups for question 1. Mean chlorophyll-a increased as expected from response A to C, but did not increase to response D, and dropped for response E. Results for response E were usually anomalous, and this is likely due to the very small number of individuals choosing this extreme response. They may be unusual compared to other survey respondents. The contrast analysis suggested that chlorophyll-a characterizing response C was significantly greater than chlorophyll-a characterizing responses A and E, but did not detect other significant pairwise differences.

For TSS, mean levels were not significantly different among response groups for

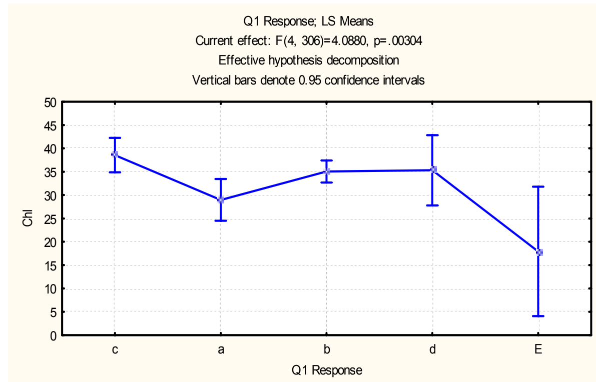

Figure 19. Comparison of average chlorophyll-a concentra-

question 1 when raw data was analyzed, but were when natural logarithms were used (P = 0.050). Mean TSS did not consistently increase as expected from response A to E, in that mean TSS was lower for response C than for other responses. The contrast analysis did not detect significant pairwise differences.

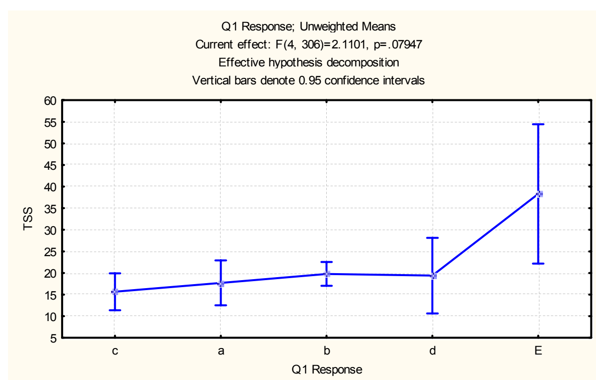

Figure 20. Comparison of average TSS concentrations to response for question 2.

Table 12. Summary of Results of ANOVA Comparing Water Chemistry to Question 1

WQ Parameter	MS Response	MS Error	F	df	P
Chlorophyll-a	1016	249	4.09	1,4	0.003
TSS	708	336	2.11	1,4	0.079
VSS	19.8	13.1	1.51	1,4	0.20
ISS	546	266	2.05	1,4	0.082

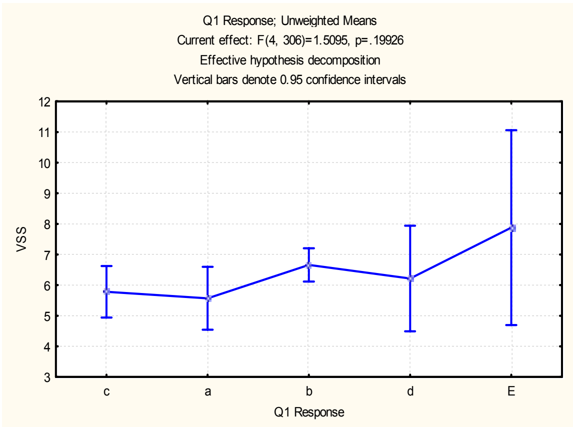

Figure 21. Comparison of average VSS concentrations to response for question 1.
SS concentrations to response for question1.

For VSS, mean levels were not significantly different among response groups for question 1.

For ISS, mean levels were not significantly different among response groups for question 1 when raw data was analyzed, but were when natural logarithms were used (P = 0.029). Mean TSS did not consistently increase as expected from response A to E, and differences in mean values for responses A to D were small, while the mean for E was larger, though based on a small sample size. The contrast analysis did not detect significant pairwise differences.

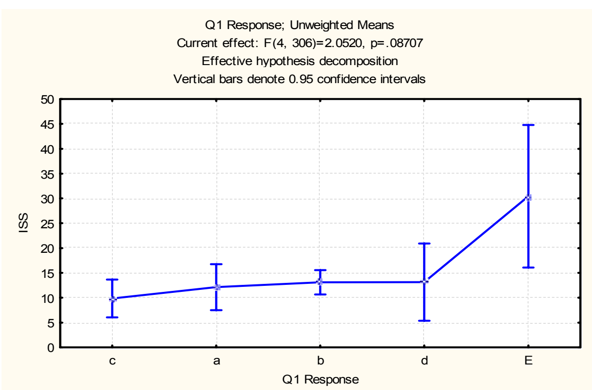

Figure 22. Comparison of average ISS concentrations to response for question 1.

In general, the strongest relationship with responses to question 1 was found for chlorophyll-a, and involved increasing values for responses A to C as expected. Responses D and especially E had smaller sample sizes. Relationships for TSS, VSS and ISS either were not detected or did not follow expectations.

Simple Analysis of Water Quality in Relation to Question 2

The table below (Table 13) summarizes results of the ANOVA's comparing means of water quality parameters in relation to response to question 2.

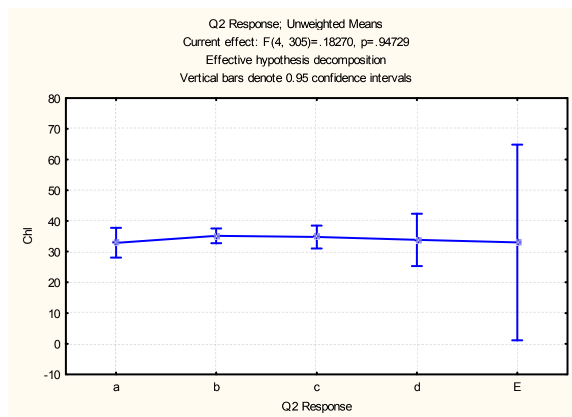

Figure 23. Comparison of average chlorophyll-a concentrations to response for question 2.

For chlorophyll-a, mean levels were not significantly different among response groups for question 2.

For TSS, mean levels were significantly different among response groups for question 2. Mean TSS increased as expected

Table 13. Summary of Results of ANOVA Comparing Water Chemistry to Question 2

WQ Parameter	MS Response	MS Error	F	df	P
Chlorophyll-a	47.9	262.0	0.18	1,4	0.95
TSS	1429	328	4.36	1,4	0.002
VSS	98.5	12.1	8.15	1,4	<0.001
ISS	990	261	3.79	1,4	0.005

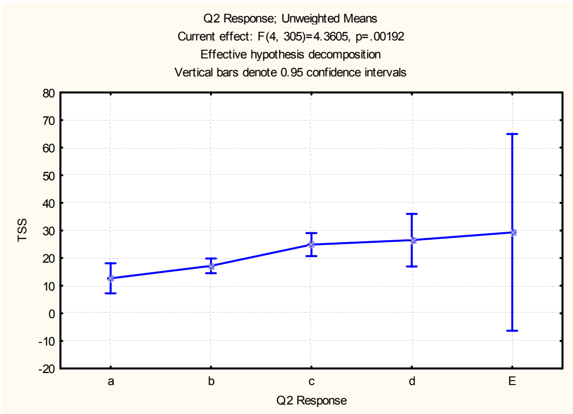

Figure 24. Comparison of average TSS concentrations to response for question 2.

from response A to E. The contrast analysis found that mean TSS was higher for response C than for responses A and B. See next page (Figure F).

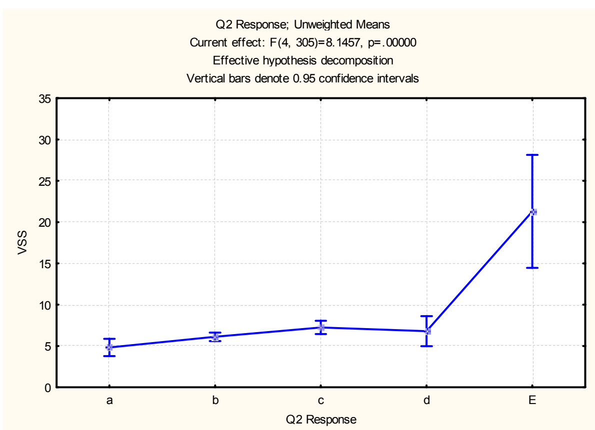

Figure 25. Comparison of average VSS concentrations to response for question2.

For VSS, mean levels were significantly different among response groups for question 2. Mean VSS increased as expected from response A to E. The contrast analysis found that mean VSS was higher for response C than for response A, and higher for response E than for other responses, but response E had a sample size of 1.

For ISS, mean levels were significantly different among response groups for question 2. Mean ISS increased as expected from response A to E, but dropped for response E, which had a sample size of 1. The contrast analysis found that mean VSS was higher for response C than for responses A and B. See Figure H.

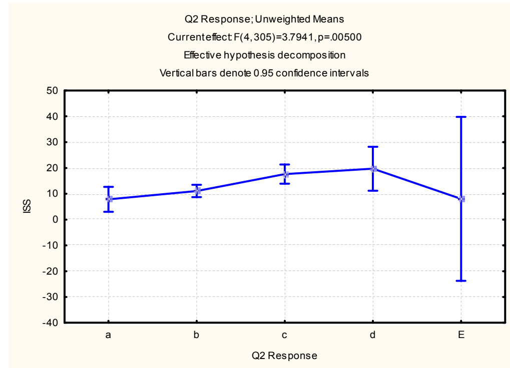

Figure 26. Comparison of average ISS concentrations to response for question2.

In general, strong relationships with responses to question 2 were found for TSS, VSS, and ISS, but not chlorophyll-a. These relationships involved increasing values for responses A to C as expected. Responses D and especially E had smaller sample sizes and did not always display the expected patterns.

Analysis of Water Quality in Relation to Question 1 and User Type

This section presents results of the two-way ANOVA examining water quality parameters in relation to responses to question 1 and user type, contact recreation versus other types. The table on the next page (Table 14) summarizes ANOVA results: there are four lines for each water quality parameter to report respective mean squares and significance tests for response to question 1, user type (contact recreation v. other), their interaction, and the error mean square. For chlorophyll-a, no significant relationships were detected when response to question 1 was jointly analyzed with user type. Without accounting for different user types, a significant relationship with response to question 1 was found, but this effect became insignificant when user type was also analyzed. This result is difficult to interpret, and could be a consequence of lack of balance in the data. A conservative

Table 14. Summary of 2-Way ANOVA Results Comparing Water Chemistry to Q1 Responses by User Type

WQ Parameter	Term	MS	df	F	P
Chlorophyll-a	Response	355	4	1.331	0.26
	User Type	126	1	0.471	0.49
	Interaction	136	4	0.511	0.73
	Error	267	263		
TSS	Response	1145	4	3.28	0.012
	User Type	590	1	1.69	0.20
	Interaction	551	4	1.58	0.18
	Error	350	263		
VSS	Response	0.279	4	1.13	0.34
	User Type	0.465	1	1.89	0.17
	Interaction	0.118	4	0.48	0.75
	Error	0.246	263		
ISS	Response	856	4	3.06	0.017
	User Type	375	1	1.34	0.25
	Interaction	429	4	1.53	0.19
	Error	279	263		

interpretation is that the relationship of chlorophyll-a with the response to question 1 is weak and influenced by other factors, though not necessarily by user type. Table 14 analysis suggesting an influence of site on this relationship is presented.

For TSS, significant relationship with response to question 1 was found, but no significant influence of user type was found. However, when natural logarithms were analyzed, all effects were insignificant (P > 0.05). Mean TSS did not consistently increase as expected from response A to E, for either user type. Ignoring response E due to its small sample size, for non-contact users, there appeared to be no relationship between mean TSS and response to question 1. For contact users, mean TSS for responses C and D lay between those for responses A and B. The contrast analysis did not detect significant pairwise differences within user types, however. Within response classes, the contrast analysis found a significant difference between contact and non-contact users who chose response B. Contact users who chose this response were associated with a higher mean TSS than non-contact users.

For VSS, no significant relationships were detected.

For ISS, results were similar to those for TSS. A significant relationship with response to question 1 was found, but no significant influence of user type was found. However, when natural logarithms were analyzed, all effects were insignificant (P > 0.05). Mean TSS did not consistently increase as expected from response A to E, for either user type. Ignoring response E due to its small sample size, for non-contact users, there appeared to be no relationship between mean TSS and response to question 1. For contact users, mean TSS for responses C and D lay between those for responses A and B. The contrast analysis did not detect significant pairwise differences within user types, however. Within response classes, the contrast analysis found a significant difference between contact and non-contact users who chose response B. Contact users who chose this response were associated with a higher mean TSS than non-contact users.

In general, no strong relationships to user type were detected. For chlorophyll-a and VSS, no statistically significant relationships were found. For TSS and ISS, significant relationships were found, although the lack of significant for transformed data casts some doubt on these. The data themselves suggest that for these variables, there is no relationship with response to question 1 for non-contact users, while there might be a complex relationship for contact users. However, the lack of significance for such differences in the contrast analysis again casts doubt on these patterns.

Analysis of Water Quality in Relation to Question 2 and User Type

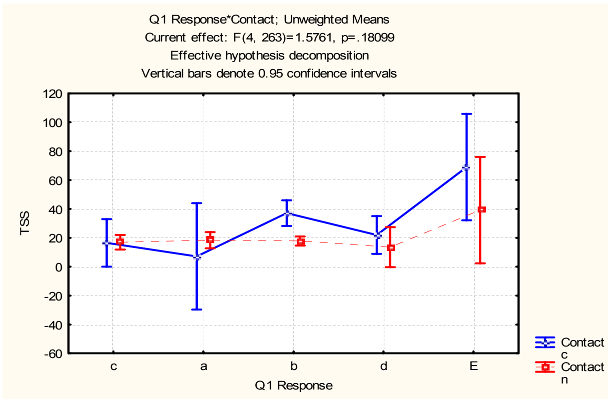

Figure 27. Comparison of average TSS concentrations to response by user type contact or non-contact for question1.

This section presents results of the two-way ANOVA examining water quality parameters in relation to responses to question 2 and user type, contact recreation versus other types. Table 15 summarizes ANOVA results: there are four lines for each water quality parameter to report respective mean squares and significance tests for response to question 2, user type (contact recreation v. other), their interaction, and the error mean square. An entry "NE" indicates that a term could not be estimated due to the unbalanced data.

Table 15. Summary of 2-Way ANOVA Results Comparing Water Chemistry to Q2 Responses by User Type

WQ Parameter	Term	MS	df	F	P
Chlorophyll-a	Response	629	3	2.32	0.076
	User Type	NE			
	Interaction	612	3	2.26	0.082
	Error	271	263		
TSS	Response	1972	3	5.75	0.0008
	User Type	NE			
	Interaction	572	3	1.67	0.17
	Error	343	263		
VSS	Response	43.6	3	4.17	0.007
	User Type	NE			
	Interaction	11.3	3	1.08	0.36
	Error	10.5	263		
ISS	Response	1455	3	5.28	0.001
	User Type	NE			
	Interaction	427	3	1.55	0.20
	Error	275	263		

For chlorophyll-a, no significant relationships were detected when response to question 2 was jointly analyzed with user type.

For TSS, a significant relationship with response to question 2 was found, but no significant influence of user type was found. Ignoring response E due to its small sample size, mean TSS consistently increased as expected from response A to D, and did so more steeply for contact users, as might be expected if such users are more sensitive to perceived differences in water quality. However, the mean TSS levels characterizing "negative" responses were higher for contact users than for non-contact users, which is not consistent with a lower absolute threshold for perceived impairment among the former group of users. However, the lack of significance for the interaction term in the ANOVA suggests that any differences between user types in the relationship with response to question 2 were weak. Also, the contrast analysis did not detect significant pairwise differences within user types, or within response categories, again implying that the effects suggested by the data are relatively weak.

For VSS, a significant relationship with response to question 2 was found, but no significant influence of user type was found. However, when natural logarithms were analyzed, all effects were insignificant (P > 0.05). Ignoring response E due to its small sample size, mean TSS consistently increased as expected from response A to C, and did so more steeply for contact users, as might be expected if such users are more sensitive to perceived differences in water quality. However, mean VSS was not higher for response D as expected. Again, the mean VSS levels characterizing "negative" responses were higher for contact users than for non-contact users, which is not consistent with a lower absolute threshold for perceived impairment among the former group of users. The lack of significance for the interaction term in the ANOVA suggests that any differences between user types in the relationship with response to question 2 were weak. Also, the contrast analysis did not detect significant pairwise differences within user types, or within response categories, again implying that the effects suggested by the data are relatively weak.

For ISS, a significant relationship with response to question 2 was found, but no significant influence of user type was found. Ignoring response E due to its small sample size, mean ISS consistently increased as expected from response A to D, and did so more steeply for contact users, as might be expected if such users are more sensitive to perceived differences in water quality. However, the mean TSS levels characterizing "negative" responses were higher for contact users than for non-contact users, which is not consistent

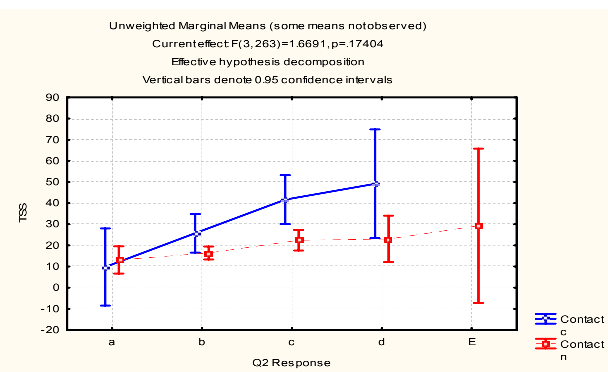

Figure 28. Comparison of average TSS concentrations to response by user type contact or non-contact for question2.

with a lower absolute threshold for perceived impairment among the former group of users. However, the lack of significance for the interaction term in the ANOVA suggests that any differences between user types in the relationship with response to question 2 were weak. Also, the contrast analysis did not detect significant pairwise differences within user types, or within response categories, again implying that the effects suggested by the data are relatively weak. In general, mean levels of TSS, VSS and ISS increased from response A to D as expected, and did so more steeply for contact users versus other types, which is consistent with a hypothesis that such users might be more sensitive to reduced water quality in relation to suspended matter. Also, the data generally displayed higher mean TSS, VSS, and ISS for contact users choosing "negative" responses than for non-contact users choosing the same responses, which is not consistent with a lower absolute threshold for perceived impairment among contact users. However, differences among user types were not strongly supported statis-

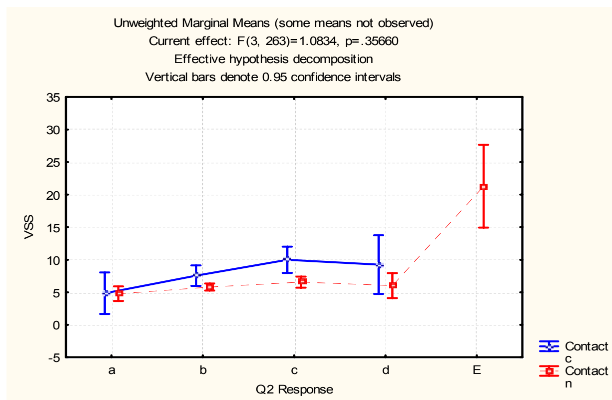

Figure 29. Comparison of average VSS concentrations to response by user type contact or non-contact for question2.

tically, as the corresponding interaction terms in ANOVA's were insignificant, and associated pairwise contrasts were not found significant. Nevertheless there is an interesting and suggestive case that contact and non-contact users differently perceive impairment in relation to suspended matter.

Analysis of Water Quality in Relation to Question 1 and Site

This section presents results of the

two-way ANOVA examining water quality parameters in relation to responses to question 1 and site. Table 16 below summarizes ANOVA results: there are four lines for each water quality parameter to report respective mean squares and significance tests for response to question 1, site, their interaction, and the error mean square. Site terms are significant, as site 10911 had higher mean values for all water quality parameters. These site differences mean levels are not in themselves of interest here, and commentary focuses on whether any relationships between water quality parameters and responses to question 1

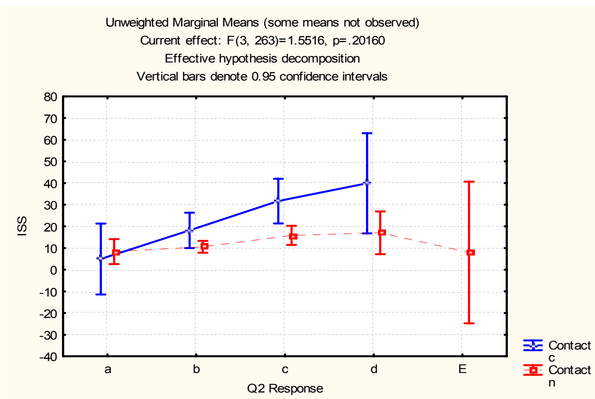

Figure 30. Comparison of average ISS concentrations to response by user type contact or non-contact for question 2.

differ between sites.

For chlorophyll-a, significant relationships were found with both site and response to question 1. Site 10911 had higher mean chlorophyll-a levels than site 10899. Ignoring response E, for which sample size was very small, there appeared to be no relationship between mean chlorophyll-a level and response to question 1 at the site with low chlorophyll-a levels. For the site with high chlorophyll-a levels, mean chlorophyll-a increased from response A to C as expected, although it was lower for response D, which is unexpected but could be related to a relatively low sample size. The pattern for response A to C suggests that impairment due to algae is perceived only at sites where chlorophyll-a levels are relatively high. The contrast analysis detected significant differences between sites, and at site 10911 mean chlorophyll-a was higher for response C than for response A, while no significant differences were found within site 10899. However, the corresponding interaction term was not significant in the ANOVA, which somewhat weakens the suggestion that the relationship between chlorophyll-a and response to question 1 differs between sites.

For TSS, a significant site effect was found, but not a significant relationship with response to question 1 or a significant interaction. However, when natural logarithms were analyzed, the interaction became significant ($P < 0.05$), suggesting that the relationship between TSS and response to question 1 might differ between sites. Mean TSS did not consistently increase as expected from response A to E, for either site.

Ignoring response E due to its small sample size, at site 10899, which had lower TSS, there appeared to be no relationship between mean TSS and response to question 1.

Table 16. Summary of ANOVA Results Comparing Water Chemistry to Reponses to Q1 and Sample Site

WQ Parameter	Term	MS	df	F	P
Chlorophyll-a	Response	1096	4	5.40	<0.000
	Site	2133	1	10.50	0.001
	Interaction	401	4	1.97	0.098
	Error	203	301		
TSS	Response	204	4	0.96	0.43
	Site	9275	1	43.56	<0.001
	Interaction	259	4	1.22	0.30
	Error	213	301		
VSS	Response	5.96	4	0.77	0.55
	Site	283.26	1	36.42	<0.001
	Interaction	13.45	4	1.73	0.14
	Error	7.78	301		
ISS	Response	183	4	0.97	0.42
	Site	6316	1	33.48	0.00
	Interaction	205	4	1.09	0.36
	Error	189	301		

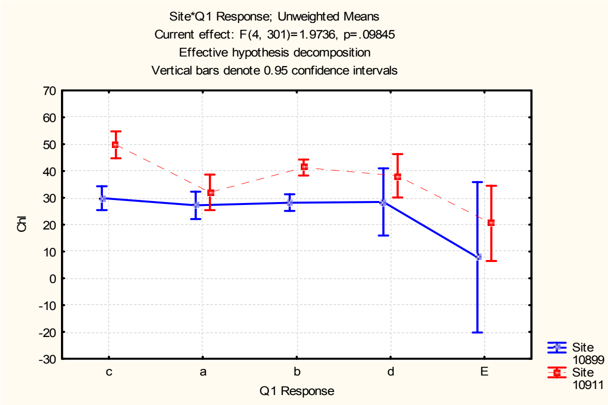

Figure 31. Comparison of average chlorophyll-a concentrations to response by site for question 1.

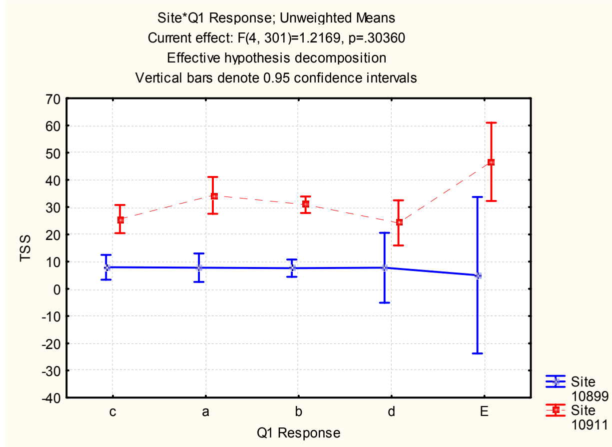

Figure 32. Comparison of average TSS concentrations to response by site for question 1.

For site 10911, which had higher TSS, mean TSS decreased for responses A to D. The contrast analysis detected significant site differences, but no differences between responses within sites, implying that the pattern suggested by the data is weak.

For VSS, a significant site effect was found, but not a significant relationship with response to question 1 or a significant interaction. These results suggest that site differences do not affect the relationship (or lack of it) between VSS and response to question 1.

For ISS, a significant site effect was found, but not a significant relationship with response to question 1 or a significant interaction. These results suggest that site differences do not affect the relationship between ISS and response to question 1.

In general, there is evidence that the relationship between chlorophyll-a and response to question 1 differs between sites, and is evident only at the site with higher chlorophyll-a. Although lack of significance for the corresponding interaction term in the ANOVA weakens this case statistically, it is also partially supported by the contrast analysis. There is weaker evidence that the relationship between TSS and response to question 1 might differ between sites.

Analysis of Water Quality in Relation to Question 2 and Site

Table 17. Summary of ANOVA Results Comparing Water Chemistry to Reponses to Q2 and Sample Site

WQ Parameter	Term	MS	df	F	P
Chlorophyll-a	Response	39	3	0.17	0.91
	Site	NE			
	Interaction	115	3	0.52	0.67
	Error	222	301		
TSS	Response	771	3	3.74	0.011
	Site	NE			
	Interaction	683	3	3.32	0.020
	Error	206	301		
VSS	Response	18.5	3	2.62	0.051
	Site	NE			
	Interaction	30.1	3	4.27	0.006
	Error	7.1	301		
ISS	Response	582	3	3.16	0.025
	Site	NE			
	Interaction	445	3	2.42	0.066
	Error	184	301		

This section presents results of the two-way ANOVA examining water quality parameters in relation to responses to question 2 and site. Table 17 summarizes ANOVA results: there are four lines for each water quality parameter to report respective mean squares and significance tests for response to question 2, site, their interaction, and the error mean square. An entry "NE" indicates that a term could not be estimated due to the unbalanced data. Site terms could not be estimated in this analysis, but the previous analysis demonstrated large differences, as site 10911 had higher mean values for all water quality parameters.

These site differences in mean levels are not in themselves of interest here, and commentary focuses on whether any relationships between water quality parameters and responses to question 2 differ between sites. For chlorophyll-a, no significant relationships were detected when response to question 2 was jointly analyzed with site.

For TSS, a significant relationship with response to question 2 was found, as was a significant interaction with site, suggesting that the relationship with response to question 2 differs between sites. However, when natural logarithms were analyzed, the interaction became insignificant (P > 0.05), weakening the case for such differences. At site 10899, with lower mean TSS, mean TSS appeared unrelated to response to question 2, while at site 10911, with higher mean TSS, mean TSS increased from response A to D as expected (again response E had very low sample size). The contrast analysis detected significant differences between sites. Within site 10899, there were no significant differences in mean TSS, but within site 10911, mean TSS was significantly higher for response C than for responses A and B.

For VSS, a significant relationship with response to question 2 was found, as was a significant interaction with site, suggesting that the relationship with response to question 2 differs between sites. When natural logarithms were analyzed, main effect of response to question 2 became insignificant (P > 0.05), but the interaction term remained significant, strengthening the case for such differences. At site 10899, with lower mean VSS, mean VSS appeared unrelated to response to question 2, while at site 10911, with higher mean VSS, mean VSS increased from response A to C as expected (responses D and E had relatively low sample sizes). The contrast analysis detected significant differences between sites. Within site 10899, there were no significant differences in mean VSS, but within site 10911, mean VSS was significantly higher for response C than for responses A and B.

For ISS, a significant relationship with response to question 2 was found, and interaction with site was very close to signifi-

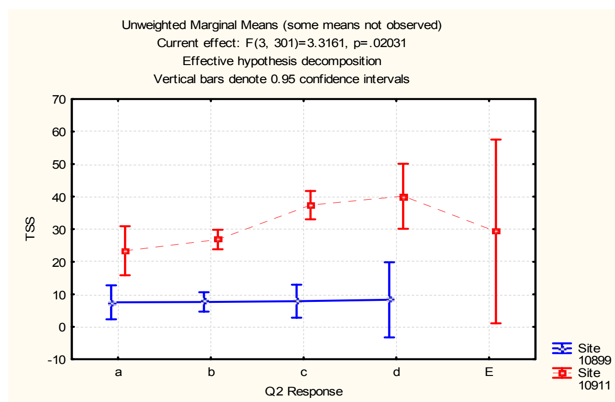

Fig. 33. Comparison of average TSS concentrations to response by site for question 2.

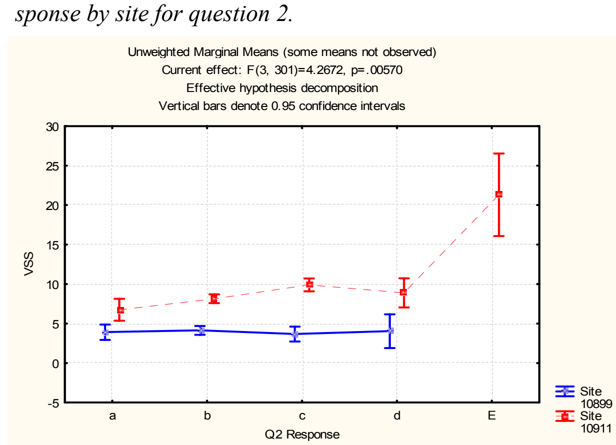

Fig. 34. Comparison of average VSS concentrations to response by site for question 2.

cant, suggesting that the relationship with response to question 2 differs between sites.

When natural logarithms were analyzed, main effect of response to question 2 remained significant, but the interaction term became clearly insignificant (P>0.05), weakening the case for such differences. At site 10899, with lower mean ISS, mean ISS appeared unrelated to response to question 2, while at site 10911, with higher mean ISS, mean ISS increased from response A to D as expected (response E had very low sample size). The contrast analysis detected significant differences between sites. Within site 10899, there were no significant differences in mean ISS, but within site 10911, mean ISS was significantly higher for response C than for response B.

In general, there is evidence that relationships between suspended solids and responses to question 2 differ between sites,

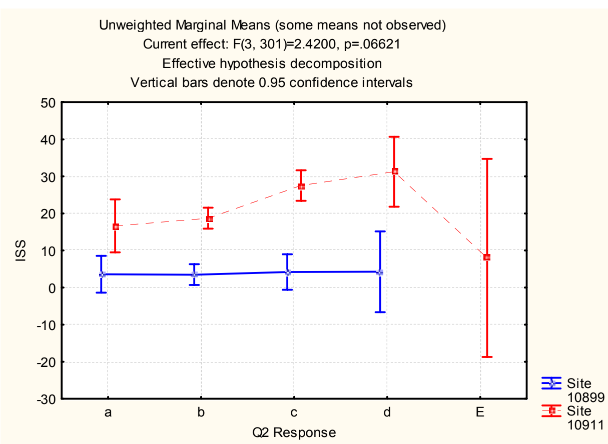

Figure 35. Comparison of average ISS concentrations to response by site for question 2.

such that there is no relationship at the site with lower mean values (10899), with the expected relationships found only at the site with higher values (10911). Perceived impairment thus appears to be associated with higher suspended solids, though only at a site where suspended solids are relatively high. Statistical support for this difference is weakened in some cases by ambiguity of the associated interaction term, but is partially supported in all cases by the contrast analysis.

Conclusions

The results of this two-year study provide insight into the relationship between water quality and recreational user perceptions. Specifically, it appears that recreators were able to discern differences in chlorophyll–a concentrations. However, respondents were not likely to indicate that they perceived the water color and presence of algae to be extreme. This tendency held even with exceptionally high concentrations of water-column chlorophyll-a (i.e. 115 ug/L). Although frequency distribution graphs suggest a parabolic relationship between concentrations of chlorophyll-a and user perceptions of water greenness and algal abundance, this does not seem plausible, and is likely an artifact of the limited number of respondents choosing the two most extreme responses. The true relationship between chlorophyll-a and user perception of greenness and algal abundance (over the range of chlorophyll-a concentrations observed) is believed to be best described as sigmoidal, with the degree of perception of greenness leveling off at the mid-point (response C) of the gradient of possible responses. The exact shape and nature of this curve are of course not known and cannot be described mathematically with the data at hand.

Despite the evidence to suggest recreators can, to an extent, discern changes in algal abundance, no relationship was found between concentrations of algal abundance and respondents' perception of the suitability of the reservoir for recreation and aesthetic enjoyment. Strong relationships were, however, found to be present between concentrations of suspended solids (TSS, VSS and ISS) and the perception of the suitability of the reservoir for recreation and aesthetic enjoyment. VSS, TSS and ISS were found to be positively related to flow but were not related to chlorophyll-a. Therefore, non-algal turbidity appears to be a much more significant factor in recreators' perception of the suitability of the reservoir for recreation than chlorophyll-a.

Despite the above, it is believed that algal concentrations negatively affect user perceptions. It then becomes a question of degrees, with the degree to which perception is affected by non-algal turbidity masking any user discontent with algal concentrations.

Improving user satisfaction by reducing algal concentrations would necessitate reducing nutrient concentrations. However at their current concentrations, light and not nutrients are limiting to algal growth. Therefore reducing nutrient concentrations would yield little or no direct benefit until their concentrations are lowered to a point where nutrients and not light are limiting. Even then however, little reduction in concentrations of chlorophyll-a could be expected until nutrients are reduced to a fraction of current concentrations[2]. This would entail not only limiting point sources of nutrients, but also drastically reducing both urban and rural non-point sources. It is questionable as to whether or not such an effort would be technically, politically or economically feasible. This is especially true when considered in light of the fact that users perceive non-algal turbidity as a deterrent to recreational and aesthetic enjoyment but not algal turbidity. Given that no connection could be made between user dissatisfaction and concentrations of algae, the findings of this report do not support the need for numeric criteria for nutrients or chlorophyll-a, as no recreational use impairment could be linked to those parameters.

[1] Gover, James P. and Chrzanowski. 2001. *Kinetics of Algal Growth in Metroplex Reservoirs: Bioassay Experiments on summertime Populations.* A Trinity Basin Clean Rivers Program Report. Dallas, Texas..