Water Resources Research Institute of The University of North Carolina

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EVALUATING EUTROPHICATION-RELATED WATER QUALITY PARAMETERS IN NORTH CAROLINA LAKES AND RESERVOIRS

By

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Division of Water Quality

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Data Inventory and Evaluation

Summary of Completed Research

Data inventory

An inventory of available data sets was completed for the DWQ monitored lakes and reservoirs. To assure the thoroughness of the inventory, we were in contact with DWQ to obtain all of their electronically available data. In addition, we also obtained or attempted to obtain data from organizations that collect lake and reservoir data. Finally, we included the laboratory procedures for the DWQ and non-DWQ data. Thus, the procedures can be compared and differences can be accounted for when used for analysis.

Data Evaluation

We conducted an exploratory data analysis of the original data set. This analysis was used to pair down the data into subsets that could be used for two assessments: the user survey and the nutrient criteria analysis. In the subset data, we only used DWQ datasets for reasons explained below.

User Survey Sample Sites and Data

- We used DWQ datasets since we could assure that we could have water quality data collected within a couple days of the survey collections.
- The lakes and reservoirs were chosen for user surveys only if DWQ was sampling them during the summer of 2005. The lakes were then chosen based on whether they would have a sufficient number of recreational lake users to participate in the user survey.
- We surveyed the lake several days before or after DWQ collected their water quality samples. Therefore, we could correlate the user surveys with the water quality data.
- We learned after the fact that DWQ did not sample Jordan Lake and Santeelah Lake during the week that we collected user surveys. Therefore, we have survey data for these lakes but not water quality data.
- Because of a laboratory error, there are no chlorophyll a data for any of these lakes. There is, however, algal biomass data for some of the surveyed reservoirs.
- We have water quality and survey information for three lakes and reservoirs: Falls of the Neuse Reservoir, Lake Phelps, and Kings Mountain Lake.

Nutrient Criteria Data Subsets

- We used the DWQ datasets so that we could assure that we had data that is representative of the type of information that could be realistically collected by North Carolina to assess nutrient standards.
- We organized the data according to the EPA ecoregions. These data were then subset so that we could elicit experts using each of the 100 rows. This was the maximum number of data rows that could be included and have reasonable responses from the experts. Also, it provided enough data to make reasonable statistical inferences using structural equation modeling.
- There are 50 data rows that were taken from a database of all the lakes within the state. These data rows are the same in all the ecoregions. The second 50 data rows were taken from data that is exclusive to that particular ecoregion. This design allows us to make

ecoregion comparisons to assess whether we could make statewide recommendations or whether we needed to make region-specific recommendations.

Summary of Information on CD

The following describes the electronic databases supplied in the CD. The readme.txt file on the main page of the CD provides the same outline, provided below, of the information on the CD. I will describe the contents according to each of the file folders on the main page.

Data from DWQ

- Ecoregions File Folder:
    - *Blue Ridge, Middle Atlantic Coastal Plain, Piedmont, and Southeastern Plain File Folders*: This includes all the DWQ data organized according to the Ecoregions.
        - It is additionally organized according to each lake or reservoir. These folders include all the DWQ data provided on these waterbodies.
        - There are several compiled Ecoregion specific datasets. These are the Excel files located within each of the Ecoregion folders.
    - *Ecoregions of NC Lakes and Reservoirs*: List of North Carolina lakes and reservoirs located in each Ecoregion.
    - *NC Ecoregion Map pdf*: A map of the Ecoregions with delineations.
- *DWQ sampling procedure and DWQ lab procedure*: The laboratory procedures for the DWQ sampling and laboratory methods.
- *Algal Biomass Data 2005*: Algal biomass data processed by DWQ during the 2005 survey year. Algal biomass data was only collected for some of the sampled lakes.

Data from Organizations

- *Alcoa*: The data and laboratory procedures for North Carolina lakes and reservoirs sampled by Alcoa.
- *Progress Energy*: The data and laboratory procedures for North Carolina lakes and reservoirs sampled by Progress Energy.
- *Other Organizations Contacted about Data*: A list of other organizations we contacted about obtaining their sampled lake and reservoir data.

Data from User Survey

- *Falls Lake, High Rock Lake, Jordan Lake, Kings Mountain Reservoir, Lake Phelps, and Lake Santeetlah File Folders:* This includes the coded survey data for each day the lake was surveyed. Additionally, within each Excel file is the survey key so that it could be used and interpreted by another individual.
- *Algal Biomass Data 2005*: Algal biomass data processed by DWQ during the 2005 survey year. Algal biomass data was only collected for some of the sampled lakes. This is the same folder that is in “Data from DWQ.”
- *2005 Data for Ecoregions*: This file contains the DWQ data that was collected concurrent with the lake user surveys.

Data Subset for Nutrient Criteria Analysis

- *Blue Ridge, Mid-Atlantic Coast Plain, Piedmont, and Southeastern Plain Ecoregions Data Subsets*: These files include the 100 data rows that were used in the expert elicitations and in the nutrient criteria analysis.
- *Comments about Data Subsets*: Includes notes about the creation and reasoning behind creating the Ecoregion specific data subsets.

Designated Use Classification for NC Lakes and Reservoirs

- *Blue Ridge, Mid-Atlantic Coast Plain, Piedmont, and Southeastern Plain Ecoregions Lake and Reservoir Designated Uses*: These are the classifications provided from Connie Brower in the NCDENR Classifications and Standards Unit.

Location of Lakes

- *Ecoregions of NC Lakes and Reservoirs*: List of North Carolina lakes and reservoirs located in each Ecoregion.
- *NC Ecoregion Map pdf and jpg versions*: A map of the Ecoregions with delineations.
- *Map of Location of NC Lakes and Reservoirs with Roads and without Roads*: A map of North Carolina with dots indicating the location of all the different lakes and reservoirs in the state.

Lake User Survey

Purpose

The Clean Water Act requires waterbodies to be protected for the designated uses. As a result, it is important to properly assess whether a waterbody is meeting its water quality goal, or designated use, to determine whether or not a waterbody should be considered impaired or not.

Since the designated use cannot be directly measured, assessment of designated use attainment is through the water quality criteria, or easily measurable water quality variables and levels that serve as the scientific surrogate for the designated use. Since criteria are imperfect measures of designated use there are other means to obtain a more qualitative assessment of designated use, through a waterbody user's perception of designated use.

Waterbody users individually and informally assess designated use attainment through their perception of a waterbody's water quality and subsequently their ability to enjoy the waterbody for a particular use, which are typically recreational uses such as fishability and swimmablity. This gives an indication of the user's sensitivity of acceptable pollutant loads.

To collect information regarding the users' perceptions, one can conduct a survey. Surveys can provide information from people who are actually using a lake. This can provide a qualitative assessment of lake pollution levels and goal attainment for particular uses. This provides invaluable information about perception designated use attainment by the people who are actually using the waterbody.

The method of using user surveys to collect data about lake user perception is not new. In fact, user surveys have been previously conducted in Minnesota, Vermont, New York, and Florida (Smeltzer and Heiskary 1990; Kishbaugh 1993; Hoyer, Brown et al. 2004). These user surveys were focused on describing a relationship between the results of the user survey and the water quality parameters. The surveys used a nonrandom sample of volunteer water quality monitors. The volunteers completed the survey on the same day they were conducting water quality sampling. Therefore, as the authors of these papers acknowledge, the results of the survey may not be representative of the perception of the population of lake users.

These surveys found that there was a relationship between the user survey results and the water quality collected data. The Minnesota, Vermont, New York and Florida surveys all found that user perception of good water quality was correlated with healthier lakes, as indicated by their water quality parameter values (Smeltzer and Heiskary 1990; Kishbaugh 1993; Hoyer, Brown et al. 2004). Additionally, in Minnesota, Vermont, and Florida, users perceptions also varied because of regional differences in the perception of water quality (Smeltzer and Heiskary 1990; Hoyer, Brown et al. 2004).

Similar to the previous surveys, we conducted a survey that could link the survey response to measured quality variables. Unlike previous studies, we collected information from a sample of people who are using a particular lake. The goal of collecting data from lake users was to assess the lake user's perception of water quality and primary and secondary contact use enjoyment at recreational lakes in North Carolina. Since much of a user's perception of water quality is based on aesthetic clues and other external clues (media reports, reactions of other users, experiences at other waterbodies, etc.), we designed our survey to ask the users' to make assessments of their view of water quality and their enjoyment of particular uses. The results of this survey would help us to better understand the user's perception of designated use attainment for lakes in North Carolina.

Methods

The user survey was designed to elicit three areas of information: (1) the user's activities and familiarity with the lake, (2) the user's perception of the eutrophication-related water quality in relation to their use activities, and (3) demographic information.

Since a user survey involves collecting data from people, we applied for and received approval form the Duke University Institutional Review Board to conduct the survey. The final survey and accompanying letter were approved and determined to be of little to no risk to any survey participant.

Prior to finalizing the survey method and protocol, we conducted a pretest of the user survey on June 4, 2005 at Falls of the Neuse Lake. A pretest is a procedure suggested for any survey research to test the survey before it is used to officially collect data (Rea and Parker 1997). We specifically performed a pretest to determine how easy it would be to get survey participants and to find any flaws or possible misinterpretations of the questions. We also used the pretest as training for my survey assistants.

The survey was modified and finalized based on the results of the pretest; the final survey for North Carolina lakes is presented in Appendix A. Two major modifications to the pretest survey led to the finalized user survey: (1) the deletion of nonrecreational use questions, and (2) the expansion of the question about water clarity. After talking with the users and examining each of the pretest user survey response forms, we discovered that, in general, the recreational users were not able to link their nonrecreational uses, such as municipal drinking water, to the lake. For example, a question was asked about a general rating of the drinking water on a scale of excellent to poor. Though some of the users recognized that the lake was actually a reservoir that supplied the drinking water for the county, many of the users interpreted the drinking water question as taking a glass, dipping it into the lake, and drinking it. As a result of multiple interpretations of nonrecreational uses questions, the survey was revised to include only recreational uses of the lake.

The survey was additionally refined for the question about water clarity and it was expanded to include four questions total. The four questions about water clarity were used to learn which method of asking questions would best assess how users perceive the clarity of the water. The first two questions, (1) How clear is the water? and (2) What is the color of the water? are aimed at the two attributes that the users most associate with their enjoyment for recreational uses. The second two questions, (1) What is the condition of the lake, in regards to algae? and (2) What is the condition of the lake, in regards to sedimentation? are to examine the two separated and related causes of water clarity. It also helps us to assess the users' perception of eutrophication as related to the response variable, algal growth.

One can think of the questions as being related in the following arrangement (Figure 1). The attributes that we were most interested in were the amount of algae and sedimentation in the lake; the attributes that the users are interested in, in general, are lake clarity and color. Therefore, one can determine the relative amount of algae and sediment that the users would assess by transforming the water color and clarity axis and put them on the algae and sedimentation axis. It is important to note that the color does not perfectly correlate with algae and sediment, largely because the color brown does not mean that it is impaired exclusively by suspended solids. Despite the lack of perfect correlation, these questions can be used to further assess water clarity, one of the most important eutrophication symptoms that affect recreational lake users.

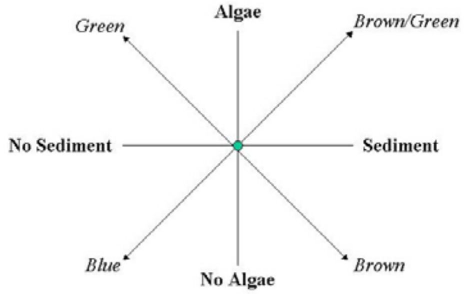

Figure 1. Eutrophication-related causes of clarity impairment. The meaningful values to the researcher are the perceived amounts of algae and sediment, where color and degree of clarity impairment meaningful to the lake user. As illustrated, these values are related and one can use the user values to project responses that better reflect values of interest to the researcher.

Given the finalized survey, we selected the lakes that we would survey. As described in the data collection section, we considered all the lakes that would be sampled monthly in 2005. We selected a subset for waterbodies that have recreational uses, a significant number of recreational users, and were located throughout the entire state.

We chose to sample multiple lakes once during the summer; these lakes were: Falls of the Neuse Lake, Jordan Lake, Lake Phelps, High Rock Lake, Kings Mountain Lake, and Santeetlah. By surveying these lakes, we were able to collect information for numerous waterbodies with a diversity of spatial, temporal, and physiographic characteristics within three of the North Carolina ecoregions (Griffith, Omernik et al. 2002). Additionally, user surveys were conducted monthly at Falls of the Neuse Lake. The goal of conducting a user survey more frequently at Falls of the Neuse Lake was to document the changing perception of users throughout the recreational season (June – August 2005).

We conducted a lake user survey on this subset of lakes concurrent with the 2005 North Carolina lake water quality sampling by DWQ. To correlate the survey responses with the water quality data, we carried out the survey within a couple days of the DWQ collection date. This procedure allowed us to assess the user's perception of designated use attainment during conditions similar to when the water was sampled.

Survey participants were randomly selected during or after they used the lake for one of its recreational goals. Though the participants were randomly selected, potential bias may have occurred from leaving out non-native English speakers, particularly the Hispanic community, and those citizens that choose not to go to the lake because they believe it does not meet their water quality expectations. Additionally, we were only able to collect samples at lake access points; as a result, we may have left out segments of users since we were unable to access them.

The survey participation was entirely voluntary and anonymous. The survey took approximately 3 minutes to complete. The participants were free to refuse to respond to any questions and to stop their participation at any time during the survey. The participants could, additionally, provide their contact information on a separate form if they wished to receive a copy of the final report that was generated using the survey data. There was no right or wrong answer to the responses of the survey, and there was no particular answer that we hoped a participant would select. If participants were interested in further information, we provided contact information and the web address for the project website (http://www.duke.edu/~mak22/).

User Survey Results and Discussion

We processed the surveys and created an electronic database. We combined the survey data, when possible, with the water quality data that was collected at approximately the same time. This data was used to learn about the users' uses and perception of the water quality for those uses. The results of the study will be presented individually for each surveyed lake.

Falls of the Neuse Lake

Falls of the Neuse Lake was sampled multiple times during the Summer of 2005. It was sampled throughout the summer so that we could obtain a larger sample that included more users and lake conditions on multiple days. Therefore, the results presented are a compilation of the samples taken once a month throughout the summer.

Table 1. Falls of the Neuse Lake Water Quality Data Summary
June – August 2005

	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)	Secchi Depth (m)
Mean	0.067	0.706	0.803
Median	0.045	0.625	0.8
Standard Deviation	0.052	0.254	0.465
Maximum	0.21	1.31	1.9
Minimum	0.02	0.38	0.2

n = 40; 10 sampling stations
There is no available Chlorophyll *a* data.

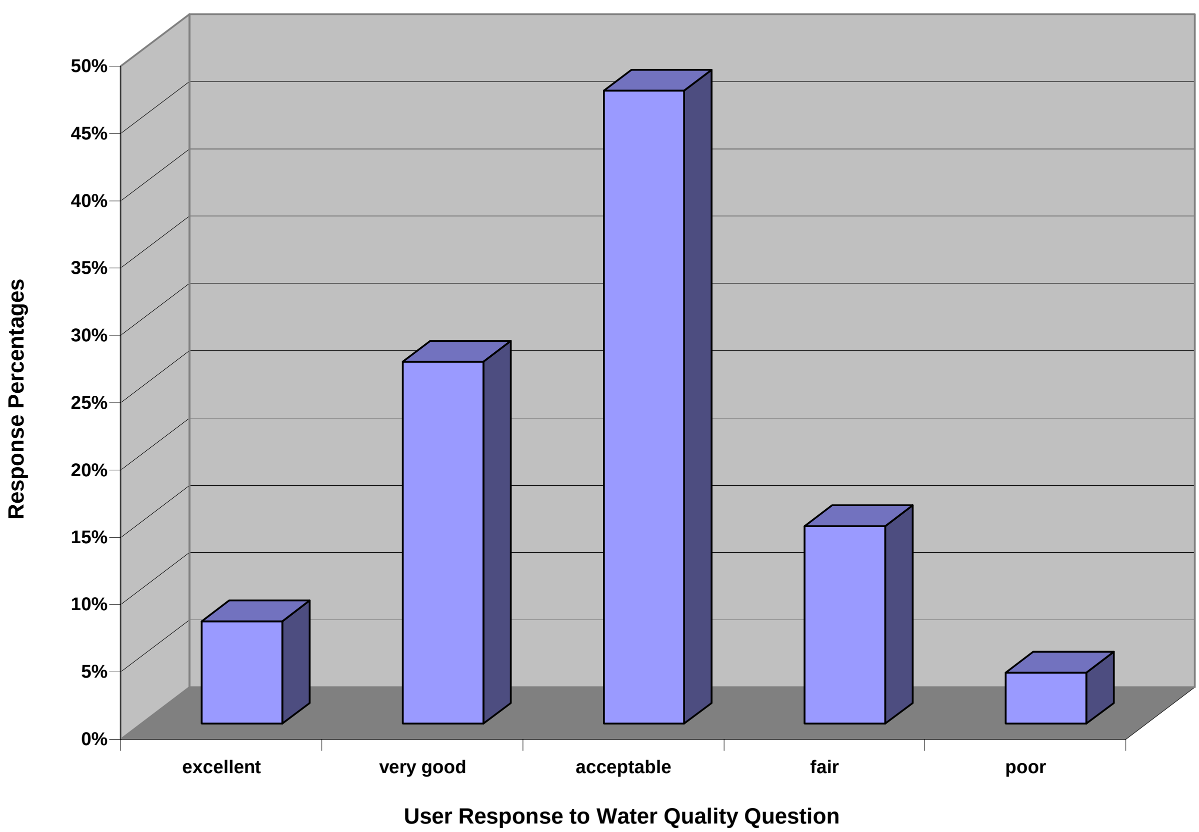

Figure 2. Falls of the Neuse Lake Users' Response to Water Quality. The responses of lake users responding to the question, "How would you rate the conditions of the lake for water quality based on your experiences today?" Most users believed the conditions were acceptable. n = 368

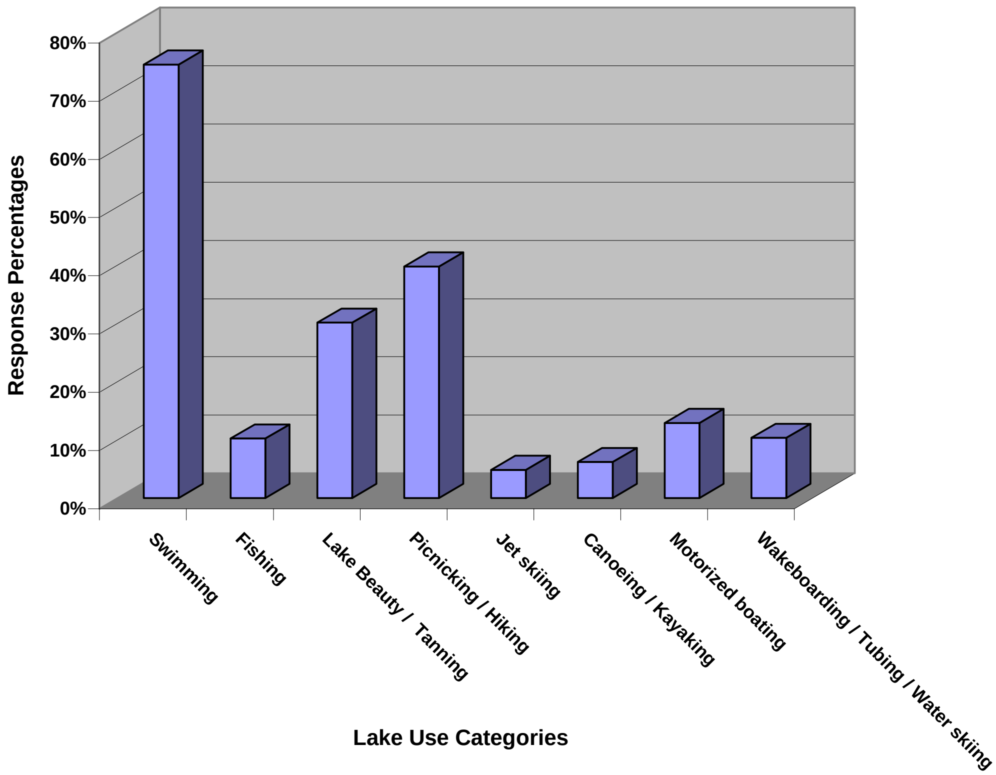

Figure 3. Types of Activities of Surveyed Falls of the Neuse Lake Users. The responses of lake users responding to the question, "What are you using the lake for today? (check all that apply)" The percentages sum to greater than 100 since some users participated in multiple recreational activities. n = 372, n = 290 (wakeboarding/tubing/water skiing)

Table 1 summarizes the results of the water quality sampling conducted by DWQ. Unfortunately, there was no chlorophyll *a* data to include in the summary, so the table includes the other major eutrophication-related water quality variables sampled. There was quite a large range of water quality for all three of the variables. The large range is primarily the result of samples taken at sampling stations throughout the waterbody. Since Falls of the Neuse Lake is a reservoir and, as a result, has many fingers the water quality is not consistent throughout the entire waterbody.

The Falls of the Lake users' perception of water quality (Figure 2) appears to be approximately normally distributed, with most users' stating that the water quality is acceptable. One speculation for the normal distribution of responses is the location of the users' activities. The users' who participated in activities where they may have viewed multiple locations within the lake may have a different perspective than those who only viewed a small segment of the lake. Additionally, because of the user's varied expectations for the water quality of the lake and because their assessments of the water quality are based on aesthetic cues, the perception of the users are not uniform.

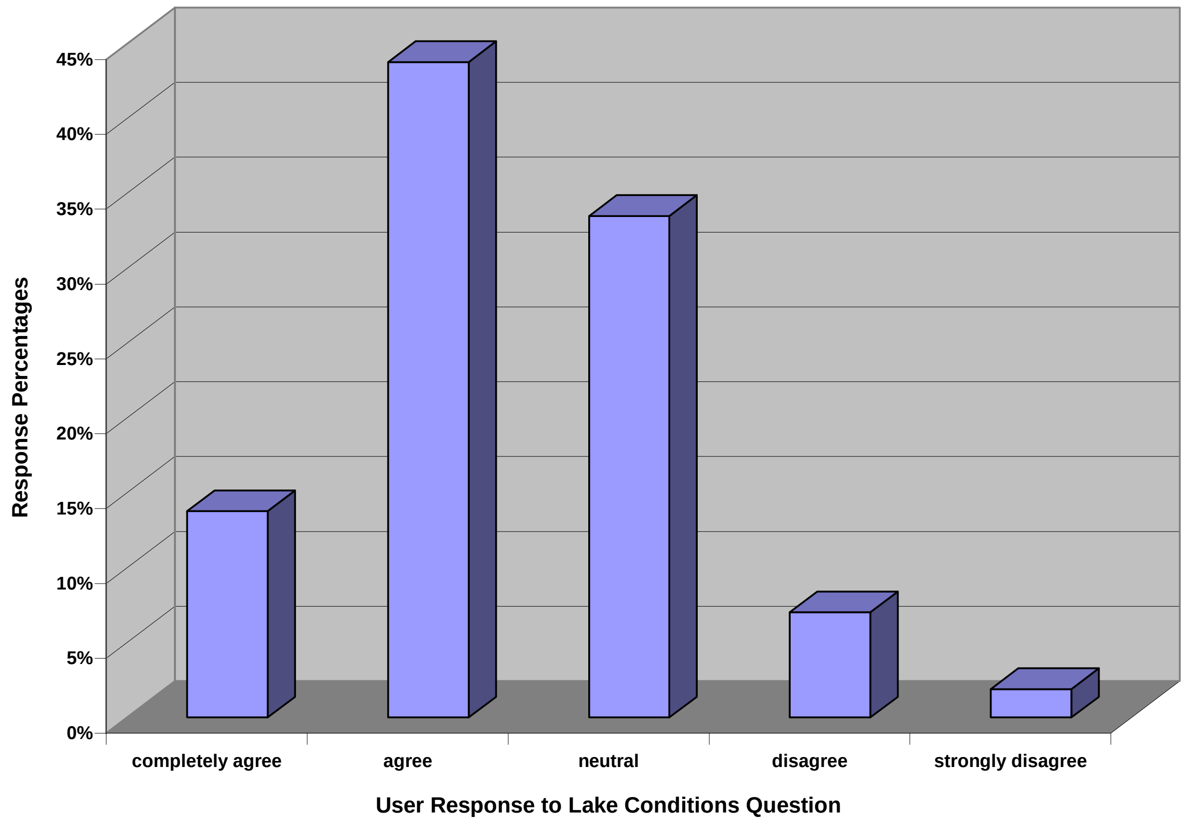

Figure 4. Falls of the Neuse Lake Users' Response to Lake Conditions. The responses of lake users responding to the question, "The conditions of the lake are perfect for my use(s) today." The majority of the users agree or strongly agree with this statement. n = 370

The Falls of the Lake users participated in a wide range of recreational activities (Figure 3). Most of the users were participating in multiple recreational activities, as indicated by the fact that users were allowed and encouraged to select all of the activities that they planned to participate in throughout their day. Of the users surveyed, the majority (approximately 72%) of users were at the lake to swim. There were other nonprimary contact recreation activities that the users participated in, however, the majority of the surveyed people at the lake planned to be immersed in the water. It is important to note that, because of the main access points at Falls of the Neuse Lake were swimming areas, we were able to access a particularly high number of those people swimming. As a result, this should not be taken as a representative, random sample of all of the lake users on a particular day; such a sample would be nearly impossible.

Given a particular users' use or uses of the lake, they responded to how they felt the conditions of the lake were for enjoying those particular uses (Figure 4). Most of the users' agreed or were neutral about the condition of the lake being perfect for their uses. As a result, there were few users (< 10%) who felt that the condition of the lake was hindering, in some way, their ability to fully enjoy or participate in a particular activity.

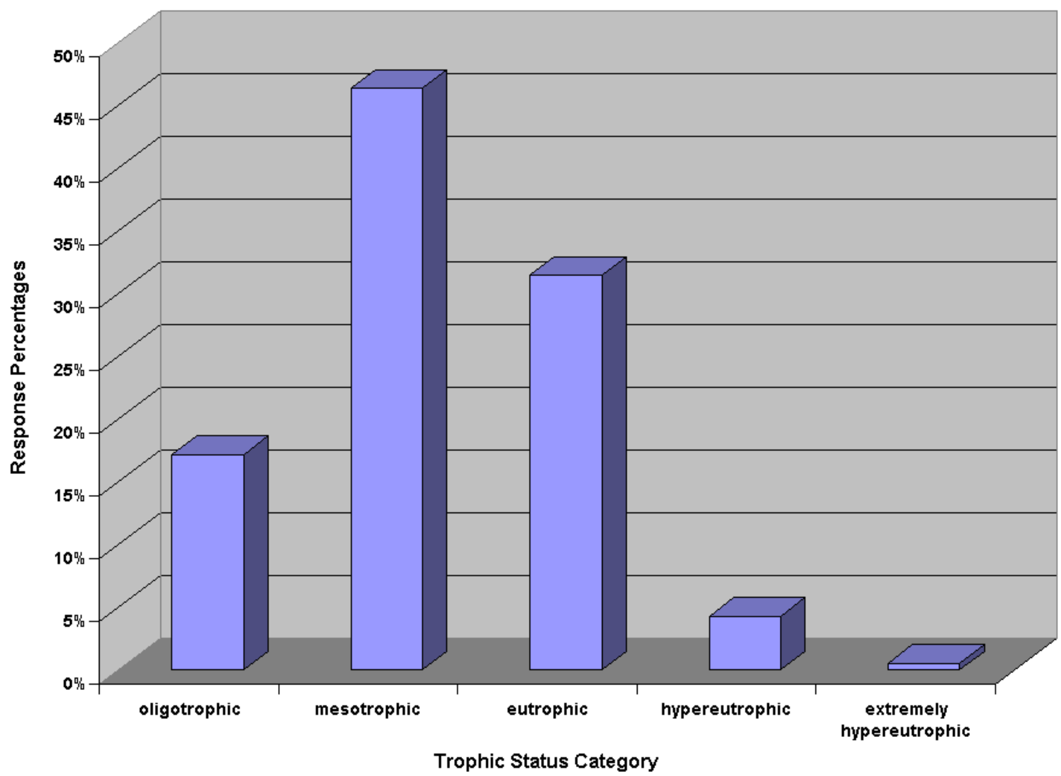

Figure 5. Falls of the Neuse Lake Users' Response to Trophic Status. The responses of lake users responding to the question, "How would you describe the condition of the lake, in regards to the algae, today?" Given the users' responses, the majority of the users would classify the lake as mesotrophic or eutrophic given a visual inspection. n = 349

Additionally, we asked the users to assess, indirectly, the trophic status of the lake. They made this assessment by responding to a question about the condition of the lake in regards to algae (Figure 5) and by providing their assessment of the clarity of the water (Figure 6). For the first question regarding the trophic status (Figure 5) most of the users assessed that, according to our categories, that the water was mesotrophic. There were also a large number who assessed the waterbody as eutrophic, but very few thought that the waterbody was hypereutrophic or worse (< 5%).

When the users were then asked to assess clarity, which decreases as eutrophication increases, the users somewhat surprisingly responded with assessments of neutral or disagreement that the clarity was far from crystal clear (Figure 6). Given that there is a reasonably high amount of sediment-related turbidity, it is not quite as surprising that the users may have realized, on some level, the difference between algal growth and sediment-related turbidity. We would expect, if there is not a large amount of suspended sediment in the water, that water clarity should be fairly well correlated with eutrophication; in Falls of the Neuse Lake the users responded in a manner that indicates that there may be sediment loading problems that might be the cause of decreased perception of designated use attainment.

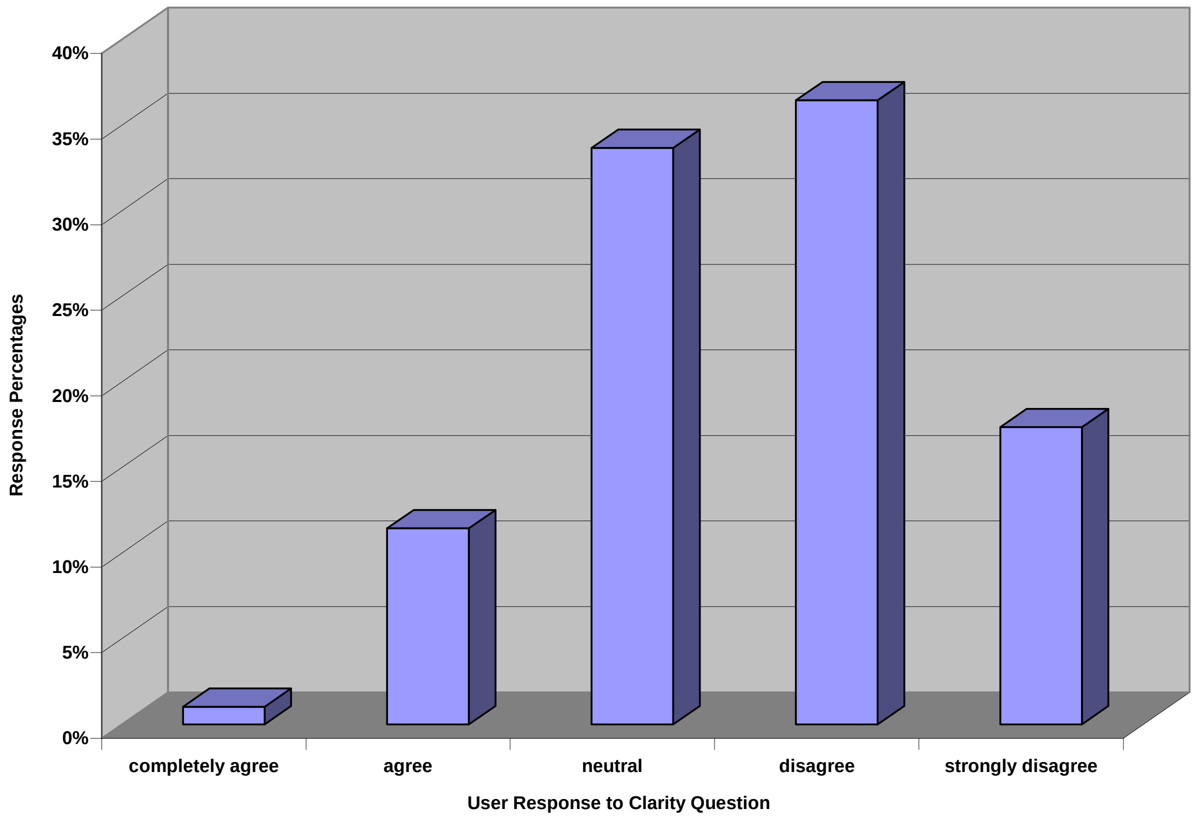

Figure 6. Falls of the Neuse Lake Users' Response to Clarity. The responses of lake users responding to the question, "The water of the lake is crystal clear today." The majority of the users responded that they were neutral or disagreed with the statement. n = 288

High Rock Lake

The only problem experienced during the survey sampling was at High Rock Lake. It was very difficult to find users, and the users that were accessible along the shore were, in general, unwilling to fill out surveys. As a result, this lake's user survey data will not be included in the final analysis.

Jordan Lake

Jordan Lake was sampled once during the summer. As a result, the sample size is much smaller than it is for Falls of the Neuse Lake, which was sampled and surveyed multiple times throughout the summer. Jordan Lake had a large number of Hispanic users who did not speak English; as a result, we were unable to survey these users and their perspective was not included in our data set.

There were no water quality data collected; as a result, we are unable to couple the water quality data with the user survey responses. We will, however, present the user survey data.

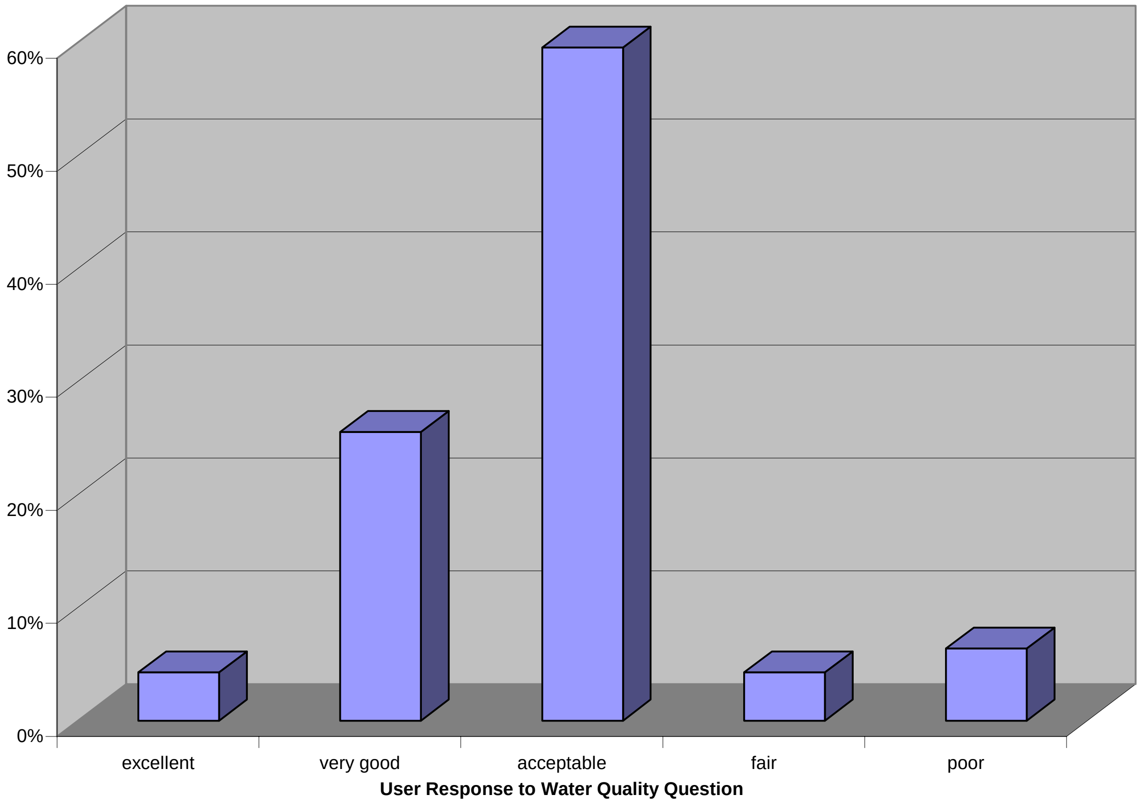

Figure 7. Jordan Lake Users' Response to Water Quality. The responses of lake users responding to the question, "How would you rate the conditions of the lake for water quality based on your experiences today?" Most users believed the conditions were acceptable. n = 47

Over half of the lake users surveyed thought that the water quality was acceptable, but less than 10% thought the water quality was fair or poor (Figure 7). Since there are not water quality data, we cannot, unfortunately, compare the users' responses to the measured water quality data.

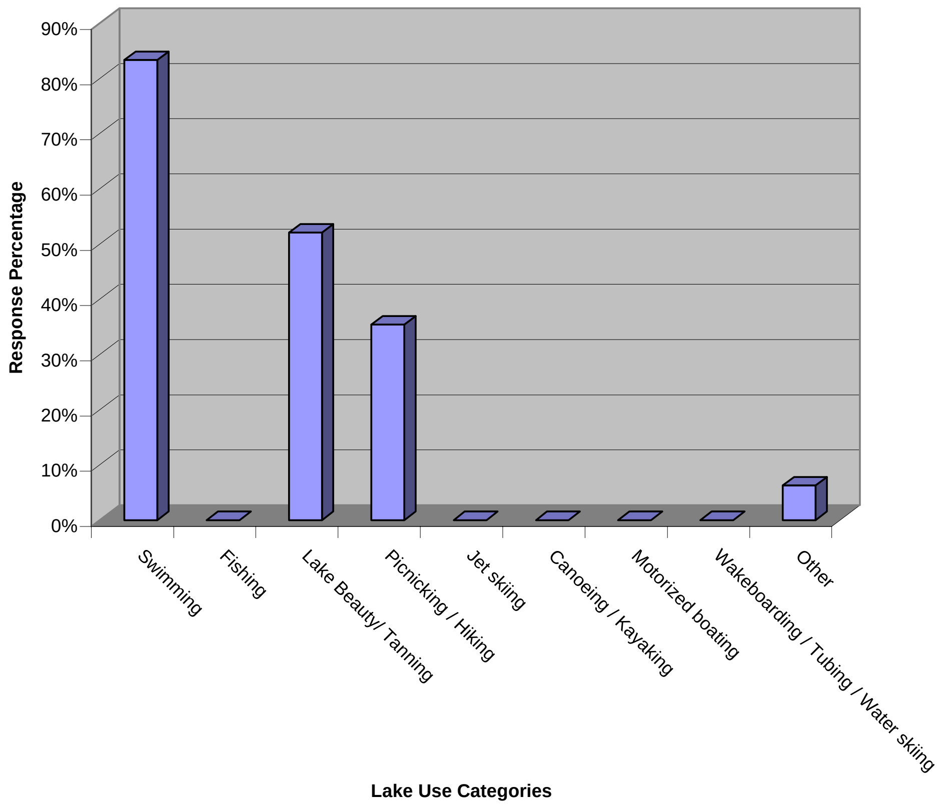

Figure 8. Types of Activities of Surveyed Jordan Lake Users. The responses of lake users responding to the question, "What are you using the lake for today? (check all that apply)" The percentages sum to greater than 100 since some users participated in multiple recreational activities. n = 48

We only surveyed people at one access point; therefore, we were not able to talk to the range of people that we might have wished. This was evidenced by the fact that the only users that we were able to survey were those swimming, picnicking, or enjoying the aesthetics (Figure 8). Since the majority of the surveyed users were swimming at Jordan Lake, primary contact recreation is an important use. Though we were able to see people boating, both motorized and nonmotorized boating, we were not able to survey these users because of difficulties surveying them at the access points. Additionally, we were not able to access those people who went fishing because we were not able to survey boaters and because we were unable to access a fishing pier.

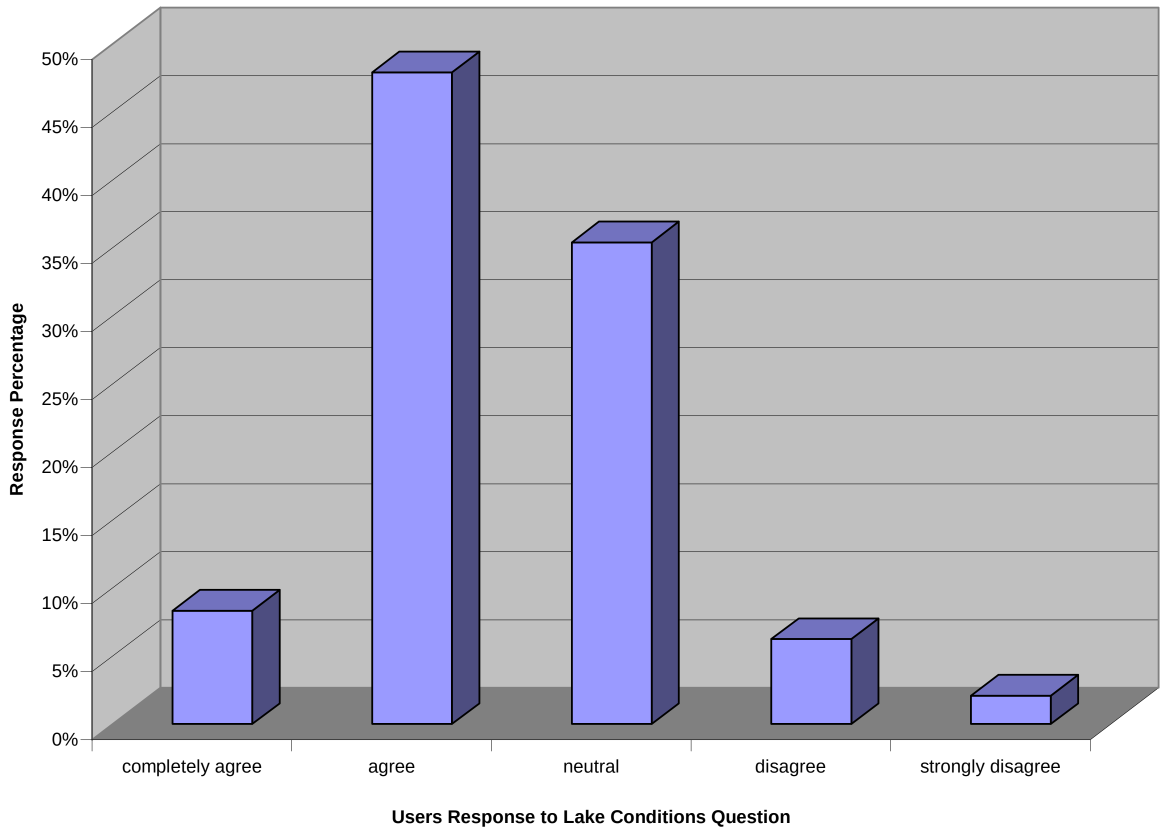

Figure 9. Jordan Lake Users' Response to Lake Conditions. The responses of lake users responding to the question, "The conditions of the lake are perfect for my use(s) today." The majority of the users are neutral or agree with this statement. n = 48

For the users that we surveyed, the users either agreed or were neutral regarding the statement, "The conditions of the lake are perfect for my use(s) today." Less than 10% of the users disagreed or strongly disagreed with the statement (Figure 9). Unlike the data at other lakes, the responses for this particular question were clustered. Since over 80% of the surveyed users were swimming, this is largely an assessment of the users' perception swimming condition.

Additionally, comparing these results to the results for some of the other questions, the response is not surprising. The large majority of the users believed that the trophic status of the lake was either mesotrophic or eutrophic (Figure 10). This is in comparison to the users' response to clarity, in which they largely disagreed that the water was crystal clear (Figure 11). The users responses could be a result of the fact that, since they were at a beach access point and either swimming, picnicking, or enjoying the aesthetics, they were only able to make their judgment based on the one location instead of a composite of multiple locations, as they would have if they had been boating in multiple locations of the lake. Therefore, since the users did not see floating algal mats, but did experience reduced clarity from turbidity, their assessment was formed based on this visual and experiential assessment.

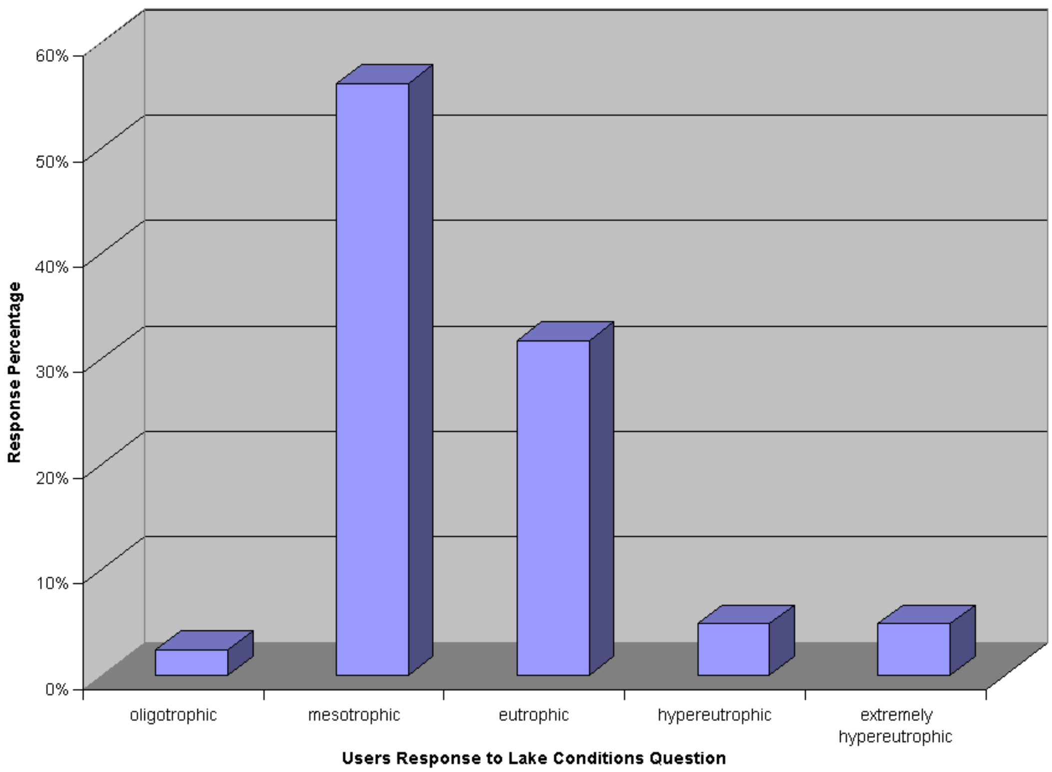

Figure 10. Jordan Lake Users' Response to Trophic Status. The responses of lake users responding to the question, "How would you describe the condition of the lake, in regards to the algae, today?" Given the users' responses, the majority of the users would classify the lake as mesotrophic or eutrophic given a visual inspection. n = 41

Another exogenous factor that may have affected the user's response was the extremely hot weather. The day that we surveyed was near 100ºF; this began effecting people's perceived enjoyment of the waterbody because they were not necessarily able to fully participate in all the activities they wished. Additionally, the location of the main swimming beach is not as scenic as some of the other lakes; from the beach the users are able to see a highway and power lines. Though these are aesthetic factors that are not related to water quality or to eutrophication, they do affect a users' perception of the lake quality since their assessment is based largely on aesthetic cues or the feel of the water if they were swimming.

Since we did not directly assess the aesthetic cues that affected a user's responses, we are only able to speculate, based on our conversations and what we observed, as to the likely reasoning behind particular responses.

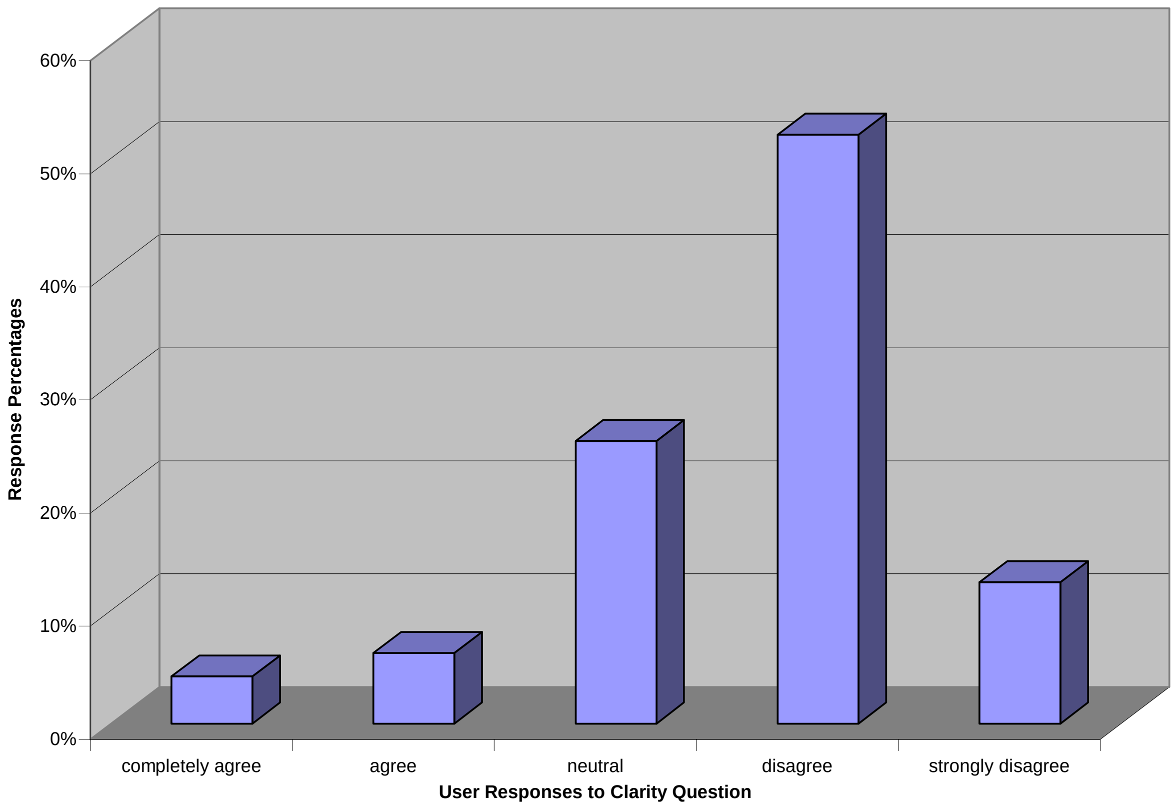

Figure 11. Jordan Lake Users' Response to Clarity. The responses of lake users responding to the question, "The water of the lake is crystal clear today." The majority of the users responded that they disagreed with the statement. n = 48

Kings Mountain Reservoir

Kings Mountain Reservoir was surveyed once during the summer. Therefore, similar to the lakes that were only surveyed once, the survey size is not very large. Additionally, since we were asking people to take surveys at a boat ramp, it was more difficult to get the users to agree to participate in the survey since most were busy preparing their boats.

Table 2. Kings Mountain Reservoir Water Quality Data Summary
August 2005

	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)	Secchi Depth (m)
Mean	0.02	0.42	1.65
Median	0.02	0.42	1.6
Standard Deviation	0	0.018	0.265
Maximum	0.02	0.44	2.0
Minimum	0.02	0.40	1.4

n = 4; 4 sampling stations
There is no available Chlorophyll *a* data.

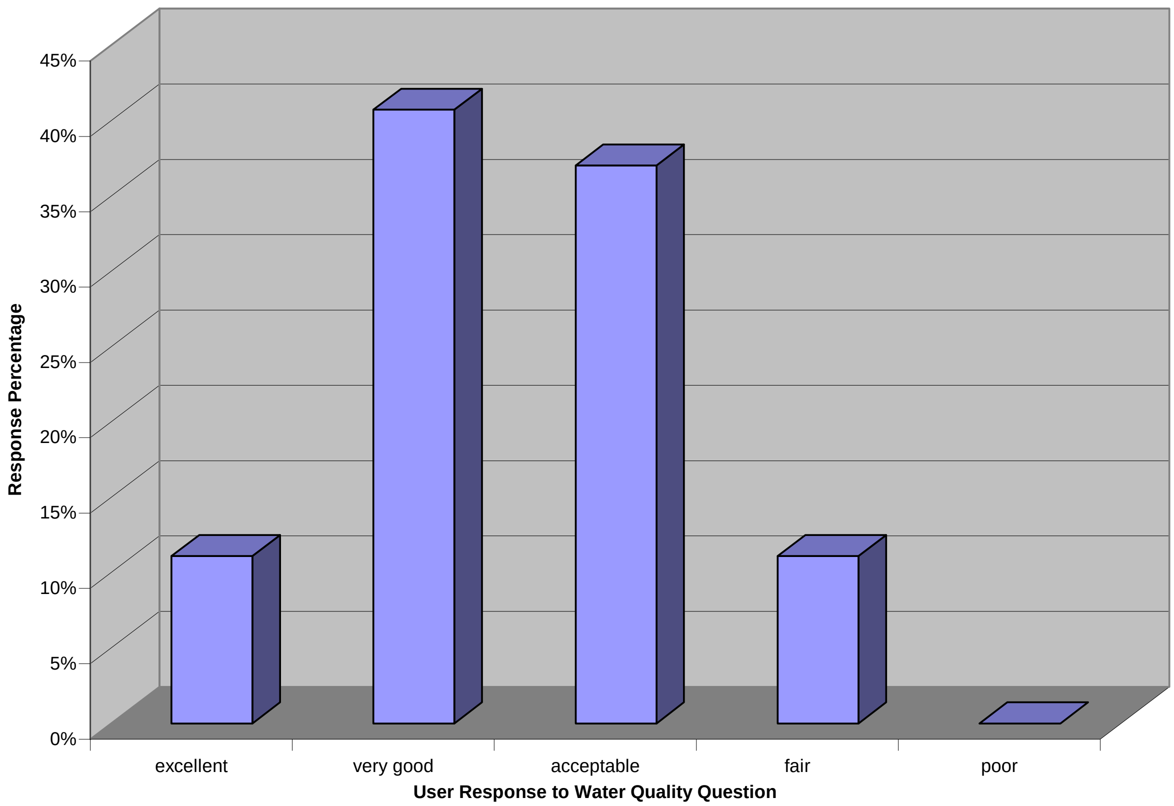

Figure 12. Kings Mountain Reservoir Users' Response to Water Quality. The responses of lake users responding to the question, "How would you rate the conditions of the lake for water quality based on your experiences today?" Most users believed the conditions were very good or acceptable. n = 27

The water quality data indicates that the conditions were fairly consistent throughout Kings Mountain Reservoir (Table 2). The total phosphorous was 0.02 mg/L at all of the sampling stations; the total nitrogen and Secchi depth levels also did not vary much for the four sampling stations.

The lake users' perception of water quality indicated that most of the users thought the water quality was either very good or acceptable (Figure 12). None of the lake users thought that the water quality was poor; however, some did think that the water quality was either excellent or fair. Given that the sampled water quality data was fairly consistent throughout the waterbody, we believe that this distribution of users' perspectives demonstrates the range of perspectives that a group of people can have looking at the same body of water. These different perspectives are largely a result of different expectations for what a lake should look like based on a user's past experiences or other influences.

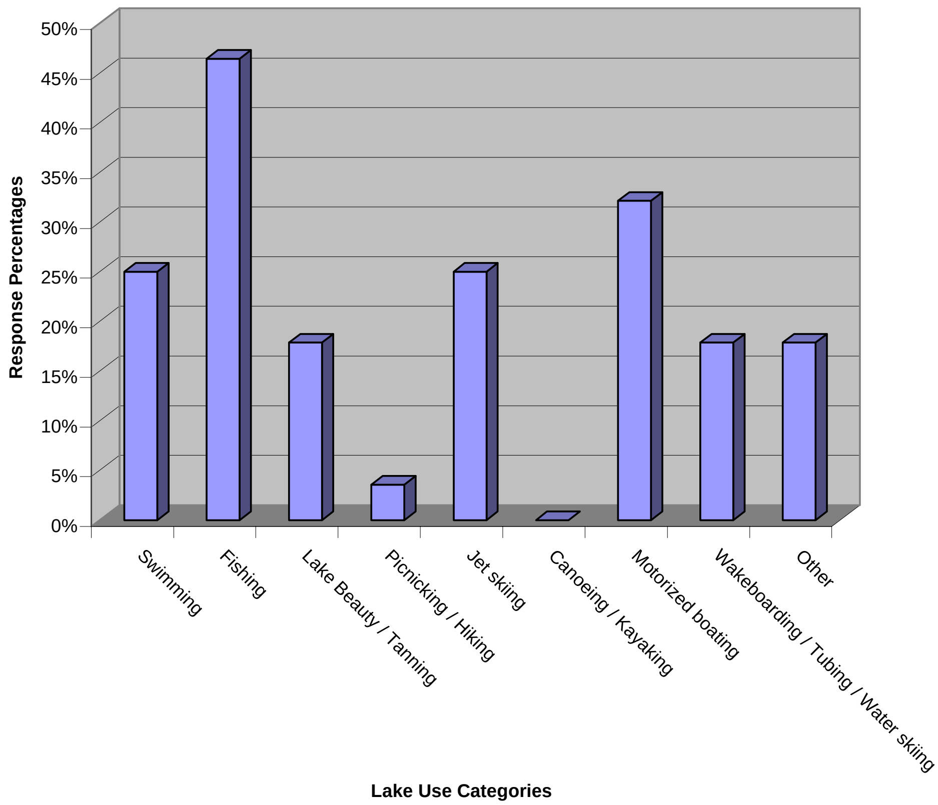

Figure 13. Types of Activities of Surveyed Kings Mountain Reservoir Users. The responses of lake users responding to the question, "What are you using the lake for today? (check all that apply)" The percentages sum to greater than 100 since some users participated in multiple recreational activities. n = 28

There was only one location where we could collect surveys, a boat ramp. As a result, the results that we were able to collect reflected a much larger percentage of users boating and fishing than in other lakes or reservoirs (Figure 13). Additionally, Kings Mountain Reservoir no longer has a swimming beach, so those users that went swimming were swimming off their boats instead of at a beach. There was also a much higher percentage of users participating in activities related to boating such as fishing, wakeboarding, and jet skiing. Unlike other locations, since we were at a boat ramp, there were not very many users picnicking and there were no users participating in nonmotorized boating activities.

Kings Mountain Reservoir has a visitor's center at the boat ramp. From informal conversations with the employees at the visitor's center, they indicated that the people that we surveyed were fairly representative of the typical lake users of Kings Mountain Reservoir.

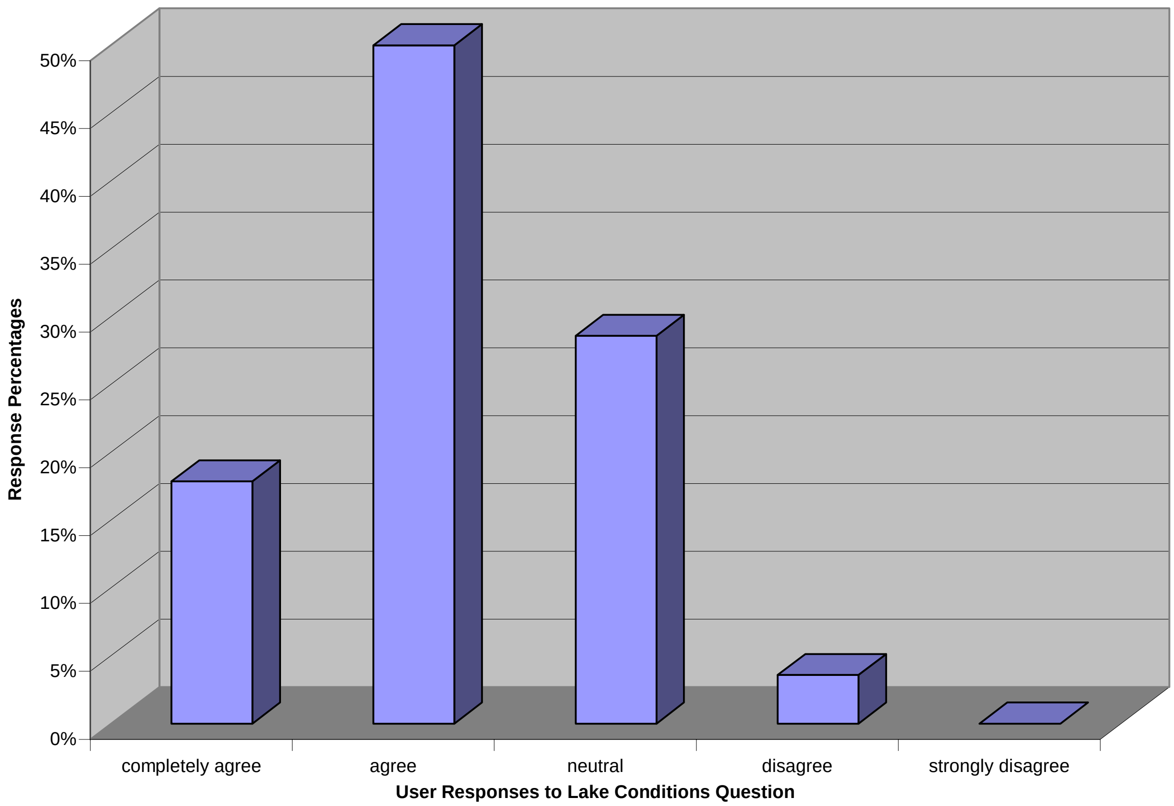

Figure 14. Kings Mountain Reservoir Users' Response to Lake Conditions. The responses of lake users responding to the question, "The conditions of the lake are perfect for my use(s) today." The majority of the users agree with this statement. n = 28

The Kings Mountain Reservoir users largely agreed that the condition of the lake was perfect for their use on the day surveyed. Few (< 5%) of the users disagreed or strongly disagreed with the statement. Since the users participated in a range of activities, they were providing an assessment of the lake conditions for all of the different uses that they participated in, their assessment of the condition was a composite assessment.

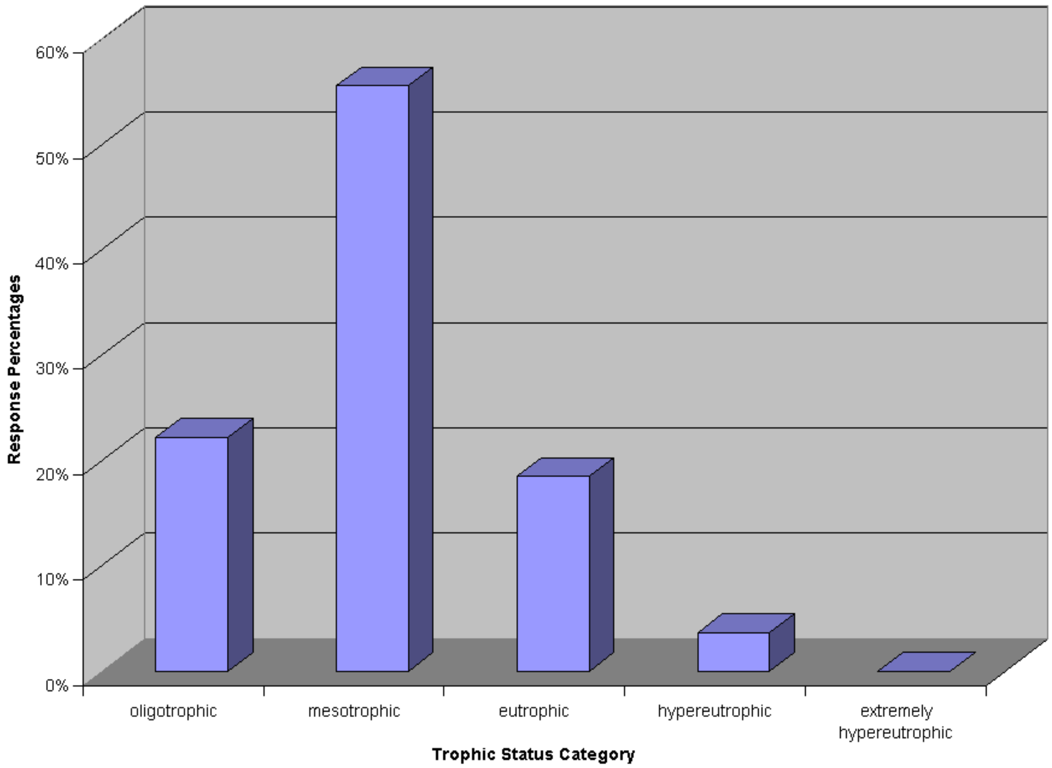

Figure 15. Kings Mountain Reservoir Users' Response to Trophic Status. The responses of lake users responding to the question, "How would you describe the condition of the lake, in regards to the algae, today?" Given the users' responses, the majority of the users would classify the lake as mesotrophic given a visual inspection. n = 27

The Kings Mountain Reservoir users assessed the trophic status of the lake based on a visual inspection of the lake during their activities. Based on their perspective, greater than half of the users thought that the lake was mesotrophic (Figure 15). The skewed distribution shows that users thought that the trophic status was oligotrophic to hypereutrophic; the only category that no users thought was possible was extremely hypereutrophic.

In addition, the users responded to the question, "The water of the lake is crystal clear today." The majority of the users were neutral in regards to the statement, and none of the users completely agreed with the statement (Figure 16). Given that the Secchi depth ranged from 2.0 m to 1.4 m at the sampling stations (Table 2), this gives one some perspective of what the users' perception of water clarity in comparison to the ideal crystal clear case.

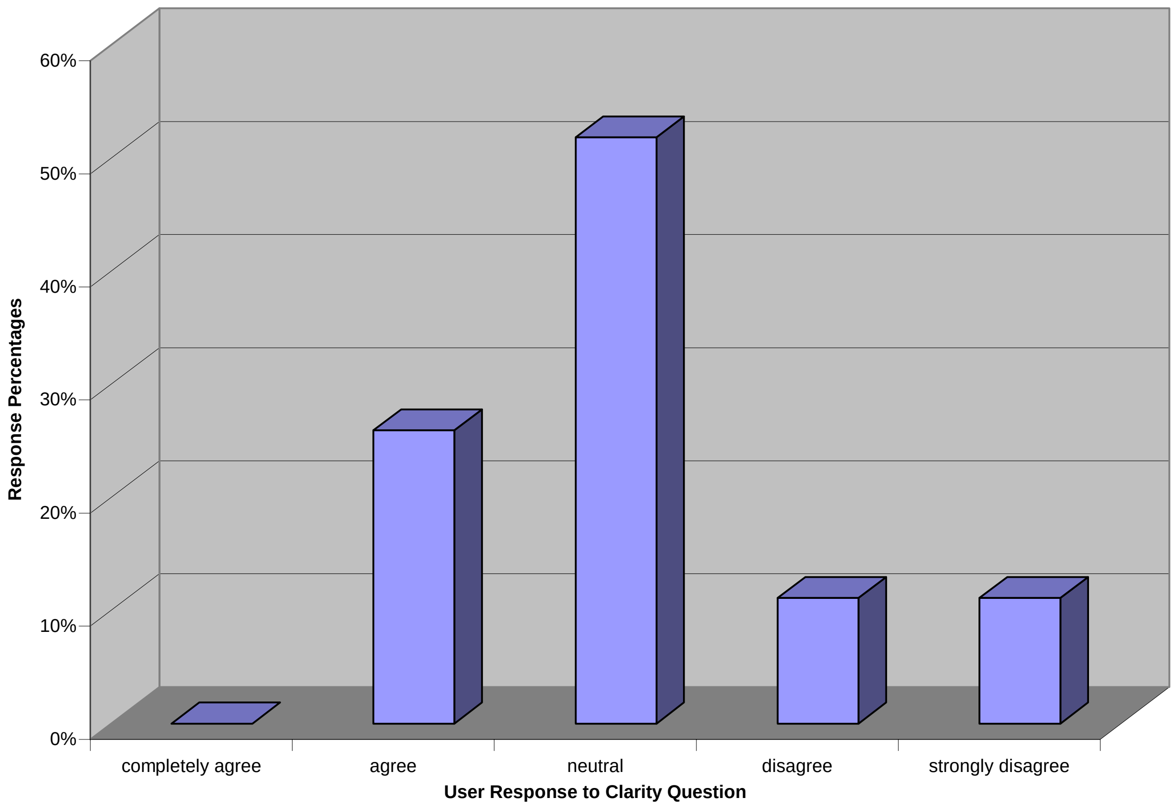

Figure 16. Kings Mountain Reservoir Users' Response to Clarity. The responses of lake users responding to the question, "The water of the lake is crystal clear today." The majority of the users responded that they were neutral in regards to the statement. n = 27

Lake Phelps

Lake Phelps was the only natural lake that we surveyed. Because Lake Phelps is located in a fairly rural part of North Carolina, it was more difficult to obtain survey responses than in other more heavily used waterbodies.

Table 3. Phelps Lake Water Quality Data Summary
July 2005

	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)	Secchi Depth (m)
Mean	<0.02	0.153	1.53
Median	<0.02	0.11	1.7
Standard Deviation	NA	0.075	0.379
Maximum	0.02	0.24	1.8
Minimum	<0.02	0.11	1.1

n = 3; 3 sampling stations
There is no available Chlorophyll *a* data.

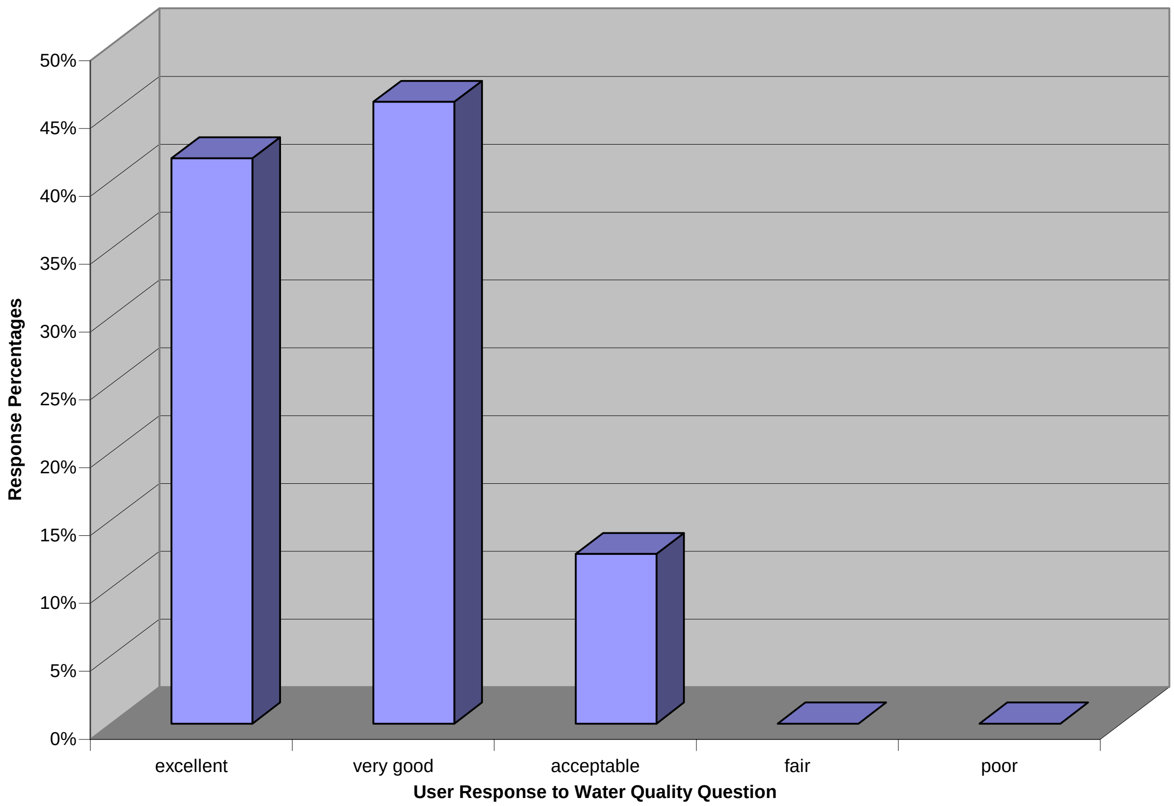

Figure 17. Lake Phelps Users' Response to Water Quality. The responses of lake users responding to the question, "How would you rate the conditions of the lake for water quality based on your experiences today?" The vast majority of the users believed the water quality was excellent or very good. n = 24

The water quality data of Lake Phelps indicates that it has fairly low nutrient levels and fairly high Secchi depth levels (Table 3). The water quality data indicated that the total phosphorous levels were at or below 0.02 mg/L. The total nitrogen levels were also low at all three of the sampling stations. The Secchi depth levels were between 1.1 m and 1.8 m at the three stations. Since Lake Phelps is a natural lake within the Carolina Bays, it is naturally shallow (2 m or less). It is unclear whether any of these Secchi depth measurements are the depth of the lake at a particular station, but given that the lake is shallow it is possible.

The users of Lake Phelps responded that the water quality was largely either excellent or very good (Figure 17). None of the users thought that the water quality was either fair or poor. Given that their responses are not distributed widely, the surveyed users agreed with each other fairly well on the quality of water.

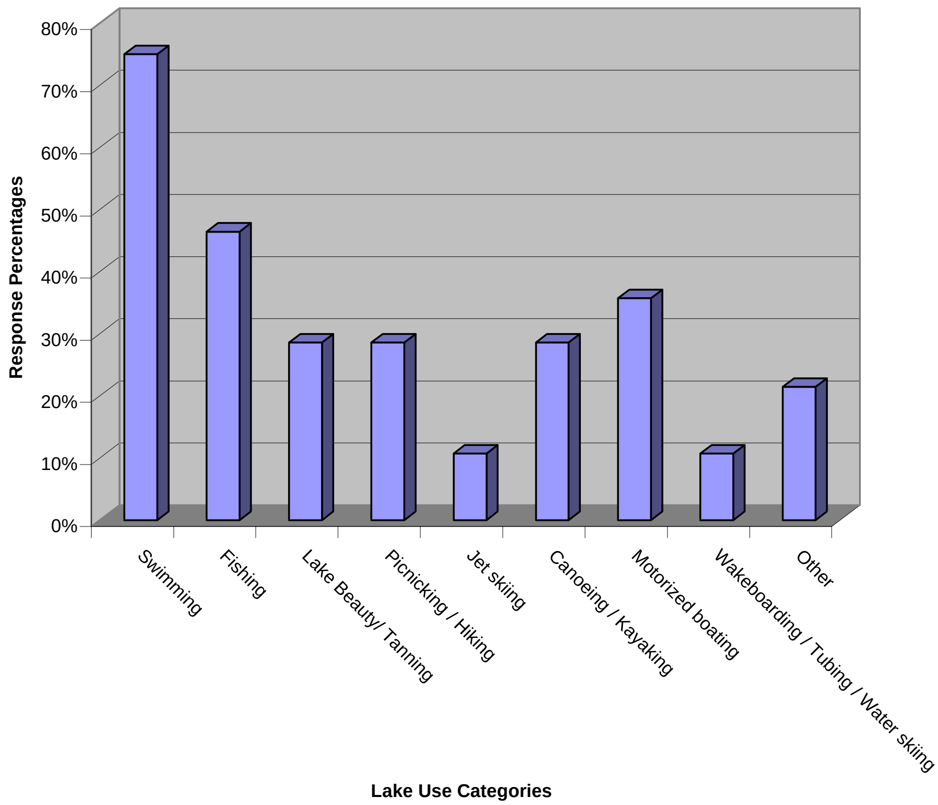

Figure 18. Types of Activities of Surveyed Lake Phelps Users. The responses of lake users responding to the question, "What are you using the lake for today? (check all that apply)" The percentages sum to greater than 100 since some users participated in multiple recreational activities. n = 27

Because Lake Phelps is located in a fairly rural part of the state, there were not a large number of people using the lake. We talked to users at the Lake Phelps State Park access point. Additionally, we talked to the owners of Conman's; Mike Noles, the owner of Conman's, is known by the Lake Phelps homeowners as the "Mayor of Lake Phelps." Mr. Noles let us talk with those people vacationing at Lake Phelps and also indicated that we could walk up to homes and talk with people that live on the lake. As a result, we were able to talk with a range of people that live on Lake Phelps and also were visiting Lake Phelps.

The surveyed Lake Phelps users participated in a range of recreational activities (Figure 18). Many of the users were participating in multiple activities that included both primary and secondary contact recreation. Notably, there were a high percentage of people (~ 75%) who went swimming in Lake Phelps. Additionally, were a large number of people that boat, both motorized or nonmotorized boating. Finally, a large number of people participated in fishing (~ 45%).

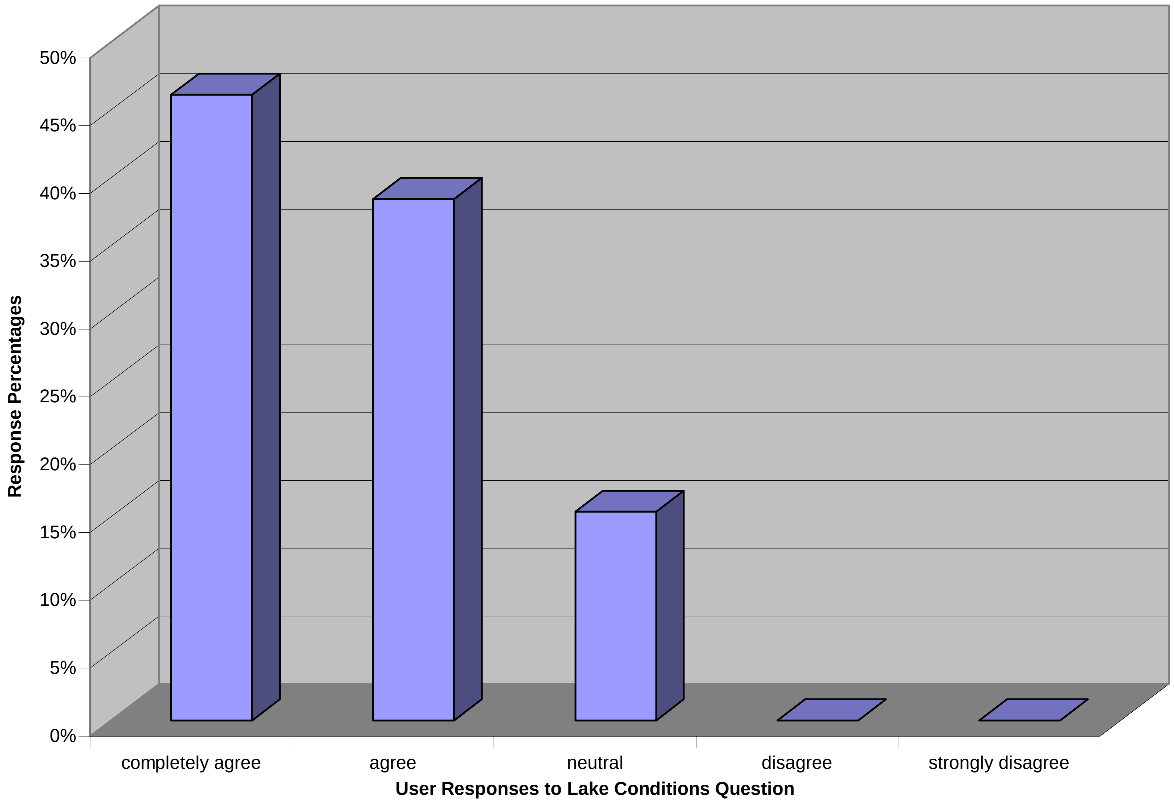

Figure 19. Lake Phelps Users' Response to Lake Conditions. The responses of lake users responding to the question, "The conditions of the lake are perfect for my use(s) today." The majority of the users completely agree or agree with this statement; none of the users disagreed with the statement. n = 26

We asked the users to assess the condition of the lake for the particular recreational uses that they participated in that day (Figure 19). The users responded overwhelmingly (86%) that they completely agreed or agreed that the conditions of the lake were perfect for their use(s). In addition, there were no users that disagreed or strongly disagreed with the statement.

This response is consistent with the users response for water quality (Figure 17); since the users thought that the water quality was very good, they also thought that the conditions of the lake were good for recreational uses of the lake.

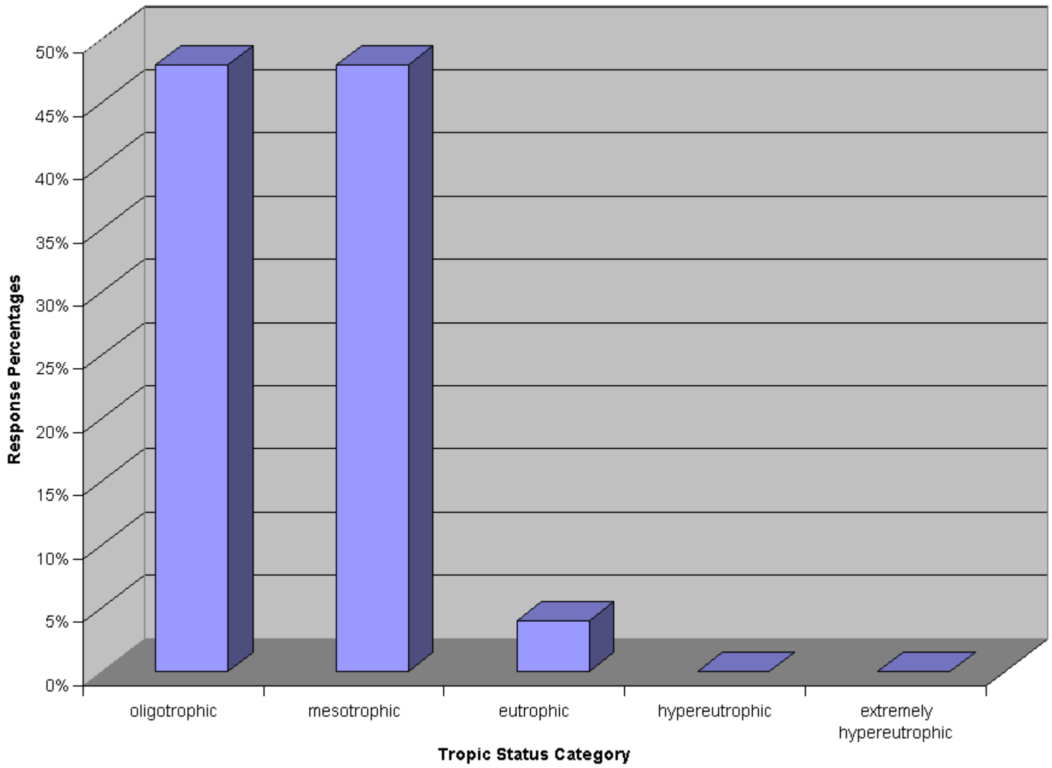

Figure 20. Lake Phelps Users' Response to Trophic Status. The responses of lake users responding to the question, "How would you describe the condition of the lake, in regards to the algae, today?" Given the users' responses, almost all the users would classify the lake as either oligotrophic or mesotrophic given a visual inspection. n = 25

The users assessed the trophic status of Lake Phelps (Figure 20). The users thought that the lake was either oligotrophic or mesotrophic (> 95%). None of the users thought that the lake was either hypereutrophic or extremely hypereutrophic. Given the low levels of nutrients sampled (Table 3), this assessment does not seem unrealistic. Since this is the only natural lake that we surveyed, the results of this assessment are particularly interesting, but it is unclear whether users at other Carolina Bays would have the same perception of the lakes that they use.

The users' perception of the water clarity was much different (Figure 21). The users did not have a standout response; instead their response was almost uniform across the categories of completely agree to disagree. None of the users strongly disagreed with the statement. We are unclear as to why there is not greater agreement regarding the lake clarity, particularly since the users more or less agreed on a pair of responses for most of the other questions. One other factor that may have affected the users' response could have been the nature of Lake Phelps. Since Lake Phelps is naturally very shallow, the users responses may be affected by the shallow nature of the lake.

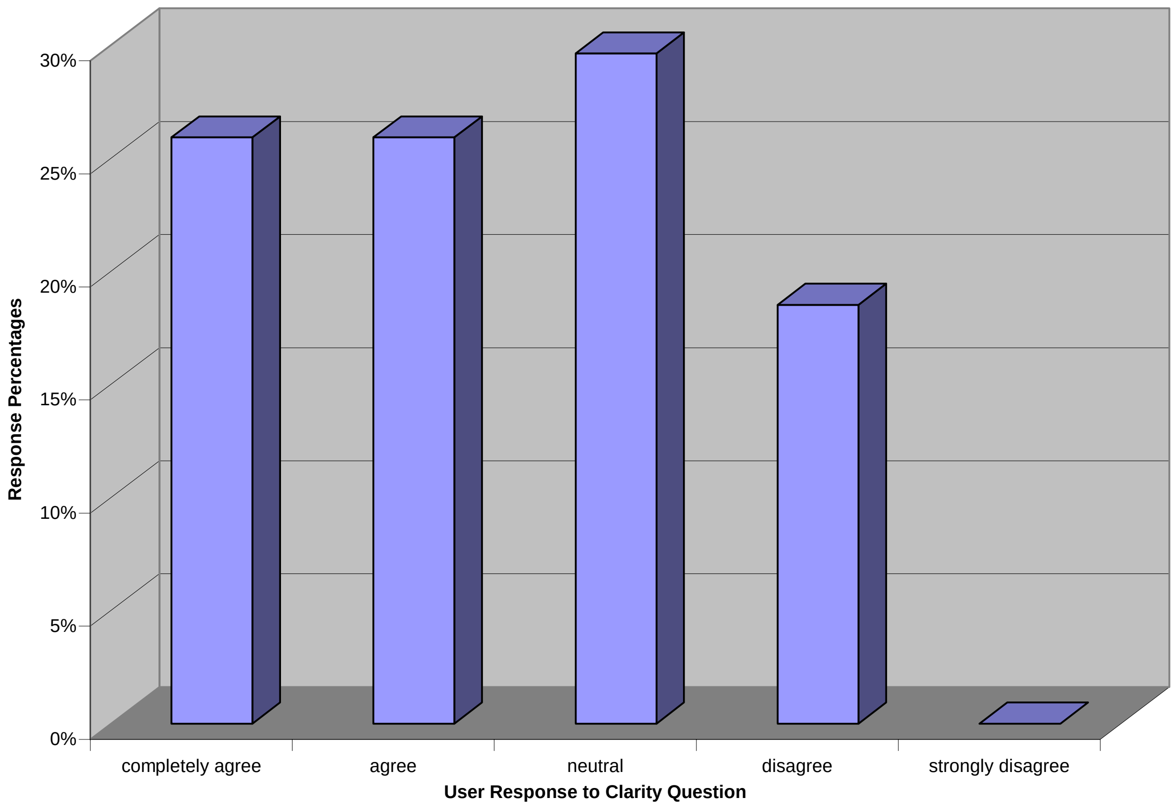

Figure 21. Lake Phelps Users' Response to Clarity. The responses of lake users responding to the question, "The water of the lake is crystal clear today." The a little over half of the users responded that they were completely agreed or agreed with the statement. n = 27

Santeetlah Lake

Santeetlah Lake was sampled once during the summer. As a result, the sample size is much smaller than it is for Falls of the Neuse Lake, which was sampled and surveyed multiple times throughout the summer. There were no water quality data collected; as a result, we are unable to couple the water quality data with the user survey responses. We will, however, present the user survey data.

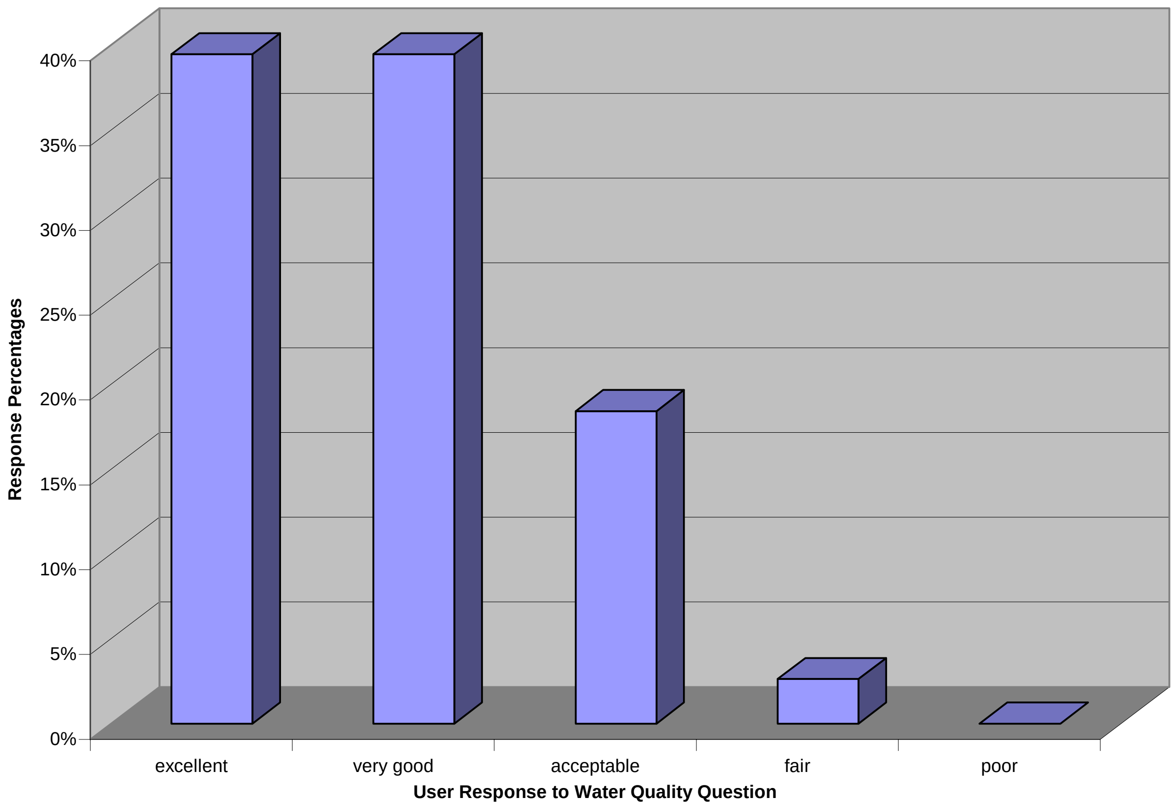

Figure 22. Santeetlah Lake Users' Response to Water Quality. The responses of lake users responding to the question, "How would you rate the conditions of the lake for water quality based on your experiences today?" The vast majority of the users believed the water quality was excellent or very good. n = 38

The users whom we surveyed at Santeetlah Lake largely believed that the water quality of the lake was either excellent or very good (Figure 22). There were some users, though a smaller percentage who thought the water quality was either acceptable or fair. None of the users thought that the water quality was poor.

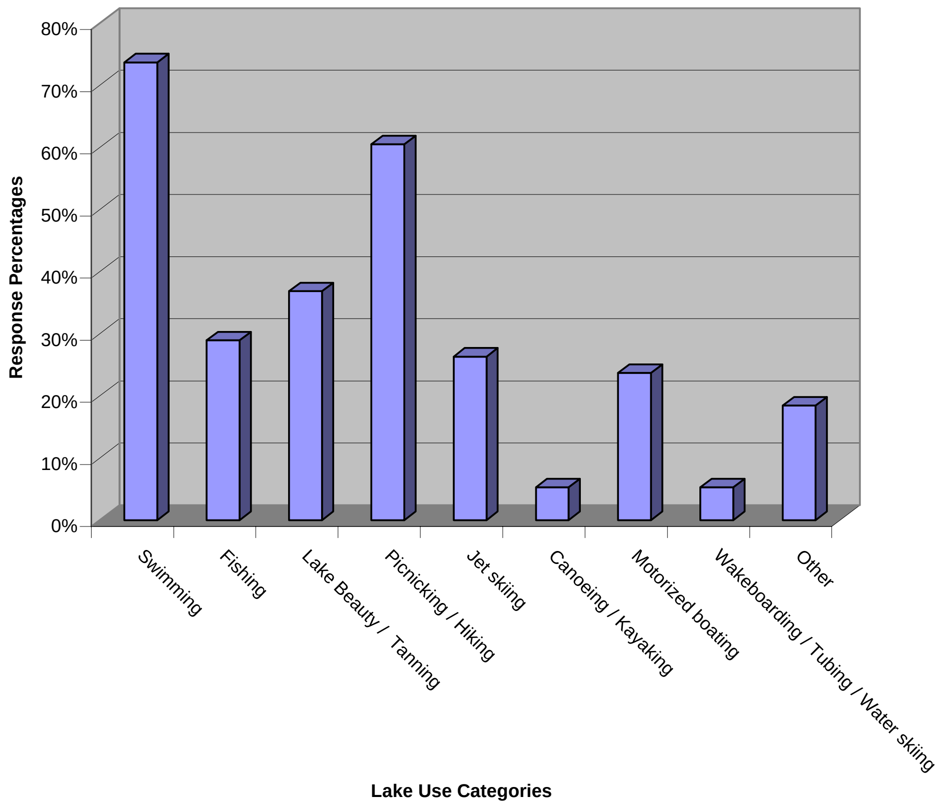

Figure 23. Types of Activities of Surveyed Santeetlah Lake Users. The responses of lake users responding to the question, "What are you using the lake for today? (check all that apply)" The percentages sum to greater than 100 since some users participated in multiple recreational activities. n = 27

Santeetlah Lake had access points scattered throughout the entire lake, but there was only one major access point. As a result, we were able to survey users throughout the watershed, but most of the users we surveyed were at the swimming and picnic access point. Additionally, we kayaked in one of the fingers of the lake to survey motorized boaters that we would not be able to survey elsewise.

Given where we were able to survey lake users, the activities of the users fell in line with what one would expect given where we surveyed (Figure 23). We were able to survey users who participated in all the major lake recreational categories. There were a large number of users who were either swimming and/or picnicking. There were also users who participated in motorized boating, jet skiing, fishing, and enjoyed the lake beauty. Fewer percentages of people either wakeboarded or canoed.

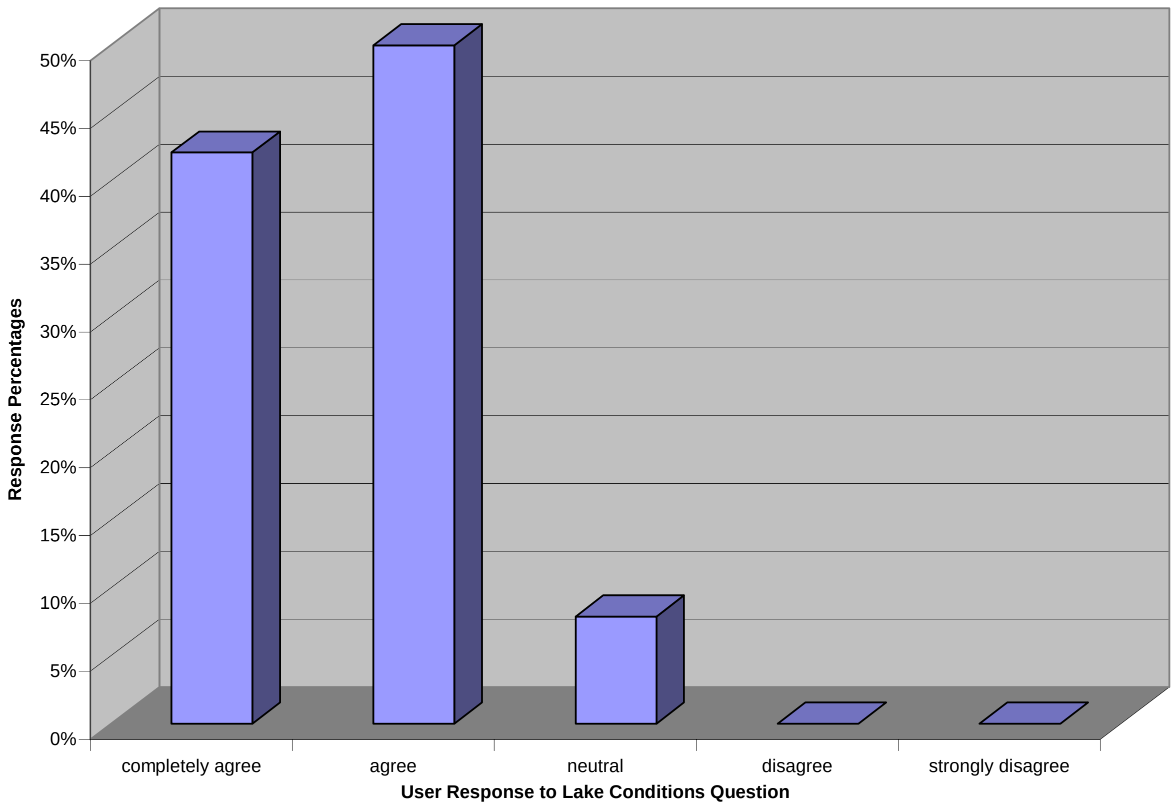

Figure 24. Santeetlah Lake Users' Response to Lake Conditions. The responses of lake users responding to the question, "The conditions of the lake are perfect for my use(s) today." The majority of the users completely agree or agree with this statement; none of the users disagreed with the statement. n = 38

The users surveyed either completely agreed or agreed that the conditions of the lake were perfect for their uses (Figure 24). None of the users disagreed or strongly disagreed with the statement. Given the range of activities, both primary and secondary, and the users perception of water quality, their responses to the lake conditions for their uses seem reasonable.

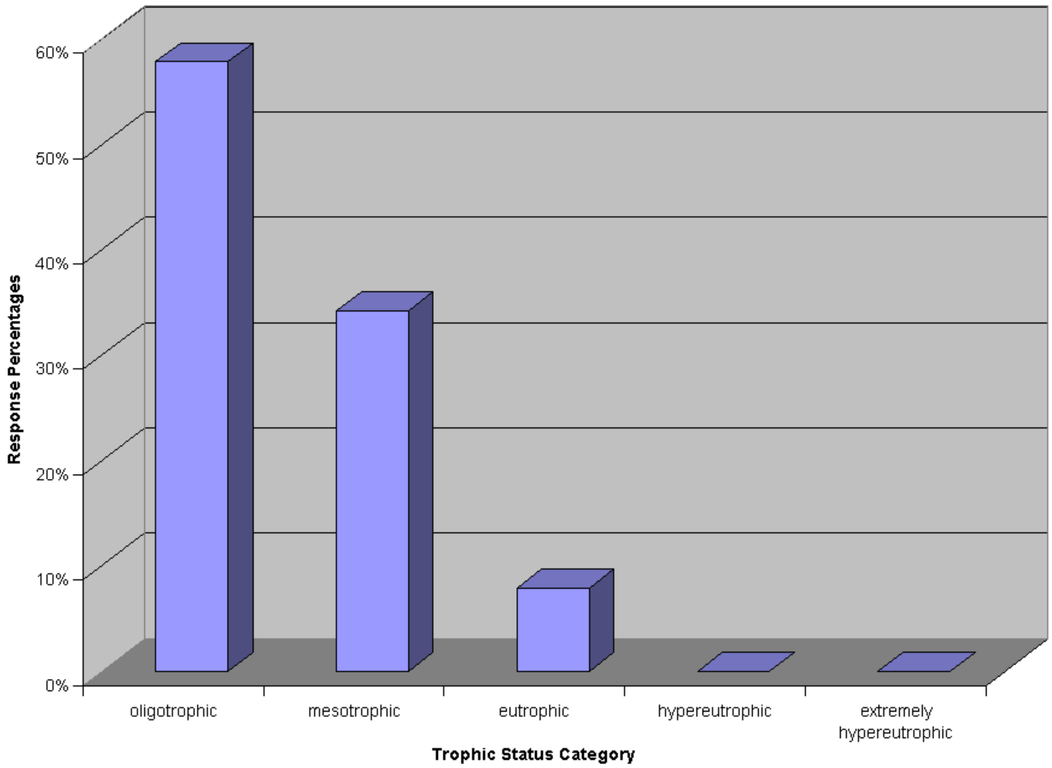

Figure 25. Santeetlah Lake Users' Response to Trophic Status. The responses of lake users responding to the question, "How would you describe the condition of the lake, in regards to the algae, today?" Given the users' responses, most of the users would classify the lake as either oligotrophic or mesotrophic given a visual inspection. n = 38

We asked the Santeetlah lake users to assess the trophic status of the lake (Figure 25). Over half of the users assessed the condition as oligotrophic, with decreasing numbers assessing the lake as mesotrophic or eutrophic. None of the users thought that the lake was either hypereutrophic or extremely hypereutrophic.

Similarly, we asked the users to assess the water clarity by asking for their response to the statement, "The water of the lake is crystal clear today." The users' responses were more widely distributed ranging from completely agree to disagree; none strongly disagreed (Figure 26). Most of the users agreed with the statement or indicated neutrality. This response does not perfectly match with the users responses to trophic status, but similar to the users in Falls of the Neuse Lake and Jordan Lake, the users could be making a differentiation between turbidity resulting from algae and sediments.

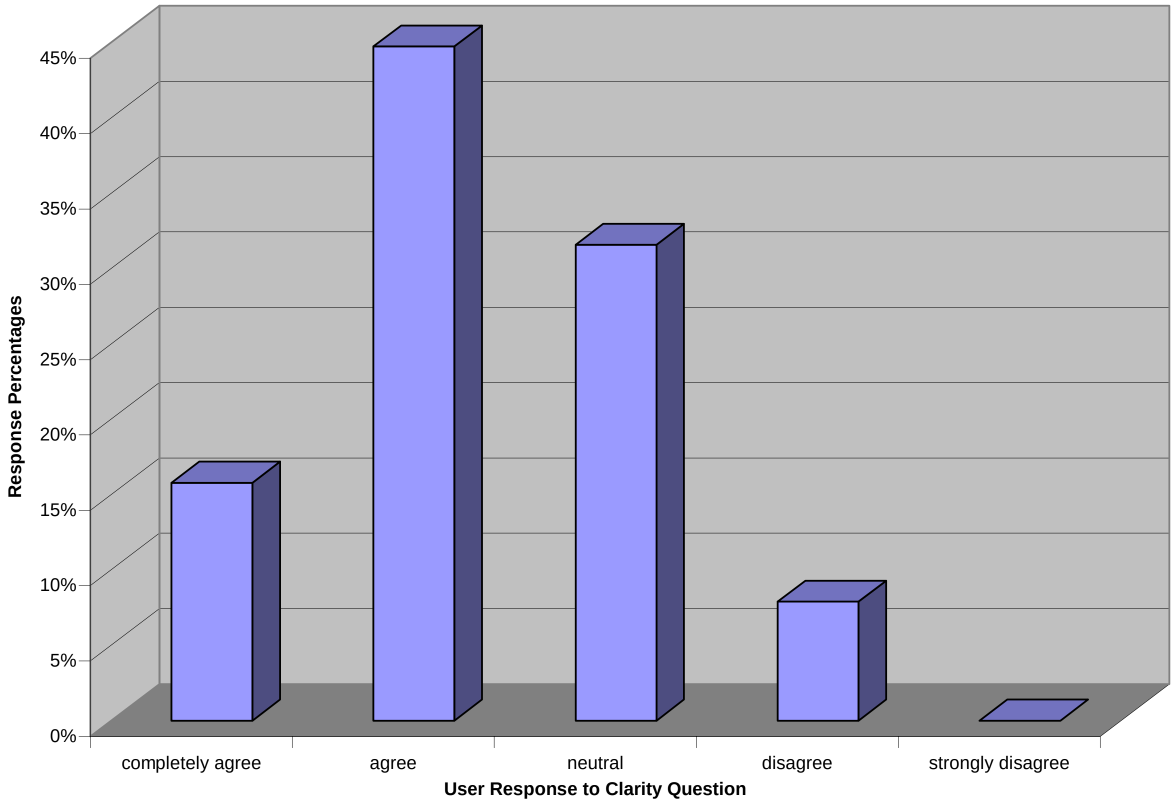

Figure 26. Santeetlah Lake Users' Response to Clarity. The responses of lake users responding to the question, "The water of the lake is crystal clear today." The a little over half of the users responded that they were completely agreed or agreed with the statement. n = 38

Other comments

One thing to keep in mind is that the only people that we were able to talk with are those people who actually chose to go to the lake to participate in a recreational activity. Therefore, those people who thought the lake did not meet their expectations for a particular use likely did not go to the lake and as a result could not be surveyed. Additionally, since we could not census the lake user population on the day surveyed, our results are not necessarily representative of the user population.

Example Data

An example of the survey and the survey key is included in the Appendix A. The survey key indicates how the categorical data is coded within the Excel databases.

Copy of questions and hard copy for archives

A copy of the survey questionnaire is included in Appendix A. The data from the user survey is included on the data inventory CD. The hard copy of all the surveys was provided to the North Carolina Department of Natural Resources, Division of Water Quality.

References

Griffith, G., J. M. Omernik, et al. (2002). Ecoregions of North Carolina: Regional Descriptions. Corvallis, OR, U.S Department of Agriculture.

Hoyer, M., C. Brown, et al. (2004). "Relations between Water Chemistry and Water Quality as Defined by Lake Users in Florida." Lake and Reservoir Management 20(3): 240-248.

Kishbaugh, S. (1993). Applications and Limitations of Qualitative Lake Assessment Data. NALMS, Seattle, Washington.

Rea, L. M. and R. A. Parker (1997). Designing And Conducting Survey Research: A Comprehensive Guide. San Francisco, John Wiley & Sons.

Smeltzer, E. and S. Heiskary (1990). "Analysis and Application of Lake User Survey Data." Lake and Reservoir Management 6(1): 109-118.

Expert Elicitation

Purpose

Ideally we would like to be able to directly measure whether or not a waterbody is meeting its various designated uses. Unfortunately, it is not possible to directly assess designated use attainment. Instead we use water quality criteria as scientific surrogates to indirectly assess attainment of the designated use.

Since an ideal criterion is one that is closely predicts designated use attainment, it is important to determine which variable or variables best predict designated use attainment. The process of determining which variable is most predictive is one that requires the use of both water quality data and expert judgments; expert judgments are necessary to consider the unmeasurable quantities of eutrophication and designated use category. These expert judgments were assessed using a procedure called expert elicitation.

The goal of expert elicitation is to extract subjective judgments from experts using a systematic procedure (Meyer and Booker 2001). This rigorous, transparent process is frequently used in the decision sciences (Morgan and Henrion 1990; Keeney and Vonwinterfeldt 1991; Meyer and Booker 1991) because it provides a defensible, well-established method for necessary information that was informally provided previously (Garthwaite, Kadane et al. 2005). This method of judgmental assessment has been used in the environmental and aquatic sciences also, although to a lesser extent (Reckhow 1988; Anderson 2001; Borsuk, Stow et al. 2002).

Much of science is inherently, but subtly, subjective. The improvement resulting from the use of expert elicitation is that it makes these subjective judgments transparent. In this study, we used expert elicitation to: (1) understand how different experts thought about the eutrophication process and designated use attainment issue in different regions, and (2) assess probability distributions on a categorical scale, given a correlated water quality data row, for the eutrophication classification, primary contact recreation category, and the secondary contact recreation category.

Method

Elicitation Design

Background and Previous Elicitations

The expert elicitation protocol was designed based on suggestions from the expert elicitation literature (Morgan and Henrion 1990; Keeney and Vonwinterfeldt 1991; Meyer and Booker 1991). Since each expert elicitation procedure differs because of the expert, judgments to be assessed, and project goals, there is not a set “cookbook” procedure to obtain these judgments. There is, however, a set of adaptive guidelines to assure that my method would provide me with the best data set possible.

Previously, the initial expert elicitation methods used a two phase procedure (Reckhow, Arhonditsis et al. 2005). The first phase consisted of a set of five questions that were designed to aid the expert in translating the designated use (see Appendix B). In the first phase we also asked the experts, after they provided the water quality variables in question 5, to describe the relationship structure between the variables. This conceptual model provided by each of the experts served as the a priori model for the structural equation model (see Appendix B). In the second phase of the elicitation, we asked the expert to quantify the probability of designated use attainment for a data row (see Appendix B). The response of the probability of designated use provided by each of the experts for each of the data rows are the data used in the structural equation models.

The previous elicitation approach was appropriate because it was easy to successfully execute and collect the necessary data. The method, however, forced the expert into a linear thought process, which may have confined their thinking. The goal of the interviewer, when asking an expert their beliefs, is to reveal their existing values (archeology) instead of structuring desired values (architecture) (Payne, Bettman et al. 1999). Ideally, the experts would have clearly formed opinions on eutrophication-related designated use attainment and revealing an expert's values would be straightforward. This assumption is rarely true (Bettman, Luce et al. 1998); the methods of questioning or information presentation can have a dramatic impact on an individual's reported values (Coupey, Irwin et al. 1998). Therefore, the interviewer must be very cautious during questioning to assure that the questions are unbiased and well articulated to minimize any elicitation bias. Additionally, constructing the interview in a less elicitor-driven manner and instead allowing the elicitee to shape the elicitation is a better method to discover preferences.

Modified Elicitation Method

Using what was learned from the previous expert elicitations, the expert elicitations for this research project were modified to better allow the experts to reveal their knowledge and values when making assessments about designated use attainment. The modified approach includes three parts: (1) a discussion of eutrophication and designated use attainment in the ecoregion, (2) quantification of the probability distribution of eutrophication and designated use categorical categories, and (3) a post-interview follow-up to calibrate the assessment and to confirm or correct the expert's judgment.

Preparation Prior to Elicitations

The first step, prior to contacting experts, was to develop the protocol and submit it to the Duke University Institutional Review Board (IRB) for approval since we were conducting research with human subjects. The proposal was approved.

In preparation for the expert elicitation, experts were identified, contacted, and prepared for the elicitation tasks. The expert elicitation used the knowledge of water quality experts who were experienced with non-flowing waters to determine the important eutrophication variables to assess nutrient enrichment in the waterbody. To capture the range of probability distributions, multiple experts were consulted for each region and designated use type. Experts were identified by completing a thorough search of potential academics, state scientists, and consultants that have knowledge of eutrophication in North Carolina, or Middle Atlantic region lakes. A list of all experts contacted and those who participated is included in Table 3-1.

Table 3-1. List of all of the experts used for the expert elicitations. We contacted many experts and this list includes only those that accepted and completed the entire elicitation exercises.

Experts	Affiliation	Ecoregion
Dr. Donald W. Stanley	East Carolina University	Coastal
Mr. Hank McKellar	South Carolina Department of Natural Resources, Freshwater Fisheries Research Laboratory	Coastal
Dr. Larry Carhoon	University of North Carolina - Wilmington	Coastal
Dr. Robert Christian	East Carolina University	Coastal
Dr. Stephen Whalen	University of North Carolina – Chapel Hill	Southeastern Plains
Dr. Samuel Mozley	Meredith College	Piedmont
Ms. Kathy Stecker	South Carolina Department of Health and Environmental Control	Piedmont
Dr. Daniel L. Tufford	University of South Carolina	Piedmont
Mr. Andy McDaniel	North Carolina Department of Transportation	Piedmont
Mr. Chris Roessler	Buck Engineering	Piedmont
Mr. Todd Kennedy	Statec Consulting	Piedmont
Dr. Jerry Miller	Western Carolina University	Blue Ridge
Ms. Barbara Wiggins	Wiggins Environmental Service	Blue Ridge
Ms. Marilyn J. Westphal	Volunteer Water Information Network / Environmental Quality Institute	Blue Ridge

In addition to identifying and preparing experts, we created a scale to quantify eutrophication or trophic status and designated use attainment. Constructed scales are a great method to elicit information using descriptions that are meaningful to the expert (Keeney 1992). It is a particularly good method when natural scales, such as money, are not readily available to express the quantity of interest, such as eutrophication status (Clemen and Reilly 2001).

Since we were not able to directly measure eutrophication or designated use and since there was not a natural scale or appropriate proxy, we created a constructed scale prior to the elicitation. The scale was created based on literature, consultation with water quality experts, and confirmation by decision analysts. The categories were the same for all of the ecoregions. The final scale constructed for eutrophication and the two designated uses was used during the expert elicitation. The categories used in the elicitation are provided below in Tables 3-2 – 3-4.

Table 3-2. Categories used in the expert elicitation for the assessment of eutrophication. These categories were designed to span the range of trophic status symptoms.

Category	Description
1	The lakes have: excellent water clarity, no color, very little algae, very low nutrient levels, very high oxygen, no odor, and very healthy, abundant aquatic life.
2	The lakes have: good water clarity, little color, little algae, low nutrient levels, high oxygen, little odor, and healthy, abundant aquatic life.
3	The lakes have: fair water clarity, some color, moderate amounts of algae, moderate nutrient levels, moderate oxygen, little odor, and somewhat healthy, abundant aquatic life.
4	The lakes have: poor water clarity, noticeable color, high algae, high nutrient levels, low oxygen, noticeable odor, and unhealthy, scarce aquatic life.
5	The lakes have: poor water clarity, considerable color, very high algae (likely scums), very high nutrient levels, low to no oxygen, strong offensive odor, and unhealthy, scarce aquatic life or no aquatic life.

Table 3-3. Alternative representation of categories used in the expert elicitation for the assessment of eutrophication. This table provides the same information as Table 3-2, but in a different arrangement.

	Water clarity	Color	Algae	Nutrient levels	Oxygen	Odor	Aquatic life
1	Excellent	None	Very little	Very low	Very high	No	Very healthy, abundant
2	Good	Little	Little	Low	High	Little	Healthy, abundant
3	Fair	Some	Moderate	Moderate	Moderate	Little	Somewhat healthy, abundant
4	Poor	Noticeable	High	High	Low	Noticeable	Unhealthy, scarce
5	Poor	Considerable	Very high	Very high	Low to no	Strong offensive	Unhealthy, scarce or none present

Table 3-5. Categories used in the expert elicitation for the assessment of primary and secondary contact recreation.

1	Excellent: Greatly exceeds expectations
2	Very good: Exceeds expectations
3	Acceptable: Meets expectations
4	Fair: Below expectations
5	Poor: Far below expectations

Expert Elicitations

As mentioned previously, the actual expert elicitations included three parts. Each of these parts were presented separately and were conducted for all the experts who completed the entire elicitation exercise.

The expert elicitation protocol is presented in detail in Appendix C. A summarized version is presented below.

The first part (approximately two hours) includes a discussion about eutrophication processes and designated use impairment as well as the use of expert judgments in this project. In the second part (approximately one hour training; 2 hours on the expert's own time), the expert provided their judgments about designated use attainment. In this part of the study, we provided them with data from a region of waterbodies. For each case, the expert was given multiple measures of eutrophication-related water quality variables. Given these measures, they were asked to assess the extent of eutrophication and designated-use attainment for lakes within an ecoregion. The elicitor worked through the first few cases with the expert until they felt comfortable working through the remaining cases on their own. In total, this process took approximately six to eight hours of the expert's time.

Expert Elicitation Part 1 - Interview

We conducted the first part of the elicitation during our face-to-face meeting with the expert. During this part we directed a discussion about eutrophication processes and designated use impairment as well as the use of expert judgments in this project. This process took the experts from 1 – 2.5 hours.

We began by describing the project, why their assessments were necessary, the protocol for the elicitation, and how their judgments would be used in the analysis. Then we moved to an open-ended discussion that was guided by two primary questions presented below:

1. What are the mechanisms leading to eutrophication?
2. What other variables (non-eutrophication) affect a waterbody's attainment of designated use?

These were not the only questions, because depending on how an expert responded, we would ask clarifying questions or probe into areas of the expert's specialty. This part of the elicitation provided us perspective on how the expert views eutrophication and designated use attainment, particularly the similarities and differences between ecoregions in North Carolina. We also learned, during this process, which of the measurable variables the expert emphasized when making their quantitative assessments of eutrophication and designated use in Part 2.

After the team received the expert's judgments, they were summarized in a brief report, which was sent to the experts for approval. The experts were able, at that time, to modify or fine-tune their judgments as they saw fit.

Expert Elicitation Part 2 – Quantification of Eutrophication and Designated Use

Part 2 of the elicitation is the most important part; it is where we ask the experts to provide their quantitative assessment, as a probability distribution, of the extent of eutrophication and designate use. More specifically, in this part of the study, we provided the expert with data from a region of waterbodies. For each case, the expert was given multiple measures of correlated eutrophication-related water quality variables. Given these measures, they were asked to assess the extent of eutrophication and designated-use attainment for that particular lake. We worked through the first few cases with the expert until they felt comfortable working through the remaining cases on their own.

For example, we provided the experts with a booklet, specific to their region of expertise, where we described the process in detail (see Appendix C). In summary, each expert was asked to assess 100 different water quality data rows for eutrophication and the designated uses. An example assessment is provided below:

1. Imagine 100 different lakes in the given Ecoregion with the characteristics specified by the given data row. Of the 100 lakes, how many of the lakes would you expect to fall into each of the following five categories of eutrophication?

2. Imagine 100 different lakes in the Piedmont Ecoregion with the characteristics specified by the given data row. Of the 100 lakes, how many of the lakes would you expect to fall into each of the five categories for the following designated uses?

Photic Total Nitrogen mg/L	Photic Total Inorganic Nitrogen mg/L	Photic Total Phosphorus mg/L	Photic Chlorophyll a µg/L	Surface Dissolved Oxygen mg/L	Secchi Depth meters	Photic Turbidity NTU
0.46	0.02	0.03	38	6.3	1.3	3.9

Eutrophication Category		Primary Contact Recreation		Secondary Contact Recreation	
1	________	1	________	1	________
2	________	2	________	2	________
3	________	3	________	3	________
4	________	4	________	4	________
5	________	5	________	5	________

The experts provided their assessment for 100 different data rows. We asked them to provide their answers as a distribution instead of simply checking the category that is most likely. Having a probability distribution allowed the expert to cluster their response when they were more certain and disperse their response when they were less certain.

Expert Elicitations Part 3 – Follow-up

Following Part 1 and 2, we summarized their qualitative assessment and created a database for their quantitative assessment. Then, looking at their responses, we picked assessments, given in Part 2, that looked interesting or odd. These data rows were used in the follow-up phone conversation so that we could calibrate the expert's assessment.

During the follow-up we asked the experts to look at the highlighted data rows and describe why they made such a particular assessment. If the experts saw an error in their assessment, they were encouraged to make a correction that more accurately reflects their belief of the eutrophication or designated use category. During this time, we were also able to gain a good deal of perspective of which variables a particular expert thought were important or not important and how they made assessments for particularly difficult data rows.

Any updates to the assessments were included in the database, and the revised dataset was used in the modeling.

Methods of Expert Combination

Expert elicitation is not a perfect method of fact determination (Morgan and Henrion 1990; Maguire 1991). It is not perfect because people are not perfect, calibrated estimators of input values. Therefore, multiple experts can be consulted to develop a range of plausible values based on the current knowledge of professionals.

When multiple experts are used to determine probability distributions, it is important to develop an appropriate method to aggregate the expert judgment (Winkler 1986). This method is contingent, in part, on the task required of the expert and the chosen experts. At the simplest level, a method is needed to aggregate experts that are assumed to be independent. However, the assumption of independence is not always warranted. Dependence among experts can occur because similar tools, training, or information are being used to create the judgment. If there is dependence among experts (the independence assumption does not hold), then the model needs to properly consider the expert dependence, a task that is more difficult than assuming independence.

There are multiple methods of expert combination that can be used to mathematically aggregate assessments. For this analysis, we chose to average the experts and used this information as an observed variable within the structural equation model. We used averaging because it is a simple, effective method of expert combination (Clemen and Winkler 1990; Clemen and Winkler 1999). A comparison of other methods of expert combination is presented in (Clemen and Winkler 1990; Clemen and Winkler 1999).

Expert Elicitation Results

After completing all of the expert elicitations, we compared the expert responses for the 50 data rows were the same for all the experts, despite the ecoregion. We made these comparisons by looking at the correlations of the experts with each other for the same data row. With this type of analysis, we can evaluate how much agreement a given expert has with the other experts in a given region or throughout the entire state. Thus if a single expert is largely out of agreement with all of the other experts, we can reevaluate whether or not we would use that expert in the analysis. In addition, we can also determine if there are systematic differences between the judgments of experts in one region of the state versus another region of the state. The results of the expert correlations for eutrophication and the two designated uses are presented in Table 3-5 – 3-7.

Table 3-5. Correlation table of all the experts in all the ecoregions for their assessment of eutrophication. The correlations within ecoregions are indicated by different coloration (coastal = pink, southeastern plains = blue, piedmont = green, blue ridge = orange).

	Coastal DS	*Coastal HM*	*Coastal BC*	*Coastal LC*	*SE Plains SW*	*Piedmont AM*	*Piedmont CR*	*Piedmont DT*	*Piedmont KS*	*Piedmont SM*	*Piedmont TK*	*Blue Ridge JM*	*Blue Ridge BW*	*Blue Ridge MW*
Coastal DS	1													
Coastal HM	0.70	1												
Coastal BC	0.55	0.73	1											
Coastal LC	0.39	0.66	0.73	1										
SE Plains SW	0.49	0.65	0.73	0.67	1									
Piedmont AM	0.57	0.72	0.66	0.62	0.76	1								
Piedmont CR	0.54	0.79	0.82	0.72	0.86	0.79	1							
Piedmont DT	0.47	0.62	0.43	0.34	0.58	0.70	0.60	1						
Piedmont KS	0.57	0.74	0.85	0.73	0.69	0.74	0.78	0.47	1					
Piedmont SM	0.53	0.62	0.85	0.69	0.81	0.71	0.86	0.42	0.79	1				
Piedmont TK	0.48	0.74	0.77	0.70	0.74	0.81	0.75	0.61	0.72	0.75	1			
Blue Ridge JM	0.48	0.59	0.62	0.58	0.72	0.77	0.70	0.49	0.58	0.68	0.70	1		
Blue Ridge BW	0.60	0.78	0.69	0.64	0.73	0.83	0.78	0.69	0.71	0.70	0.81	0.74	1	
Blue Ridge MW	0.64	0.80	0.67	0.64	0.64	0.76	0.75	0.63	0.77	0.70	0.72	0.67	0.80	1

Table 3-6. Correlation table of all the experts in all the ecoregions for their assessment of primary contact recreation. The correlations within ecoregions are indicated by different coloration (coastal = pink, southeastern plains = blue, piedmont = green, blue ridge = orange). Correlations that are particularly unusual are highlighted in red.

	Coastal DS	*Coastal HM*	*Coastal BC*	*Coastal LC*	*SE Plains SW*	*Piedmont AM*	*Piedmont CR*	*Piedmont DT*	*Piedmont KS*	*Piedmont SM*	*Piedmont TK*	*Blue Ridge JM*	*Blue Ridge BW*	*Blue Ridge MW*
Coastal DS	1													
Coastal HM	-0.18	1												
Coastal BC	0.09	0.46	1											
Coastal LC	0.14	0.50	0.69	1										
SE Plains SW	-0.08	0.79	0.63	0.60	1									
Piedmont AM	-0.08	0.89	0.48	0.51	0.81	1								
Piedmont CR	-0.11	0.77	0.69	0.63	0.83	0.78	1							
Piedmont DT	-0.03	0.92	0.55	0.55	0.81	0.91	0.82	1						
Piedmont KS	0.02	0.77	0.71	0.66	0.78	0.77	0.85	0.81	1					
Piedmont SM	-0.14	0.74	0.69	0.57	0.76	0.81	0.73	0.77	0.72	1				
Piedmont TK	0.14	0.58	0.64	0.66	0.77	0.67	0.68	0.67	0.71	0.64	1			
Blue Ridge JM	0.02	0.39	0.68	0.56	0.66	0.49	0.69	0.45	0.65	0.57	0.68	1		
Blue Ridge BW	0.06	0.81	0.62	0.63	0.83	0.86	0.76	0.85	0.81	0.78	0.74	0.54	1	
Blue Ridge MW	-0.14	0.88	0.44	0.46	0.75	0.86	0.78	0.88	0.77	0.73	0.59	0.41	0.80	1

Table 3-7. Correlation table of all the experts in all the ecoregions for their assessment of secondary contact recreation. The correlations within ecoregions are indicated by different coloration (coastal = pink, southeastern plains = blue, piedmont = green, blue ridge = orange). Correlations that are particularly unusual are highlighted in red.

	Coastal DS	*Coastal HM*	*Coastal BC*	*Coastal LC*	*SE Plains SW*	*Piedmont AM*	*Piedmont CR*	*Piedmont DT*	*Piedmont KS*	*Piedmont SM*	*Piedmont TK*	*Blue Ridge JM*	*Blue Ridge BW*	*Blue Ridge MW*
Coastal DS	1													
Coastal HM	-0.42	1												
Coastal BC	-0.37	0.40	1											
Coastal LC	-0.23	0.35	0.59	1										
SE Plains SW	-0.59	0.72	0.58	0.42	1									
Piedmont AM	-0.49	0.77	0.56	0.43	0.78	1								
Piedmont CR	-0.57	0.66	0.60	0.42	0.76	0.78	1							
Piedmont DT	0.00	0.36	0.02	0.12	0.11	0.47	0.22	1						
Piedmont KS	-0.43	0.67	0.61	0.45	0.62	0.74	0.68	0.31	1					
Piedmont SM	-0.42	0.70	0.67	0.45	0.72	0.78	0.66	0.26	0.71	1				
Piedmont TK	-0.55	0.51	0.62	0.55	0.73	0.57	0.59	-0.06	0.43	0.56	1			
Blue Ridge JM	-0.59	0.29	0.69	0.39	0.61	0.48	0.51	-0.20	0.38	0.50	0.68	1		
Blue Ridge BW	-0.58	0.71	0.50	0.59	0.80	0.76	0.68	0.24	0.67	0.69	0.66	0.48	1	
Blue Ridge MW	-0.51	0.84	0.45	0.32	0.79	0.85	0.77	0.38	0.77	0.75	0.52	0.36	0.74	1

The correlation tables compare a single expert to another single expert in the same ecoregion or in another ecoregion. This information provides us with insight into how much a particular expert agrees with the other experts in their ecoregion as well as the experts throughout the state. The correlation tables of the experts (Tables 3-5 – 3-7) demonstrate that the experts, in general, agree with the other experts in their ecoregion as well as the other regions.

For the eutrophication assessment, the experts judgments were largely in agreement (Table 3-5); almost all of the correlations the experts were 0.5 or above. For primary contact recreation, on the other hand, for the most part the correlations between experts remained high (above 0.5) (Table 3-6). There was one expert, however, who had correlations with the other experts consistently near 0. Since DS's correlations are near zero, thus stating that his assessments for this area are unpredictable, it lends question as to whether this expert's assessments should be included in a final dataset. Finally, similar trends were seen in secondary contact recreation (Table 3-7). Overall, the correlations were not quite as high across the board, but there were two assessments that were questionable, DS and DT. These assessments, which are highlighted in red, are either negatively correlated with the other experts or have a correlation around zero. Again, this calls into question whether these assessments should be included in the final dataset.

Table 3-8. Average correlation table between ecoregions with all the experts for their assessment of eutrophication.

	Coastal	*SE Plains*	*Piedmont*	*Blue Ridge*
Coastal	0.63			
SE Plains	0.64			
Piedmont	0.65	0.74	0.70	
Blue Ridge	0.64	0.69	0.71	0.74

Table 3-9. Average correlation table between ecoregions with all the experts for their assessment of primary contact recreation.

	Coastal	*SE Plains*	*Piedmont*	*Blue Ridge*
Coastal	0.28			
SE Plains	0.48			
Piedmont	0.49	0.79	0.76	
Blue Ridge	0.45	0.74	0.72	0.58

Table 3-10. Average correlation table between ecoregions with almost all the experts for their assessment of primary contact recreation. This average correlation table excluded DS's assessments of primary contact recreation.

	Coastal	*SE Plains*	*Piedmont*	*Blue Ridge*
Coastal	0.55			
SE Plains	0.67			
Piedmont	0.67	0.79	0.76	
Blue Ridge	0.61	0.74	0.72	0.58

Table 3-11. Average correlation table between ecoregions with all the experts for their assessment of secondary contact recreation.

	Coastal	*SE Plains*	*Piedmont*	*Blue Ridge*
Coastal	0.05			
SE Plains	0.28			
Piedmont	0.28	0.62	0.51	
Blue Ridge	0.26	0.73	0.56	0.53

Table 3-12. Average correlation table between ecoregions with almost all the experts for their assessment of secondary contact recreation. This average correlation table excluded DS and DT's assessments of primary contact recreation.

	Coastal	*SE Plains*	*Piedmont*	*Blue Ridge*
Coastal	0.45			
SE Plains	0.57			
Piedmont	0.58	0.72	0.65	
Blue Ridge	0.53	0.73	0.64	0.53

To gain further insight about how well the experts agreed with each other and to assess whether all of the assessments should be included or whether we should exclude certain experts from particular elicitation variables, we calculated the average correlation between ecoregions (Tables 3-8 – 3-12). In this assessment, we calculated the average correlation of the experts for a particular ecoregion and correlated it with the average correlation of the experts in a different ecoregion. In general, we would like to see average correlation values greater than 0.5.

For eutrophication (Table 3-8), we included all the experts in the assessment and the average correlation was fairly high. As a result, there was no reason to consider excluding any of the experts from the dataset. For primary contact recreation, we calculated the average correlation for all of the experts and the average correlation excluding DS's assessments, for reasons discussed earlier (Tables 3-9 and 3-10). Comparing the results of these two tables, it is apparent that the exclusion of DS's assessments for primary contact recreation negatively affects the results of the correlations. For example, the average correlation of coastal-coastal changed from 0.28 to 0.55 when DS's data was not included. Similarly, we calculated the average correlation for secondary contact recreation that included all of the experts and all of the experts except DS and DT (Tables 3-11 and 3-12). Again, comparing the results of the average correlation tables, the average correlations increase when DS and DT's assessments were removed. For example, the average correlation of coastal-coastal changed from 0.05 to o.45 when DS and DT's assessments were not included.

For use in the structural equation models, we decided to use all of the experts' assessments of eutrophication. This was because the experts were largely in agreement, particularly when we calculated the correlation of the expert correlations for each ecoregion. We made different choices for the designated uses. For primary contact recreation, we included all of the experts except for DS. We did not include DS's recommendations because when his assessments were included it drastically effected the overall correlation. Similarly, for secondary contact recommendation, we chose not to include DS's and DT's judgments since their assessments were different to a degree that they drastically affected the results when correlations were compared and the assessments averaged. Therefore, unless there was overwhelming evidence that would warrant an exclusion of an expert's assessments, we included all expert judgments in the dataset for modeling.

Copy of questions and hard copy for archives

The expert elicitation booklet for each ecoregion is included in the Appendix C. Each of the expert's probability assessments as well as the combined assessments for each region was included in the data inventory CD. A qualitative summary of each of the experts believes about eutrophication and designated use attainment with their approach to making the probability assessments is incorporated in a report for each expert in Appendix D. Finally, a hard copy of each of the expert's responses was provided to the North Carolina Department of Natural Resources, Division of Water Quality.

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Structural Equation Modeling

Purpose

Often times in environmental science or ecology, we do not simply want to describe observations or report simple trends in data, but would prefer to find a way to describe the causal structure explaining an underlying phenomenon (Shipley 2000). Fortunately, there is a statistical method, called structural equation modeling that can be used to represent such relationships among variables. Though historically the method has not been used frequently in the natural sciences, more recently, structural equation modeling has been increasingly used to represent some of the complexity inherent in environmental systems (Grace and Pugesek 1997; Grace and Pugesek 1998; Pugesek and Grace 1998; Smith, Brown et al. 1998; McCune and Grace 2002; Weiher, Forbes et al. 2004).

Structural equation modeling was used in this project to better predict designated use attainment by modeling the eutrophication process and linking this process to designated use attainment. We used a combination of water quality data and expert elicitation data to parameterize the statistical model.

Method

Structural Equation Modeling Introduction

Structural equation modeling (SEM) is a multivariate statistical technique that can be used to describe linear relationships between variables. SEM is a more general extension of multiple regression where the causal relationship between the variables can be described with multiple linear equations. The SEM implies a covariance structure between the variables included in the model. Therefore, SEM is an excellent statistical technique to use when there are processes, such as eutrophication, that can be described through causal interactions that can be represented by the covariance between variables.

SEM has several advantages over multiple regression. SEM can: 1) represent the effect of indirect relationships, 2) incorporate measurement error, 3) use latent variables, and 4) use variables collected on categorical scales. First, SEM allows one to model and test both the direct and indirect effects between variables. Second, you can explicitly incorporate measurement error uncertainty (Bollen, 1989). As a result, since water quality variables and latent variables that are not measured with perfect certainty, the uncertainty can be incorporated into the model so that the model estimators are not biased. Third, latent variables, not just indicator variables, can be used in SEM. Latent variables are unobserved theoretical constructs, method effects, or other phenomena (Kline 1998). For example, we may want to include water clarity in our model. Instead of representing water clarity with a single, imperfect measure, such as Secchi depth, a latent variable entitled water clarity could be created that is constructed using several measurable water quality variables such as Secchi depth, turbidity, and total suspended solids. Finally, SEM can include variables that are measured on ordinal or dichotomous scales. Thus, categorical data, such as survey data, can be included and modeled using SEM.

SEM is primarily a confirmatory, rather than exploratory, method. By this it is meant that a modeler will propose and test a hypothesized model structure that reflects her scientific understanding of the natural processes and processes. The validity of this structure is then tested by comparing the model-implied covariance structure to the data-implied covariance structure. If the covariance structures are consistent with each other, than the SEM is deemed a plausible representation of the underlying causal structure. If the initial model is not the best representation of the system, then the model is modified, through exploratory techniques, to better represent the studied system. The model validity is then tested using the same procedure described earlier.

More specifically, a SEM is fit by minimizing the difference, or residual, between the model-implied covariances matrix and the data-implied covariance structure. Commonly used fitting functions include maximum likelihood (ML), unweighted least squares (ULS) and generalized least squares (GLS). The model is then tested using a number of different methods that assess the overall fit of the model. The model is tested using methods that assess the overall fit of the model such as χ^2, Tucker-Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA) (Bollen 1989). By looking at the correlation between the parameters, one is able to gain a greater understanding of the relationships inherent in the ecosystem and represented by the measured water quality variables. This offers notable benefits when contrasted to what is learned by examining single variable values.

Since water quality data, in general, are noisy, the data may not strictly adhere to the SEM multivariate normality assumption. Therefore, more robust methods can improve the predictive power in certain analyses. Such estimators will be called robust estimators because they are robust to departures from multivariate normality of the data (Hampel, Ronchetti et al. 1986). If normality is assumed when the distribution is not multivariate normal, then the estimators will behave unexpectedly; this is a result of failures of the distribution assumption that lead to possible bias, inconsistencies, and estimator inefficiencies.

Structural Equation Model Equations

Below is a more detailed mathematical representation of structural equation models. It is useful to understand the matrix algebra that is inherent in all visual structural representations.

There are two types of variables in SEM, latent and indicator variables. Latent variables are unobserved theoretical constructs, method effects, or other phenomena (Kline 1998). Indicator variables are variables observed within the data (Kline 1998). The general SEM equations are:

$$\eta = B\eta + \Gamma\xi + \zeta \qquad (1)$$

where, η is latent endogenous variables, B is the coefficient matrix for the latent endogenous variables, Γ is the coefficient matrix for the latent exogenous variables, ξ is latent exogenous variables, ζ is the latent errors in equations. The equation can also include an intercept, although less common, which is represented by α.

$$x = \Lambda_x\xi + \delta \qquad (2)$$

where, x is the observed indicators of ξ, Λ_x are the coefficients relating x to ξ, and δ is the measurement error for x.

$$y = \Lambda_y \eta + \varepsilon \qquad (3)$$

where, y are the observed indicators of η, Λ_y are the coefficients relating y to η, and ε is the measurement error for y.

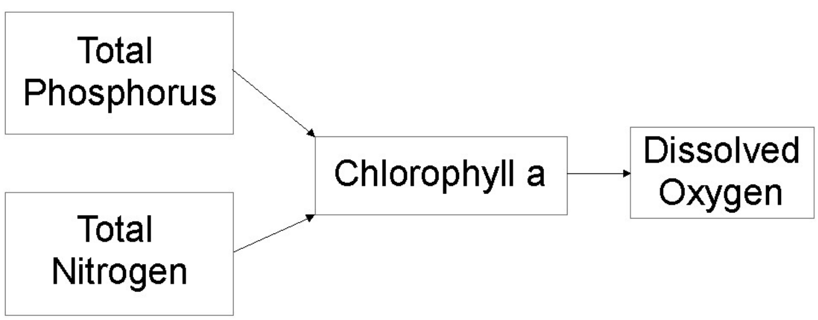
The hypothesized structural model (expected covariance structure) is tested against the covariance matrix from the observed variables. The fundamental null hypothesis H_o that formalizes the basis of structural equation modeling is:

$$H_o : \sum = \sum(\theta) \qquad (4)$$

where $\sum$ is the population (or sample) covariance matrix of observed variables, θ is a vector that contains the model parameters and $\sum(\theta)$ is the model-implied covariance matrix. In contrast with conventional statistical models, where the rejection of a null hypothesis is sought, the goal of structural equation modeling is acceptance of the null hypothesis, and thus statistical validation of the proposed model.

Structural Equation Modeling Illustrative Example

As mentioned previously, structural equation modeling is an extension of multiple regression where the relationship amongst the variables can be explicitly modeled. For illustrative purposes, consider Figure 4-1.



$$Chlorophyll\ a = \alpha + \beta_1\ Total\ Phosphorus + \beta_2\ Total\ Nitrogen + error$$

$$Dissolved\ Oxygen = \alpha + \beta_3\ Chlorophyll\ a + error$$

Figure 4-1. Example Structural Equation Model with the Associated Linear Equations. By extending multiple regression methods and applying SEM, more complex relationships can be represented as a system of equations. In the equations, α represents the intercept and β represents the coefficients.

Dataset for Structural Equation Models

As discussed in the Expert Elicitation section, we created a subset of data from the entire North Carolina database for the expert elicitations and structural equation modeling. Each ecoregion had 100 rows of correlated water quality data that we asked experts to assess for eutrophication, primary contact recreation, and secondary contact recreation. In addition, all of the ecoregions had 50 data rows that were exactly the same so that we could assess whether certain or all of the regions could be pooled.

Since structural equation modeling compares the covariance matrix of the data to the model-implied covariance matrix, it was important to set up the data set in the manner described above. Obviously, it would be better to have a larger data set, but since we are using experts, 100 data rows was the maximum number of assessments that we could reasonably ask the experts to complete.

Results and Discussion of Structural Equation Models for North Carolina

We created multiple structural equation models that linked the water quality data to eutrophication and designated uses. We created separate models for primary contact recreation and secondary contact recreation. Additionally, these models were created for the different ecoregions and for the entire state. In all, we created over 350 models to evaluate which variables are the most predictive of designated use. Many of the models produced significant (non-desirable) results in all the ecoregions, but some of the model designs performed consistently well.

We compared the structure of the same models to the data from different ecoregions and the entire state. Remembering that in structural equation modeling we would like to show that our model is a plausible representation of reality and thus fail to reject the null hypothesis, we have highlighted in red those model results that have a Chi-squared test statistic p-value greater or equal to 0.05. Though many of the models proved non-significant in more than one ecoregion, none of the models were non-significant in all the ecoregions and entire state. As a result, there is not one model that out performs some of the others; instead, we have to consider that there are multiple candidate models and no way to rank one plausible model against another, since the size of the p-value does not indicate that one model is more probable than another, only that is a plausible representation.

The results of the models that consistently performed well are presented in Table 4-1 and Table 4-2. A description of the models and the visual representation of these models are presented in Table 4-3. As Tables 4-1 and 4-2 display, there were no models that produced non-significant results in all the ecoregions and the entire state. The models that are presented are those that had at least one non-significant result.

Overall, for primary contact recreation there were multiple models that performed well for the natural lakes in the Coastal ecoregion and the Blue Ridge ecoregion; for the other ecoregions, on the other hand, there were only two or three models that proved non-significant. Similarly, for secondary contact recreation, multiple models performed well for the Blue Ridge ecoregion and the Coastal ecoregion for both the natural and non-natural lakes. There were fewer models for the other ecoregions; most notably, there was only one model that performed well (Model 12) in the Piedmont ecoregion.

For both designated uses, the models that produced the best results were those that performed in the entire state and in all but two of the ecoregions. With this condition, Models 12 and 29 produced the “best” results. In these models, a single water quality variable was the best predictor: in Model 12 the predictor was total phosphorous and in Model 29 the predictor was total inorganic nitrogen. We also created slightly more complex models with multiple variables and an additional hierarchy; however, these models did not perform as well as Models 12 and 29.

One thing to note is that the number of experts for each ecoregion had an immense effect on the model results. For the Southeastern Plains ecoregion, which had only one expert, the models that we created represented just that expert's believes. As a result, there were only a few models that proved non-significant because that expert placed emphasis on a few variables. On the other hand, if there were a large number of experts, such as the six experts in the Piedmont ecoregion, we are capturing a range of expert judgments. Since each expert comes with their own expertise that effects their assessments, the experts may be emphasizing different variables. This feature, which is important to capture the range of current knowledge, can also cause difficulty in finding model consensus.

Another feature to notice is that the results for the same model structure are not the same for primary and secondary contact recreation; the same model could also be significant for one use and non-significant for another use. This makes sense since the experts were assessing different uses and as a result there might be water quality variables that are predictive for one use but not predictive for another use.

Given the table results, there is not one clear set of recommendations regarding the most predictive variable or variables to assess eutrophication impairment. There are a number of approaches that can be considered including multiple variables, a single variable, ecoregion specific criteria, and statewide criteria. First, multiple variables provide a nutrient criteria that is more robust. It is more robust because you are able to assess a complex process with more than one variable, which provides more information regarding the eutrophication impairment status. Second, a single variable is a more simple assessment method. If there is a single criterion, then it can be easier logistically to determine whether the criterion indicates that a waterbody is considered impaired or not. Third, an ecoregion specific criterion allows for the variable and level to be tailored to different regions in the state. If there are multiple diverse regions in the state, then it may be more accurate to set criteria specific to the region. Last, statewide criteria are simpler to employ logistically since the same variable and level are used throughout the entire state. Statewide criteria are a good choice when there is not a huge difference between the ecoregions or when the ecoregions indicate similar results.

Given the model results and the considerations listed above in choosing nutrient criteria, we would advise the state consider a statewide total phosphorous criterion (Model 12). We make the following recommendation because none of the models indicated a clear choice; however, the total phosphorous model performed consistently well across the ecoregions and the entire state. Total phosphorous is also a recognized causal variable of eutrophication and is recognized largely as a more important nutrient than nitrogen because North Carolina lakes are phosphorous limited. Furthermore, there have been no collection and analysis problems with the total phosphorous, which make it a more reliable nutrient criterion. Additionally, though a response variable, such as Secchi depth or chlorophyll *a*, may be closer to the designated use in terms of the effects of eutrophication impairments, the performance of the response variables was not as strong as the causal variables. Finally, since we cannot evaluate how much better one model is in comparison to another model in the same ecoregion, we recommend a model that performed well across all ecoregions, which would set a statewide criterion. Therefore, for these reasons, we would recommend that North Carolina consider a statewide total phosphorous criterion.

Table 4-1. Models for Ecoregions and NC for Primary Contact Recreation

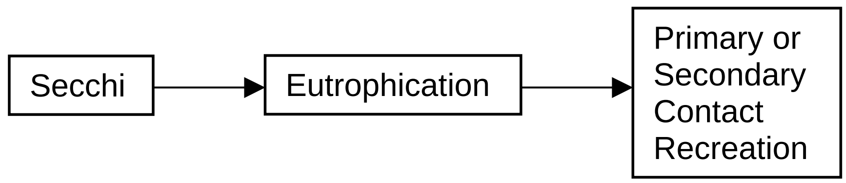
	Coastal Natural Lakes	Coastal Non-natural Lakes	Southeastern Plains	Piedmont	Blue Ridge	All Ecoregions in North Carolina
Model 7	0.09	0.71	0.17	0	0.17	0
Model 12	0.80	0	0.02	0.77	0.05	0.66
Model 13	0.07	0.34	0.86	0.04	0.33	0
Model 19	0.11	0.03	0	0.04	0.01	0
Model 21	0	0.03	0	0.03	0.02	0
Model 23	0	0.02	0.01	0.08	0.01	0
Model 24	0.08	0.02	0	0.01	0.03	0
Model 26	0.52	0	0	0.03	0.70	0
Model 27	0.06	0.03	0	0.02	0.61	0
Model 29	0.10	0.02	0.05	0.93	0.17	0.24

Table 4-2. Models for Ecoregions and NC for Secondary Contact Recreation

	Coastal Natural Lakes	Coastal Non-natural Lakes	Southeastern Plains	Piedmont	Blue Ridge	All Ecoregions in North Carolina
Model 7	0.39	0.30	0.09	0	0.53	0
Model 12	0.67	0.81	0.03	0.05	0.02	0.97
Model 13	0.75	0.20	0.84	0	0.42	0
Model 19	0.81	0.41	0.01	0	0.01	0
Model 21	0.75	0.03	0	0	0	0
Model 23	0.85	0.60	0.03	0	0	0
Model 24	0.93	0.61	0	0	0.07	0
Model 26	0.84	0.56	0	0	0.88	0
Model 27	0.95	0.43	0	0	0.68	0
Model 29	0.58	0.84	0.06	0.02	0.04	0.85

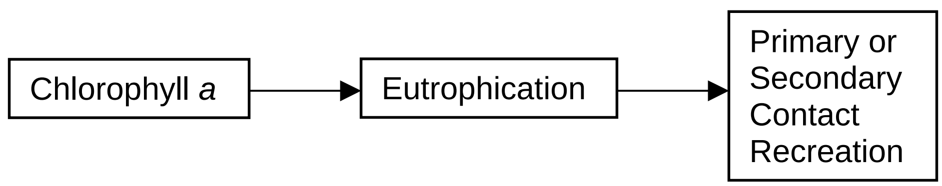
Table 4-3. Pictorial Representations of the Structural Equation Models Developed to Assess Predictive Nutrient Criteria for North Carolina.

Model7

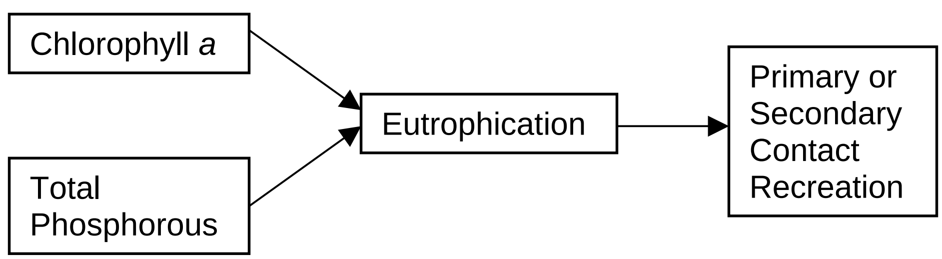


Model 12

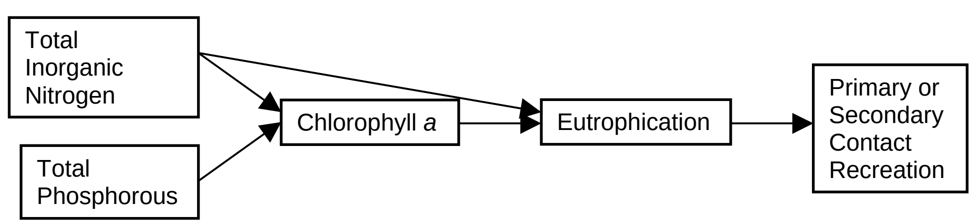
Model 13



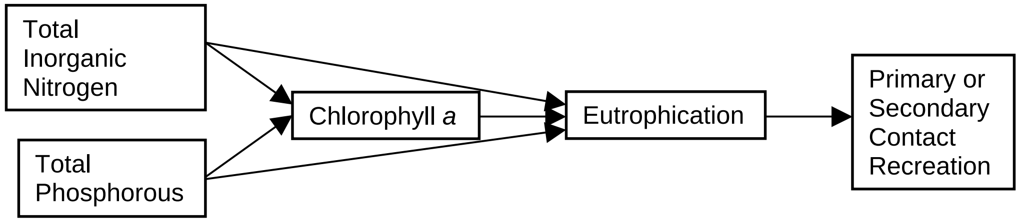
Model 19



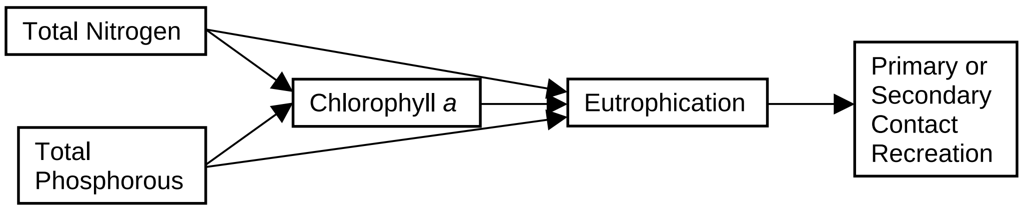
Model 21



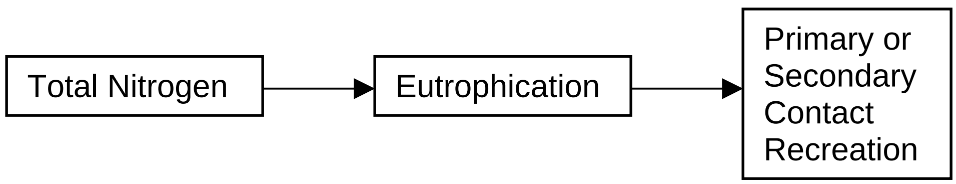
Model 23



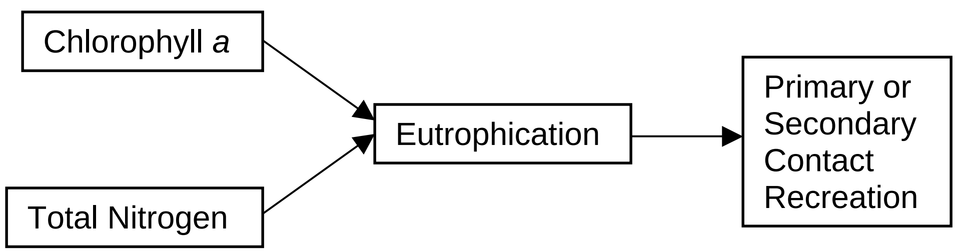
Model 24



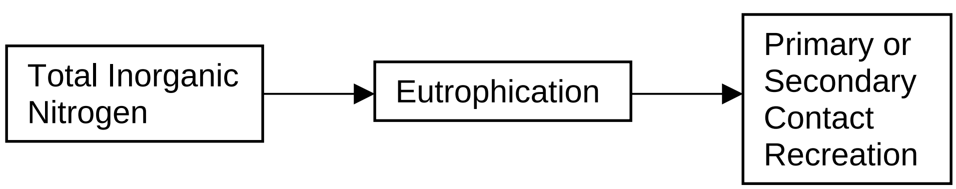
Model 26



Model 27



Model 29



Future Research

This study does not recommend a specific nutrient criterion level. We do not recommend a specific criterion level because it requires a decision maker's value tradeoff between environmental protection and waterbody research and implementation costs, which is called a decision maker's utility function. Therefore, our suggesting a criterion level would cloud the difference between scientific assessment and value judgments; ideally, this difference should be transparent.

Fortunately, there is a method that shows promise for transparently recommending nutrient criteria threshold levels: multiattribute utility analysis. Multiattribute utility analysis is a quantitative method to evaluate and compare alternatives using a decision maker's utility.

For nutrient criteria, we would use multiattribute utility analysis, to assist decision makers in making value tradeoffs to establish nutrient criteria based on their utility function. After assessing the utility functions for several decision makers, using we would be able to analytically integrate the probability of use attainment, for a given criterion level, with the decision makers' utility functions. In North Carolina, we would compare different criteria levels using the utility functions of the North Carolina Environmental Management Commission.

After conducting the analysis, the "best" criteria threshold level would be the one that is associated with the highest expected utility. Using this approach provides a rigorous approach to assist a decision maker in choosing nutrient criteria and the associated threshold levels.

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APPENDIX A

USER SURVEY PROTOCOL

June 4, 2005

Dear User Survey Participant:

You are invited to participate in a survey as a part of research for Melissa A. Kenney's doctoral dissertation project (http://www.duke.edu/mak22) at the Nicholas School of the Environment and Earth Sciences (advised by Kenneth H. Reckhow). The goal of this study is to better choose water quality indicators and levels that protect the use goals of North Carolina lakes.

You were selected because you are using the lake for one of its recreational goals. The survey will take approximately 3 minutes to complete. In the survey, you will be asked to share your opinions your use of the lake today. Your participation is entirely voluntary. You are free to refuse to respond to any questions and to stop your participation at any time during the survey. If you choose to complete the survey, we will use the survey data to help us assess whether the state is meeting its water quality goals. There is no right or wrong answer to your survey responses, and there is no particular answer that the researchers are hoping you will select.

Your survey responses are anonymous. Your name or contact information is not required or necessary for you to complete the survey. You may, however, provide your contact information on a separate form if you would like to receive a copy of the final report (available by September 2006) that will be generated using the survey data. The survey data will also be used to answer research questions that will lead to publishable manuscripts. You can keep up-to-date with the project progress at http://www.duke.edu/mak22.

If you have any questions about the survey, please contact Melissa A. Kenney (919-613-8133; m.kenney@duke.edu). If you have any questions about your rights as a research participant, please contact Ms. Lorna Hicks (lorna.hicks@duke.edu), Director of Human Protections Administration at Duke University.

Sincerely,

Melissa A. Kenney

Ph.D. Student in Water Quality Modeling and Decision Analysis

Duke University Nicholas School of the Environment and Earth Sciences

Enclosure (User Survey)

Lake User Survey

Please respond to the following questions for the conditions and your uses today.

1. What are you using the lake for today (check all that apply)?

____ Swimming
____ Fishing
____ Lake Beauty/Tanning
____ Picnicking / Hiking
____ Jet skiing
____ Canoeing / Kayaking
____ Motorized boating
____ Wakeboarding / Tubing / Water skiing
____ Other (specify)____

2. How often do you use the lake?

____ Couple times a week
____ Once a week
____ Twice a month
____ Once a month
____ Occasionally
____ First time

3. What qualities of the water do you believe are important to be able to use the lake (check all that apply)?

____ High clarity
____ Water temperature
____ Little water odor
____ High oxygen level
____ Little water color
____ No algal scums
____ Sport fish populations
____ Little sediment (dirt) in the water
____ Other (specify)____

4. The water of the lake is crystal clear today.

____Completely agree

____Agree

____Neutral

____Disagree

____Strongly Disagree

5. What is the color of the water?

____ Blue

____ Green

____ Brown

____ Brownish / Green

____ Other (specify)______________________________

6. How would you describe the condition of the lake, in regards to the algae, today?

____The water is crystal clear. There are no apparent problems.

____It's not perfectly clear; there is a little algae.

____There is algal growth; water appears green, yellow, or brown from algae.

____There are high levels of algal growth limiting water clarity or causing odor.

____Severe water impacts from algal growth causing massive algal scums on the lake or washed up on shore, strong offensive odor, or fish kill.

____Other impacts, not algal related (specify)___________________________________

7. How would you describe the condition of the lake, in regards to the sediment, today?

____The water is crystal clear. There are no apparent problems.

____It's not perfectly clear; there is a little sediment.

____There is obvious sediment; water appears brown from sediment.

____There is a large amount of sediment limiting water clarity.

____Severe water impacts from sediment; the water appears and feels like muddy water.

____Other impacts, not sediment related (specify)_________________________________

8. The conditions of the lake are perfect for my use(s) today.

____Completely agree

____Agree

____Neutral

____Disagree

____Strongly Disagree

9. How would you rate the conditions of the lake based on your experiences today?

a. Water quality

____Excellent

____Very good

____Acceptable

____Fair

____Poor

____N/A

b. Lake Beauty

____Excellent

____Very good

____Acceptable

____Fair

____Poor

____N/A

c. Swimming or Wakeboarding / Tubing / Water skiing

____Excellent

____Very good

____Acceptable

____Fair

____Poor

_____N/A

d. Fishing

____Excellent

____Very good

____Acceptable

____Fair

____Poor

____N/A

e. Motorized Boating or Jet Skiing

____Excellent

____Very good

____Acceptable

____Fair

____Poor

____N/A

f. Canoeing or Kayaking

____Excellent

____Very good

____Acceptable

____Fair

____Poor

____N/A

10. What factors, if any, are impacting or limiting your use of the lake today (check all that apply)?

____ Poor clarity

____ Water temperature

____ Water odor

____ Low oxygen level

____ Water color

____ Algal scums

____ Few sport fish populations

____ Sediment (dirt) in the water

____ None

11. If you went fishing, how many fish have you caught today?

____0

____1

____2

____3-4

____5-6

____more than 6

____N/A

12. If you went fishing, what type and how many of each fish have you caught today (if applicable)?

____ Crappie

____ Catfish

____ Walleye

____ Bass

____ Bluegill

____ Shad

____ Sunfish

____ Perch

____ Trout

____ I don’t know

____ N/A

____ Other (specify)____________

Optional Demographic Information

A. What is your age?

____under 18

____18-25

____26-35

____36-49

____50-65

____65 or older

B. What is your gender?

____ Male

____ Female

C. What is your race or ethnicity?

____ Caucasian/White

____ African American

____ American Indian

____ Hispanic

____ Pacific Islander

____ Asian

____ Other (specify)________________________

D. What is the highest level of education you have completed?

____ some High School

____ High School degree

____ some College

____ College degree

____ some Graduate School

____ Graduate degree

E. Where do you live?

____ on lake INSERT

____ INSERT TOWN/CITY

____ INSERT REGION

____ North Carolina

____ United States

____ outside United States

F. Do you participate in an association related to the lake, such as homeowners' organization, friends of the lake, fishing club, etc.?

____ No

____ Yes (specify) ____________________________________

APPENDIX B

ORIGINAL EXPERT ELICITATION PROTOCOL

Dear INSERT NAME:

My name is INSERT and I am a graduate student at Duke University working with INSERT and Dr. Reckhow. I am writing to provide you with some background information on our project, and the expert elicitation process.

We are conducting a statistical modeling assessment intended to improve methods for the establishment of water quality standards. Specifically, we are addressing the EPA's national nutrient strategy, which requires states to establish eutrophication-related water quality criteria that are protective of designated uses.

We will be asking you a series of questions based on INSERT DESIGNATED USE for INSERT REGION. Your role in this process is to help identify a quantitative metric for the designated use statements. Our ultimate goal, following a phone interview, will be to estimate the INSERT DESIGNATED USE attainment/non-attainment threshold.

Included with this email (as attachments) are:

a) A few "pre-interview" questions. We will be using your responses to these questions to tailor our interview questions and use your time as efficiently as possible.
b) Statutory definitions of INSERT DESIGNATED USE, for your convenience.

Thank you for your time, and I look forward to speaking with you in the near future.

Sincerely,

INSERT NAME

Master of Environmental Management Candidate

Nicholas School of the Environment and Earth Sciences

Duke University, Durham, NC

INSERT EMAIL@duke.edu

Statement of Informed Consent

You have been invited to participate in an interview as a part of the research for INSERT NAME Master's Project at the Nicholas School of the Environment and Earth Sciences (advised by Kenneth H. Reckhow and Melissa A. Kenney). The goal of this study is to improve the understanding of the relationship between quantitative nutrient criteria and narrative water quality goal statements.

This interview will last approximately 1-2 hours. During the interview you will be asked to share your opinions on the appropriate quantitative metric for the narrative designated use statements of a waterbody. We will then use the information you provide during the interview to estimate points at which attainment/non-attainment of each designated use occur. There is no right or wrong answer to anything that will be discussed in the interview, and there is no certain answer that the researchers are hoping to hear from you. Results from this interview will be used to develop the following types of research reports: Master's Project, future research protocol, peer-reviewed manuscripts, grant and research reports, and presentations.

You were selected based on your knowledge of the waterbody system and your ability to provide insights regarding appropriate nutrient related water quality indicators. The data generated from the interview process will be recorded by written correspondence, digital recordings of phone and face-to-face communications, taking copious notes, and by creating formal elicitation reports. The results of the research may be presented in research reports. Access to data will be provided upon request after initial publication. Additionally, the information you provide us is not confidential and the interview and results that you provide us *may* be identified in research reports.

Your participation in this interview is entirely voluntary. You are also free to refuse to respond to any questions and to stop your participation at any time during the interview.

If you have any questions about this research project, please contact the project manager Melissa A. Kenney (m.kenney@duke.edu). If you have any questions about your rights as a research participant, please contact Ms. Lorna Hicks (lorna.hicks@duke.edu), Director of Human Protections Administration at Duke University.

I have read the information in this consent form and have been given the opportunity to discuss it and ask questions.

Print name Sign name Date

Preliminary Questions for INSERT REGION

CHECKLIST

INSERT REGION's Designated Uses:

select designated use that is most stringent to elicit judgments.

1. How would you define INSERT DESIGNATED USE?

    - Depends on the DU

2. What aspects of INSERT DESIGNATED USE do you consider to be most important?

    - Depends on the DU

3. If you had unlimited resources and were able to measure any biological, chemical, or physical variables, what variables would you measure to determine whether or not INSERT DESIGNATED USE was attained?

    - Higher level trophic indicators or other variable that makes sense?
    - Is there any other variables that would perfectly or near perfectly measure the designated use? If yes, what?
    - If multiple variables provided, what would be the single best variable?
    - Why would this variable be ideal to measure designated use?

4. Given the variable that you just identified as ideal to measure the aspects of INSERT DESIGNATED USE, what do you believe is the attainment vs. non-attainment change point level for this variable?

    - Measured value the same as #3.
    - Value provided?
    - Units clear?
    - Does it pass the clairvoyant test?

5. Given the variable that you just identified as ideal to measure the aspects of INSERT DESIGNATED USE, what commonly measured water quality variables would you use as a proxy for assessing your identified ideal variable?

    - N
    - P
    - Secchi depth
    - Temperature
    - pH
    - Chlorophyll a
    - What is the relationship among the variables you listed?
    - What is the ecological structure? (conceptual model)
    - Are there any seasonal effects that would change the model?

Expert Elicitation Phase 2

CHECKLIST

Question:

Given 100 lakes and reservoirs in INSERT REGION, all with identical average levels of these variables in the data row and assuming other factors not listed (e.g., morphological, climatic) vary randomly, how many of the 100 lakes and reservoirs would be in attainment of the designated use?

Example data rows:

Chla	**DO**	**Secchi**	**TN**	**TP**	**DAP (#/L)**	**ZOOP (#/L)**	**………..**	**# (out of 100) in attainment**
1.8	9.2	4.1	201	4.6	0.69	11.78		?
1.4	9.2	5.5	187	6.2	0.70	21.62		?

The expert would answer the question that was stated above in the box labeled "# (out of 100) in attainment."

Procedure:

1. Look at a single data row. Look at all of the values for each of the variables. These variables were chosen based on your (the expert's) statement regarding measurable eutrophication related variables that are important for assessment of the designated use, using the ideal variable measure of designated use attainment.
2. Think about the relationship among the variables. Using this conceptual model, make an assessment of the number of lakes that will be in attainment of the designated use (out of 100 lakes).
3. Consider again the value you (the expert) chose as number of lakes in attainment of the designated use. If 5 more lakes had the exact same values for each of the variables in the data row, would the lake be in attainment of the designated use? If your answer changes, please make the appropriate modifications.
4. Once you are satisfied with the value chosen, move to the next data row and repeat the process.
5. When you have finished providing values for each of the data rows, please look through your responses to make sure that you still agree with your response.

These values will be used as data in the structural equation models created for INSERT REGION.

APPENDIX C

REVISED EXPERT ELICITATION PROTOCOL

Dear INSERT,

I am a doctoral candidate in water quality modeling and decision analysis at the Duke University, Nicholas School of the Environment and Earth Sciences. For my dissertation (advised by Professors Ken Reckhow and Bob Clemen), I am developing a method for establishing nutrient criteria that are predictive of a waterbody's goals, or designated uses. Specifically, my research addresses the EPA's national nutrient strategy, which requires states to protect designated uses by establishing eutrophication-related water quality criteria. As a demonstration of our method, I am assisting North Carolina in re-assessing their nutrient standards for lakes and reservoirs.

Since there is no existing method for determining whether a waterbody is meeting its designated uses, such as swimmable or fishable, your judgments are needed to help us understand what characteristics of a lake lead to designated use attainment. Using your judgments, coupled with water quality data, we will be able to develop a model that links eutrophication and designated use attainment. (The model and this project do not try to assess compliance of a waterbody with the current water quality standards.)

For this project, I need to find individuals who are experienced and knowledgeable about North Carolina lakes. You were recommended as an expert by INSERT.

I am writing to find out whether you would be interested in serving as an expert for my study. The process includes two parts, both of which can be completed during a one-day meeting. The first part (approximately 2 hours) will include discussions about eutrophication processes and designated use impairment as well as the use of expert judgments in projects such as this one. In the second part (approximately 1 hour training; 2 hours on your own time), you will provide your judgments about designated use attainment. In this part of the study, I will provide you with data from a number of North Carolina lakes or reservoirs. For each case, you will have multiple measures of eutrophication-related water quality variables. Given these measures, you will be asked to assess the extent of eutrophication and designated-use attainment for that particular lake. We will go through the first few cases together, so that you can work through the remaining cases on your own. In total, this process will take approximately six hours of your time.

After I receive your judgments, I will summarize them in a brief report, which I will send to you for your approval. You will be able at that time to modify or fine-tune your judgments as you see fit.

In return for your efforts, you will be acknowledged in the project's publications, and I will send you, if you wish, a copy of my dissertation and the resulting publications.

I hope that you will agree to participate, because I would enjoy working with you. Please contact me (919-613-8116; m.kenney@duke.edu) if you have any questions.
Sincerely,
Melissa Kenney

Expert Elicitation Discussion Questions for INSERT LAKE REGION

1. What are the mechanisms that lead to eutrophication?
    - Indicators
        - Nitrogen
        - Phosphorous
        - Chlorophyll a
        - Total Suspended Solids
        - Turbidity
        - Secchi Depth
        - Dissolved oxygen
        - pH
        - Temperature
        - Benthic organism
    - Symptoms
        - Algal growth
        - Reduced clarity
        - Reduced oxygen levels
        - Fish kills
        - Ecosystem change
        - Excessive nutrient loading
    - Chain of events
        - Important factors or major effects of eutrophication in particular region

2. What other variables (non-eutrophication) affect a waterbody's attainment of designated use?
    - Variables
        - Toxic algae
        - Sport fish population
        - Fecal coliform
    - Mechanisms
        - Land use
        - Pollutant loading
    - How do the other variables, mechanisms, etc. relate to eutrophication?
        - Fish biodiversity changing with trophic status
    - What does designated use mean? (if necessary)

Expert Elicitation

1. Consider a single data row. Look at all of the values for each of the variables.

2. Given the values for the specific variables in the data row:

Imagine 100 different lakes with the characteristics specified by the given data row. Of the 100 lakes, how many of the lakes would you expect to fall into each of the following five categories of eutrophication?

Category	Description
1	The lakes have: excellent water clarity, no color, very little algae, very low nutrient levels, very high oxygen, no odor, and very healthy, abundant aquatic life.
2	The lakes have: good water clarity, little color, little algae, low nutrient levels, high oxygen, little odor, and healthy, abundant aquatic life.
3	The lakes have: fair water clarity, some color, moderate amounts of algae, moderate nutrient levels, moderate oxygen, little odor, and somewhat healthy, abundant aquatic life.
4	The lakes have: poor water clarity, noticeable color, high algae, high nutrient levels, low oxygen, noticeable odor, and unhealthy, scarce aquatic life.
5	The lakes have: poor water clarity, considerable color, very high algae (likely scums), very high nutrient levels, low to no oxygen, strong offensive odor, and unhealthy, scarce aquatic life or no aquatic life.

(alternate presentation) The lake has:

	Water clarity	**Color**	**Algae**	**Nutrient levels**	**Oxygen**	**Odor**	**Aquatic life**
1	Excellent	None	Very little	Very low	Very high	No	Very healthy, abundant
2	Good	Little	Little	Low	High	Little	Healthy, abundant
3	Fair	Some	Moderate	Moderate	Moderate	Little	Somewhat healthy, abundant
4	Poor	Noticeable	High	High	Low	Noticeable	Unhealthy, scarce
5	Poor	Considerable	Very high	Very high	Low to no	Strong offensive	Unhealthy, scarce or none present

3. Given the values for the specific variables in the data row:

Imagine 100 different lakes with the characteristics specified by the given data row. Of the 100 lakes, how many of the lakes would you expect to fall into each of the five categories for the following designated uses?

A. Primary Contact Recreation (Swimming, Wakeboarding, Tubing, Water skiing, etc.)
    1. Excellent: Greatly exceeds expectations
    2. Very good: Exceeds expectations
    3. Acceptable: Meets expectations
    4. Fair: Below expectations
    5. Poor: Far below expectations

B. Secondary Contact Recreation (Fishing, Motorized Boating, Jet Skiing, Canoeing, Kayaking, etc.)
1. Excellent: Greatly exceeds expectations
2. Very good: Exceeds expectations
3. Acceptable: Meets expectations
4. Fair: Below expectations
5. Poor: Far below expectations

C. Trout waters (include?)
1. Excellent: Greatly exceeds expectations
2. Very good: Exceeds expectations
3. Acceptable: Meets expectations
4. Fair: Below expectations
5. Poor: Far below expectations

4. Once you are satisfied with the value chosen, move to the next data row and repeat the process.

5. When you have finished providing values for each of the data rows, please look through your responses to make sure that you still agree with your response. These values will be used as data in our study of eutrophication and designated use attainment in North Carolina INSERT LAKE REGION.